Section VI:

Wireless

Wireless Local Loop in Emerging Markets

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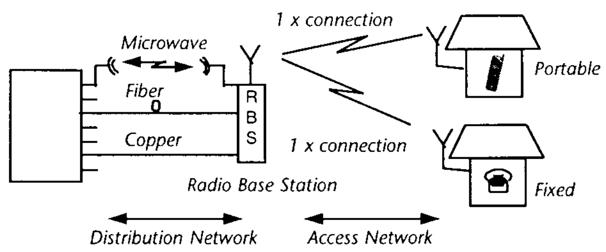
This essay discusses the marketplace for wireless local loop (WLL) in broad terms. It begins with an overview of wireless local loop in emerging regions and then explains some of the obstacles to wireless local loop uptake that have become apparent over the last year or so. Next, it provides case studies, one from Hungary and one from Argentina, and concludes with an outlook for wireless local loop.

FIGURE 1

Wireless Local Loop Architecture



Wireless Local Loop Market Overview

Pyramid Research defines WLL as a system that connects subscribers to the public switched telephone network (PSTN) using radio signals as a substitute for copper wire for all or part of the connection between the subscriber and the switch (see *Figure 1*). This definition includes cordless access systems, proprietary fixed radio access, and fixed cellular systems.

As *Figure 2* shows, wireless local loop is being deployed in every major emerging market region around the world. Several typical deployment patterns for wireless local loop have developed. In the first, competing operators use WLL to provide services quickly in order to compete with entrenched players. This is the case for Atlantic Telecommunications, Ltd. in the United Kingdom, which is using wireless local loop to establish subscribers quickly to compete with British Telecom, Cabletel, United Artists, and Mercury. Elsewhere, emerging firms are using wireless local loop as a tool to meet license requirements and service targets established by regulatory authorities. This is the case, for example, for PT Asia West in Indonesia, which the government has required to install 500,000 new main lines over three years. The company is

FIGURE 2

WLL Deployment Plans

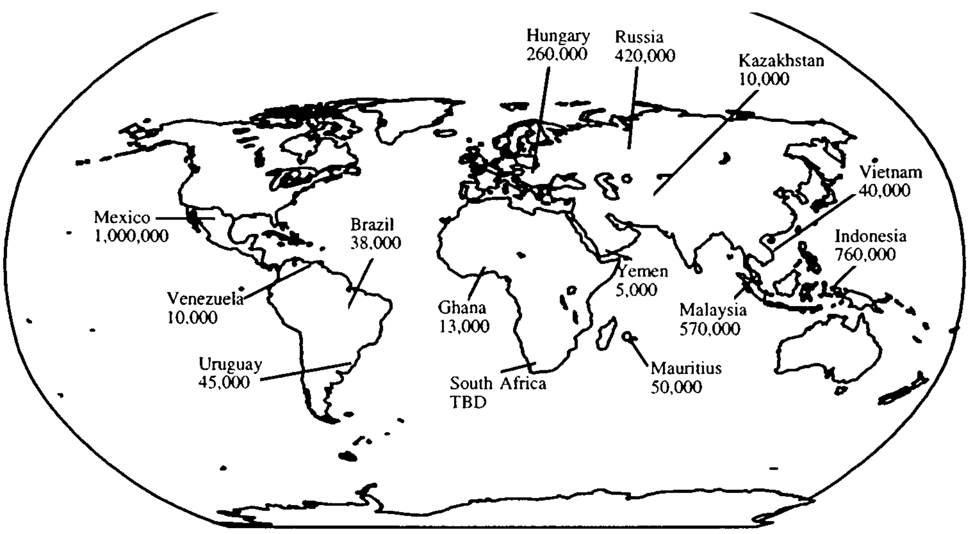


FIGURE 3

WLL Subscribers, Contracted vs. Installed

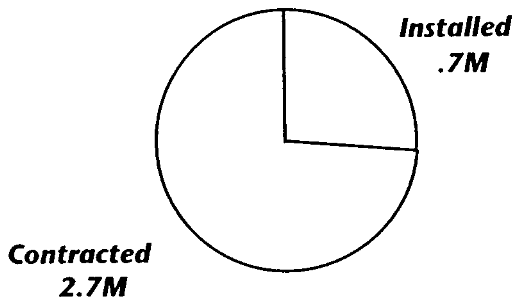


TABLE 1

WLL Uptake Hamstrung by Regulators

Mexico
- *94:* Iusacell requests first WLL license
- *95:* Telecom Law stipulates charges for spectrum
- *95:* Grupo Pulsar abandos WLL plans
- *96:* Telinor granted local concession
- *96/97:* WLL frequency auctions

India
- *96:* First WLL trials
- *96:* DoT issues tender for WLL equipment
- *96/97:* WLL tender pushed back to 1997

China
- *93:* First supplier tries to implement WLL
- *96:* Trials of WLL begin

using wireless local loop for 97,000 of these lines. Wireless local loop is also being used in some cases to provide affordable rural service. In Hungary, Matav uses wireless local loop for this purpose, and in Russia, Tatincom uses wireless local loop as a hybrid fixed mobile service for its subscribers. Finally, wireless local loop can be used to provide service for small business applications.

Wireless local loop has been a buzzword in the industry for the last couple of years. Regulatory authorities, operators, and vendors are all interested in wireless local loop because it has the potential to provide faster network build-out than is currently possible with copper solutions, and at a lower cost. WLL has the potential to fulfill rural needs where copper lines would be too difficult or costly to install. Also, WLL enables competition. With WLL, new operators can build networks quickly in competition with entrenched providers. Finally, wireless local loop offers flexibility: The system can be expanded as demand grows, and wireless local loop systems can be moved from one area to another as copper-wire solutions become available.

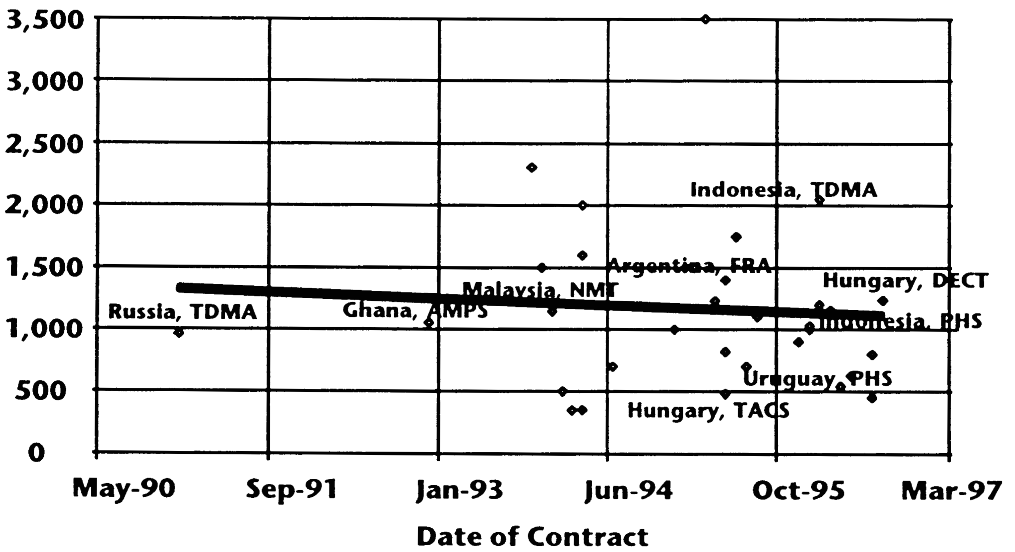
Despite wireless local loop's potential to provide a low-cost alternative to copper, deployment has been slow. As *Figure 3* indicates, a wide disparity exists between the number of subscribers contracted and the number of subscribers actually installed in the top nine emerging wireless local loop markets as of year-end 1996. In total, emerging markets by the end of 1996 had less than 1 million installed subscribers.

Obstacles to WLL Uptake

There are several reasons for wireless local loop's slow uptake. Delayed licensing, spectrum allocation, and pricing have dampened wireless local loop rollout in virtually every major emerging market. Of these reasons, spectrum allocation is the single most important. Wireless local loop's success depends on efficient use of scarce frequencies, adequate allocation of frequencies by regulatory authorities, and compatibility with a wide range of standards. Wireless services are gobbling spectrum, and how regulatory authorities choose to allocate this resource will have a significant impact

FIGURE 4

WLL Pricing Based on Selected Contracts



on start-up cost, network expansion, and the level of competition. Spectrum allocation is likely to differ significantly from country to country depending on objectives.

Regulatory issues have held up wireless local loop uptake in some of the biggest potential markets, as regulatory authorities continue to struggle over how to define wireless local loop services, license operators, and allocate frequencies. In Mexico, for example, the regulatory authority has dragged its feet on frequency allocation for wireless local loop, delaying network rollout indefinitely (see *Table 1*). Mexico opened local services to competition during 1997, and operators such as Telinor are planning extensive wireless local loop rollout to compete with the former entrenched monopoly, TELMEX. In India, repeated delays have stalled plans to license operators by the Department of Telecommunications in twenty-one regional circles, pushing network build-out plans well into 1997 and possibly beyond. Although China's MPT has yet to adopt a national standard, local and provincial authorities have deployed the first pilot wireless local loop systems. However, widespread acceptance still hinges on the MPT's decision.

FIGURE 5

Wll Subscribers by Standard

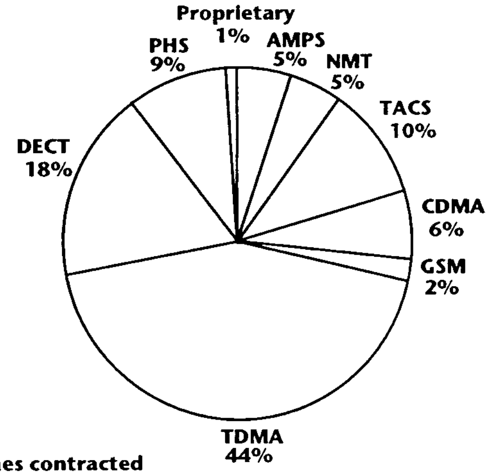


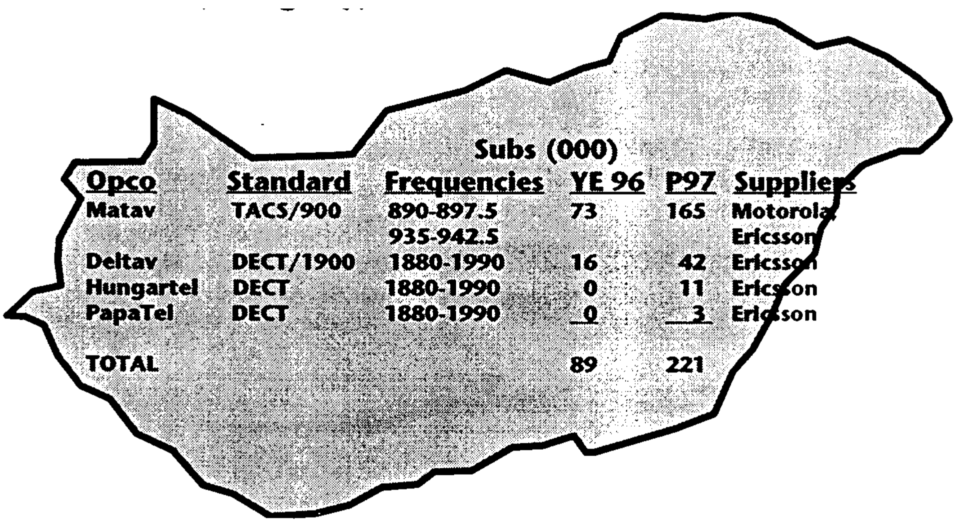
Figure 4 helps explain the pricing obstacles to WLL uptake. It shows wireless local loop pricing based on contracts awarded between 1990 and 1997. Although a growing number of wireless local loop contracts are coming in below $600 per line, the average still ranges between $800 and $1,200 per line, which is a competitive—although not a compelling—alternative to copper. Many of the most aggressive plans for wireless local loop hinge on attaining price points of around $500 per line. Such prices have made wireless local loop attractive to operators such as Matav in Hungary and Entel in Uruguay, which have made significant wireless local loop procurement decisions in recent years. However, pricing at that level has remained elusive for most other carriers.

Wireless local loop uses a wide array of standards (see *Figure 5*). No single wireless local loop product adequately addresses the broad range of applications, performance specifications, and population densities typical of emerging markets. Analog cellular wireless local loop systems are probably the least expensive. However, voice quality suffers, and less capacity is available on these systems. Their best use is for hybrid fixed / mobile applications. Proprietary systems are more flexible in terms of the spectrum they can use, and they promise faster data rates. However, these systems are unproven and cannot offer mobility. Their best use is for newly licensed operators in competition with incumbent carriers. Finally, cordless access systems provide a low-cost, low-power solution, and they promise faster data rates. However, cordless access systems cover smaller cell radii and are, therefore, best used in dense urban settings and for hybrid fixed / mobile applications.

Wireless local loop also has been held up because it does not typically offer quality of service equivalent to copper-line. Voice quality continues to be an issue, particularly for analog cellular-based systems. Also, most commercial implementa-

TABLE 2

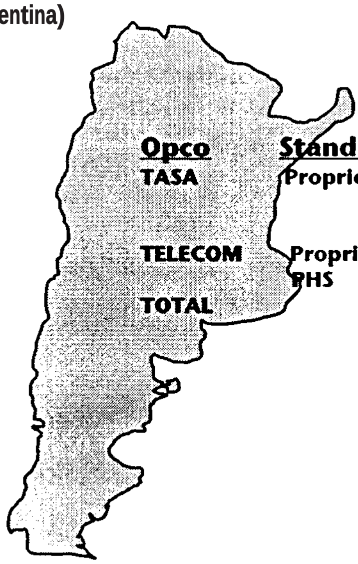
MATAV (Hungary)



Opco	Standard	Frequencies	Subs (000) YE 96	Subs (000) P97	Suppliers
Matav	TACS/900	890-897.5	73	165	Motorola
		935-942.5			Ericsson
Deltav	DECT/1900	1880-1990	16	42	Ericsson
Hungartel	DECT	1880-1990	0	11	Ericsson
PapaTel	DECT	1880-1990	0	3	Ericsson
TOTAL			89	221	

TABLE 3

TASA (Argentina)



Opco	Standard	Frequencies	Subs (000) YE 96	P97	Suppliers
TASA	Proprietary	1910-1930 3425-3430 3475-3480	6.5	TBD	Tadiran
TELECOM	Proprietary, PHS	Same	6	51	Tadiran, NEC
TOTAL			12.5	51	

tions provide data speeds of only 9.6 kbps. However, some of the digital and proprietary systems are addressing these issues and making improvements to voice quality and data rates.

Case Studies

Pyramid Research interviewed several wireless local loop operators to determine the reasons they selected WLL, the standards they chose, how they chose a vendor, how well the system has performed since installation, and, finally, future deployment plans. This section will look at the responses from Matav in Hungary and TASA in Argentina as case examples.

Hungary

Matav, the former state-run monopoly provider in Hungary, was privatized in December 1993 and Magyarcom, a consortium of Deutsche Telecom and Ameritech, now owns 67 percent. In 1995, Matav transferred 18 of its 54 primary districts to private companies that will provide local telephony in their respective concession areas. Matav, Deltav, Hungartel, and PapaTel all currently provide wireless local loop systems, and the country's cellular operators are not permitted to provide these services (see *Table 2).*

Deployment Status. In June 1995, Matav awarded a $100 million contract to Motorola for the installation of 200,000 lines of analog WLL. Initial plans called for the installation of all 200,000 lines by year-end 1996. By mid-December, however, capacity was installed for only 100,000 subscribers and service was actually provided to 65,000. Even though installation has been behind schedule, Matav still believes that the roll-out was faster than would have been possible with a copper solution.

Technology Choice. The overriding factor Matav cited for choosing wireless local loop was price. Motorola's system cost approximately $500 to $600 per line, which is much less expensive than a copper solution. The need for rapid deployment was another key factor in Matav's selection of wireless local loop. Matav is required to provide a certain number of lines, and the company uses wireless local loop for 40 percent of them.

Standards. The standard Matav chose was an analog wireless local loop system, which was the best standard available in the 890B897.5 MHz and 935B942.5 MHz bands that it was assigned for wireless local loop.

Vendor Selection. Matav held a competitive tender in 1995 and tested systems from Ericsson, Nokia, and Motorola. Nokia was eliminated from contention due to the high price of its wireless local loop system in comparison with Ericsson and Motorola. Motorola subsequently won the contract for offering a better price and a faster deployment schedule than Ericsson.

Performance. According to Matav, the Motorola system provides acceptable voice quality, although it is not equivalent to copper. Matav's wireless local loop network provides fax transmission at 9.6 kbps and data transmission at 7.2 kbps.

Future Deployment. Looking to the future, Matav has begun evaluating code division multiple access (CDMA) wireless local loop. The company wants a system that will be able to provide integrated services digital network (ISDN) and high data rates. One of the options that Matav is currently evaluating is the CDMA wireless local loop system that Motorola is trialling in Warsaw.

Argentina

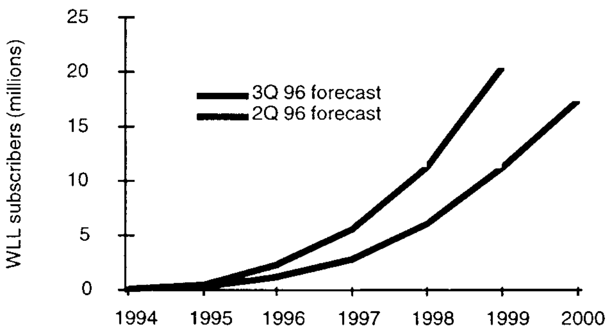
TASA and Telecom were formed as a result of the privatization of the former state-run provider, Entel, in 1990. *Table 3* provides summary statistics for these two organizations.

Deployment Status. TASA provides coverage in 53 percent of Argentina, concentrated in the southern region of the country. Telecom holds a license to operate fixed wireless service in the northern half of the country, and Argentina's five cellular operators are not permitted to provide wireless local loop services. TASA issued a tender offer for wireless local loop equipment in late 1995 and subsequently awarded the contract to Tadiran. Installations began in 1996, and by year-end TASA reported approximately 6,500 subscribers in service, principally in suburban areas around Buenos Aires. Investment requirements for the project are about $8 million. Initial investment plans were for $25 million to $35 million and for the installation of 25,000 lines of wireless local loop, primarily in rural areas. However, the original plans were scaled back, possibly due to the high price of wireless local loop.

Technology Choice and Price. The overriding factor that TASA cited for choosing wireless local loop was its ease of installation, which allowed the operator to extend coverage to areas where no existing copper or outside plant was available. Price will be a key factor in determining TASA's future wireless local loop plans. At $1,250 per line, TASA's system is comparable to the cost of a copper-wire solution. TASA chose a proprietary system from Tadiran because it was the only system capable of operating in the 3,425B3,430 MHz and the 3,475B3,480 MHz bands. TASA tested the personal handyphone system (PHS), but found problems with its interface to public phones. TASA anticipates digital European cordless telephony (DECT) frequencies and 900 MHz cellular to become available in the future.

FIGURE 6

Wireless Local Loop Forecast



Vendor Selection. TASA conducted trials of Nortel's and Siemens' systems, and it awarded the contract to Tadiran because its equipment complied with all the technical requirements specified, whereas Nortel and Siemens did not satisfy as many. TASA considers the system's voice quality and fax capabilities acceptable.

Future Plans. TASA's plans for wireless local loop in the future seem to hinge on the development of a regulatory policy for the allocation of spectrum. TASA hopes that the appropriate frequencies become available for more open standards, such as DECT. Reduced costs, economies of scale, and vendor interoperability—especially between the terminal equipment—would be the key advantages of an open system. Another key factor for TASA's future will be the ability of wireless local loop systems to extend coverage to rural areas cost-effectively.

Outlook

Despite recent setbacks, the future of wireless local loop continues to look bright. Pyramid Research has pushed back its forecast for wireless local loop, but we still expect it to be a substantial market with approximately 17.4 million subscribers by the year 2000 in emerging markets and just under $7 billion in cumulative infrastructure between 1997 and the year 2000 (see *Figure 6*).

Demand for wireless local loop will be driven by its anticipated advantages over copper-wire solutions such as speed of deployment, price, and suitability for applications such as extending coverage to rural areas and enabling competition. WLL will offer improved voice quality and data rates, with the potential of evolution to wireless broadband. The accelerating trend toward privatization and deregulation worldwide will encourage wireless local loop uptake, particularly in emerging markets, although deployment patterns will vary and the market will be characterized by fierce vendor competition.

On Implementing Personal Mobility in the North American Network

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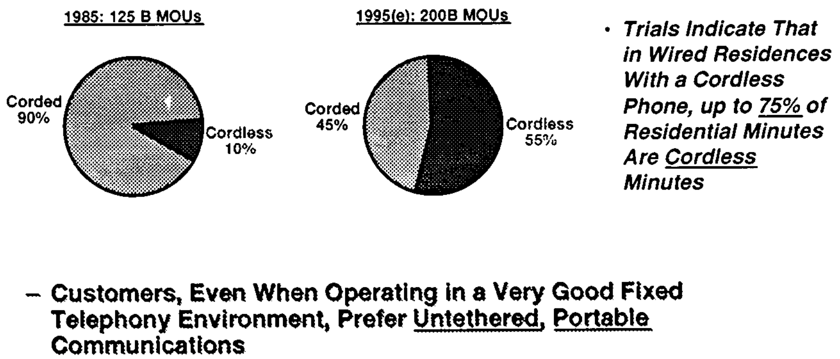
FIGURE 1

The User Speaks **Cordless telephony Penetration in the U.S.: 1985 to 1995**



As can be seen in *Figure 1*, customers prefer untethered, portable communications, even when operating in a very good fixed telephony environment. Trials indicate that in wired residences with a cordless phone, up to 75 percent of residential minutes of use (MOUs) are logged on the cordless phones. Users like to roam. They appreciate mobility—the ability to migrate from place to place with the same services—and would like to have that mobility supported electronically. This paper provides an overview of personal mobility and how it differs from the mobility currently available, outlines options for implementing personal mobility in the North American network, and concludes with a discussion of the future of mobility.

What Is Mobility?

Mobility is the ability for telecommunications users to move from place to place with the same services. This type of mobility exists in a variety of existing communications services, including cellular telephony, paging, and cordless telephone. However, there are many other mobile services that do not require a mobile terminal. Consider, for example, calling cards. Calling cards allow subscribers to originate from foreign phones while billing the call to their home numbers. The service supported is the origination of a telephone call, and the mobility demonstrated is that of billing. The succeeding section discusses some types of mobility and states how the calling-card example fits within them.

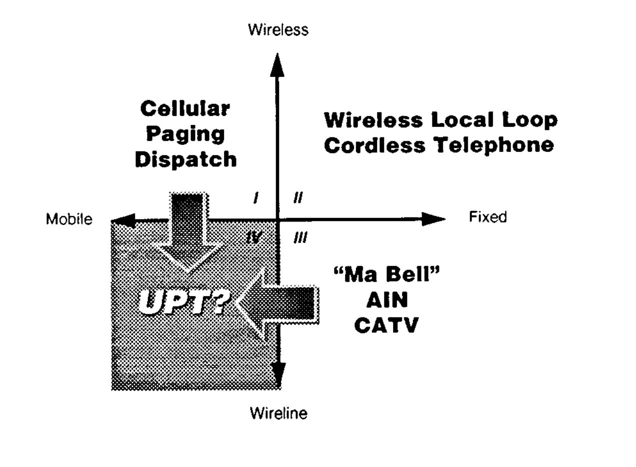
Types of Mobility

There are three types of mobility: terminal, personal, and service. Terminal mobility describes users' ability to take their terminal (such as a phone or a pager) with them and still receive service. This type of mobility is seen with cellular phones and roaming. For this type of mobility to function, both the home and visited networks must provide similar system capabilities, such as a physical interface. For example, a North American cellular phone simply will not work in Europe.

Personal mobility is the users' ability to bring their identities with them and receive service using a terminal wherever they happen to be. For example, in the global system for mobile (GSM), this type of mobility is well supported by the separable subscriber identity module (SIM) card. The SIM card detaches from the phone and can be plugged into another handset, which enables it to receive the same services as the first, independent of the physical interface to the network. In GSM, there are two common frequency bands used within Europe: 900 Mhz and 1800 Mhz (also referred to as DCS1800). While dual-band phones are possible, the separable SIM allows a subscriber to use either system through a single-banded (dedicated) phone. Even with personal mobility, limitations exist. Some network-based services, such as voice-activated dialing (VAD), may not be available in all locations, even when the subscriber identity is known. Voice-activated dialing difficulties stem from basic issues: if the service is provided by the user's home network and the user

FIGURE 2

Mobile vs. Wireless



is roaming at a great distance, it is not practical to use this feature due to the significant backhaul cost and delay associated with starting the call, speaking a name, calling back to the home network, and returning a routing number. Even if the local network offers voice-activated dialing, the user's dictionary would have to be transferred, with the hope that such dictionaries are compatible.

These difficulties lead to service mobility, or the third type of mobility. Service mobility describes the ability for users' services to follow them as they move about networks. True service mobility would likely require a broadband signaling network, which is several years away, as well as significant standardization efforts regarding compatibilities. One near-term example of service mobility is Java. The Java environment uses a common virtual machine (the Java Virtual Machine) that is locally implemented and conforms to the Java API specification. Java applications, called applets, can be moved around the network and will execute everywhere as long as the Java Virtual Machine implementation is conforming. While not from the communications domain, the Java example highlights the amount of commonality required for such mobility.

Table 1 places some existing services into the categories described above.

Mobility vs. Wireless

It is not necessary to be wireless in order to be mobile, nor is being wireless necessarily being mobile. *Figure 2* helps clarify this distinction. The telecommunications arena is divided into four quadrants, where the first covers existing capabilities. Quadrant III represents wired and fixed services, such as telephone or cable television (CATV) service and advanced intelligent networks (AIN). Quadrant II signifies wireless and fixed, covering mostly transmission equipment such as wireless local loop, cordless telephone, or direct station select (DSS). Quadrant I represents the traditional mobile arena, including paging and cellular service. Quadrant IV (mobile and wired), unlike the others, is not very well addressed. This is the area of universal personal telecommunication.

Universal Personal Telecommunications

Universal personal telecommunications (UPT) is a set of standards defined by the International Telecommunications Union–Telecommunications Sector (ITU-T) to support personal mobility, where "the fixed association between terminal and user identification is removed." UPT services include authentication (to verify the bona fides of the user), registration for location update, InCall for call delivery for incoming UPT call, outgoing UPT call (OutCall) for call origination, and more than twenty optional services. UPT has been trialed in Europe and was found to be a good service, but not a big commercial success. This may be due to the fact that UPT was a new service and people did not know enough about it to be interested.

There are certain notable differences between UPT and cellular. Cellular currently provides many of the same services as UPT: roaming supports essential UPT services such as registration, call delivery, and the ability to make outgoing calls if there is a roaming agreement between the two carriers. However, there are several services that cellular does not support. One of these is mobility-to-fixed terminals. Except for

TABLE 1

Existing Services

Service	Category
Calling Card	Personal Mobility
Call Forwarding	Personal Mobility
Cellular Roaming & Hand-Off	Terminal Mobility
Nationwide Paging	Terminal Mobility
Cordless Phone	Terminal Mobility
"One-number" Service	Personal Mobility
"Plastic Roaming" (smart-card based subscriber identities)	Personal Mobility
E-mail	Service Mobility
World Wide Web	Service Mobility
Local Number Portability	Personal Mobility

FIGURE 3

AIN–Based Personal Mobility

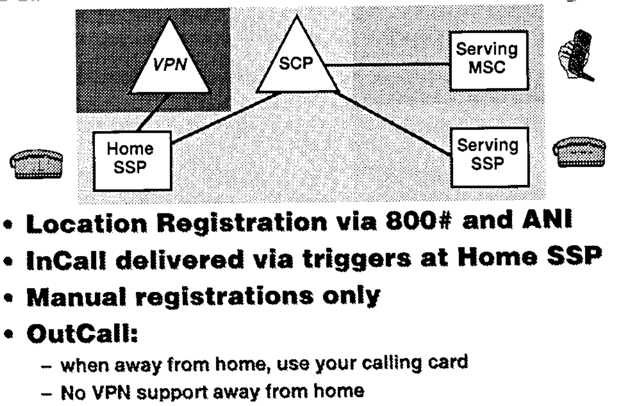
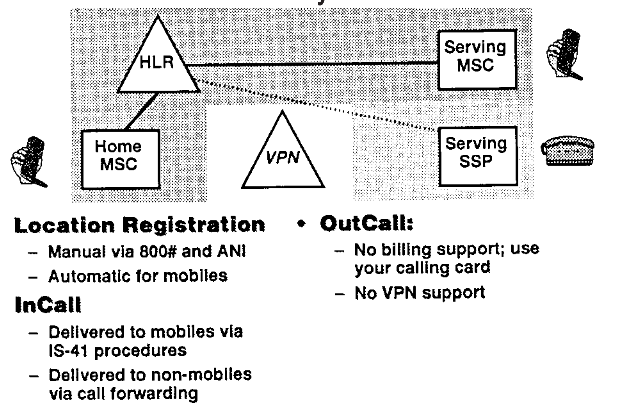


FIGURE 4

Cellular–Based Personal Mobility



the five percent of North America that uses PCS1900 (GSM in North America), it is not possible to separate the user's identity from his or her terminal. Cellular also does not support intelligent network services, although it will when wireless intelligent networks (WINs) are deployed. Finally, cellular does not have very good integration with fixed network services such as the virtual private network (VPN).

Implementation Options

Given the current state of the North American network, there are three ways in which true mobility could be achieved: AIN-based, cellular-based, and Internet-based personal mobility.

AIN-Based Personal Mobility

The first possibility is to leverage the capabilities of AIN to provide mobility. In AIN-based personal mobility (see *Figure 3*), users have home bases—places where they are located most often—and from which the personal mobility service provider is accessed. This service provider provides service from the service control point (SCP). In this instance, location registration is a manual process. The user would call an 800 number and enter an ID number and a PIN. It would also be possible to have a shortcut for configuring from the home location. Remember that in the wired mobile case, the home location is well known.

Given that the user's location is registered, a trigger can be set in the home service switching point (SSP) so that a call to the user's UPT number triggers a request to the SCP for routing directions. Information regarding the destination UPT number (as multiple UPT users can be registered at a given terminal) as well as the calling party identification will be sent to the destination for presentation.

One of the most positive aspects of the InCall part of this approach is that billing is quite straightforward—a billing record is generated for both the initial call as well as for the forwarding leg. But, as mentioned, there are only manual registrations. There is no way to automatically register, even from the mobile network. It is possible that at some time in the future, service providers and cellular operators could determine a way to arm WIN triggers, but this is not an option today.

When away from the home location, OutCall subscribers must use a calling card to receive the bill at the right address, and there is no VPN support. Both of these are potentially major problems. AIN-based personal mobility, then, only offers the ability to have calls delivered from the home to wherever the user may be, which is already possible through the use of pagers or mobile phones.

Cellular-Based Personal Mobility

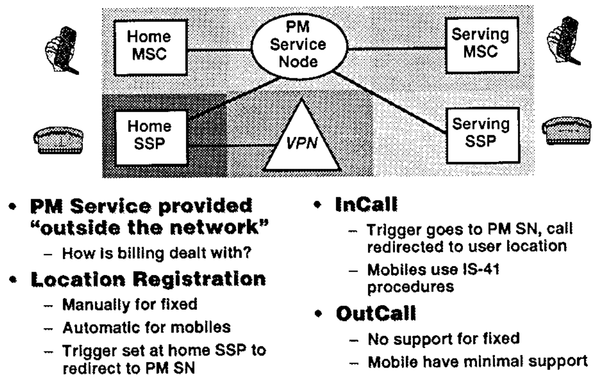
Another approach for UPT implementation is to leverage the capabilities of mobile networks. *Figure 4* shows how cellular-based personal mobility could work. This arrangement begins with a cellular system consisting of a mobile switching center (MSC) and a home location register (HLR) instead of SSPs and SCPs. The support for personal mobility service involves a straightforward extension of basic cellular and mobility as it is today. The registration procedure is automatic on a mobile phone as long as the UPT user and mobile user are the same. Additional complexity comes from separating the terminal's inherent identity from the UPT user. The standards support this today, though it is doubtful that it is implemented. On a fixed phone, it is necessary to register manually, again through an 800 number, automatic number identification (ANI), and also through PIN entry.

Calls in this scenario are delivered to mobile phones via IS-41 procedures and to fixed phones via call forwarding. The billing for this scenario is straightforward, both for call delivery as well as for the forwarded leg of the call. One issue that complicates billing, both in this case and that of AIN-based mobility, is that the mobile party pays for air time in North America. Unless a way to separate the user identity from the phone is devised—such as the GSM SIM—the person to whom the terminal is registered will be charged regardless of who is using the telephone.

Cellular-based mobility has the same problem with OutCall that exists in AIN-based mobility. There is no explicit billing support, and it is necessary to use a calling card. There is also no VPN support in this scenario. If there is a roaming agreement, then the mobile subscriber will receive the bill rather than the UPT user.

FIGURE 5

Internet–Based Personal Mobility



Internet-Based Personal Mobility

Figure 5 shows how Internet-based personal mobility could work. The term "Internet-based" is mildly inaccurate; "outside the network" is perhaps more correct. This scenario involves a personal mobility (PM) service node somewhere, not necessarily inside the network. While billing is the nemesis of the UPT service in general, it is particularly problematic in this approach. Billing already exists in the network, but it is uncertain how the service provider for the personal mobility service will tap into that billing stream and which parts of the revenue it will share.

Location registration in this scenario uses the same approaches as those used in the previous two systems: manual for fixed units, automatic for mobile units, and a trigger set at the home SSP to redirect to the PM service node. Essentially, the service node will be treated as though it were inside the network. It is run by another carrier, but that carrier is not in the network. InCall will use the same mechanisms as those found in cellular-based mobility. By the same token, Internet-based mobility has the same problems with OutCall—there is no support for fixed units and minimal support for mobile phones.

The positives here include the fact that the InCall registration and InCall services are well supported in all of these models. User identification can be accomplished, albeit in a somewhat clumsy manner. In addition, extensions are limited to the (home) service provider.

On the other hand, there are several problems with Internet-based personal mobility. There is no fully integrated service and little or no VPN support. Additionally, outgoing UPT calls are not supported any more than they are with calling cards. Finally, the process of user identification and authentication must be simplified.

Discussion

While the indications are that mobility is an important and potentially huge and untapped service, the implementation approaches that seem most viable indicate many problematic issues. First and foremost is that the outgoing call is poorly supported. While it is inarguable that the ability to receive calls independent of location is valuable, without supporting the reciprocal service with equal ease, the UPT service is destined to failure. Other significant issues include operator revenue realization and user education. These are discussed in greater detail below.

Another problem is that the economic model is confusing. Revenue-sharing in this situation affects the fixed network engineering model in uncertain ways. No one has figured out a way to share revenues equitably, and there is no way to tell how much traffic will be generated on an SS7 network. Every call to a UPT user would require at least two AIN queries, which might call for additional switches, signal transfer points, and links, with very marginal increases in revenue to cover those expenses.

Another problem involves user education. Trials have shown that UPT will have to be sold aggressively. While it does offer many services that people will want, they must be reminded that they need these services. UPT will also require a certain amount of user training, which may further delay its success.

FIGURE 6

Worldwide 3G Standards

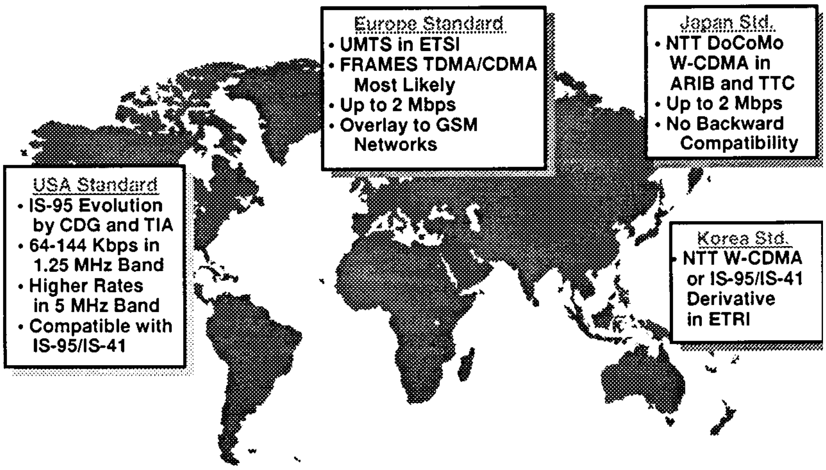
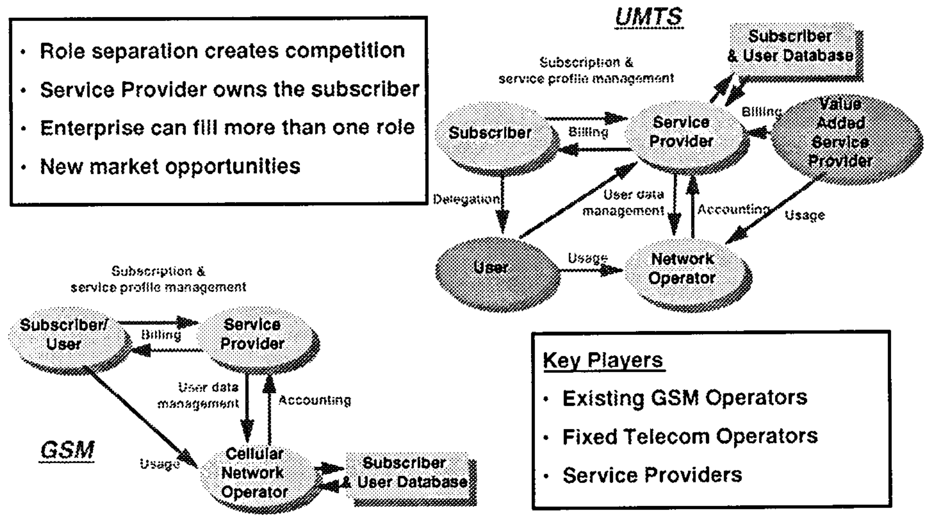


FIGURE 7

UMTS Commercial Model



There are several other smaller issues that will have to be addressed as well. One is that terminals are "stupid"—as the UPT service allows multiple parties to register at a given location, called-party identification becomes important. These, and many other similar issues, remain to be resolved prior to UPT becoming a real and broadly available service.

Third-Generation Cellular Technology

As evidenced by *Figure 6*, many regions of the world are currently working on what is being called third-generation (3G) cellular technology. Right now, Europe is fairly well ahead of the rest of the world in this area, focusing on a wideband code division multiple access (CDMA) approach. Korea is also making great strides. In the United States, there is a major effort being made by the CDMA development group and by the IS-136 TDMA group on third-generation standards. The Japanese have defined a new radio interface and a new network interface.

Many people in the industry believe that 3G is the solution to IS-41 / GSM interoperability. The ITU IMT-2000 supports terminal mobility, and it also supports UPT. However, IMT-2000 varies among regions. The European 3G is called Universal Mobile Telecommunications Systems (UMTS) and supports a "virtual home environment." Defined by the European Telecommunications Standards Institute (ETSI), a virtual home environment is a type of service mobility, but for a very small subset of services. These include announcements in the user's language, a service that demonstrated similar problems as voice-activated dialing.

In Japan, there are some very interesting concepts related to mixing terminal and personal mobility. One of these is the fact that multiple users can be registered on a mobile phone, which implies that the mobile phone is not a personal device, but rather a shared device. It could be a wireless conferencing phone, for example. Finally, in North America, 3G is largely undefined as yet, with significant differences between the CDMA and TDMA philosophies.

IMT-2000 requires global roaming. This presents an interesting problem, as IMT-2000 supports terminal mobility but has not defined global roaming very clearly. All of the regions mentioned above consider roaming across like networks, yet the networks of these four basic regions are not alike. As yet, there is no single technology that would unite the four global regions.

The UMTS Commercial Model

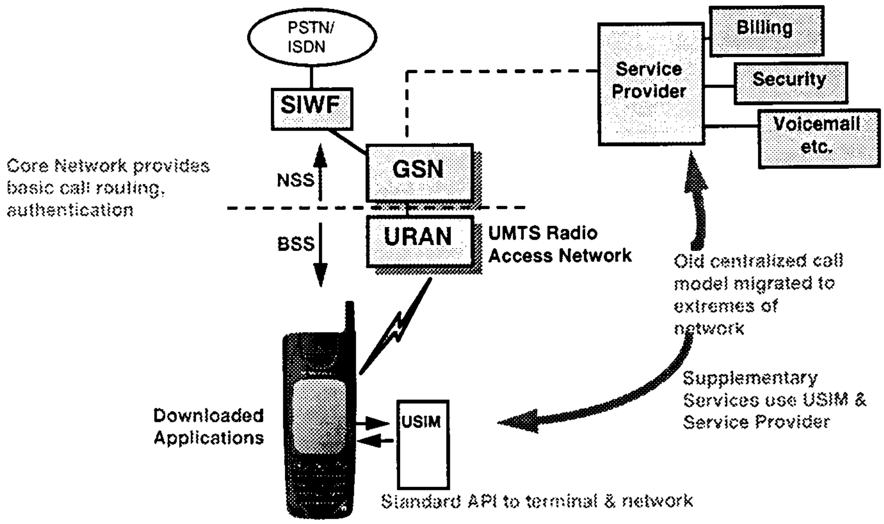
Figure 7 shows the commercial model that the UMTS community has presented, as well as the GSM view. It is interesting to note that in this view the user is not important—or at least not as important as the person who pays the bill. Also, the service provider and the network operator are very tightly coupled. In the UMTS proposal, the roles are changed for the third generation. Here users are identified separately from those who end up paying the bill, and users, as an entity, have a set of services to which they subscribe. Some of these services come from a service provider that may not own any radio resources.

Why switch from the older model? Many GSM-related entities want the change because they believe that by embracing these services, by moving outside the network, they will be allowed to focus on their strongest area: running networks. They can also be more competitive by leveraging other service providers that can be signed up as value-added service providers. In the UMTS commercial model, role separation creates competition. The service provider owns the subscriber.

In the Internet-based mobility model discussed above, billing processes are in question. In the UMTS model, where there is still a move outside the network, billing is

FIGURE 8

Service Plane



well defined. This "outside the network" service provider could receive billing information and service triggers as well as operating UPT service.

This UMTS model could also move some of the services away from the access network and into the terminal and the network. This concept is exemplified in *Figure 8*. Through increased focus on the service provider role, the access network would become a sort of a dumb pipe. Most of these services fall into the category of originating services. The terminal has support for those originating services, and, by collaborating with the service provider, it can receive and maintain them. One of those services could be a dialing plan, which, because of the virtual home environment and this extension, will work as well.

While this idea works for originating services, terminating services are still problematic: If the service is in the phone and the phone is unreachable, then where is the service? Proponents of the UMTS service still believe that this solution will be faster than trying to develop network-based or intelligent network–based mobility solutions.

There are classes of services that are very amenable to the approach shown in *Figure 8*, and it will be done this way in GSM extensions. It should also be noted that because the service is on the subscriber-identity module, the addition of another capability—the SIM tool kit—makes it possible to use various capabilities on the terminal. This means that the terminals are not stupid anymore, and that user identities are separable along with the services. Hence, this solution provides for both service mobility and intelligent terminals.

Another emerging service is mobile Internet protocol (mobile IP), which is another type of service where data is encroaching into the communications network. With mobile IP, the terminals themselves can migrate from place to place and maintain their IP address, which allows them to have access to their home services. This concept, shown in *Figure 9*, would support services in a manner similar to cellular mobility: location registration would be similar to location update, inbound packet routing would be similar to call delivery, and outbound routing would be similar to call origination. It is arguable whether mobile IP constitutes terminal mobility or personal mobility. This does not need to be determined immediately, since mobile IP is not yet robust enough for commercial service—it still has unsolved issues regarding authentication, billing, and (radio-level) mobility.

Different Perspectives

There have been a variety of reactions to these types of services. One of them, the operator perspective, has been largely one of disbelief. Many do not believe that these services could ever exist outside the network. Likewise, they are not sure why they should participate in these advances and are unsure as to what their cost benefits might be, since there would almost certainly be additional overhead.

The Internet community, on the other hand, has appeared fairly enthusiastic. Internet entities are excited by the challenges inherent in this type of system. If the phone network will not support these services, then the phone network can simply be used as a dumb pipe. Users can dial up to their Internet services providers (ISPs), who will provide service over this link. In addition, billing complications do not apparently daunt Internet parties—surely it should not be difficult to charge a fee at the ISP.

Finally, users are beginning to be more aware of and vocal about their needs, and they are enthusiastic about the prospect of this type of service, if somewhat skeptical about its advent. Users definitely want the ability to take their services with them. Many are already using ISPs, conference bridges, and other "outside network" services, and they have no trouble envisioning the expansion of these services. Finally, should they be expanded, users do not seem averse to paying more for mobility, which could provide great benefits to them in their communication needs.

Summary

It seems inarguable that personal mobility will eventually be a real service in the phone network. It will not, however, be in the fixed network in the near term. One reason for this is the disbelief on the part of the operators discussed above. Indeed, it is not unreasonable for these parties to be resistant to putting so much energy and expense into their networks with no certainty of return. It should be realized, however, that personal mobility might never be in the fixed network unless it can be proven to be a real service, one that can be commercially viable and create revenue.

This may be a moot point, however, if this and other teleservices are taken over by Internet telephony. If this happens, fixed and wireless operators may end up being reactive—struggling to figure out how to capture a large group of people who have migrated away from them. Above all, it is important not to discount the Internet as a source of competition. There is little doubt that within a relatively short period of time the Internet will provide real telephony with good quality service, low prices, and high availability. Certainly, it is critical for fixed and mobile telephony companies to understand the inevitability of personal mobility and plan accordingly.

Key Business Factors to Achieving Success in the Wireless Arena

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This essay explains the approach that Century Mobile Communications has taken to achieve success in the wireless communications industry. The company's approach is like a pyramid: It has a broad foundation in the chief executive officer's strategic plan, then becomes more narrow with a profile of Century's strategic strengths, and finally builds to a peak, which is the description of critical success factors in the industry. Those factors include customer service, quality networks, timely service delivery, and efficient operations. The common thread that runs throughout this discussion is that to get and keep a customer, the wireless service provider must deliver service that is fast, fair, and frequent.

To provide a little background, Century provides local, cellular, long-distance, Internet, and personal communications services (PCS) in geographic clusters located primarily in the Midwest and the mid-South. Century is the 12th largest cellular company in the country and the 16th largest local exchange company, with over 1 million customers.

Strategic Business Plan Elements

The foundation for Century's PCS wireless services is made up of the strategic elements that the CEO identifies, which cut across all business units—wireless as well as wireline. Providing convenience and choice for the customer through multiple services is one of these basic elements. Another is quality of service (QoS). The provider must make sure the wireless network provides a high degree of availability and does not allow calls to be dropped. Addressing customer needs is another critical element, and the provider must learn what the customer's needs are in order to be able to address them. Strong relationships—both with customers and with vendors—are also important. Vendors, in fact, are strategic partners in meeting customer needs. Maintaining strong relationships requires some effort—they cannot be accomplished simply by voice mail messages instead of direct conversations. Finally, employee roles are another key strategic factor. The company must communicate exactly what each employee's role is in the company from the top down, starting with the CEO. Adequately communicating roles avoids inefficiencies. These strategic elements are the foundation upon which all other business decisions are based.

Strategic Wireless Strength Profile

After identifying the overall directives and elements of the strategic business plan, the next step for a cellular company is to develop a wireless strength profile. What does the company do well?

For Century Mobile Communications, the first wireless strength is financial fortitude. Wireless is a very capital-intensive business and requires hundreds of millions of dollars in order to put infrastructure into the field. Cellular and PCS are not like an Internet start-up, where an entrepreneur can throw in a few bucks and work from his or her garage. In our type of business, a competitor must have the ability to acquire capital. Other strengths include management vision and the ability to communicate that vision to the employees. From management vision comes employee enthusiasm. If employees know what is expected of them, if management's goal is clear and clearly communicated, then employees will be enthusiastic about that goal.

Flexible pricing and speed to market, other important strengths, directly relate to one of the core strategic goals: providing choice and convenience for the customer. A wireless service provider should be able to react quickly to changes in the market. Wireless providers also must keep their core market share and, of course, try to build more.

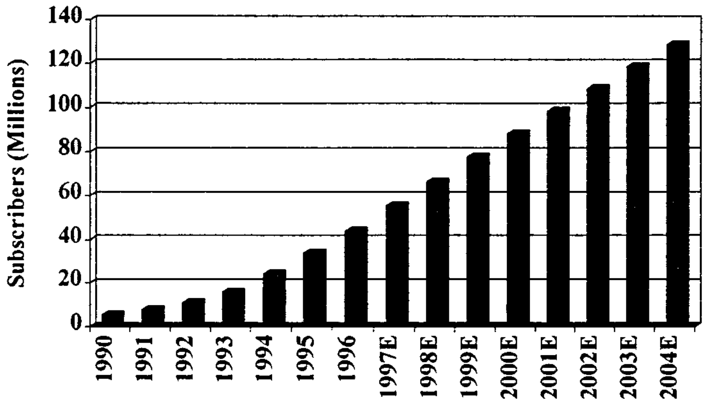
Not every wireless provider has the same strengths that Century offers. By extension, ours is not the only way to do business. As *Figure 1* shows, the wireless market has been growing steadily, and continued growth is anticipated through 2004. The other companies contributing to that growth do not necessarily have the same strengths as Century, but they all have some strengths on which they build to produce this kind of success and growth in subscribers.

Critical Success Factors

Four other strengths in the strategic wireless strength profile are customer service, quality networks, timely service delivery, and efficient operations. These are critical factors for success. These factors are necessary if a wireless provider is to compete effectively in acquiring and keeping customers.

FIGURE 1

Wireless Market Growth



Customer Service

In Century's case, customer service involves bringing together all services in a one-stop shop. Customers want timely and accurate billing statements that reflect Internet access, local service, long-distance service, PCS, and cellular service all in one bill. They want a readable bill. The detail-oriented accountants, for example, probably want to see detailed billing that reflects every call made. Other customers just want a bottom line. If that bottom line goes up or down 20 percent, they are satisfied. If it goes up 70 percent, on the other hand, customers will want to know why such a change occurred. The wireless provider needs to be flexible enough to provide billing that satisfies both types of customers: the detail-oriented and the "bottom line-er."

Another important aspect of customer service is maintaining a dialogue with the customer about value. That means being able to communicate to customers why they should stay with a firm rather than take their business elsewhere. We are endeavoring to do that today using technology and some of the new solutions that vendors offer. Another way to discuss the value of staying with your firm is through phone calls. The introductory call is a response to signing the contract in which the service provider calls to thank the customer for joining. It's also an opportunity to ensure that the customer is receiving a fair exchange: a worthwhile service for the money. Then, ten months later, two months before the contract expires, the provider calls again to say, "I hope you have enjoyed the service. We really want you to stay." This type of approach communicates to the customer that you care. Responding to customer needs quickly sends the same message.

Customer service also means transforming call-in situations into opportunities. Customer service representatives in the wireless industry take many calls each day, and most of them are negative. Customers call to complain that a call dropped or that they found a dead spot or they do not understand their bill. These call-ins, however, can be transformed from negative situations into positive ones. For example, a customer in Michigan was convinced that voice mail never worked. He did not want it, he saw no value in it, and he saw no reason to have it. This customer called in with a problem, and somehow the conversation turned to voice mail. He told the representative that he was so against voice mail that he even urged his friends not to try it. A short demonstration of the value of the product by the representative, however, proved to the customer that the voice mail system actually does work. It really does store all the messages, and he really can access them easily by calling his own number. The customer subscribed to the voice mail system and convinced his friends to get voice mail, too. This is a good example of transforming a call-in situation into an opportunity, of making the negative into a positive experience.

Expanding customer service technology and mining billing systems are other ways to provide positive customer service. Both of these approaches involve keeping track of the services a customer uses and deploying technology to meet needs in the most cost-effective way.

Quality Networks

The second critical success factor is quality networks. This involves technology, but customers in general really do not care what technology is used as long as they perceive quality as the result. They want a system that "stays up," and they want solutions to their needs.

Quality networks mean system capacity—getting a connection almost every time. It means features such as voice mail, caller identification, and short message service (SMS). It means offering a superior outage response time through having a core team of technicians in place who can respond to an outage and bring the network back up quickly. Note that in most cases, outage response time is not technology related; it is personnel related. It is a function of having a well-trained staff.

Vendor relationships are a part of a quality network as an extension of being a strategic partner. A good relationship with a vendor allows the service provider to try new services and build a quality network infrastructure.

Timely Service Delivery

A third critical success factor is timely service delivery—that is, sales, distribution, and the policies and procedures that allow sales to be handled efficiently. "Sales" means more than just selling the product; it means making sure customers' needs are fulfilled and that they receive what was promised.

TABLE 1
Summary

Wireless Strength Profile
Critical Success Factors
Customer Service
Quality Networks
Timely Service Delivery
Efficient Operations

New distribution channels can contribute to timely service delivery. Century has expanded into Wal Mart, Radio Shack, and its own retail stores. In addition, the company uses direct marketing more frequently. Distribution is no longer just a business-to-business relationship. Instead, we are reaching the end customer directly. Consequently, the company must provide a product that appeals to consumers rather than just to businesses. Finally, operating policies and procedures hold together all of the people who make up sales and distribution.

Efficient Operations

The last critical success factor is efficient operations. Wireless providers must reduce customer acquisition costs by providing innovative pricing plans on the handset. The old method of giving the handset away is very, very expensive. If the customer base turns over by 1.5 to 2.5 percent monthly, the company gives a $350 handset away to 1.5 to 2.5 percent of customers every month—all while producing an average revenue of only $50 per customer. At that rate it would take seven months just to break even on the handset, not to mention the cost of the rest of the infrastructure. Hence it is very, very important to keep customer acquisition costs down.

Investment in departmental communication technology allows the sales and distribution staff within the corporation to communicate. Reducing interconnection and transmission costs is good engineering that promotes efficiency. Bundling services meets customer demand at the same time as it lowers the cost of advertising and sales campaigns. A careful infrastructure investment is also good engineering that any efficient company must pursue. Pricing to acquire and retain customers is a necessity, though it can be both a plus and a minus at the same time if a plethora of pricing plans lead to customer confusion.

Summary

What did Century Mobile Communications do to pursue success in the wireless arena? *Table 1* recaps the steps. We took the CEO's strategic business plan and used its tenets as pillars upon which to build. Next, the company narrowed that plan down for its wireless business unit, focusing on Century's strengths and developing a wireless strength profile. Then we identified four critical success factors that are necessary for success in the future: customer service, quality networks, timely service delivery, and efficient operations. In summary, then, wireless services providers must always remember the three "F"s—they must endeavor to provide service, which is fast, fair, and frequent.

A New Paradigm—Broadband Digital Wireless

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This paper examines the past, present, and future of wireless communications with an emphasis on the role of broadband digital radio technology. AirNet Communications Corporation is a world-leading pioneer in the introduction of such equipment, and the case is made here that this technology creates a true paradigm shift. The paper presents many aspects of the wireless broadband technology paradigm, verifies its robustness for commercial application, and provides a glimpse of how different the future of wireless will become as broadband equipment enters the market.

Introduction

Cellular technology is well over a decade old, yet it remains a rapidly evolving discipline. The early analog systems suffered from their own success and quickly ran low on capacity in dense urban areas. Worldwide deployment of second-generation digital systems has been underway for several years, and these systems are now undergoing the fine-tuning required of any new technology functioning in a complex, real-world environment.

Providers hope to obtain greater capacity from the new digital protocols but must deal with the quandary of making complex choices concerning protocols and equipment. The protocols chosen must be compatible with their service area and equipment suppliers, and they must permit easy integration of new equipment into existing infrastructure. Cellular providers must also deal with potential future competition from wireline, cable, and satellite media that are also expanding their service options. Success is by no means assured in the face of more competitors, services, and complex technology; the odds will favor providers who have made choices that do not lock them into expensive and rigid technology that is not easy to upgrade.

The PCS arena presents much technological uncertainty, offering a plethora of options to service providers. Not all of these technologies are firmly proven in the field, and issues over voice quality, system capacity, realizable cell radii, and other concerns will have large effects on a provider's startup costs, revenue, and eventual market penetration.

Even as the second generation of wireless is being deployed, a third generation of cellular infrastructure is emerging. This new generation justifiably represents a new wireless paradigm, involving a broadband transceiver system (BTS), with all signal processing being done digitally. The BTS permits one broadband (5 MHz) radio to do the work of many narrowband transceivers. This new approach provides great flexibility to the provider, because the base station (BS) is programmable much like a digital computer. As the demand for services changes, the base station can be reprogrammed to encompass new contexts. This architecture is intrinsically lower in cost, maintenance, size, and complexity than traditional architectures.

This paper will discuss the pending choices facing service providers and will contrast traditional cellular techniques with third-generation wireless broadband base station technology. It is our belief that this new architecture introduces a wireless communications paradigm that provides far and away the most flexible approach to the high-technology, high-velocity wireless communication market of the future.

A Brief History of Cellular

Spurred by apparently insatiable demand, wireless communications technology has exploited innovative concepts in both digital information processing and radio frequency (RF) technology to reach its present status as a major worldwide industry. The growth of cellular capacity worldwide has been the result of innovations sometimes evolutionary. A history of commercial wireless services will provide a perspective on the state of wireless today and why wireless broadband technology is poised to play a major revolutionary role in worldwide wireless development.

Mobile Telephone System

The original commercial wireless systems were based on mobile telephone system (MTS) technology, which afforded its subscribers mobility in a local area. MTS systems used each RF channel only once in a given service area. The RF channels, all broadcast from a single base station, were operated at power levels high enough to ensure effectively that mobile subscribers would have continuous coverage provided they remained within the service area. Operating RF channels at high-power levels assured mobility to subscribers throughout the service area but prevented any RF channel from simulta-

FIGURE 1

Mobile Unit Entering a Handoff Region Between Cells

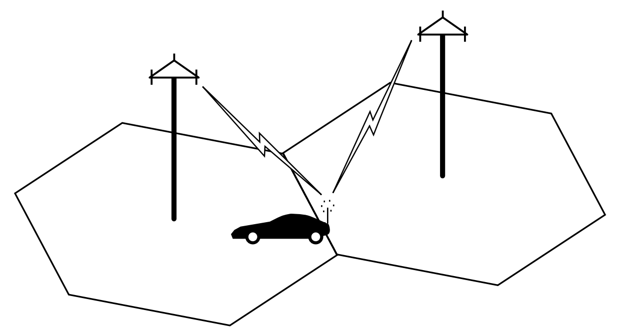
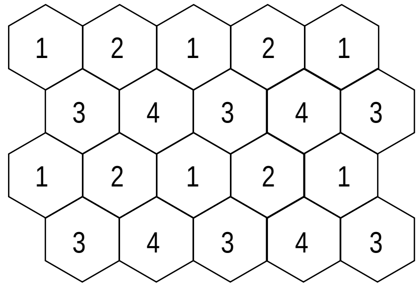


FIGURE 2

A 4-Cell Frequency Reuse Pattern



neously serving two customers within the service area. As a result, the demand for MTS services greatly exceeded the supply, and subscribers became accustomed to long queuing delays when attempting to place calls.

The Advent of Analog Cellular

The inability of the MTS industry to meet the apparent demand inspired the birth of cellular telephony, which addressed the huge imbalance between supply and demand by allowing reuse of each RF channel within a service area. This technique depends on operating the allocated RF channels at relatively low power levels so that an RF channel in use in one part of the area diminishes to an acceptably low interference level by the time it propagates to an area where the same channel may be used again. Since a cellular RF channel is used at a lower power level than with MTS, subscribers could not maintain continuous communications with a single BS as they moved about in the service area.

The cellular paradigm resolved this difficulty by using a new mechanism called handoff. Handoff involved a given mobile subscriber unit being automatically directed to change frequency to a new RF channel transmitted from a closer base station, at which moment the landline side of the call was also switched to the new base station. Handoff was thus a revolutionary concept that provided a large multiplier to the value of each allocated RF channel. The typical architecture of a cellular system is depicted in *Figure 1,* where the mobile unit is shown moving into the area of a new cell.

The first cellular systems all used analog frequency modulation (FM) to establish the radio links with subscribers and RF bandwidths of 25 or 30 kHz per traffic channel. In the United States, the advanced mobile phone system (AMPS) began with a total frequency allocation of 20 MHz per service provider, which was shortly expanded to 25 MHz to meet the rapidly increasing demand arising in major urban centers. The 25 MHz allocation of channels actually provided 395 traffic channels directly supporting subscriber conversations.

The Art of Frequency Reuse

Each AMPS service provider thus had up to 395 separate (but reusable) traffic channels available to generate revenue from subscribers, and a large body of practice grew up around the science of making the best use of those channels. The advent of the cellular paradigm permitted reuse of frequencies in a service area. In practice, frequency reuse adhered to the concept of dividing the whole RF channel set into subsets and then allocating those subsets to the cells so that a single subset was allocated to cells in a regular, repeating pattern as shown in *Figure 2*. This regularity of the reuse pattern ensures that reuses of an RF channel occur at a fixed distance from each other.

Figure 2 demonstrates a four-cell frequency reuse pattern, but many other patterns are possible. The choice of a reuse pattern is driven by the need to ensure that the interference level experienced by the receivers supporting a call is not too large to overshadow the valid signal information arriving at the receiver. From this arises the concept of the minimum signal-to-interference ratio (S/I) for a receiver, which is the factor by which the signal must exceed other RF energy at the same frequency in order for the subscriber to experience acceptable voice quality.

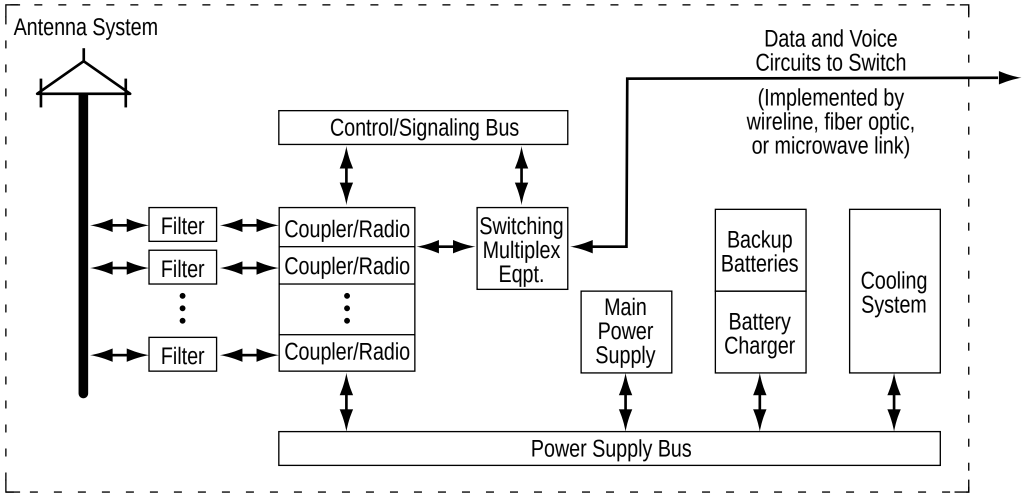
The minimum S/I needed in a cellular system depends upon the radio protocol in use; for analog systems such as AMPS, it is in the neighborhood of 17 dB. It is not difficult to calculate the average S/I expected for a specific frequency plan, and Table 1 shows minimum S/I values for a range of frequency reuse plans.[1] Some of these reuse plans include the use of directional antennas at each cell site to "sector" the cell into separate RF areas, which limits the direction of propagation of RF energy, lowering the average interference levels arising in nearby cells.

The number of channels per cell site that a provider may supply is primarily determined by what minimum S/I is possible for the RF protocol in use, which in turn determines the closest distance at which frequencies may be reused, which finally determines which frequency-reuse schemes have adequate co-channel spacing to support the minimum S/I specified. If a provider can use a four-cell reuse scheme, then a single cell site can offer one-fourth of all the allocated channels to subscribers in the cell. That is clearly better than using a seven-cell reuse scheme, which provides only one-seventh of all frequencies to a single cell.

The interference experienced by a receiver due to the reuse of the same RF channel in other cells is called co-channel inter-

FIGURE 3

Base Station Equipment Profile



ference, but a system designer must also attend to the fact that two adjacent RF channels (i.e., right next to each other in the allocated spectrum) should not be used in the same cell. This is because receivers generally cannot adequately reject RF signals very close to the frequency that they are tuned to, and some part of the adjacent channel signal may interfere with the receiver's assigned channel. Standard cellular system design uses an "every N-th frequency" rule in the frequency allocation scheme, meaning that if an N-cell reuse plan is to be used, a given cell will be assigned all frequencies mutually spaced N-channels apart. If the 395 traffic channels for AMPS are allocated among the 7 cells in a reuse pattern, the 7 frequency subsets will have the forms:

- Set 1 Channels 1, 8, 15, ,393,
- Set 2 Channels 2, 9, 16, ,394,
- Set 3 Channels 3, 10, 17, ,395,
- .
- .
- .
- Set 7 Channels 7, 14, 21, ,392,

comprising 56 or 57 channels available per cell.

The subsets of channels that have been allocated according to a frequency reuse plan may be further subdivided if the cells are sectored. A sectored cell subdivides the service area by using directional antennas, usually three with a main beamwidth of 120°, thus splitting the service area into equal "pieces of the pie." Directional antennas provide greater gain in the sector that they serve but transmit very little signal outside that sector.

Proper use of sectoring results in lower co-channel interference, but there is a tradeoff: even though the same number of channels per cell are available in a sectored cell, the cell can support fewer subscribers. This is due to the statistical principle of trunking efficiency, which states that as the number of channels available decreases, the number of subscribers that can be served at a fixed grade of service decreases faster. Thus, sectoring does not decrease the total number of channels per cell, but does decrease the number of subscribers that can be served in the cell if a fixed grade of service is to be maintained.

TABLE 1

90 Percentile S/I for Various Frequency Reuse Configurations

Frequency Reuse Configuration	90-percentile S/I
12-cell, omnidirectional antenna	20.8 dB
7-cell, omnidirectional antenna	14.2 dB
7-cell, 3 120° sectors	20.8 dB
7-cell, 6 60° sectors	24.9 dB
5-cell, 4 90° sectors	17.5 dB
5-cell, 3 120° sectors	16.2 dB
4-cell, omnidirectional antenna	8.3 dB
4-cell, 3 120° sectors	15.0 dB
4-cell, 6 60° sectors	19.4 dB
3-cell, omnidirectional antenna	5.6 dB
3-cell, 3 120° sectors	12.5 dB
3-cell, 6 60° sectors	16.7 dB
2-cell, 6 60° sectors	12.4 dB
1-cell, 6 60° sectors	7.8 dB

Limitations of Traditional Narrowband Cellular Systems

The first cellular systems used analog modulations and one RF channel for each subscriber's conversation. The implementation of a base station was essentially as shown in *Figure 3*. A base station comprised an antenna system (usually involving two or more antennas per sector), one narrowband transceiver per RF channel, and a number of telephone trunk lines over which subscriber traffic from the base station was multiplexed and connected to a traffic switch, allowing interconnection with the wireline telephone system. As can be seen from *Figure 3*, there is also a substantial amount of supporting equipment required at the base station.

In most systems, multiple base stations are controlled from a common site called the base station controller (BSC). The BSC maintains a global view of the operations at the base stations and is involved in the handoff process when a mobile station (MS) moves across a cell boundary.

Traditional narrowband analog systems required that many separate radios all be attached to a single transmit antenna as shown in *Figure 3*. Each connection of a transmitter to a common antenna must be filtered to prevent damage from the energy from all other transmitters combined to the same antenna, which introduces a significant loss (60 percent) between the transmitter and the antenna.

Another problem arises because the filters only work adequately if there is a substantial gap between the RF channels all attached to the same antenna. Traditional analog AMPS requires that this gap be around 20 RF channels, so only every twenty-first RF channel may be attached to a single antenna. This severely limits the frequency-planning possibilities for a cellular system, and, for analog AMPS, explains why the most popular frequency plan by far uses a seven-cell pattern with three 120 sectors per cell (i.e., every twenty-first channel per sector).

Another substantial limitation of the first-generation analog systems is the lack of downlink (base station to mobile) transmit power control. The analog cellular protocols did use uplink (mobile to base station) power control to preserve the battery life of the hand-held mobile units. The primary technique relied on measuring the signal strength of the MS-transmitted signal at the BS receiver, adjusting MS power up or down so that only enough power is transmitted to maintain a successful radio path. This process is called reverse power control, and besides the benefit of longer MS battery life, it results in less RF interference propagating in the system than would be the case if they all transmitted at full power all of the time.

But the mobile units were not designed to provide a symmetrical technique for controlling the power of the BS transmitter. This would require the MS to measure the signal strength of the BS signal it receives and report back some data to permit the BS to modulate its transmitting power on the downlink. Downlink power control can contribute greatly to the reduction of interference in a cellular system, which in turn can increase the average S/I ratio at the MS.

The lack of downlink power control seems to have led to a rule of thumb in the cellular industry, which is to use as much transmitting power as possible on the downlinks to the MSs. Depending on the equipment available, this means that many cellular operators are supplying between 40 W and 100 W per downlink to maintain a connection with an MS that may have a maximum transmit capability of only 0.6 W! This is clearly not an imbalance but instead a "better safe than sorry" approach constrained by the limitations of typical narrowband cellular technology.

With an operational downlink power-control algorithm, the cellular industry could use a better frequency plan (e.g., moving from N=7 to N=4). Unfortunately, the better frequency reuse would be difficult to implement because of the 21-channel spacing rule. Also, downlink power control would realize a savings on the order of 67 percent of actual transmit power needed at the BS, with concomitant savings in the cost of power supplies, battery backup systems, and air conditioning at the BS sites.

The Introduction of Digital Cellular

Traditional analog cellular represented a huge leap forward in capacity compared to the previous MTS systems. However, narrowband analog cellular still operated with one subscriber per channel and suffered from two intrinsic limitations that placed a ceiling on the capacities of systems: the 21-channel spacing rule imposed by multiple transmitters operating on a common antenna created a severe limitation for frequency reuse, and the inability to control power on the downlink created unnecessary interference, limiting the use of potentially "tighter" frequency-reuse plans, which would have permitted greater capacity per cell.

As time passed and lessons were learned from deployment of the first generation of cellular, scientists and engineers in major communications companies are learning from the past to design better systems for the future. While extant analog systems made evolutionary steps in the field, the advanced product teams in major corporations were busy birthing a revolutionary step—the advent of digital signal processing (DSP) techniques in voice communications.

A voice waveform can be sampled at a high rate and expressed digitally, and DSP scientists had already developed many ways of "compressing" digitally expressed information to remove the redundancy contained in the information. The purpose of this compression had been to make more efficient use of the communications bandwidth available in any transmission medium. It was well-known that voice could be compressed to 64 kbps but that did not yet translate into any improvement over FM analog voice requiring a 30-kHz RF bandwidth. However, while analog cellular was still cutting its teeth in the field, back in the laboratories voice-compression technology reached the point where a single voice conversation could be transmitted using only 8 kbps of digital data.

Also, new RF modulation technologies were emerging coincident with this improvement in voice compression. The large capacity of analog cellular compared to MTS was rapidly being absorbed by demand levels beyond the wildest dreams of economic forecasters, and the industry recognized that digital technologies and the decreasing cost and size of computational hardware pointed toward far more efficient ways to use the available spectrum. In the United States, the industry began the standards-definition process for digital AMPS (DAMPS), which transmitted voice digitally and used a modulation that could place a voice channel in one-third of the spectrum required for an analog voice channel.

The standards process took pains to create backward frequency compatibility with the existing AMPS system, and it did so by packing the voice information for three conversations into the same bandwidth previously occupied by a single AMPS call. This was done by splitting a single 30 kHz AMPS RF channel into a repeating cycle comprising six time slots, with a single DAMPS subscriber using only two of the six slots. A single subscriber channel now became effectively 10 kHz wide, which in theory tripled the capacity provided by the same spectral allocation of an analog AMPS system.

This technique, called time division multiple access (TDMA), was also being adopted by another major standard evolving from a cooperative European effort. The European community was defining a standard called global system for mobile communications (GSM), which also used voice-compression techniques and TDMA to pack eight subscriber channels into a 200-kHz RF bandwidth, with a given subscriber effectively using 25 kHz of bandwidth.

There is a distinction here with respect to digital-cellular techniques that contains valuable lessons. First, the use of 25-kHz subscriber channel bandwidth for GSM was partially due to a more generous bandwidth allotment for GSM digital voice encoding. In retrospect, experience with the two systems has shown that U.S. DAMPS voice quality is marginal in the judgment of most users, while the GSM protocol is now widely used and accepted throughout the world with good voice quality.

A second very important lesson is that the effective use of RF bandwidth for any cellular protocol is not just dependent on the RF bandwidth per subscriber channel. Within that bandwidth are transmitted the encoded voice, error correction data, and other data intended to allow the demodulation process to correct for deficiencies in the transmission path. Additionally, some RF modulation techniques are inherently more robust against interference sources: for example, FM commercial radio provides far higher quality audio signals than does AM radio.

The distinctions between RF modulation techniques and error-amelioration processes built into different cellular protocols imply distinctions between the minimum acceptable S/I ratios for the protocols. A lower acceptable S/I ratio means that the allocated RF channels for the system can operate in a frequency-reuse plan allowing closer spacing. For example, the GSM protocol has in practice been deployed in a 4-cell reuse pattern, while DAMPS is still used in the traditional seven-cell, three-sector arrangement of analog AMPS systems. Consequently, the apparent 25 kHz bandwidth of GSM actually achieves an edge over the DAMPS 10 kHz bandwidth (i.e., the number of subscribers served in a service area per Hz of available RF bandwidth is higher for GSM than for DAMPS).

In summary, the digital standards that have evolved or are evolving have provided many important lessons. First, comparisons of digital cellular standards as to capacity offered depend not only on actual DSP techniques and RF modulation, but also on how the systems actually reject interference. Second, just as in the analog phase of cellular, the final laboratory for testing these systems has proven to be the actual service areas, and many lessons can only be learned after deployment occurs and real subscribers use the equipment.

Most importantly, the real breakthroughs in increasing spectral efficiency have been driven by improved integration of computing power to control the modulation and spectral utilization. MTS yielded to analog cellular when just enough computing power could be built into mobile phones to permit them to be switched among RF channels while a call was active. Digital cellular became feasible when small, inexpensive digital signal-processing engines could be incorporated in the mobile phones. But there is another chapter about to be written and that involves the migration of high-computing power into the infrastructure equipment.

The Digital Advantage

The thrust of this paper so far can be summarized in one short phrase: the only constant in cellular/PCS technology is change. Besides the many new protocols already in service or emerging, there will be new services offered by wireline, cable, and wireless providers, and each will need to find ways to cope with a constantly changing competitive field. If ever the provider of wireless services needs a Swiss Army knife, the time is now.

A radically new cellular architecture that offers reduced equipment and maintenance cost, reduced need for real estate and site acquisition, simplified cell-site system architecture, unique frequency-planning agility, and considerable immunity to the vagaries of the many emerging standards will be described in detail. These claims will also be examined.

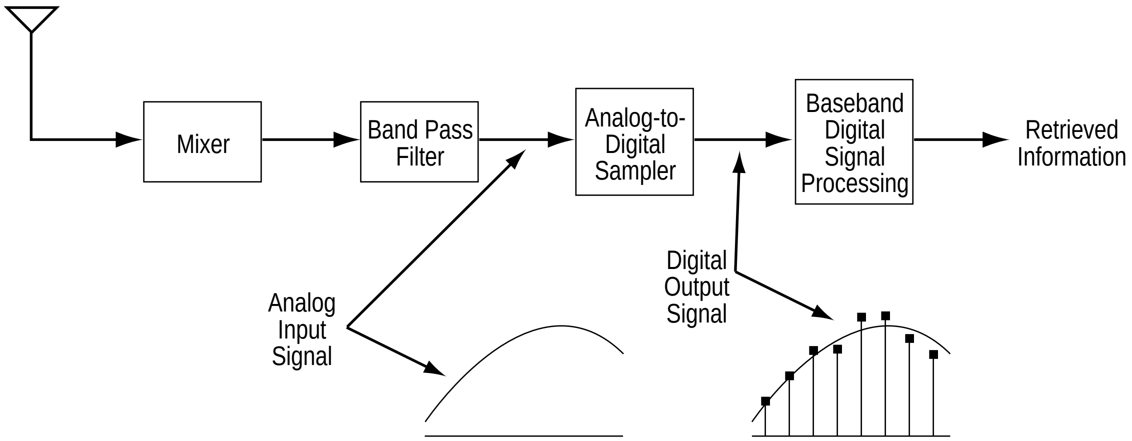
Digitizing Signals

Digital signal-processing techniques continue to benefit from faster and smaller integrated circuits, and, for a long while, engineers envisioned the day when a receiver or transmitter could be essentially an all-digital device. However, even an all-digital receiver still requires an analog “front end” (i.e., that part of the receiver that detects a signal from the antenna input and amplifies and converts it to a lower intermediate frequency (IF) signal).

The IF signal, in analog form, must be presented to an analog-to-digital converter, which is simply a device that samples the frequency at regular intervals and converts the voltage level at the sampling instant to a digitally represented value. The resulting sequence of digitized samples is then forwarded to further digital signal-processing circuits that condition the signal as desired and extract the transmitted information. *Figure 4* provides a schematic representation of such a conventional digital receiver.

FIGURE 4

An "All Digital" Receiver Architecture



The sample resolution determines how closely the sampled digital values conform to the input waveform.

The two most important parameters of the digital receiver are its sample rate and its sample resolution. An important theorem of digital signal processing, the so-called Nyquist Theorem, states that a signal must be sampled at a rate that is at least double the highest frequency of interest in the signal. The sample resolution represents the level of detail to which the sampled signal is recovered. For example, if the digitized samples only contain eight bits, then the recovered signal is one part in 256 or 28 bits. Obviously, higher sampling resolution provides a greater representable dynamic range (the multiplicative factor between the smallest non-zero signal value and the largest value representable in digital form). Perhaps the most familiar example of this process is the standard compact disc music format, with a sampling rate of 44.1 kilosamples / second, with each sample represented by a 16-bit quantity. The sample rate permits all frequencies up to 22.05 kHz (which exceeds the range of normal human hearing) to be preserved. The 16-bit samples permit 96 dB of dynamic range for the digitally recorded music.

What is Broadband Digital Radio?

The principles discussed above underlie the new digital communications protocols such as (DAMPS), GSM, and the CDMA standard. The advantages of digitization are broad enough so that one might refer to digital communications techniques as revolutionary, rather than evolutionary. Broadband digital radio is a revolutionary development, as it is based on the dual concept of broadband RF processing and a digital software-defined base station. Broadband radio refers to the capability of a radio to receive a very wide bandwidth of RF spectrum, as compared to a traditional narrowband radio.

While a standard cellular transceiver receives and demodulates a single subscriber channel (i.e., 30 kHz), the broadband radio receives a 5-MHz RF bandwidth,[2] and every other narrowband RF channel within that spectrum is available for both transmission and reception through that single transceiver). In an AMPS system, the single broadband radio can replace 84 standard AMPS transceivers. In a TACS system, 100 25-kHz channels are available, and in a GSM system, with a 200-kHz RF-channel bandwidth, a single transceiver can replace 12 or 13 transceivers and provide service for 92 to 100 subscribers.

Another large advantage accrues to broadband radios because there are no limitations as to which channels can be connected to a common transmit antenna. Channels no longer need to be at a minimum spacing to prevent narrowband transmitters from effectively destroying each other. In other words, only one transmitter is involved, and every other channel within the 5-MHz range of the transmitter can be transmitted on a single antenna. A single antenna could transmit every other AMPS channel (a maximum of 84) in its bandwidth, and there are no combiner losses of 4 dB to be reckoned with between transmitter and antenna. But the most significant advantage of this spectral flexibility is that many new possibilities open up for frequency assignment and frequency-reuse plans, as will be discussed in later sections.

Cellular systems using broadband radios thus gain a large advantage in simplifying base station architecture by eliminating the many radios and the consequent complex RF distribution and filtering structure. Broadband radios magnify that advantage by opening up a previously forbidden range of frequency-planning schemes, allowing very different ways of assigning channels and even permitting dynamic assignment of channels among cells to follow variations in traffic.

Thus, the broadband radio offers a large simplification in base station hardware and a great increase in the options available to the wireless system planner. But even with that, the broadband paradigm is only half revealed. The broadband radio is the RF front end for a completely digital approach to demodulating the subscriber channels as shown in *Figure 5*. Note that in the figure the wideband transceiver outputs a signal that has been converted to a very rapidly sampled digital representation of the 5-MHz received bandwidth. That digital signal then enters the Carney Engine that separates it into digital data streams representing all of the narrowband channels within the original 5-MHz bandwidth.[3] These separated signals are passed to circuit cards containing an advanced and very high-speed DSP architecture to be demodulated and converted to the baseband (i.e., digital voice) format required for the protocol in use. This entire architecture is called the AirNet broadband transceiver system (BTS). Because both the Carney Engine and the DSP cards of the AirNet architecture are controlled by software, the terminology "software radio" is used to describe the architecture shown in *Figure 5*.

This digital software radio architecture has several unique advantages over traditional narrowband approaches to wireless services. The first is that a single, unchanging hardware unit can be configured by software to perform many functions, and, in fact, to support many separate wireless protocols and services. This feature would not be of much value in a world where wireless protocols were static, but experience shows that new protocols and service options will continue to emerge.

A service provider operating a system using these BTSs can adapt the base station equipment to most major protocol changes with only a download of new software into the BTS and minor hardware changes. For example, a provider could switch from the 900-MHz nordic mobile telephone system (NMTS) to GSM, operating in the same frequency band with software downloads and small modifications to the RF front-end equipment in the BTS and BSS.[4] Of course, the product development cycle required to implement a new protocol is simplified, reducing the cost of the product and improving the time to market.

In fact, a provider can simultaneously support multiple protocols within a single BTS using the same antenna structures and backhaul infrastructure. A TACS / NMT-900 system, an AMPS / DAMPS system, a GSM / NMT-900, or GSM / TACS system are all possibilities, although the switching equipment required for these combinations is currently different. The provider would have the advantage in these cases of having a dynamically movable capacity boundary between the two protocols (e.g., if an AMPS / DAMPS system began with a large proportion of AMPS customers, who then migrated to the DAMPS, the BTS would not be changed in any respect, because at any moment its total capacity can be split in any ratio of (30 kHz) channels devoted to AMPS versus DAMPS.

Another large advantage of the broadband software radio is the capability to monitor conditions and exert real-time control at levels that are well beyond the scope of narrowband architectures. For example, AirNet has developed a four-cell frequency-reuse plan for analog TACS and AMPS and a three-cell frequency-reuse plan for GSM / PCS 1900 systems. Both of these configurations represent spectral reuse at higher levels than have been available before and rely on the highly resolved capability of the software-controlled BTS to analyze and adapt to the environment in real time. These frequency plans will be discussed below in much more detail.

This completes the top-level description of this latest revolutionary step in wireless architectures, and it is likely that this new paradigm will eventually overwhelm the narrowband wireless industry. The broadband / software BTS represents as profound a change in commercial wireless as did the move from MTS to cellular, as will be illustrated in the sections below. From this new perspective, the traditional techniques of cellular design must be viewed as of historical value only, and cellular system engineers must open their minds to very different ways of viewing the allocation of resources within cellular systems. The huge flexibility offered in this new architecture may result in the realization of power-control algorithms, channel-assignment techniques, and smart antenna systems with two to five times the capacities already offered by digital cellular systems. This process has begun with the three- and four-cell frequency-reuse configurations to be described in the following sections.

Transmit Power Demand in Broadband Systems

With the BTS, the downlinks for all subscribers are transmitted through a single amplifier. This amplifier must be linear over the entire 5 MHz of bandwidth served by the BTS. A cursory analysis of the power demand for such an amplifier can be misleading, however, if it is based on the traditional narrowband paradigm of supplying 40 to 100 watts per channel output from the transmitter.

If the narrowband requirement applied to a broadband system, then a BTS supporting 96 traffic channels on separate RF carriers could require as much as 9600 watts of output to the antenna system![5] Such a product cannot be built using current technology, but, fortunately, the actual power demand is much less.

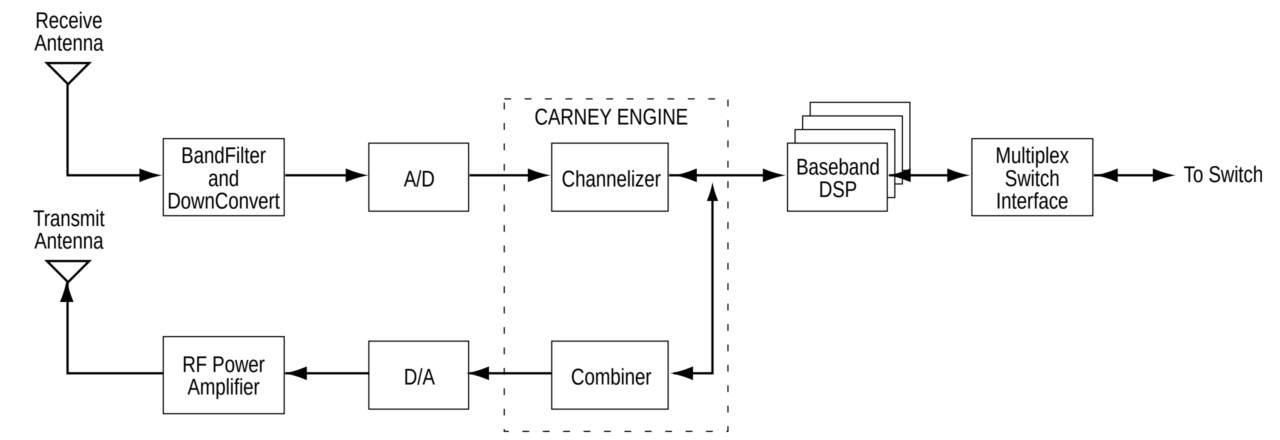
First, because the BTS uses a single 5-MHz signal to transmit all downlinks, the usual cavity combining of transmitters is eliminated. The energy loss associated with a cavity combiner is generally more than 60 percent (4 dB), so a broadband transmitter begins with a 60 percent advantage in terms of power required.

An even stronger advantage comes from the fact that the total amplifier power of a broadband transmitter can be shared as a linear sum of the individual signal powers needed to support the active downlinks. Thus, even though each narrowband transmitter must be sized to support a link to the cell boundary, it is statistically an extremely remote likelihood that all mobiles would ever simultaneously be at the cell boundary.[6] Another factor that must be accounted for in deriving a realistic transmit power budget is the fact that the demand for power to support a link falls off roughly in inverse proportion to the fourth power of the distance from the transmitter.[7] This means that at half the distance to the transmitter, only one-sixteenth the power is needed.

Another useful feature of the GSM / PCS 1900 protocol is discontinuous transmission (DTX), which cuts transmit power to

FIGURE 5

Digital Software Radio Architecture



a minimum whenever one side of a (duplex) conversation is inactive. Statistically, this means that a transmitter supporting N channels need only be supplying significant energy to 40 percent of the channels at each moment.[8] Of course, there is some variance to this, and a transmitter is more safely sized if a higher voice-activity factor is assumed.

Finally, the most important factor in the analysis of power demand is that downlink power and uplink power are related (i.e., if a mobile unit has a total transmission power of between only 0.6 watts to 3 watts, then by what amount does the downlink transmit power need to vary from that?). A link-budget analysis for the uplink and downlink will normally show that about 5 - 8 dB more downlink power is needed to support the path than is available on the uplink.[9] Thus, a provider should limit each cell radius so that the weakest transmission power of any mobile unit is able to complete an uplink, and then the downlink power required is 5 - 8 dB (3.16 - 6.31 times) higher than the downlink required.

AirNet has derived a transmitter power demand density for four scenarios and for both analog and GSM / PCS 1900 protocols as shown in *Table 2*.[10] The table shows the total power demand expected in a cell for various numbers of channels and for systems with downlink DTX implemented or not implemented. It also accounts for the cell shape [i.e., either hexagonal (first value of each entry) or circular (second value of each entry)].[11] Finally, it allows for a higher power level (1 dB) on each control channel.

The results in the table are quite remarkable, showing that the total amplifier power required at a base station is still well below 100 watts in the very worst case illustrated. These levels of power are easily achieved in linear power amplifiers using current technology.

In summary, the broadband paradigm must create the same result (i.e., a successful subscriber link) as a cellular system with very different ingredients. The management of power for broadband systems permits high-resolution software control and sharing of the power. Early testing of these concepts has so far shown that the model of power demand in a broadband-based cell is valid.

Receiver Saturation in Broadband Systems

While the requirements for broadband amplifiers were addressed in the previous section, it is useful to examine an important aspect of broadband receiver technology. Any receiver has a dynamic range that denotes the maximum range of signal strength that can be accommodated. A typical lower limit of dynamic range for cellular receivers that still permits detection and demodulation of the signal is from 105 dBm to 115 dBm. This lower limit, together with the co-channel interference levels in a cellular system, determines the maximum cell radius for the system.

There is also a maximum signal level that any receiver can accommodate, and a higher signal level will overload the receiver circuitry and prevent successful receipt of the signal. Almost any base station receiver could be overloaded by a mobile transmitter operating very close to the antenna, but the consequences for a narrowband versus a wideband receiver are different: a narrowband receiver serving one call might drop the call, while a broadband receiver supporting many subscribers might drop or disrupt many calls.

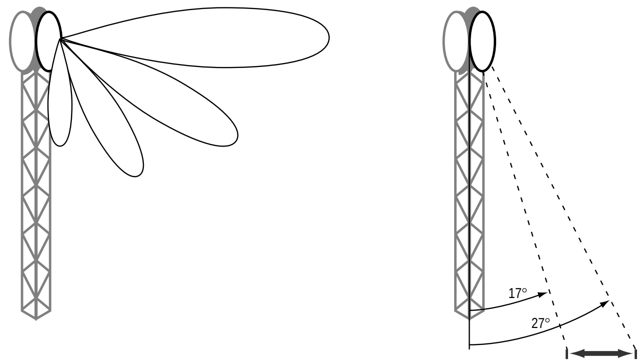
TABLE 2

99.999 Percentile Power Demand for BTS-based Cell

Channel Count (includes control ch)	Protocol: PCS 1900 (1 watt mobile with 6.3 watts (8 dB) downlink maximum)		Protocol: AMPS (0.6 watt mobile with 1.9 watts (5 dB) downlink maximum)	
	DTX	No DTX	DTX	No DTX
24	19/21	20/21	16/21	24/31
48	27/33	31/38	25/32	40/53
72	32/41	40/50	32/43	54/73
96	37/47	48/62	39/52	69/93

FIGURE 6

Example of Cellular Antenna Pattern in the Vertical Plane



a) Vertical Antenna Pattern b) Vulnerable Region

The issue of broadband receiver dynamic range thus needs careful attention.

Radio receivers generally ameliorate the problem of potential receiver saturation by employing an automatic gain control (AGC) circuit which limits or boosts the level of the input signal to the receiver. If AGC were not available, a very strong signal might overwhelm the capacity of the initial receiver circuitry, causing temporary loss of the received signal; this effect is called "saturation."

A broadband receiver employed in a commercial wireless system must deal with the widely disparate signal levels that might arrive from subscribers who are both very near and very far from the receiver. The AGC in a broadband receiver acts only on the total signal energy received across the bandwidth of the receiver: thus, a very strong signal from nearby will predominate and trigger the AGC circuit even if a very weak signal from a distant subscriber is also present. The AGC applies proportionally to all signals within the receiver's input bandwidth, so the receiver AGC, while decreasing the level of the strong signal, will also attenuate the weak signal so much so that the receiver can no longer successfully detect and demodulate it.

The broadband receiver has a dynamic range specification of 80 dB, indicating that the difference between the greatest and weakest signal to be received should not exceed 80 dB. Currently, the receiver can handle signals (at its input) at values as high as -35 dBm, and the AGC circuitry operates to attenuate signals received within the range from -35 dBm to -50 dBm. The overall dynamic range thus spans the range from -35 dBm to -115 dBm, which meets the sensitivity requirements for GSM and AMPS/TACS base station receivers. This dynamic range will increase in future AirNet receiver designs.

The question then arises as to whether there are circumstances under which nearby subscribers might exceed the -35 dBm signal level and might cause temporary loss of some weaker signals within the receiver bandwidth until the high signal level ceases. This question has been investigated with respect to several wireless protocols of interest, with the conclusion that receiver saturation is at best a remote possibility, and even that possibility can be prevented by appropriate antenna siting.

In order to establish the context of the discussion, it must be noted that the signal received from a mobile unit is affected both by the distance between the mobile and the BTS antenna and the effect of the antenna gain pattern on the subscriber signal. Even if an omnidirectional antenna is used at the BTS, the subscriber's signal strength at the BTS will be affected by the angle of arrival of the subscriber's signal as measured in the vertical plane. A generic vertical pattern of a standard omnidirectional 10 dB gain antenna is shown in *Figure 6(a)*.

Note that such an antenna has a main lobe that is centered on the horizon and has a number of side lobes in which subscribers closer to the base station will fall. Most subscribers will be in the main lobe of the antenna pattern, but signals from subscribers very close to the base station antenna may arrive within the side lobe region of the antenna pattern. The side lobes have lower gain than the main lobe, and an exact accounting of the effect of subscriber position is necessary to determine when receiver saturation might occur.

Also, it is important to recognize that commercial wireless protocols almost without exception include the capability for the base station to control the power level being received from the mobile. Generally, the mobile is allowed to initiate contact with the base station at a maximum power level that is adequate to ensure a successful contact for mobiles anywhere within the coverage area of the base station. The base station may measure the received signal level from the mobile upon first contact and then may command a change in mobile transmit power based on that initial signal-level measurement. Thus, the opportunities for receiver saturation can be limited to the occasion of first contact of a mobile with the base station on the control channel, and it is feasible to react to and power down a mobile in a very short interval, thereby preventing actual loss of any calls.

In order to exemplify the possibility of receiver saturation, we will consider the particular case of a mobile with a 0.8-watt maximum transmit power. This transmit level repre-

TABLE 3

Radii and Area of Vulnerable Region

Antenna Height	Inner Radius	Outer Radius	Vulnerable Area
100 ft.	30.6 ft.	53.2 ft.	5950 ft.^{2}
200 ft.	61.2 ft.	106.4 ft.	23,800 ft.^{2}

sents a level as high or higher than is permitted for hand-held mobile units in GSM or PCS 1900/DCS 1800 applications. Although there are other classes of mobiles that may transmit higher power, the coverage area of the base station must be limited to an extent which can accommodate all classes of mobiles and so the base station may normally limit the transmit power of all classes of mobiles upon initial contact to the maximum power level of the minimum power class mobile (i.e., 0.8-watt in this example).

Given this situation, a typical link budget comprising the gains and losses for the mobile signal was established, and the mobile was stepped through positions approaching the antenna in 1 degree increments. All of the terms in the link budget except the distance and antenna gain in the elevation plane (both due to the position of the mobile relative to the antenna) are fixed. Thus, as we step the mobile through positions approaching the base station antenna, we can compute the signal strength from the mobile at the input to the BTS receiver, thereby determining at what points there is a risk of BTS receiver saturation.

Figure 6(b) displays the vulnerable region found by stepping the mobile through successive positions for an actual antenna pattern of a standard base station cellular antenna. What is displayed is a range of angles for which the antenna gain and signal strength make the BTS receiver vulnerable to saturation. Path loss is computed by use of the Lee propagation model at substantial distance, but free space propagation loss is assumed for mobile positions very near the antenna.[12]

This vulnerable region in fact is an annular ring around the cell-site antenna, corresponding to antenna gain in the sidelobes of the E-plane antenna pattern and contains an area that varies depending on antenna height as shown in *Table 3*. As a first approximation, we may assume that the subscriber population is uniformly distributed within the cell.[13] If that is the case, then the proportion of the areas shown in *Table 3* compared to the area of the whole cell represents the probability that a subscriber is in the vulnerable area. That probability, together with an estimate of how often a subscriber might access the control channel (at full power), will provide some sense of the likelihood of receiver saturation.

The overall cell area and number of subscribers depends on the demographics and traffic engineering of the cell. *Table 4* reflects cell sizes based on the Lee propagation model, four demographic categories, and an assumption that subscribers power up and access the control channel an average of once per busy hour.[14] As shown in *Table 4*, two of the cases involve capacity-limited cells (i.e., the area of the cell is not determined by the distance possible for successful propagation, but by the fact that the subscriber density is so high that the demand uses up 92 channels in an area much smaller than that implied by the propagation limit).[15]

Note that for the capacity-limited cases, the maximum mobile transmit power needed to operate out to the cell boundary is much lower than the nominal 0.8 watts. Thus, BTS receiver saturation never occurs, since the mobiles can be directed at powerup (via the control channel overhead message) to use a low initial power. For both suburban and rural cases, there is a possibility of saturation, but the overall cell size is large, so that the proportion that is vulnerable is very small. The resulting probabilities represent saturations per day, if three hours of traffic per day is the busiest level.

Thus, saturation might occur on the control channel but at a rate of once every three to four days. There are several factors that may further ameliorate the effects of these remote possibilities.

- First, most suburban and rural antennas are in fenced-in sites, or at least well away from normally accessed public areas, so that subscriber access to the vulnerable region is an extremely remote likelihood.
- If such siting circumstances cannot be arranged, then presence of a wire-mesh shielding placed below the antenna can eliminate the risk altogether.
- Finally, even when a saturation occurs, it should last for at most about 0.5 seconds, which at the rarity shown, will not noticeably degrade overall call quality.

TABLE 4

Receiver Saturation Rates for Different Demographics

Cell Type	Population Density per mile^2	RF Radius (miles)	Capacity Radius (miles)	Maximum Mobile Power	Vulnerable Fraction[14]	Saturation Rate (per day)
Dense Urban	356,932	1.17	0.42	0.013 W	0	0
Urban	72,190	2.23	0.94	0.025 W	0	0
Suburban	1026	3.72	7.89	0.8 W	4.9×10^{-6}	0.385
Rural	365	8.72	13.22	0.8 W	3.6×10^{-6}	0.283

The overall conclusion then is that base station receiver saturation will not occur in dense urban or urban settings, and is, in fact, avoidable in any context by selecting proper antennas and doing careful site planning.

Four-Cell Reuse in Analog Cellular

Just as the computer vastly expanded the capabilities of the calculator, the arrival of all-digital, software-controlled radio will greatly transform the capabilities and capacities of wireless systems. A four-cell frequency-reuse plan is currently in testing for analog cellular that will provide substantially greater capacity than is provided by traditional seven-cell configurations. The current four-cell project uses a dynamic frequency-assignment scheme and is nominally a four-cell, two-sector frequency reuse scheme. If it could be operated at a theoretical upper limit of capacity, then it would provide 78.6 Erlangs per cell (2 percent blocking), rather than the 34.3 Erlangs possible in a seven-cell, tri-sectored system. This would represent a capacity improvement of 129 percent but that will not be realizable in practice, because the dynamic channel assignment scheme involves a form of soft-blocking; that is, there will be circumstances under which a channel may be free in a cell, but should not be assigned due to a high-ambient co-channel noise level. Simulation results to date indicate that actual capacity gain should be in the range of 75 percent to 90 percent.

Background

The signal-to-interference ratio for a receiver specifies the ratio of the energy within its receiver bandwidth comprising the intended signal versus the unintended interference. In cellular systems, each RF frequency available to a base station will be reused in cells at some distance from the base station. These other base stations using the same frequencies are the co-channel neighbors, and their uses of the same frequencies account for most of the interference present. The seven-cell omnidirectional frequency-reuse scheme for analog AMPS provides an average S/I of about 18.5 dB, which is adequate for AMPS receivers.

Dynamic Channel Assignment

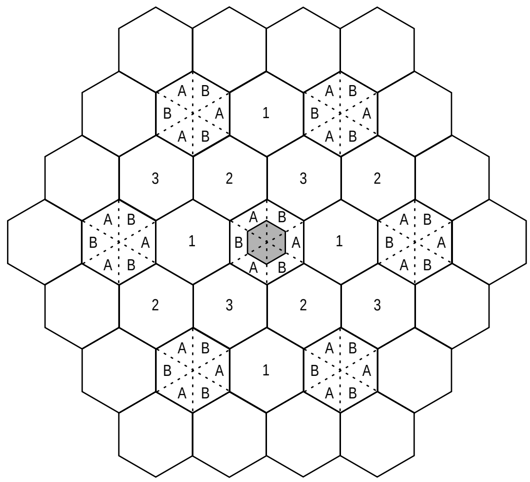
A four-cell frequency-reuse plan would normally fall short of providing an adequate S/I for analog cellular. However, a number of techniques to ameliorate interference are possible using the advantages of broadband architecture, and these techniques will permit a four-cell, two-sector frequency-reuse configuration for AMPS (or TACS) as illustrated in *Figure 7*.

The four-cell configuration requires that certain features that were automatically included in the newer digital standards be retrofitted as non-standard additions in the analog protocols. Specifically, a technique for forward link (i.e., base station to mobile) power control and for assigning channels intelligently was created so that co-channel interference levels from nearby neighbors are taken into account.

The essence of the dynamic channel-assignment scheme is best explained by *Figure 7*. In that figure, the co-channel cells

FIGURE 7

The 4-Cell, 2-Sector Frequency Reuse Scheme



in a four-cell frequency configuration are shown with sectoring. Note that each sectored cell involves six 60 degree sectors, but, in fact, alternate sector antennas broadcast the same RF signal, so that logically, the three commonly labeled 60 degree sectors comprise a single 180 degree sector. Thus, the configuration is logically a four-cell, two-sector reuse pattern. Note that each sector is also subdivided into an inner and outer tier (illustrated in the central cell of the figure), the purpose of which will be explained later.

The co-channel cells in *Figure 7* are inadequately separated to provide an adequate S/I ratio for standard analog-cellular operation. If no power control were in use, a mobile at the outer boundary of the center cell would receive interference from as many as three surrounding cells in the first ring of co-channel cells. This would result in S/Is of 14.3 dB, 16.1 dB, and 19.0 dB for 3, 2, and 1 active interferers, respectively.

However, with downlink power control, it will rarely be the case that all of the interfering signals are at full power (i.e., that the mobiles on the same channel are simultaneously at their cell boundaries), and, in fact, the average power needed for a mobile in a randomly chosen location within the cell is 1/3 the maximum power needed to close a link to the cell boundary. Accounting for this fact, the S/I above for three active interferers becomes, on average, 19.0 dB, which is slightly better than the 18.5 dB S/I of a seven-cell omni configuration.

Thus, use of forward power control in an analog system can result in an acceptable S/I relationship even in a four-cell frequency-reuse configuration. However, the situation can be improved even more if the assignment of channels to mobiles in a given cell is based on cooperation with the major interfering co-channel cells.

Specifically, the channel assignment plan involves subdividing each sector into an inner and outer tier, separated by a boundary parallel to the outer cell boundary but at 0.707 of the cell radius.[16] The channel assignment algorithm accounts for the fact that mobiles using channels in the inner tier operate at much lower power levels than mobiles in the outer tier. Each base station advises its neighbor-co-channel base stations of the current channels in use and whether they are in use in the inner or outer sector. When new calls are assigned channels, the channel assigned will be selected based on the interference and power level needed to adequately support the call.

The ability to "fit" mobiles to channels based on the power level needed to support the call, compared to the interference expected in every available channel, provides the capability to control the S/I to a much finer resolution than would be possible in a typical AMPS implementation and makes the four-cell co-channel spacing feasible. Since the decisions as to which channels to assign are made based on dynamic information, it is not possible to determine without simulation and field trials exactly what S/I level would be achieved in this system. The 19 dB cited above would appear to be a lower bound, so the four-cell system will realize RF quality at least at the level of seven-cell omni systems.

This assignment algorithm has an intrinsic soft-blocking potential, because an RF channel may remain available in a cell but not be assignable to a mobile when it is already in use in all outer tiers of the major co-channel interferers. This has been subjected to a closed-form probability analysis, which demonstrated that this soft-blocking effect is very low for channel allocations per sector of more than 24 channels. Since the four-cell configuration is intended to provide high capacity to currently congested AMPS/TACS systems, it is unlikely that fewer than 24 channels per sector would be implemented in this configuration.

Use of Alternate Channels

A four-cell, two-sector configuration, applied to a full 12.5 MHz AMPS system, should provide 59 channels per sector or 128 per cell. The traditional spacing for this arrangement would require that every eighth channel be selected for a sector spanning approximately the full 12.5 MHz of AMPS spectrum, but the BTS cannot accommodate that spacing within its 5 MHz bandwidth. However, if every other channel is used in a sector, the 5 MHz bandwidth of any BTS comprises 83 usable channels, which is more than adequate.

A reasonable concern arises as to whether or not mobile units can adequately reject signals on channels so close to the tuned channel. This problem has been examined, both theoretically and in the lab. The analog mobiles can be expected to provide about 55 dB of attenuation for a signal operating two channels away from the tuned channel. Tests of a mobile unit in the laboratory have shown that a mobile channel provides good voice quality even when the two surrounding alternate channels are operating at a signal level 35 dB higher than the subject channel.

However, in an actual cell, a mobile operating near the cell-site antennas may require a very low signal level, while a distant mobile served on an alternate channel might require a signal level 30 dB to 50 dB higher. Thus, alternate channels cannot be assigned to traffic arbitrarily: there must be some attempt made to prevent a near and distant mobile from occupying an alternate channel pair.

TABLE 5

Soft-Blocking Effects Associated for Alternate Channel Usage

Alternate Channel Constraint	Blocking Probability	
	First Free	Tapered
none	0.0201	0.0201
30 dB max	0.0234	0.0234
25 dB max	0.0254	0.0250

To that end, a constrained channel-assignment process has been considered, which will attempt to assign alternate channels in a single sector to mobiles that are at power levels within a 30 dB difference. The algorithm for this process was simulated in an event-driven simulation, incorporating pseudo-randomly scheduled traffic arrivals, exponentially distributed call lengths, and a 30 dB constraint between alternate channels. Busy-hour traffic loading was at 51.52 Erlangs for a 62-channel cell (2% blocking), and mobile positions were also pseudo-randomly drawn from a uniform positional distribution within the sector. The equivalent of 600 hours of busy-hour operation was simulated, and representative results for a 25 dB and 30 dB constraint are shown in *Table 5*.

In *Table 5*, two assignment algorithms are compared, the "first free channel" and the "tapered" algorithms. First free channel simply assigns a new mobile to the first inactive channel, working from one end of the channel allocation, which meets the power difference constraint (i.e., the center channel is within 25 dB or 30 dB of both neighbors). The tapered algorithm attempts to assign high-power channels to one end of the allocation and work downward toward the lowest powered channels at the other end. Interestingly, the two algorithms produced essentially identical results, and, as can be seen, the blocking probability imposed by the constraint climbed only modestly (by 17%) from the usual (unconstrained) blocking probability, representing the lack of any idle RF channel at a call origination.

These results were suitably encouraging to indicate that alternate channel assignment should not decrease sector capacity by more than a few percent, and, in any event, there is also the possibility that intrasector handoff may be applied to alleviate the occasional soft block represented by these results. In summary, the four-cell configuration provides proof that the all-digital software paradigm represents not an evolution of, but a revolution in wireless techniques.

Three-Cell Frequency-Reuse for GSM/PCS 1900 Systems

The case has been made that the advantages of broadband software radio could support a four-cell frequency-reuse configuration for AMPS and TACS. Similarly, a dynamic frequency-assignment scheme is in development of GSM/PCS

1900 cellular systems that will provide a substantial increase in traffic capacity over traditional seven-cell or four-cell, tri-sectored arrangements. This configuration is nominally a three-cell, two-sector frequency-reuse scheme, and, if it could be operated at a theoretical upper limit of capacity, then it would provide 160.5 Erlangs per cell (2 percent blocking) rather than 109.5 Erlangs as possible in a four-cell, tri-sectored system. This would represent a capacity improvement of 47 percent, but that would slightly decrease in practice, because the dynamic channel assignment scheme involves a form of soft-blocking: that is, there will be circumstances under which a channel may be free in a cell, but should not be assigned due to a high-ambient co-channel noise level.

Background

Broadband radio equipment comprises all-digital, software-driven equipment that is capable of permitting highly resolved, real-time control in cellular systems. This capability should be exploited in all products to offer potential customers features that they cannot obtain with traditional narrowband cellular architectures. The first major technical breakthrough in the area of real-time system control was a three-cell, two-sector cellular architecture for the GSM / PCS 1900 digital wireless standard. The three-cell architecture is based on using several noise-amelioration techniques—specifically, power control on both the forward and reverse radio paths to the mobile, discontinuous transmission (DTX), and a channel-assignment scheme that accounts for the current co-channel activity in nearby cells.

Dynamic Channel Assignment

The three-cell channel-assignment scheme is dynamic in the sense that it attempts to implement cooperation with neighboring co-channel cells. The essence of channel assignment is best explained by *Figure 8*.

In this figure, the co-channel cells in a three-cell frequency configuration are shown with sectoring. Note that each sectored cell involves six 60 degree sectors, but, in fact, alternate-sector antennas broadcast the same RF signal, so that logically, the three commonly labeled 60 degree sectors (labeled with "A") comprise a single 180 degree sector and likewise for the unlabeled sectors. Thus, the configuration is logically a three-cell, two-sector reuse pattern. Each sector is also subdivided into an inner and outer tier (shown in the center cell), as was the case for the analog four-cell system.

The co-channel cells in *Figure 8* are inadequately separated to provide an adequate S / I ratio for standard GSM cellular operation. If no power control were in use, a mobile at the outer boundary of the center cell would receive interference from as many as three surrounding cells in the first ring of co-channel cells. The remaining three co-channel cells in the ring also have A-sector antennas, but they are pointed away from the central cell and contribute interference at a much lower level (somewhat under 10 percent of the total). With power control, it will rarely be the case that all of the interfering signals are at full power (i.e., that the mobiles on the same channel are simultaneously at their cell boundaries). In fact, the average power needed for a mobile in a randomly chosen location within the cell is one-third the maximum power needed to close a link to the cell boundary.

In effect, the interference-amelioration techniques described for the four-cell AMPS / TACS system are also applicable here. GSM and PCS 1900 have closed-loop power control on both the uplink and downlink, so that feature will be easily implemented and is not unique to this system. The dynamic channel-assignment scheme, as described for the four-cell system, will also be implemented, which is unique. Finally, discontinuous transmission is automatically available in the GSM protocol and will further reduce average interference levels in the system. The analysis to date indicates that the three-cell system is feasible and will provide greater spectral reuse than has been achieved prior to this in GSM-based systems, and a 23-25 dB average S / I ratio for subscribers.

The Range Extender—Migration from Low to High Density

The three-cell, two-sector configuration can accommodate very high demand (conservatively estimated at 120 Erlangs per cell). Many PCS 1900 operators are essentially beginning with no subscriber base (a "greenfield" application) and must install the equipment in the face of no initial revenue.

It is recognized that providers require a reasonable and cost-effective migration path from the no-density through the low-density to the ultimate high-density situation. The ideal integration plan permits cells to be established initially using a single 200-kHz PCS 1900 carrier (serving 3 Erlangs) and ultimately growing through a sequence of density stages to the high-density, three-cell, two-sector configuration. Moreover, this migration plan permits different cells in the area to coexist at different densities and facilitates equipment upgrade in stages that are very compatible with the increasing demand. The provider can begin with a low-cost system and wait for demand to grow in the coverage area. The upgrades needed as demand grows are specific to the situation and require

FIGURE 8

The 3-Cell, 2-Sector Frequency Reuse Scheme

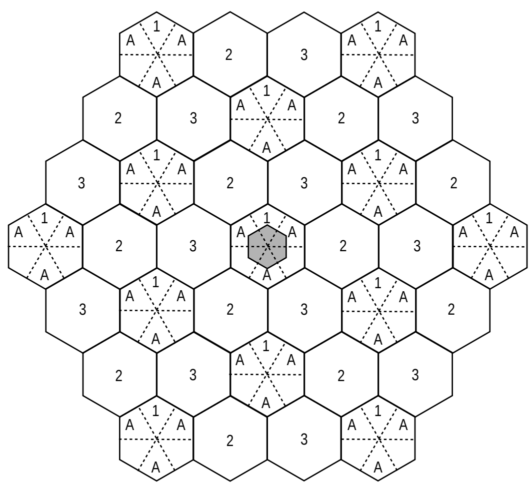
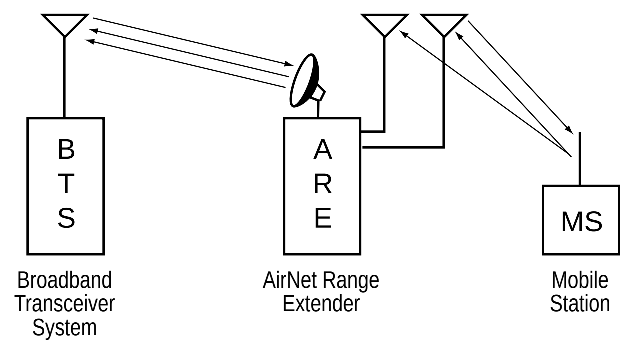


FIGURE 9

AirNet Range Extender Deployment



much less replanning and complex rearrangement of the system than in typical cases.

The fundamental element in this migration plan is the AirNet range extender (ARE) which permits a single GSM 200 kHz carrier to service a coverage area. A single GSM carrier can serve a capacity of 3 Erlangs at 2 percent blocking or approximately 150 subscribers, assuming a typical 20 milliErlang demand level per subscriber.

The range extender is not a repeater, because it translates the frequency in-band and implements receive diversity from the mobile. This means that the signal on the uplink from the mobile is received at two separated antennas, which strongly compensates for the usual fading losses due to multipath effects. The ARE thus provides a signal quality indistinguishable from a transceiver sited at a base station, while a repeater signal would provide a noticeably lower quality to the customer.

The ARE is not simply a transceiver, however, because a transceiver operating alone to cover an area needs a separate interface (e.g., T-1 line and associated multiplex equipment), while the range extender communicates via a duplex RF link back to a BTS as shown in *Figure 9*. In areas of low customer demand, up to 12 range extenders can be deployed around a BTS, communicating with the BTS via dedicated in-band air links. The range extenders are purely analog-signaling devices communicating back to the BTS, and the BTS provides downconversion, demodulation, and multiplexing / backhaul to the mobile switching center or PSTN.

The initial deployment of range extenders in a twelve-cell, 3-Erlang per cell configuration allows an easy migration to a six-cell, 9 Erlang per cell configuration (450 subscribers) comprising two RF carriers per cell. This migration is shown in *Figure 10*.

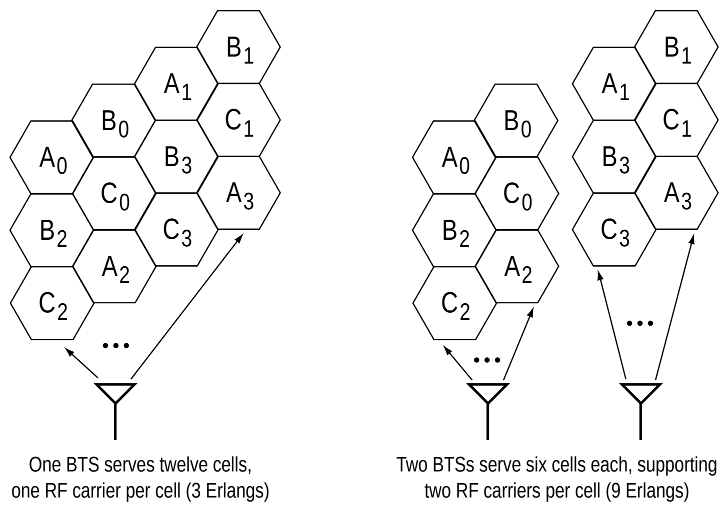
This pattern is not an ideal 12-cell pattern for frequency reuse (i.e., providing minimum S / I) in that spacing between co-channel cells is not uniform. An ideal 12-cell omnidirectional pattern has a 20.8 dB S / I as the 90 percentile level. The minimum distance shown between co-channel cells in *Figure 10* indicates that the 90 percentile S / I for this system would exceed 18.3 dB, which is adequate for operation of PCS 1900.

The reason for the nonstandard pattern of *Figure 10* is that this pattern lends itself to a reconfiguration scheme permitting the cutover of low-demand cells supported by range extenders to omnidirectional cells comprising six RF carriers per cell (36.5 Erlangs or 1575 subscribers), then to sectored cells (as shown in *Figure 8*) providing 12 carriers per cell (73 Erlangs), and finally to high-demand, three-cell reuse configuration as discussed in *Figure 8*. This occurs with minimum impact on the surrounding low-demand cells, which continue to operate with S / Is, which are well above the level needed for suitable GSM / PCS 1900 signal quality.

The original low-demand frequency plans (one, two, or six carriers per cell) function in a typical fashion, with no need for coordination between cells. As a provider builds a customer base, the low-demand cells can be converted, cell by cell, to two-sector cells, in the usual alternating 60 degree sector pattern of a three-cell plan. When a cell is converted to

FIGURE 10

Low Demand Configuration Using AREs



two sectors, the power control and channel-assignment scheme of the three-cell system go into effect for the sectored cell. The co-channel interference levels present for any mix of these five densities of cells will always remain acceptable for GSM / PCS 1900 operations.

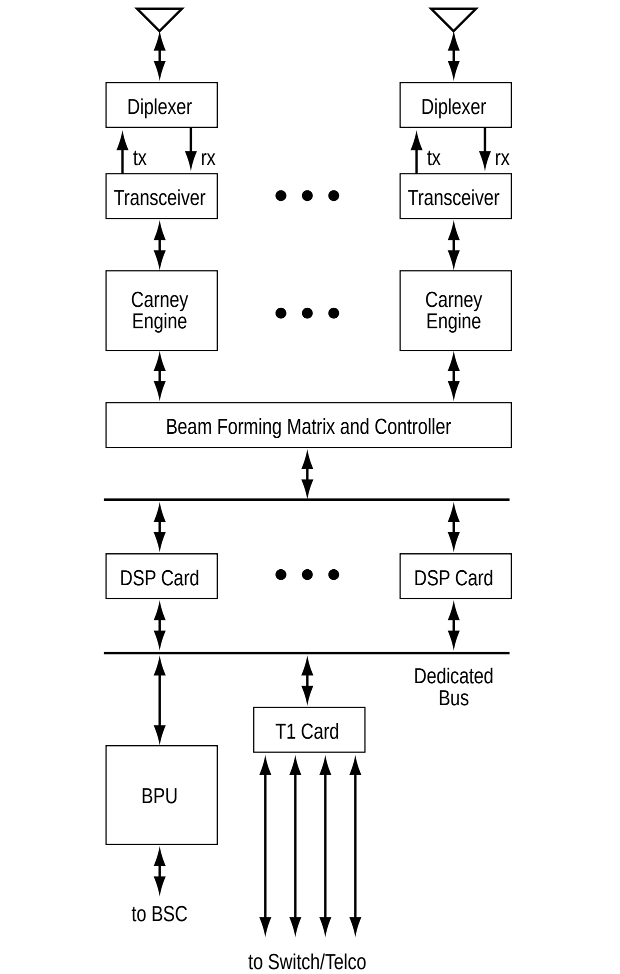
In summary, there is a feasible, pay-as-you-go migration strategy for the product line supporting five levels of demand per cell, and all cells supporting these various demand levels can coexist with each other in a provider's service area. Upgrade of equipment is on a cell-by-cell basis, and only slight modifications of frequency planning are required, which at most require modifying the frequency band of a BTS. Providers may install the initial system with the confidence that they will not need to continue purchasing expensive upgrades involving equally expensive replanning efforts.

Broadband Radio and Smart Antenna Technology

Earlier, the paper described the radically new hardware approach to cellular that was taken with this product line. It has introduced some of the large advantages that can be realized utilizing this equipment and has justified considering that the BTS can be revolutionary rather than simply evolutionary. But even the advent of tighter spectral reuse and smooth migration plans do not exhaust the capabilities of this new paradigm.

FIGURE 11

A Wideband Base Station Supporting Spatial Diversity



There is also the new technology of "smart" antennas, which can form beams of RF energy directed specifically toward a subscriber's location. This not only provides the effective advantages of highly directional antennas, thereby lowering interference, but also allows the possibility for a single frequency to be reused multiple times in a single cell. This reuse factor can be from two to five, depending on the environment in which the signal must be propagated.

What smart antennas have to do with the broadband radio revolution can be seen in *Figure 11*, which displays a typical smart-antenna architecture. The architecture of *Figure 11* bears some resemblance to the original BTS architecture as shown in *Figure 5*, but note that there are now multiple receive and transmit paths in the system. These multiple transceiver paths permit multiple copies of a single signal to be received and transmitted. Because of this, a comparison of differences (phase and time-of-arrival) for the multiple copies of a signal permit the direction from which the signal is arriving to be determined. Knowing the direction of arrival from a mobile permits the transmitted signal to be focused (again, using the multiple transceiver paths at the BTS) so that it places much more energy in the direction of the subject mobile.

Several advantages accrue to this "smart antenna" technology, as listed below:

- The focused signals do not spread over as much of the service area, lowering interference in other co-channel cells.
- The total need for transmitter power is decreased by a factor of N2, where N is the number of transceiver paths operating.
- Cell radii can be expanded because the computational gain of the smart-antenna system is equivalent to greater directionality in a standard antenna.
- It is possible to actually support more than one subscriber on a frequency using spatial diversity multiple access (SDMA) from the same cell site, provided there is an adequate separation of the azimuths of the subscribers.

In any specific environment, some of these advantages are more attainible than others. In general, early trials with smart antenna systems applied to mobile wireless applications have indicated that spectral efficiency can generally be doubled (i.e., twice as many subscribers can be served per available RF channel).

Smart antenna technology is not dependent per se on a broadband communications architecture. However, if this technology must be implemented using narrowband radios, then a base station providing M RF channels would have to have not just M narrowband radios, but M narrowband radios connected to each antenna element. In an AMPS seven-cell system, the 55 channels per cell site operating with a ten-element

TABLE 6

Traffic Capacities – Broadband versus Narrowband Deployment

Protocol	Spectrum	Frequency Plan	Channels/sector	Erlangs/Cell[16]	VC Utilization
AMPS	12.5 MHz	7-cell/3-sector	19	36.9	65%
AMPS	12.5 MHz	4-cell/2-sector	49	70.1[17]	72%
PCS-1900	15 MHz	4-cell/3-sector	48	115.2	80%
PCS-1900	15 MHz	3-cell/2-sector	92[18]	160.4	87%
PCS-1900	5 MHz	4-cell/3-sector	15	27.0	60%
PCS-1900	5 MHz	3-cell/2-sector	32	47.4	74%

antenna would require 550 radios and a complex, synchronized interconnect architecture to support the exact phasing of signals required to form directed beams. A broadband architecture requires only one radio per antenna element (i.e., ten radios can replace the 550 radios of the previous example, and the interconnect structure is vastly simpler).

The BTS technology is a very natural architecture in which to implement smart-antenna technology as *Figure 11* illustrates. In practice, the narrowband base station using smart antennas may never be reduced to economical commercial use, and economically feasible smart-antenna technology in commercial cellular / wireless applications will depend on broadband radio technology.

A Synopsis of the Broadband Software Radio Paradigm

This paper has provided an extensive treatment of the distinctions between traditional narrowband wireless applications and the new paradigm—broadband, software radio. It should be evident that broadband wireless equipment can compete in the commercial wireless market and offer very substantial advantages to service providers—all despite the fact that all prevailing wireless specifications were developed with no consideration of broadband equipment. But broadband is very flexible, and we have demonstrated that the commercial wireless cake can be baked from a different set of ingredients: all that matters, ultimately, is that the mobile unit, designed as a narrowband instrument, will establish and complete calls with absolutely no indication as to whether the serving base station is narrowband or wideband.

Even if the subscriber cannot tell what the cake is made of, the ingredients really do matter to the provider. The major differences, as discussed in this paper, are reiterated below.

- **Complexity.** The broadband BTS uses one transceiver to serve all subscribers in a cell, vastly decreasing the interconnect complexity, power requirements, and air conditioning demands at a base station.

- **Reliability.** This much simplified architecture eliminates much scheduled service time (no frequency tuning ever required) and likewise will eliminate much unscheduled downtime because of the vastly lower total component count in an AirNet BTS.

- **Compactness.** The BTS and all supporting equipment, except for the antenna system, occupies less than a 19” half-rack and can be sited in many small spaces in existing buildings.

- **Flexibility.** Because it is fully software-controlled, the BTS can adapt to protocol changes and can offer multiple protocols from a single platform.

- **High Spectral Efficiency.** The software control of the BTS permits real-time measurement and response to conditions within the cell and promises to offer frequency reuse configurations that are not realizable with narrowband architectures. This means a provider can get substantially more revenue per Hz of allocated spectrum and per voice channel, than any narrowband provider can hope to realize. *Table 6* illustrates the greater capacity and higher revenue per voice channel (VC utilization) achievable with this product line for both PSC-1900 and AMPS protocols.

- **Economy.** Finally, the bottom line: a provider who spends less on hardware per cell site can take advantage of existing buildings for siting, hire fewer maintenance personnel, readily add new services, and sell more Erlangs per Hz is a provider who will be in control of the competition, and the icing on the cake will be the higher profit margins possible with such a system.

We feel the case made in this paper should be convincing. The systems of the future may eventually all be broadband, but today, the only way to share the advantages of this paradigm is with AirNet.

Footnotes

1 Hess, Gary, C., Land Mobile Radio System Engineering, (Boston: Artech House, 1993).

2 AirNet’s current radio receives a 5Hz RF bandwidth.

3 Named for Ron Carney, one of the founders of AirNet.

4 Switching equipment for the two protocols is very different and would require upgrade activity.

5 The current upper limit of the AirNet product.

6 This assumes that forward power control is available in the air link protocol. That is automatically the case in GSM / PCS 1900.

7 Lee, William C. Y., Mobile Communications Design Fundamentals, (New York: Wiley Interscience, 1993).

8 Studies have shown that normal telephone conversations have a net total of 40 percent voice activity on both the downlink and uplink.

9 This is because the base station has a higher receive gain than the mobile, due-to-receive diversity at the base station using two antennas with spatial separation.

10 Doner, John R., “Amplifier Power Requirements for Wideband Wireless Applications,” Presented at SuperComm’96, Dallas, June 26, 1996.

11 A hexagonal cell has more of its area closer to the base station, thus requires less total power.

12 Free-space loss is proportional 1 / r2, rather than the usual 1 / r4 for cellular, where r is the transmit path length. Free space loss occurs within 4h1h2 / where h1h2 are the antenna heights, and is the wavelength.

13 Many cellular antennas are on sites where general access is not possible, and subscribers would never be within the ranges shown in *Table 3*.

14 Based on Chicago population densities.

15 Based on 92 traffic channels per cell, 2 percent blocking, and 20 milliErlangs per subscriber busy-hour demand.

16 The dividing line is actually based on dividing the suscribers evenly between the inner and outer tier.

Direct to Home: Growth and Opportunities

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Introduction

With the ongoing liberalization in the Indian economy, more and more private participation is expected in the broadcasting sector. Satellite channels and cable television (CATV) networks that are already growing at a fast rate are expected to expand further. The global advances in the state-of-the-art digital video and audio compression technology are expected to spur the growth. Liberalization has resulted in the expansion and improvement in telecommunication infrastructure in the country, paving way for the networking of more homes. This will aid in the introduction of near video on demand and interactive audio and video services. The above will require increased program production and distribution facilities.

The term *direct-to-home* (DTH), commonly used for satellite TV signals, in digital mode in Ku band, helps reception, with less than a meter-diameter dish antenna that can be easily installed in individual homes.

Background

On the national front, widespread access to and impact of satellite broadcasting signals on individual homes—by DTH or by cable TV distribution—raises a number of regulatory issues. The inadequacies of the antiquated Indian Telegraph Act of 1885, the Cable TV Act, and the lack of any act to deal with broadcasting immediately came into focus in dealing with issues emerging from hardware and software aspects of satellite broadcasting. Regulatory policies governing uplinking facilities for private entities would need liberalization. Indian private entities' commercial entry into the business of satellite broadcasting and owning or operating satellite networks may also be facilitated. The whole gamut presents a wide spectrum of challenges and opportunities to the national policy makers.

If DTH is the new buzzword in the satellite broadcast industry, it is not without reason. DTH transmission eliminates the cablewallah altogether. Moreover, since the signal on DTH is encoded, subscribers can choose their pay channels. At present, if a cable operator is supplying an encrypted channel's signal, the signals reach every household in the area. Under DTH, however, the supplier can individually control the programming in the household. DTH opens up immense possibilities for the channels. It is the only way to circumvent cable operators.

DTH Operation

The DTH technology hooks every home TV to a satellite through a 47- to 60-cm receiver dish antenna and TV set-top box and integrated receiver / decoder (IRD). Together the receiver dish and the IRD constitute a receiver console by which the television owner-subscriber receives programs that the satellite-TV-service provider beams. The IRD gives conditional access to only those subscribers who are authorized by the DTH company upon payment of a monthly subscription fee, which may be higher than the average monthly subscription fee for cable and satellite channels.

DTH—in sharp contrast to cable TV—lends itself to easy monitoring and control. A regulatory authority can prescribe which channels are open for transmission and which are not out of the foreign programming content. The other advantage of DTH technology is the large number of channels it offers. Because the platforms use digital compression technology, they can accommodate six to eight channels on each transponder as compared to one in the analog format. As a result, a single DTH platform can offer thirty to sixty channels—all with premium programming and laser-disk quality, including a host of niche channels.

Market Potential

Market Projections

There is a window of opportunity for the next five to seven years for all players to make direct broadcast satellite (DBS) a mainstream communications tool. That is at least how long it will take cable operators to upgrade their plants to deliver true high-capacity digital broadband services. At least 30 – 40percent of all cable subscribers—more than 20 million households—will still have 1970s-style cable services.

It is emphasized that DBS has a broader mission than just consumer television. It is more than just a satellite service. It is an enabling technology, a tool that when combined with the existing terrestrial narrowband network will provide all the interactivity that customers will need in the foreseeable future.

According to the Carmel Group, a media research firm has projected DBS / DTH growth in a moderate scenario—for ESS medium-power Ku-band (the domain of PrimeStar and Alpha Star) and BSS high-power (including DirecTV, USSB and Echo Star)—from 5.7 million homes and businesses at the end of 1996 to 15.9 million at the end of the year 2000. Carmel's upbeat hot scenario for year-end 2000 is 18.4 million in contrast to Kagan's upbeat aggressive projection of 14.8 million.

On the other hand, the moderate projections of Paul Kagan Associates for DBS and DTH (not including the FSS C-band universe) are 5.3 million subscribers through 19percent and 11.5 million through the year 2000. Kagan's past forecasts for DBS and DTH have been too modest and it is said that the former aggressive estimate is now a conservative estimate.

India

Much extensive market research has been conducted that suggests that there is a huge market for DTH technology in India. The recent market research conducted shows that of the 50 million households in India only 12 to 15 million are satellite and cable homes. Hence, there are at least 35 million households, largely in the rural areas, that receive just DD. There is no cable penetration in this huge market. Therefore rural India will be the key market for DTH.

India's broadcasting network is one of the largest in the world, with over 185 radio broadcasting centers, 700 TV transmitters, and 17 satellite channels. While the TV network has access to 50 million homes and 250 million prime viewers, the radio broadcasting provides coverage to approximately 97percent of the population of over 900 million. The cable TV distribution network is estimated to provide service to 18 million homes with penetration varying from 30 percent in metropolitan areas, 15 percent in satellite towns, 12 percent in district towns, 6 percent in urban villages, and 2 percent in rural villages.

At present, even with 750 terrestrial TV transmitters and as many as 17 satellite channels operated by Doordarshan, there are only 50 million TV homes, out of which only a third—16 million—are cable connected. Vast unsatisfied potential of TV viewership still exists. Growth of Indian economy with higher disposable incomes and change in lifestyles and leisure pursuits offer more scope for multi-choice DTD viewing.

There are several joint-venture proposals pending with the government like from Sinawatra, Measat, and other South Asian companies. Star TV has asked the national network to join it on its DTH platform on Panamsat 4. The Murdoch-run company has already tied up the requisite transponders with Panamsat. While the country has yet to witness DTH, there has been much talk and activity in this region of electronic media. Currently, apart from DD, Star TV, Zee TV, and the Modi group have shown keen interest. Of these, only Star TV appears to have finalized things and has signed Sun TV from India onto the platform.

Asia Pacific

A study on the Asia Pacific region conducted by the U.K.-based Cultures Group shows that there will be a demand for 200,000 decoders in the region by 1998. Of these, 40 percent will be from India since the metropolitan markets are saturated. There is definitely a market in the rural areas and small towns.

The population base of Asia Pacific is 3 billion, out of which India will have more than one billion by the year 2000. The Asia Pacific region is expected to record the highest demand for fifty-four satellites by year 2000, up from the existing number of twenty-six. There are seventy-eight transponders operational on INSAT series of satellites and another twenty-four will be commissioned soon. By the year 2020, it is expected that 3000 transponders (including foreign satellites) will be available. Programming is expected to rise to 5000 hours per week from the present level of 500 hours per week. Anticipating such spurt of activity, Asia Broadcast Centre in Singapore has recently commissioned state of the art TV production studios, eight digital on-line suites and satellite uplink facilities. TV advertisement revenues are expected to rise from 800 crores to 15000 crores.

United States

Comparable DBS figures for the United States suggest some 4.4 million subscribers eighteen months after the rollout of true DBS. Although Europe's broadcasters are just beginning to launch digital DBS services via Eutelsat or Astral, the first digital satellite in the North American market was launched by DirecTV in June of 1994. United States Satellite Broadcasting (USSB) shares the same satellite but offers a different programming package and subscribers are able to purchase the same 18-inch dish for both services. USSB's success relies heavily on its ability to give consumers the choice of mixing and matching low cost USSB channels with other low-cost tiers available on DirecTV.

By comparison, the U.S. multichannel universe totaled 69 million homes at midyear. Of those, 63.7 million came from cable distribution, according to the Nielsen Media Research, and 5.3 million from the burgeoning U.S. direct-to-home market, according to the Satellite Broadcasting and Communications Association (SBCA).

United States cable penetration, which is the primary multichannel driver in the country, grew at the rate of just one percent in the first half of this year, compared to European multichannel's overall five percent growth. However, multichannel penetration in the United States, which has 97 million TV households, is still far higher than Europe's at 70 percent, and U.S. DTH sales are building steam.

Satellite TV networks such as Star TV earn 20 percent income by subscription and 80 percent revenue from advertisements. A famous rating agency in the United States estimated that out of total advertisement spending of $60 billion on all media, $20 billion comes from advertisements, and pay TV takes a 12 percent share of the total.

Latin America

With nearly 77 million television homes surviving on a steady diet of off-air television and with only a few pockets tuning in through cable technology, Latin America could produce more than 10 million direct-to-home customers. With the hardware averaging US$500 per subscriber and subscription rates at around $20 to $30 a month, the market for Latin America

DTH could be worth US$5 billion in hardware sales and around US$ 3 billion annually in program subscriptions. Over the next few years at least six more satellites will be launched that will be used to provide DTH entertainment television to Latin American viewers with small dishes.

For the high power Ku-band DTH providers, Latin America marks the satellite industry's next biggest market place. The market is nevertheless very attractive. Cable is not a significant competitor except in Argentina where it serves 50 percent of TV households. Over all, Latin America represents a fertile market for DTH. With 47 million TV households in Brazil and Venezuela alone, garnering just ten percent of the noncabled market of these two countries would net about 4 million subscribers. That itself is enough to make Latin American DTH service profitable.

Europe

Powered by penetration growth in key markets such as Britain and Germany, Europe is about to surpass the United States as the world's largest multichannel marketplace. Europe had 68.5 million multichannel homes at midyear, according to figures released late last month by Societe Europeenne des Satellites (SES). Of those, 43.5 million came from cable and 25 million came from direct-to-home distribution. That figure represents a 5 percent increase from the 65.5 million European multichannel homes reported by SES at the end of 1995. Because of Europe's faster multichannel growth rate, it is expected to surpass the United States as the world's largest multichannel market when 1996 figures are compiled. Europe still has only 42 percent multichannel penetration of its 162 million TV households. The figures put out by SES, which runs the European Astra satellite system, show that one of Astra's most significant boosts in Europe came from British DTH growth. One of the SES reports stated that "The United Kingdom is one of the most successful DTH markets in Europe," and also that Britain's satellite market is second only to Germany's. It attributed the British growth to a "powerful line-up" of channels. Other places where multichannel growth is accelerating in Europe include Scandinavia, Central and Eastern Europe, France, Italy, and Spain.

While growth is picking up in Britain, the United Kingdom still ranks behind the Netherlands in terms of total multichannel homes, but Holland's penetration is saturated, so its subscriber growth is slower. Britain's cable industry is just hitting its stride, by most accounts. However, Germany still ranks far ahead of all other European countries as the largest multichannel market, with a total of 27 million cable and satellite homes, or nearly 40 percent of all European multichannel homes. Of those, 17 million come from cable and 10 million from DTH.

Considering the estimated 20.5 million DBS receivers in Europe, one can easily forget that before the late 1980s there was no true European DBS market. Indeed, many years have elapsed since the 1977 World Administrative Radio Conference (WARC '77) allocated member countries five frequencies for broadcasting DTH television using high-powered satellites before DBS became visible in Europe.

Impediments

As far as viewers' expectations are concerned, several are common:

- ample choice of programs
- studio quality picture and sound
- more regional language programs

All of the above expectations can be reasonably met by digital compression and DTH reception on a small 60 cm (18") dish, which can be conveniently installed in the home.

These DTH services, however, are an expensive proposition for platform owners as well as subscribers. Industry experts say that setting up a DTH platform requires an investment of at least $200 million, which includes the cost of leasing a transponder, uplinking and hardware costs. The cost of merely leasing the Panamsat transponder package, for instance, is around $21 million. That is not all, though: subscribers have to fork out at least Rs.40,000 to install DTH equipment, which includes a small dish antenna and an IRD unit. Then they have to pay a monthly subscription fee of Rs.150-300 per channel.

Price is not the only deterrent. The availability of equipment is another bottleneck. At present, nobody in India manufactures Ku-band dishes or digital IRD units. Even the leading manufacturers of satellite dishes have no plans to manufacture Ku-band dishes at the current time. There is no way to tell which manufacturer will get into the business, since both the size of the market and the quality of software are still unknown.

A study conducted by a Hong Kong-based company, AIM Asia, along with Delhi-based merchant bankers First Capital India points to yet another problem with which DTH operators will have to contend. The heavy rains during the monsoon, it says, often cause "rain fade" and a disruption in satellite signals. Apparently, none of the Ku-band transponders currently available in India has the capacity to prevent rain fade. Rain attenuation, though, can be taken care of by leaving a wider signal margin. PAS-4 had no problems during the last tests carried out on Ku-band signals.

It is essential to have open industry standards in DBS rather than adopting proprietary technologies like the one adopted by PrimeStar, DirecTV / USSB. Otherwise, there will be another beta versus VHS problem. If an open architecture exists, the DBS industry will not have the same technical baggage that has burdened cable TV in its attempts to catch up in the new digital world.

Ultimately, DTH technology will turn out to be commercially viable in the long run since the rate at which hardware costs in the satellite industry have been falling will prove the point that it is premature to talk about economic viability as hardware prices are constantly changing. In addition, IRD costs in the U.S. market have already crashed from over $600 to $200.

Regulatory Aspects

DTH, along with other broadcasting forms, will attract regulatory concerns on national as well as international levels. Internationally the two specialized agencies of the United Nations, the UNESCO and the International Telecommunication Union (ITU), are directly involved in these aspects.

ITUs Radio Regulation

The ITU recognizes the sovereign right of the member states to conduct their telecommunications in any manner they deem fit. However, recognizing the need to universally share the two natural resources—the radio frequency spectrum (RFS) and the geostationary satellite orbit (GSO)—the member states have voluntarily agreed, in ratifying the radio regulations, to restrict their absolute sovereign right.

The regulations regarding DTH are as follows:

- specifying frequency bands for different radio services and their operating and technical parameters

- ensuring harmonious, coordinated, and interference free operation of radio services

- providing equitable access by the member states to the natural resources, RFS and GSO, which sustain all radio services

- promoting economic, efficient, and standardized use of radio spectrum

Provision in radio regulation for fixed satellite services (FSS) and broadcasting satellite service (BSS) are particularly relevant in the context of DTH TV systems. In the international radio regulatory framework, the term *DTH* or *DTH service* is not recognized. Only *FSS* and *BSS* are commonly recognized. Fixed satellite service is essentially a radio service between point to point radio communication service via satellite. It was not intended to convey broadcast signals to the general public. However, technological developments led to the use of C-band FSS signals for satellite TV reception by the general public in recent years. This has obliterated the distinction between FSS and BSS signals. This is posing a major challenge to the ITU in revising the radio regulations to take into account the reality of merging FSS and BSS.

Articles 11 and 13 of Radio Regulations specify regulatory procedures for access to orbit and frequency spectrum for ESS. The spectrum for FSS' various frequency ranges such as C band, Ku band and Ka band is specified. In general, the procedures give access on first-come, first-served basis. To overcome this bias, in favor of late entrants and developing countries, certain frequency ranges (in 8/4 and 11/14 Ghz) are covered by allotment plans adopted at WARC-1988. The allotment plan provides for each country's national coverage only coordinated GSO position, along with 800 MHz spectrum. The Ku-band spectrum for FSS is also relevant to DTH service exploitation. Radio Regulations also specify detailed technical criteria such as limits of signal level at ground to protect terrestrial radio services, using the same frequency bands with the FSS.

Any satellite service or network using FSS will have to coordinate with other countries, as per Articles 11 and 13 for use of orbit and spectrum. Hence, a satellite platform for DTH in FSS bands will require extensive international coordination for its technical parameters to ensure protection to other satellite and terrestrial networks. This is also necessary to receive protection from other networks.

In the broadcasting satellite services, higher signal levels on the ground are provided for to facilitate better reception by simpler installations, as compared to FSS. ITU has launched a plan for BSS using Ku-band for Region 1 (Europe/Africa) and Region 3 (Asia, Australia, etc.). Major characteristics are

• Downlink Frequency Range	11.7 – 12.2 Ghz
• Uplink Frequency Range	17.3 – 118.1 Ghz
	14.5 – 114.8 Ghz

Developed for analog TV, orbital spacing of six degrees.. Five channels assigned to each service area, 16 channels, C/l protection ratio 31 dB. o±r.p63 -65 Db~i PId~ -103 dB/w/rn2 Channel bandwidth 27 Mhz.

A similar plan for the United StatesAmerica was adopted in 1983.

These BSS plans provide assured, coordinated orbit positions and frequency channels to all countries for national coverage, based on projected requirements. India was able to secure assignments for forty-eight satellite TV beams in the BSS-77 plan, which is likely to be revised because of significant changes in technology. Extensive revision of BSS-77 plan will be contemplated in forthcoming conferences of the ITU.

The European region exploited the BSS-77 plan very early on. In Asia, exploitation is yet to start effectively. Barring an experimental Japanese system, there is no regular service. For the deployment of DTH service in this region, though, the BSS-77 plan appears to be most suitable.

Besides specifying limits of signal level on ground for FSS and BSS to protect terrestrial systems, the Radio Regulation Number 2674 provides an additional stipulation for BSS space station of the need to reduce, to the maximum extent practicable, the radiation over the territory of other countries unless an agreement has been previously reached with such countries. This illumination of other countries' territory by BSS signals is not permissible without prior agreement. This is, however, possible in FSS, as is presently being done in C-band by Asia Sat, etc., by adherence to specified technical parameters such as signal level limits and coordination as per Article 11 and 13 procedures. The FSS Allotment Plan and BSS assignment plan provide for deployment of national/domestic service provision to develop subregional or regional satellite communication and broadcasting networks.

UN/UNESCO Guidelines

The United Nations in its Resolution 2916, dated November 9, 1972, stressed the need to elaborate principles governing the use by states of artificial earth satellites for international direct TV broadcasting. The outer space is governed by international law. The development of satellite broadcasting is therefore to be guided by the principles and rules of international law, in particular the charters of the United Nations and the Outer Space Treaty. Recognition of sovereignty and equality of all states is the most important element of any international regulation.

The UNESCO Declaration of November 15, 1972, proclaims a set of guiding principles on the use of satellite broadcasting for free flow of information, the spread of education, and greater cultural exchange. This declaration recognizes the need to reach or promote prior agreements concerning direct satellite broadcasting to the population of countries other than the country of origin of the transmission. It also specifies that transmission of commercial advertisements will be subject to specific agreement between the originating and receiving countries. Programs for direct broadcasting to other countries shall be prepared, taking into account differences in the national laws of the countries of reception.

The UN General Assembly ruled on the following:

- international responsibility for TV broadcasting by satellite, carried out by various states or under their jurisdiction

- cooperation for protection of copyright and neighboring rights with special consideration to the interests of developing countries, in the use of direct TV broadcasting for accelerating national development

- notification of the UN regarding activities in satellite broadcasting

A state intending to establish international (satellite) direct TV broadcasting should also notify the proposed receiving state(s) of such intention and enter into agreement with the receiving state(s).

Such a TV service should also be in conformity with the relevant instruments of the ITU, which will be exclusively applicable to the unavoidable overspill (outside the national boundary) of the radiation of the satellite signal.

Challenges and Opportunities

The greatest challenge that DTH operators face today is how collection fees from individual beneficiaries. In the United States, users receive encrypted cards when they pay their bills. The encryption is changed periodically to prevent defaulters from receiving the DTH service. Private parties can succeed in providing DTH service only if they have the facility of an interactive return path to individual subscribers to enable them to meet the video-on-demand request. One practical way of dealing with this problem is either, as has been done in telecom services, to franchise private operators by auctioning DTH services to specific areas, locations, and regions or based on spectrum and bandwidth allocation. Legal issues— to distribute services such as the applicability of consumer act to DTH beneficiaries, broad control of the program content to prevent misuse of DTH for broadcasting sensitive or pornographic material, and methods—of preventing DTH access to illegal as well as defaulting users need to be addressed.

The high cost of DTH, which is about a $200 down payment and a monthly service charge of about $40, would be an inhibiting factor for the rapid development of DTH in India and, hence, is not likely to impact cable operators in the near future. Consequently, a large percentage of TV homes in urban India will continue to favor cable operators, and practically all of the TV receivers in rural India will depend mostly on terrestrial transmissions for a considerable period of time. However, as the volume increases resulting in a substantial reduction in the fees, cable operators will face a serious challenge from both DBS and DTH TV in the years to come. India is likely to see the emergence of large cable operators across the country who could transform themselves into DTH TV service providers. The telephone companies are also likely to compete in providing DTH TV services. It is obvious that the government policies, modality of revenue collection, and legal issues need to be tackled quickly to meet the challenges posed by the emerging DTH scenario.

Conclusions

With a large number of foreign operators such as Asiasat, Panamsat, Jintelsat, DirecTV, and Measat planning to provide DTH services over India, the government needs to explicate a clear cut, unambiguous policy. Government monopoly on DTH, which is possible if interactive return connection to private service providers is not permitted and the collecting of fees is banned, is not advisable. While most agree that private operators should be allowed to uplink, the question is whether uplinking should be restricted to only Indian satellites or whether they should have the freedom to use foreign satellites, where they will have no control.

The government is working out on the legislation to allow issuance of licenses and / permission to prospective DTH television broadcasters. The government is planning to impose license fees over a certain period of time. A strategy paper in circulation says that DTH or the DBS service in the country may be operated only by the corporate bodies incorporated in India. The strategy paper also states that the foreign investment (with restriction up to 25 percent) may be allowed in the DTH corporates in India. It is understood from the guidelines that the strategy paper being prepared has many conditions like foreign-equity participation, cap on foreign investment cap, advertisement content in channels, and so on.

As per the recommendations of the Kagan International Conference organized on the future of cable, there is a place for only two DTH players in India, the first entrant being a clear winner. This is indeed a fact and should be noted by all the entrepreneurs wanting to enter this area. Even though a number of players are scrambling for a piece of the pie, whoever gets to the post first is the only one who will succeed.

The emergence of any new technology is invariably accompanied by debate and skepticism, and DTH is no exception. Eventually the success of any DTH platform depends on its packaging. The success lies in the channel mix on how well the market is managed—whether the box is purchased, subsidized, or leased to the consumer. One thing is certain: DTH will be here soon. As one industry expert has said: "You cannot wish away DTH. It is the medium of the 21st century." The DTH technology will be successful in India certainly, but it is still important to come up with the right marketing strategy.

Finally, the phenomenal progress made in satellite technology, optical fibers, development of digital compression techniques, and multiple access protocols combined with the availability of powerful computers has resulted in the creation of the information superhighway. Comparative advantage has shifted to those nations that can instantaneously access the vast and powerful worldwide database and utilize it for national development. High-power satellites of today have the capability to beam a few hundred channels from a single location to just 45 cm dish antennas to provide DBS services. Introduction of interactive capability is the next logical step for promoting video-on-demand DTH service, which has the added advantage of providing other value-added services through Internet connection.

We Can Hear the Future: Clear Sounding Digital PCS Could Become the Next CLEC

Michael Elling and Michael Turits
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Prudential Securities Equity Research

This paper presents the results of a voice clarity survey conducted on eight different wireless and wireline platforms in seven different markets. Nothing matches wireline, but pure digital systems are getting close. The sound of digital overlay on existing analog systems appears to be of lower quality, particularly in dense urban markets. Among pure digital systems, call division multiple access (CDMA) consistently outranks Global System for Mobile Communications (GSM), time division multiple access (TDMA), and iDEN. On average, digital beats analog.

The researchers believe that voice clarity—one of the "Four Cs" of wireless—will help differentiate the multiple competitive networks developing in markets across the country by the end of 1998. Wireless pricing approaching wireline levels should boost usage from today's approximately 150 minutes per month (5-7 minutes per day) to 300-700 minutes per month (15-40 minutes per day). At these levels, we believe consumers will demand near-landline quality.

Differences in voice clarity may show up in relative marketing expense, customer service costs, or higher network capital spending. We believe some of the new pure digital platforms may approach wireline in overall voice clarity. Early digital systems overlaid on existing analog systems appear to be of lesser quality. AT&T appears to be tweaking its overlay TDMA signal on the uplink portion of the call to improve quality. Overlay CDMA providers are improving their voice quality as they move to 13-kilobit vocoders.

Multiple live systems were tested across seven markets. The survey was sent to over 1,000 participants, and over 200 responses were compiled. This paper includes not only the survey results, but also an opportunity for the reader to retest the systems.

After talking on digital systems for over two months, the researchers turned reluctantly back to their own analog handsets. Even though some of the digital systems "sounded digital"—and many of the new ones do not—they regretted being greeted again by the "snap-crackle-pop" of good old analog cellular.

The 'Four Cs" Of Broadband Wireless

The researchers identified four features of broadband wireless service that they believe will drive investor interest:

1. *Clarity*. The focus of this report is the voice clarity of broadband wireless service providers in the 800 and 1900 megahertz frequency bands. Based on the analysis, voice clarity does vary quite substantially, and generalizations can be made about the relative quality of the major digital platforms (see *Table 1*). The results of this voice clarity survey are reviewed later in this paper.

2. *Cost*. The authors believe that innovative pricing plans, such as Microcell's $40, 400-minute plan, will be used by PCS providers to offset coverage limitations. Under this kind of plan, the customer perceives a deal for $0.10 per minute, although breakage will likely yield much more revenue to the carrier. Most of the existing PCS pricing models and the incumbent cellular providers' responses have been analyzed resulting in the development of an optimal pricing plan that should provide a bridge between mobility wireless and virtual wireless local loop (see *Figure 1*). The bottom line is that as price-per-minute drops and wireless service becomes more ubiquitous,

TABLE 1

Average Score of All Calls Made on Each System

	Average Score	
	8-Call Surveys	Complete
Wireline	4.30	3.95
CDMA 1900	4.07	3.71
TDMA 800	3.71	3.53
iDEN	3.37	3.46
GSM 1900	3.17	3.04
Analog/AMPS .	3.05	3.29
CDMA 800	2.85	3.27

FIGURE 1

PoWeR Pricing Plan

Plan	Included Minutes	Monthly Charge	PPM	PPM (Cum.)	PPM (Incr.)
Mobility-Cell	300	$30.00	$0.100	$0.100	$0.200
Rez-Cell	300	$10.00	$0.033	$0.067	$0.100
Biz-Cell	300	$15.00	$0.050	$0.061	$0.100
Total	**900**	**$55.00**	**$0.061**		

Source: Prudential Securities Inc.

TABLE 2

The D/E/F Auctions have Created More Seamless National Networks

Rank	Company	Net Bid	%	10 MHz POPs (Mil.)	$/POP (Net)
1	SprintCom	$544.2	21.6 %	83.8	$6.49
2	AT&TWire	406.8	16.2	139.5	2.92
3	BellSouth	205.1	8.1	12.6	16.27
4	OPCSE	181.4	7.2	89.4	2.03
5	AllTel	144.8	5.8	28.9	5.00
United States		**2,517.4**	**100**	**755.1**	**3.33**

Source: Federal Communications Commission.

users are more likely to differentiate offerings on the basis of factors such as voice clarity. Variations in voice clarity are shown in *Figure 2*.

3. *Coverage.* Buildout limitations are likely to be only a short-term issue for A and B block personal communications service (PCS) providers since they are required to build out 33 percent of their population within five years and 66 percent of their population within ten years of license grant. Coverage will remain a concern, however, in terms of strategic differences in the total footprints held by regional and national carriers. *Table 2* summarizes how the recently concluded D/E/F block auctions have changed the PCS and cellular landscape. The trend is clearly toward national, or supra-regional, networks. Various bidding strategies emerged: footprint expansion, increasing spectrum depth, and acquisition of licenses in noncontiguous markets for partnering or trading purposes. Prices ranged from as low as a few cents per point of presence (POP) to over $50.00 per POP. The authors believe that these variances—combined with network issues such as the availability of dual-mode, dual-band handsets—will likely lead to a wide array of pricing schemes.

4. *Capacity*. Capacity issues are somewhat more nebulous, since the real-world capacity of certain systems is still unknown (see *Table 3*). The capacity of existing cellular duopolies relative to the new PCS systems, however, might be envisioned this way:

FIGURE 2

Based on Our Analysis, Voice Clarity Does Vary Quite Substantially

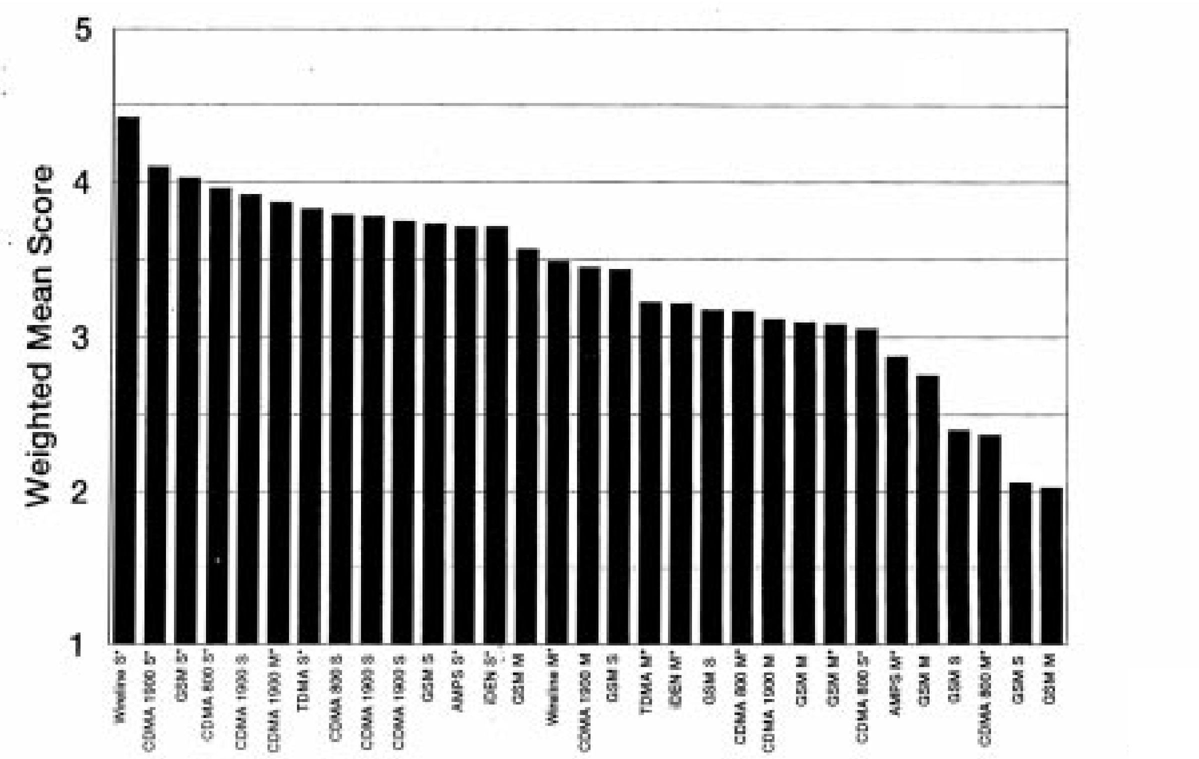


TABLE 3

Digitizing New and Existing Spectrum Should Lead to a 15-Fold Gain in Capacity Relative to Full U.S. Coverage

Frequency	Designated License	Spectrum Per License	Theoretical Analog Capacity	Capacity Gain Through Digital (1)	Comparable Analog Capacity	Theoretical Digital Capacity
Cellular						
800	A	25	10.0%	3	75	30.0%
800	B	25	10.0%	8	200	80.0%
PCS						
1900	A	30	10.0%	3	90	30.0%
1900	B	30	10.0%	8	240	80.0%
1900	C	30	10.0%	3	90	30.0%
1900	D	10	3.3%	3	30	10.0%
1900	E	10	3.3%	8	80	26.7%
1900	F	10	3.3%	3	30	10.0%
SMR						
800	Public	14	6.0%	3	42	18.0%
800/900	Private	13	6.0%	3	39	18.0%
Total		**197**	**72.0%**		**916**	**332.7%**

(1) GSM and TDMA @ 3 times, CDMA @ 8 times.

Source: Prudential Securities Inc.

- Two tiny analog-minute sweatshops in each market face the prospect of three to five turnkey, high-capacity digital-minute factories going up next door. Each is complete with walls, roofs, and fixtures.

- Initially, these new digital factories will have only two or three out of eleven production lines in operation. The sweatshop companies may have the advantage right now in terms of customer relationships, but in the end, the new digital factories will produce a lot of minutes.

The question is, how long will these factories run at just 3–15 percent of theoretical capacity? If we look to the historical example of the paging industry, the answer is, "not long." Investors should recall that the paging industry started with 40–80 first-generation digital POCSAG "cheap-beep" sweatshops before being supplanted by eight high-capacity second-generation digital FLEX providers—which will probably ultimately yield to three to five two-way inFLEX and reFLEX digital messaging providers.

Voice Clarity Survey Overview and Results

As a number of digital PCS and cellular systems went commercial during November of 1996, the authors traveled across the country sampling numerous markets and systems (see *Table 4*). All told, they sampled 12 different systems. Two wireline calls were included as control samples, using a pay phone as a proxy for a "mobile" landline call. Messages were recorded via each system onto an Octel digital voice messaging system and pooled to create the three surveys.

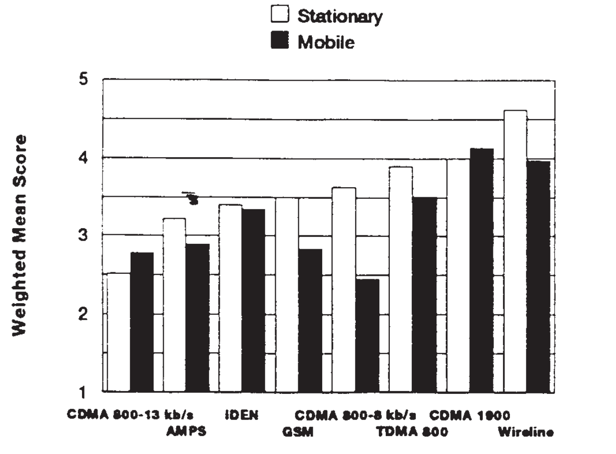
TABLE 4

Markets Visited

Company	System	Location
PrimeCo	CDMA 1900	Tampa
Aerial	GSM	Tampa
Pacific Bell	GSM	San Diego
Nextwave	CDMA 1900	San Diego
AirTouch	CDMA 800	San Diego
360° Communications	CDMA 800	Las Vegas
Nextel	iDEN	Las Vegas
Intercel	GSM	Georgia
AT&T	TDMA	New York
Omnipoint	GSM	New York
Centennial Cellular	CDMA 1900	Puerto Rico
APC/Sprint	GSM	Washington, D.C.
NYNEX	Wireline	New York

FIGURE 3

Stationary/Mobile Comparison



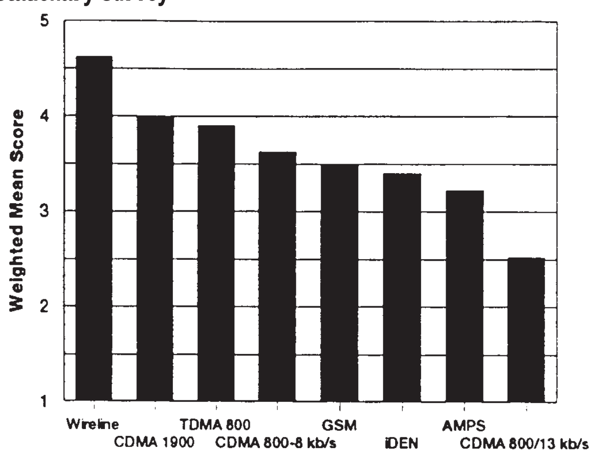
It is true that digital voice messaging systems tend to distort other digitally originated calls. However, the researchers believe that all the calls recorded on the system are subject to equivalent distortion, although this effect may highlight the weaknesses of the various systems. While they originally attempted to play back a single message, variances in tape speed and battery performance, as well as other audible differences, required them to record their messages live. These messages were delivered as consistently as possible with the same content each time.

Clarity May Be Asymmetric

The survey attempts to simulate real-life phone usage. However, since handset-originated calls were recorded on a wireline system, only wireless-to-wireline (uplink) communications are evaluated, not wireline-to-wireless (downlink). One thing that was observed in live tests of the system was that carriers can boost the signal once it gets into the wireline system, but can do very little to improve voice clarity the other way around. The net result is that wireless handset users' experience is the true measure of a system. Unfortunately, since it was not feasible to fly 100 users around the country, it was not possible to compare both sides of the call.

FIGURE 4

Stationary Survey



The Calls Came From Several Markets

In total, the researchers tested in eight markets with five digital cellular and PCS systems. Of the 31 calls made, 2 wireline calls served as proxies. Sixteen calls were stationary, including 4 CDMA 1900, 6 GSM 1900, 1 iDEN 800, 1 TDMA 800, 1 CDMA 800/13 kbps, 2 CDMA 800/8 kbps, and 1 AMPS 800. The only major system not tested was TDMA 1900.

On Balance, Eight Stationary Calls Were Better…

For the most part, the stationary calls rated higher than the mobile calls (see *Figure 3*), with the exception of CDMA-800/8 kbps and CDMA-1900/13 kbps. The highest-rated stationary call, as expected, was a wireline office phone (see *Figure 4*). Next came CDMA-1900, followed by TDMA-800. TDMA's high score may be biased by the greater downlink than uplink clarity in the TDMA system tested. GSM and iDEN came in just below the middle of the pack. Analog scored poorly here, as did CDMA-800/8 kbps. The latter is surprising but supports both the researchers' first-hand experience and their notion that digital systems in general, and CDMA systems in particular, must be optimized and fine-tuned. The CDMA-800/8-kbps system that scored relatively well was a first-generation overlay system installed in Las Vegas, and the researchers experienced dramatic improvement between September and November of last year. We can only expect the CDMA-800/13 kbps overlay system in San Diego that scored so poorly will also improve.

A number of observations can be made when we compare the score of the eight stationary calls with their respective rankings in the larger survey (see *Figure 5*). First, the large number of samples that participants heard in the complete survey tended to "smooth" the results. Seven of the eight stationary calls placed in the top 15 in the overall comparison (see *Figure 6*). Analog, CDMA-1900, and TDMA-800 all saw their relative leads decline, while GSM, CDMA-800/13 kbps, and iDEN saw the largest improvements. CDMA-800/8 kbps stayed at approximately the same level. Overall, the complete survey supports the results of the stationary survey.

FIGURE 5

Stationary Vs. Complete Scores

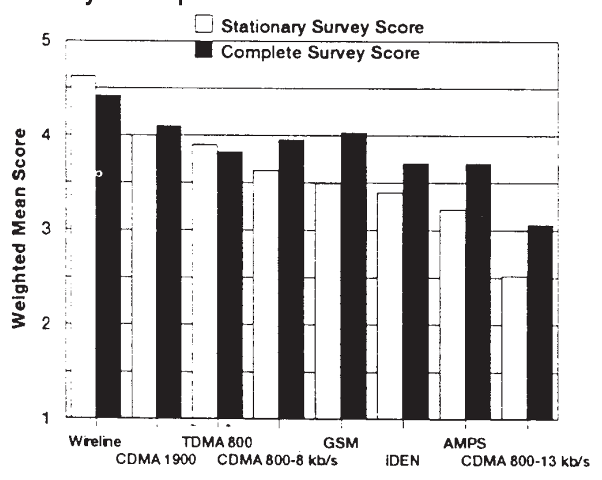
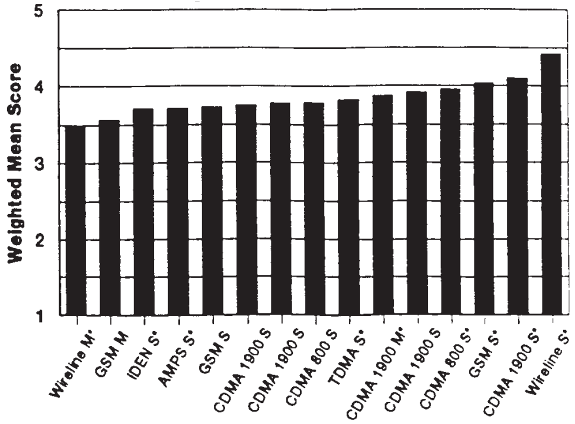


FIGURE 6

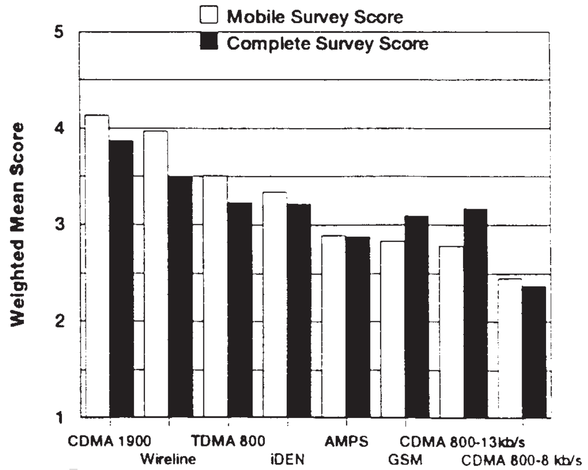
Complete Survey: Top 15 Calls



*Call was used in eight-call survey.
M=Mobile.
S=Stationary.
Source: Prudential Securities Inc.

FIGURE 8

Mobile Vs. Complete Scores



...Than Eight Mobile Calls

As a proxy for a wireline mobile call, the researchers used a pay phone in an office building. Surprisingly, this call placed second to CDMA-1900 in the mobile call survey (see *Figure 7*). It is possible that CDMA's soft-handoff, rake-receiver, and high-bit-rate sampling gives it the current edge in sound clarity, particularly in mobile situations. Another positive surprise in this survey was iDEN, which improved its standing over the stationary test, coming in just behind TDMA. Again, TDMA's positive ranking was surprising to both researchers and, probably, most people who have had real-world experience with the systems. The two lowest-ranking systems were the CDMA overlay systems. It seems probable that all overlay systems are challenged in mobile environments because of stray signals from the analog system and the fact that the digital system has been built around an optimized analog network.

The researchers were surprised by the comparisons between the eight mobile calls and the complete survey. Most of the calls scored substantially lower on a relative basis, except GSM-1900 and CDMA-800/13 kbps (see *Figure 8*). Only three mobile calls scored in the top 15 of the complete survey, including CDMA-1900 (ranked number six), GSM-1900 (ranked 14, although this was not the GSM sample included in the eight-call group), and the wireline proxy (ranked 15). Instead, most of the mobile calls tended to place in the bottom 16 (see *Figure 9*).

These results are supported by a system-by-system comparison of all systems using the complete survey results. Again, stationary calls tended to outperform mobile calls (see *Figure 10*). Two systems that bucked this trend and performed better in the mobile test were GSM-1900 and CDMA-800/13 kbps. It was found that the GSM systems tend to pick up a lot of background noise outdoors and may also perform badly in terms of in-building penetration. Placing the mobile call from a closed and protected car environment may therefore have benefited the GSM calls. We can only speculate that the CDMA-800/13 kbps system performed better in the mobile setting because of sampling characteristics particular to CDMA. The strongest overall

FIGURE 7

Mobile Call Survey

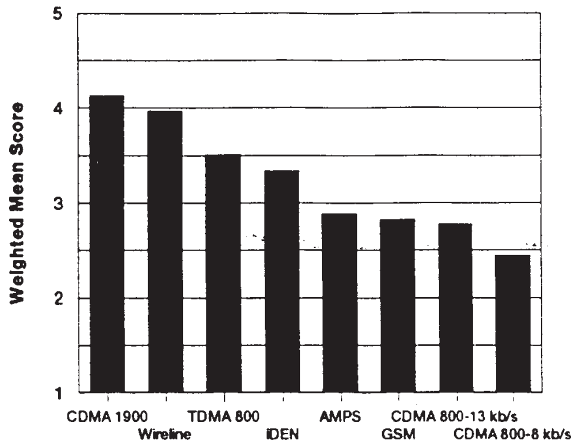
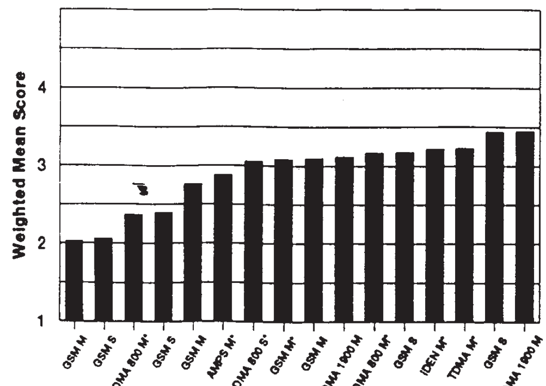


FIGURE 9

Complete Survey: Bottom 16 Calls



*Call was used in eight-call survey.
S=Stationary.
M=Mobile.

FIGURE 10

Complete Survey: Comparison by System

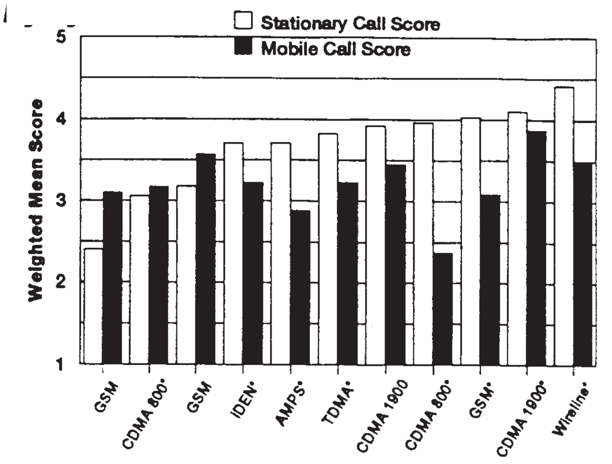
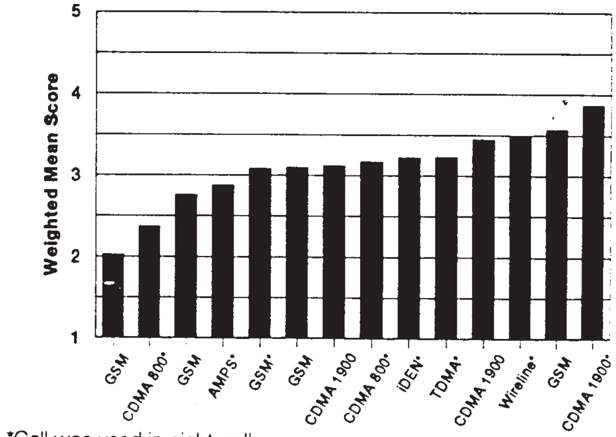


FIGURE 12

Complete Survey: Mobile Calls



*Call was used in eight-call survey.
Source: Prudential Securities Inc.

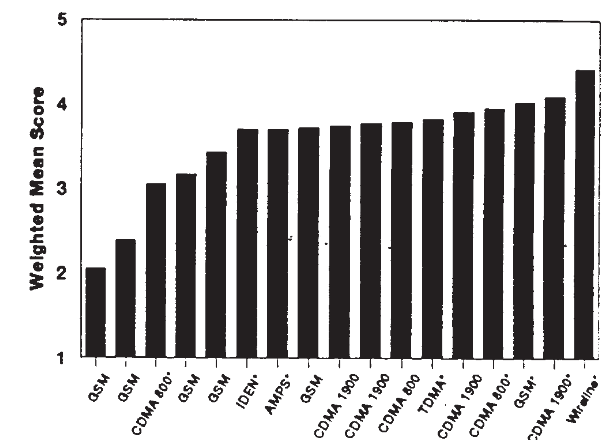
performer, CDMA-1900, exhibited the least amount of variance between stationary and mobile tests, but scored highest in the mobile environment relative to the degraded performance of the other systems.

The Complete Survey Supports the Primary Results

Similar ranking and dispersion were observed between the stationary and mobile calls in the full survey (see *Figures 11* and *12*). Of the 17 stationary calls, CDMA won six of the top nine leading slots. GSM-1900 won another two, but also made up six of nine worse-rated calls. Among 14 mobile calls (see *Figure 13*), CDMA-1900 systems placed three times in the top eight, while GSM scored four times in the bottom six. We believe this poor performance is primarily a function of the particular GSM system used as opposed to the platform in general. The benefit of the eight-call surveys is that they utilize the best individual system we tested from each platform, netting out this type of idiosyncratic performance. Still, some of GSM's poor performance in mobile calls may stem from its relatively inferior background noise suppression.

FIGURE 11

Complete Survey: Stationary Calls



*Call was used in eight-call survey.
Source: Prudential Securities Inc.

Survey and System Discussion

As noted earlier, digital systems can clearly be tuned and optimized. GSM is the longest-running first-generation digital PCS technology, and it is seeing gradual improvement. New GSM vocoders promise better overall clarity and throughput. With GSM vocoders, however, the handset must be replaced during an upgrade. CDMA's variable-rate vocoders allow carriers to optimize system performance, clarity, and capacity in real time without changing handsets.

Again, the authors wish to stress that this survey only sampled the uplink direction of a wireless call, and that all calls were recorded on a digital voice-mail system, which gave the analog and wireline platforms an advantage. It was found that downlink performance varied even more widely than the uplink calls in our survey. Handset voice clarity will become more important as digital system usage increases.

And The Winner Was—CDMA…

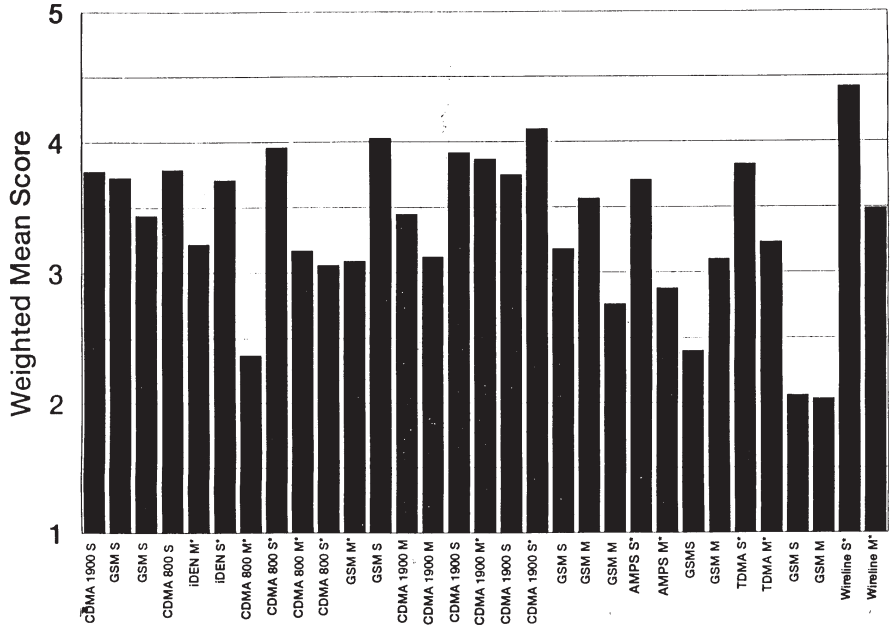
The CDMA 1900 systems of PrimeCo in Tampa, Nextwave in San Diego, and Centennial in Puerto Rico achieved high scores in both stationary and mobile situations (see *Figure 13*). At the time of the test, researchers were not able to obtain a handset to use on the Sprint (Fon–45 $\frac{1}{4}$, rated Buy by Guy Woodlief) system in San Diego, which uses cable backhaul for a portion of the system. On calls made from that system to the office PBX (including an hour-long mobile call), however, the system provided the best clarity of any the researchers had heard.

With the exception of a stationary outdoor call in Las Vegas, both 8- and 13-kbps CDMA-800 tended to perform in the bottom half of both the stationary and mobile calls. We suspect these CDMA overlay systems are subject to "cell-dragging," where distant cells interfere with the guardband in the intended cell.

On balance, we found that CDMA 1900 offered near-landline clarity, its only weakness being the user's ability to distinguish foreground and background voices in a small, enclosed environment.

FIGURE 13

Complete Survey—In Order



*Call was included in the eight-call survey.
S=Stationary call.
M= Mobile call.
Source: Prudential Securities Inc.

...Followed, Surprisingly, By TDMA Overlay

Distant cell interference also appeared to affect TDMA. In our survey, AT&T's TDMA system (see *Figure 13*) scored in the top half of both the mobile and stationary categories. This runs contrary to both the researchers' real-world experience and reports from other users. A definite disparity in voice clarity was noticed between the downlink and uplink paths. Apparently, carriers may be able to process a signal and improve its clarity once it is on the wireline system. Such processing is not cost-effective in the handset, however; hence the disparity.

It is worth noting that in the D/E/F auctions, AT&T had megahertz of 1900 spectrum in nearly all of its 800 megahertz cellular markets, suggesting that, in addition to the demands of the wireless local loop applications AT&T has planned for some of this spectrum, the incremental spectrum may be used to supplement relatively low-capacity TDMA overlay mobile service. In terms of voice quality however, it is probable that TDMA-1900 performance will eventually equal, or possibly exceed, that of GSM-1900.

GSM Also Scored Well...

GSM is a relatively mature, first-generation digital system that averaged in the middle in most categories, although it actually produced some of the best and worst scores. PacBell (PAC—41 $\frac{17}{32}$, rated Hold by Guy Woodlief) in San Diego scored among the highest in stationary calls, while Aerial in Tampa scored among the best in mobile calls. On the other hand, Omnipoint in New York reported some of the worst calls. This is probably a function of New York's challenging multipath environment (heightened by 1900 MHz signal propagation characteristics), as well as the early optimization stage of Omnipoint's network.

As noted earlier, GSM tended to pick up greater ambient noise that worsened with higher vehicle speeds or greater environmental noise. We suspect that new-generation vocoders can solve this problem, although we do not believe that GSM will ever achieve the sampling and processing rates of CDMA.

The "Four Cs" Of Wireless, Part II: Clarity, Or "I Can't Understand You—You Must Be On A Cell Phone"

Wireless service voice quality is likely to be an issue in 1998 as lower per-minute pricing of PCS and cellular systems stimulates overall demand and usage. Comparisons among users are likely to become an important benchmark. With broadband wireless penetration estimated to increase to 45 percent over the next five years, many more consumers will have the opportunity to use their own (and other people's) mobile phones.

The authors believe that voice clarity—the word most listeners use to describe the quality of a call—is one of the "Four Cs" key to wireless success along with cost, coverage, and capacity. To evaluate listener reactions to the eight major broadband digital technologies now being deployed, researchers recorded both stationary (low background noise) and mobile (high background noise) calls made on 13 different digital, analog, and wireline platforms (see *Table 5*). Surveys were sent to over 1,000 potential participants who rated the calls according to five criteria: distortion, clipping, background noise, tone, and in comparison to analog.

TABLE 5

We Visited Seven Digital Markets

Market	System
Puerto Rico	CDMA 1900
Georgia	GSM
D.C.	GSM
Las Vegas	CDMA 800, iDEN
San Diego	CDMA 800, GSM, CDMA 1900
Tampa	CDMA 1900, GSM
New York	Analog/AMPS, GSM, TDMA, Wireline

Wireline calls, as expected, rated among the highest. Mobile calls fell short of stationary calls, with one exception—CDMA 1900. Upbanded CDMA consistently received among the highest scores for both stationary and mobile calls. CDMA shone in particular on the mobile calls, where mobility and background noise put the greatest demands on voice quality.

Digital overlay on analog systems appears to be somewhat problematic. It remains to be seen whether or not these technical issues can be "engineered" away by incumbent analog cellular carriers. Pure digital PCS providers may have the advantage over cellular carriers in terms of migrating customers to digital from existing analog channels, particularly in high-density urban markets.

...As Did iDEN

iDEN is a leading-edge digital platform based on time-division technology such as TDMA and GSM. Where GSM uses 200 kilohertz-wide channels and TDMA uses 30 kilohertz-wide channels, iDEN uses 25 kilohertz-wide channels. Importantly, iDEN requires no guardbands, which improves overall capacity and allows for a highly efficient vocoder sampling algorithm. IDEN, like the commercial "tool" that it is, performed consistently in the middle of the pack on both surveys and compared well with analog calls. For this project, the Nextel (NXTL—13 3/8, rated Buy) system in Las Vegas was tested and found to be consistent with the same system in Boston. Overall, it appears that iDEN has a competitive product offering. It was not possible to sample the dispatch call clarity in this survey, but it was found to be fairly consistent with interconnect.

Overlays In General Scored Poorly

It seems probable that densely packed urban analog providers will have a hard time keeping up with their digital competitors in voice clarity comparisons going forward. Airtouch's Los Angeles system was not sampled during this survey, but on other occasions it has been found to be inferior to CDMA overlay systems in less-crowded San Diego and Las Vegas. It remains to be seen how well BellAtlantic / NYNEX Mobile performs in New York with its CDMA system. The same issues appear to affect TDMA systems in large metropolitan areas, and, as indicated earlier, it appears that AT&T bought 10 megahertz of new spectrum to address this issue. The authors suspect that if GSM had ever been used as an overlay application, it would have negatively colored public perception of the technology, just as CDMA overlay problems colored public perception even of upbanded 1900 MHz CDMA. It is possible that incumbent analog providers never wanted to publicize this issue.

These Are Not Lab Results

Several engineers queried by the researchers criticized the methodology of this study. The authors, though, view this as a virtue, particularly given the real-world characteristics of the survey. After all, the broadband PCS / cellular wars will be fought over real subscribers with real preferences using systems in the real world.

More so than in any other competitive telecommunications model, the users of wireless services will be confronted with myriad choices. Therefore, it is probable that carriers will focus on inherent advantages; e.g., pricing (cost), voice quality (clarity), footprint (coverage), and network technology and deployment (capacity). As a result, some or all of the "Four Cs" will most likely emerge as the wireless investment themes of the near future.

Service Provider's Perspective on Wireless Local Loop

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Abstract

Wireless local loop (WLL) issues are discussed from a service provider's perspective. Technology options are considered for both voice and data applications in terms of the Erlang efficiency per MHz of bandwidth in each cell site. The comparisons are made in terms of narrowband second-generation systems, wider band third-generation systems, and broadband systems. Numerous issues need to be resolved in terms of defining customer requirements, matching technology to the identified customer needs and, in the United States, availability of dedicated spectrum.

Introduction

The rapid growth of the cellular telephone industry over the past two decades, together with developments in digital technology and resulting performance improvements and declining equipment costs, has spurred interest in wider applications of wireless systems for the delivery of communications services. This has led quite naturally to consideration of wireless technology as an alternative to the traditional wired lines connecting homes and businesses to the public switched telephone network (PSTN). This wireless access to basic telephone services is referred to as wireless local loop (WLL).

Wireless local loop can be approached from the perspective of the subscriber or the service provider. When the subscriber picks up the handset, expectations include dial-tone, quick call setup, and toll-quality voice. In addition to a quality of service (QoS) comparable to wireline, where voice quality attains mean option scores (MOS) of at least 4.0 and blocking probability less than 2 percent, the subscriber might expect at least cordless mobility, custom local area signaling services (CLASS) such as call waiting, call forwarding, conferencing, etc., and data service at a minimum rate of 28.8 kbps. The service provider offers WLL in cases where it is less expensive than wireline, where an access network can be built more rapidly than wireline (i.e., first to market), or where ready access to customers can be gained, thereby bypassing the local exchange. To minimize costs while providing acceptable quality, the access network must have minimum complexity, offer the customer expected services, permit simple access network monitoring, and allow rapid network buildout.

Prior to describing technologies appropriate for WLL, it is worth examining specific opportunities. The most immediate and obvious opportunity is in international markets where developing countries have limited or nonexistent wireline service. In this case, WLL can be deployed rapidly, providing customers with voice, data, and Internet access well before cable can be laid. Successful WLL deployments have already begun in many countries including England, Sri Lanka, Malaysia, Russia, China, and others. In the United States, WLL has been deployed in rural markets where cable lengths and costs are excessive but in-franchise customers must be serviced. An example of a system in this category is basic exchange telephone radio service (BETRS), developed in the mid-1980s to provide wireless telephone service to subscribers in remote areas. BETRS operates under state-certified licenses in 152/158 and 454/459 MHz bands as well as in 10 channel blocks in the range from 816 to 865 MHz.

Other WLL opportunities in the United States are potentially attractive for service providers seeking revenues from near-out-of-franchise operations. In this case, WLL can be used to bypass the local exchanges. An example of this strategy has been suggested by AT&T Wireless where WLL technology operating at personal communications services (PCS) band frequencies can be used to penetrate the local market. Since WLL service in the United States is expected to be flat rate, as in the case of wireline service, a detailed business case analysis is required to determine if the service provider can gain more revenue by using the spectrum for cellular customers who pay by minutes of use. In the United Kingdom, the service provider Ionica has begun deployment of WLL systems and has developed a business plan based on capturing a significant portion of the revenue from the major incumbent service provider.[1]

The remainder of this paper will focus on WLL architecture, technology options, efficiencies of selected technologies, and specific issues to be resolved prior to a large scale deployment of WLL technology.

What Is Wireless Local Loop?

WLL is an alternative access mechanism to support existing wireline terminals and communications services, though support of other types of terminals is usually not precluded by this definition. The WLL replaces all or part of the connection between the public network and the customer premises, and the costs of installation and maintenance of the local loop can be significantly lower than costs typically incurred with conventional wired loops. The wireless system also lends itself to rapid deployment, which can be a valuable feature in some applications.

There are two different types of WLL systems that address different markets. The first system, termed wireline replacement, applies where standard telephone equipment and services must be supported for users who have the expectation of service that will not differ from that ordinarily provided by traditional wired access. The basic requirements for wireline replacement can be summarized as follows:

1. delivery of toll-quality speech with performance equivalent to wired access

2. support, as a minimum, for Group-3 facsimile and for voiceband modem transmission at rates up to 28.8 kbps (support for higher data rates will be desirable)

3. optional support for integrated services digital network (ISDN) service

4. fixed radio access equipment at the customer premises

5. optional mobility for end-user terminals, e.g. using cordless telephones

A second type of WLL system is applicable where the primary requirement is reduced cost or greater speed and ease of deployment and installation. Here, the requirements for equipment support or the customer's service expectation are different from full wireline support; this type of system is referred to as Wireless Wireline. The basic requirements for this type of system can be summarized as follows:

1. support of "wireline-like" services

2. voice quality equivalent or similar to that experienced with cellular systems

3. fallback rate support for facsimile devices and voiceband modems

4. optional limited mobility support, e.g. "neighborhood mobility"

All WLL systems, of either type, should support the basic services provided by the local central office (CO) switch connected to the WLL system.

The local loop is the term used to describe the connection between a subscriber and the local exchange. Typically, the connection consists of a distribution network, which interfaces the switch in the local exchange to a distribution point, and an access network, which connects the distribution point to the subscribers. For a WLL system, the access network provides a radio interface between a base station located at the distribution point and the subscriber residence or business building. *Figure 1* illustrates the difference between a wireless and a wireline local loop. In the wireline case, the switch is connected to the distribution point and the distribution point

FIGURE 1
What Is the Local Loop?

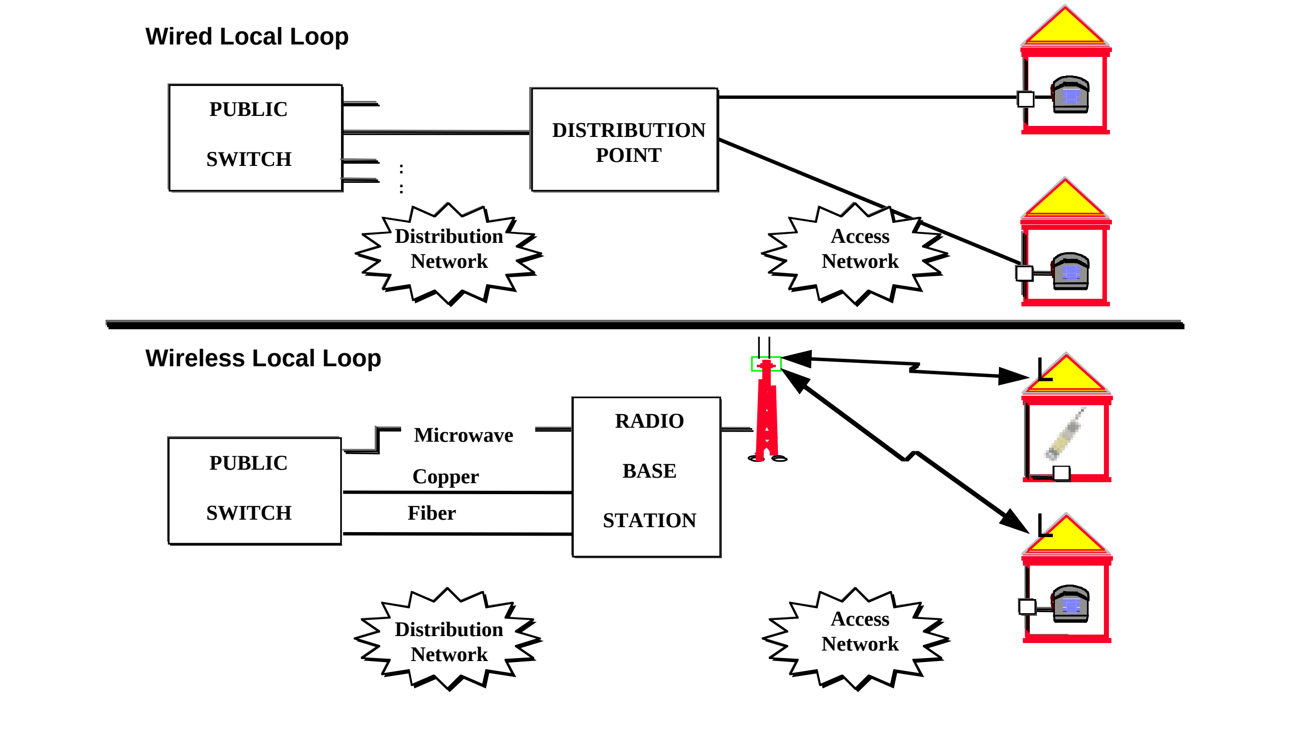
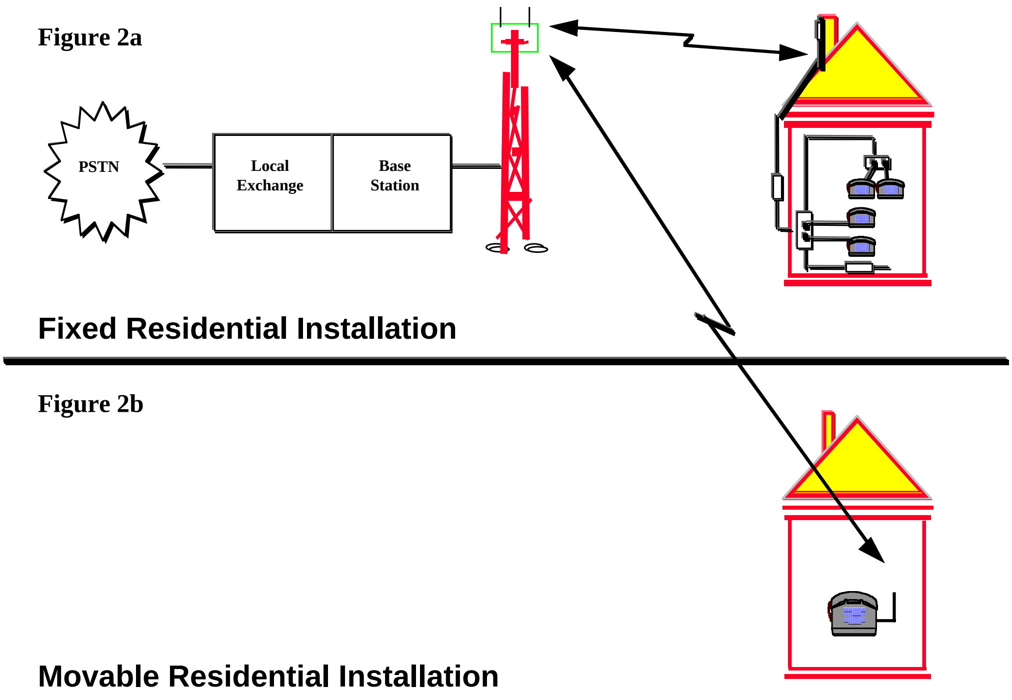


FIGURE 2

Wireless Local Loop Installation



is connected to the subscriber by copper pairs or fiber. For a WLL system the distribution network may be copper, fiber, microwave, etc., to a radio base station with an antenna mounted on a tower or the top of a tall building. A radio link then is used to provide access to the subscriber. Depending on the subscriber terminal selected, the end user can have a standard fixed or cordless wireline phone, a special terminal that may or may not have dial tone, or even a cellular phone.

Figure 2 illustrates WLL installation options. In *Figure 2a* the dwelling has a roof- (or eaves-) mounted antenna with a wireless interface to a base station in the building. Cordless or fixed terminals with an available dial tone are typical. Many vendors also provide multiline capability for a mix of voice and data users. An alternate configuration has been implemented in which the user terminal communicates directly with the base station. This installation option can be problematic in that a customer might move the terminal and unknowingly degrade signal quality.

The technology solutions for WLL have typically evolved from existing or planned cellular systems. A major difference between cellular and WLL is that cellular systems conform to well-established standards such as IS-95 code division multiple access (CDMA), IS-136 time division multiple access (TDMA), and Group Speciale Mobile (GSM), whereas WLL systems can be standards-based or proprietary. Another major difference is that WLL systems are not ordinarily designed to support unlimited mobility, but only local mobility for cordless terminals and therefore do not need roaming capability. Therefore, infrastructure elements such as home and visitor location registers (HLRs and VLRs) and IS-41 roaming protocols are irrelevant. Other major differences between cellular and WLL are summarized in *Table 1*. Notice that in the United States, dedicated spectrum for WLL is unavailable, whereas international spectrum allocations are readily available at 2–2.5 GHz or 3.4–3.5 GHz. For example, in the United Kingdom, Ionica operates in the 3.4–3.5 GHz band. Handoff between base stations, required for cellular, is not needed in WLL. The soft handoff advantage of CDMA, whereby the cell phone gains a combining advantage by communicating simultaneously with two or more base stations, is normally not available, since a minimum complexity network is expected to be implemented where the subscriber is connected to only one base station.

The WLL subscriber antenna need not be omnidirectional as in the cellular case. Typically, the antenna is elevated, is directional with an associated gain, and has a line-of-sight (LOS) path to the base station. As a result, networks can be designed so as to reduce interference to levels much lower than those encountered with cellular, and to permit improved frequency reuse and increased capacity.

Since the WLL propagation path is usually fixed, its path loss is closer to 20 dB/decade (LOS) rather than 40 dB/decade (cellular case). Fast Rayleigh fading is replaced with slower Rician fading, in which there is a strong dominant path plus a random multipath component. Note that traffic requirements are likely to be higher for WLL than for cellular, particularly where multiple lines are available. Bandwidth allocation is expected to be wider than for cellular in order to

TABLE 1

Comparison of Cellular and WLL

Requirement	Cellular	Wireless Local Loop
Mobility	Vehicle/Pedestrian Speed, Roaming	Fixed, No Roaming
Spectrum	824-849 MHz (Mobile to Base) 869-894 MHz (Base to Mobile)	None in UNITED STATES 3.4 - 3.5 GHz (International) 2.0 - 2.5 GHz (International)
Bandwidth	30 kHz to 1.25 MHz	5 - 20 MHz
Handoff	Hard or Soft	N/A
Channel	Rayleigh Fading, Shadowing	Rician Fading, Near-LOS
Radio Configuration	BS (omni or multi-sector) to omni at ground level	Multi-sector at BS to elevated directional antenna
Frequency Reuse	Required	Required
Range	Variable (1-15 km)	15 km (typical)
Traffic	15-25 milliErlangs/subscriber	100-150 milliErlangs/subscriber
Standards	CDMA, TDMA, GSM	Proprietary & Standards-Based

support data rates of 128 kbps as in ISDN (2B+D). Note that the range for WLL will vary widely depending on geographical terrain and land-use characteristics in the serving area. For dense urban environments the range might be 1.5 km whereas for rural areas, the range might extend to 20 km.

Technology Options

There are numerous technology choices available to a service provider in deploying WLL. Restricting the choices to digital techniques, *Table 2* summarizes the characteristics of several important options.[2] In addition to the systems listed in the table, third-generation systems and local multipoint distribution service (LMDS) need to be included as alternatives. Third-generation systems are expected to utilize greater bandwidth and support higher data rates than do first- and second-generation systems.

WLL alternatives can be broadly categorized as: (1) narrowband second-generation systems, (2) wider band third-generation systems, and (3) broadband. Vendors are currently producing narrowband systems operating in cellular/PCS bands (or slightly higher bands for international applications) using IS-95 CDMA, IS-136 TDMA, GSM/DCS-1800, digital European cordless telecommunications (DECT), and hybrid variations. An example of a TDMA variation is being deployed by Ionica in the United Kingdom where ten time slots are used, instead of three as in IS-136 or eight as in GSM.

TABLE 2

Characteristics of Several Potential WLL Technologies

Attributes	DECT	IS-136	IS-95	IS-95 (2d Gen)	Ionica	GSM	DCS-1800
Frequencies (MHz)	1880-1900	824-849 (R) 869-894 (F)	824-849 (R) 869-894 (F)	824-849 (R) 869-894 (F)	3425-3442 (R) 3475-3492 (F)	880-915 (R) 935-960 (F)	1710-1785 (R) 1805-1880 (F)
Channel BW (kHz)	1728	30	1250	1250	307.2	200	200
Multiple Access	TDMA-FDM (12 slots)	TDMA-FDM (3 slots)	CDMA-FDM	CDMA-FDM	TDMA-FDM (10 slots)	TDMA-FDM (8 slots)	TDMA-FDM (8 slots)
Channel Trans. Rate (kbps)	1152	48.6	1228.8	1228.8	512	270.8	270.8
Data Rate (kbps)	64	8	14.4	64	64	9.6	9.6
Modulation	GMSK	p/4 DQPSK	OQPSK	OQPSK	p/4 DQPSK	GMSK	GMSK
Comments	Freq Hop					Freq Hop	Freq Hop

Other variations use some combination of CDMA and TDMA. DECT using a frequency hopped TDMA scheme is actually a European cordless system for use in applications, such as wireless PBX, where users have local mobility. These second-generation systems are limited in data rate to no more than 128 kbps. Overall, bandwidths of these systems ranges from 20 to 35 MHz.

Third-generation wider band systems will be extensions of the second-generation systems with the same bandwidth used to offer higher data rates. For mobile applications the data rate is limited to 384 kbps and for fixed applications to 2 Mbps.

On the other hand, broadband systems such as LMDS operating at 28 GHz have bandwidths of about 1 GHz, resulting in data rates ranging from 10 to 25.6 Mbps. These systems can support asynchronous transfer mode (ATM) traffic.

From the service provider's viewpoint, then, it would seem that the broadband systems are the logical choice for being able to offer the greatest range of services. However, other factors such as architecture characteristics, network interfaces, network complexity / cost, and customer premises equipment (CPE) complexity / cost must be considered. For example, the base-station spacing for systems operating in the PCS band can be much larger than spacing used in an LMDS system. For free space propagation where the loss is inversely proportional to the square of the frequency, a factor of 14 increase from 2 GHz to 28 GHz represents a 23 dB loss. Accounting for terrain and other propagation factors, practical PCS base-station spacings are 10 miles whereas LMDS base station spacing is closer to 1–2 miles, depending on rain fade margins. Thus, many more base-stations are required for LMDS than for PCS. The LMDS CPE, which supports the higher data rate, is also expected to be higher in cost and complexity than a PCS band solution, making the technology choice even more difficult. The principal advantages of the broadband technology choice are the increase in capacity and the availability of high-speed data services.

At this point, it is useful to compare technologies on the basis of the number of users operating at a specified source data rate with a selected vocoder technology.[3] (The last entry for 128 kbps is not a vocoder technology but simply an ISDN data service.) Assuming a 20 MHz available bandwidth with each user requiring 30 kHz implies that 666 channels can be assigned. Each user is assumed to generate 100 milliErlangs of traffic. Setting aside 26 channels arbitrarily to provide control channels leaves 640 traffic channels. *Table 3* then indicates the number of users supported for several vocoder data rates, the corresponding vocoder technologies, and the traffic in Erlangs at 1 percent and 2 percent blocking rates.

Efficiency of Technology Options

In this section, the efficiencies of second- and third-generation systems are compared with the broadband case.[4] The cases under consideration include voice using QPSK / CDMA, data using QPSK / CDMA and LMDS with QPSK or QAM. The CDMA cases all assume that the maximum number of calls / sector, K, can be computed[5] as

$$K = 1 + (W/R)(F/v)(1/\gamma)$$

where W is the channel bandwidth, R is the source data rate, W/R is the spread-spectrum processing gain, the frequency reuse efficiency is $F = 0.667$, the voice activity factor is $v = 0.45$ for voice and 1.0 for data, and the required energy contrast ratio is $\gamma = Eb/No$. For QPSK / CDMA in a cellular system $\gamma = 7$ dB is an accepted value for 13 kbps voice. This value must be increased by about 6 dB for the WLL case, where no soft handoff gain is available, so that the value of γ used in the above equation is 13 dB. The spectral efficiency assumed for QPSK is taken conservatively to be 1 bps / Hz.

Using these assumptions with an underlying QPSK / CDMA transmission format, *Table 4* compares the efficiency of second and third-generation systems with LMDS. The technology comparisons are based on three-sector cell sites. However, LMDS sectorization is ordinarily accomplished by use of horizontal and vertical polarization and is typically implemented with four-sector cell sites. Note that the efficiency is stated in terms of Erlangs / cell / MHz based on an Erlang-B calculation with 2% blocking. If the operating energy contrast ratio can be reduced to $\gamma = 7$ dB, the efficiencies in Erlangs / cell / MHz corresponding to the last row of *Table 4* become 55.1, 43.5, 61.8, and 82.4.

Table 5 provides a calculation for the CDMA case assuming full duplex data is to be supported with a value of $\gamma = 13$ dB. The data rates considered include 64 kbps and 2 Mbps, with a corresponding increase in required channel bandwidth. With $\gamma = 7$ dB, the efficiencies in Erlangs / cell / MHz, corresponding to the last row of *Table 5*, become 3.97, 3.56, 0.03, 8.4, and 0.26.

TABLE 3

Number of Users for Specified Data Rate

Vocoder Data Rate	Vocoder Technology	Number of Channels	Erlangs @1%	Users @1%	Erlangs @2%	Users @2%
8 kbps	VSELP	640	613	6130	627	6270
16 Kbps	CELP	320	297	2970	306	3060
32 kbps	ADPCM	160	141.2	1412	146.6	1466
64 kbps	PCM	80	65.4	654	68.7	687
128 kbps	ISDN (service)	40	29	290	31	310

TABLE 4
CDMA Voice Efficiency

	Second Generation	Third Generation	LMDS	
Total Bandwidth (MHz)	5	20	1000	
Channel Bandwidth (MHz)	1.25	5	10	
Number of Channels	4	4	100	
Source Data Rate (kbps)	14.4	14.4	14.4	
Chip Rate (Mchips/s)	1.2288	3.6864	10	
Processing Gain	85.33	256	694.4	
Max No. calls/sector, *K*	7	19	52	
Voice channels/sector	28	76	5200	
Erlangs/sector @2%	20.2	64.9	5200	
Number of sectors	3	3	3	4
Erlangs/cell	60.6	194.7	15,600	20,800
Erlangs/cell/MHz	12.1	9.7	15.6	20.8

TABLE 5
CDMA Data Efficiency

	Second Generation	Third Generation	Third Generation	LMDS	LMDS
Total Bandwidth (MHz)	5	20	20	1000	1000
Channel Bandwidth (MHz)	1.25	5	20	10	40
Number of Channels	4	4	1	100	25
Source Data Rate (kbps)	64	64	2000	64	2000
Chip Rate (Mchips/s)	1.2288	3.6864	16.384	10	40
Process Gain	19.2	57.6	8.2	156.2	20
Max. No. of calls/sector, *K*	1	2	1	6	1
Voice channels/sect	4	8	1	600	25
Erlangs/sect @2%	1.09	3.63	0.02	587.2	17.5
Number of Sectors	3	3	3	4	4
Erlangs/cell	3.27	10.89	0.06	2349	70
Erlangs/cell/MHz	0.65	0.54	0.003	2.35	0.07

The LMDS cases shown in *Tables 4* and *5* are artificial in that the selected waveform is assumed to be QPSK/CDMA whereas a QAM format is more likely to be used, in order to take advantage of the increased spectral efficiency of the higher order modulation format. *Tables 6* and *7* provide results for data usage via LMDS where the data rates considered are 64 kbps, 2 Mbps, and 25.6 Mbps using modulation formats of QPSK, 16QAM and 64QAM, respectively. The spectral efficiency of the 16QAM case is assumed to be 2 bps/Hz with required $\gamma = 18$ dB; for 64QAM the spectral efficiency is 2.6 with $\gamma = 23$ dB. The number of sectors is assumed to be four. For this signal format cell sites are distributed in a hexagonal arrangement and frequency reuse is utilized. To compute the efficiency in Erlangs/cell/MHz the following formula for frequency reuse, F_r, is needed:[6]

$$F_r = (6\gamma)^{2/n}/3$$

where n is the path loss exponent, taken to be 2 for LOS or 4 for cellular. Values of $n = 3$ and $n = 4$ will be used for the WLL case. It can be seen from the results that the efficiency in Erlangs/cell/MHz increases with a higher path loss exponent. For example at 64 kbps, the efficiency for n = 2, 3, and 4 is 0.34, 1.9, and 3.86, respectively.

TABLE 6

LMDS Data Efficiency for *n* = 3

	Total Bandwidth (MHz)		
	1000	**1000**	**1000**
Channel Bandwidth (MHz)	0.064	1	10
Number of Channels	15625	1000	100
Modulation	QPSK	16QAM	64QAM
Spectral efficiency(bps/Hz)	1	2	2.6
Source Data Rate (Mbps)	0.064	2	25.6
? (dB)	13	18	23
Frequency Reuse, F_r	8	17	37
Voice channels/sect	488	14	1
Erlangs/sect @ 2%	474	8.2	0.02
Erlangs/cell	1896	32.8	0.08
Erlangs/cell/MHz	1.9	0.033	0.00008

TABLE 7

LMDS Data Efficiency for *n* = 4

	Total Bandwidth (MHz)		
	1000	**1000**	**1000**
Channel Bandwidth (MHz)	0.064	1	10
Number of Channels	15625	1000	100
Modulation	QPSK	16QAM	64QAM
Spectral efficiency(Bps/Hz)	1	2	2.6
Source Data Rate (Mbps)	0.064	2	25.6
?(dB)	13	18	23
Frequency Reuse, F_r	4	7	12
Voice channels/sector	976	35	2
Erlangs/sector @ 2%	966	26.4	0.223
Erlangs/cell	3864	105.6	0.892
Erlangs/cell/MHz	3.86	0.1	0.0009

WLL Architecture and Economics

An architecture implementing WLL capability is shown in *Figure 3*. It is assumed that multiple base-station controllers (BSCs) are connected to a central office (CO) which in turn connects to the PSTN. Each BSC can accommodate a number of base stations (BSs) with associated transceivers and antennas. The customer side of the wireless loop is assumed to include residences, businesses, and multiple-unit dwellings/businesses. The BSC contains vocoders, equipment to distribute traffic to individual base stations, operation and maintenance equipment, and network management and control facilities.

To illustrate WLL economics, cost calculations are presented for various levels of penetration in a postulated market area. A single BS is assumed to cover 30 square km where 100,000 potential subscribers reside. For this computation, 100 milliErlangs of traffic per subscriber is assumed. For this example, three-sector cell sites are assumed with the capacity of the base station taken to be 600 subscribers. The assumed BS, BSC, and CPE costs are estimated to be representative of industry pricing. *Table 8* provides the results, which illustrate that the CPE is the dominant cost element.

WLL Issues

Several issues confront the service provider choosing to deploy WLL. In addition to the technology selection discussed above, numerous practical items include:

1. lack of dedicated spectrum in the United States

2. lack of WLL standards

FIGURE 3

WLL Architecture

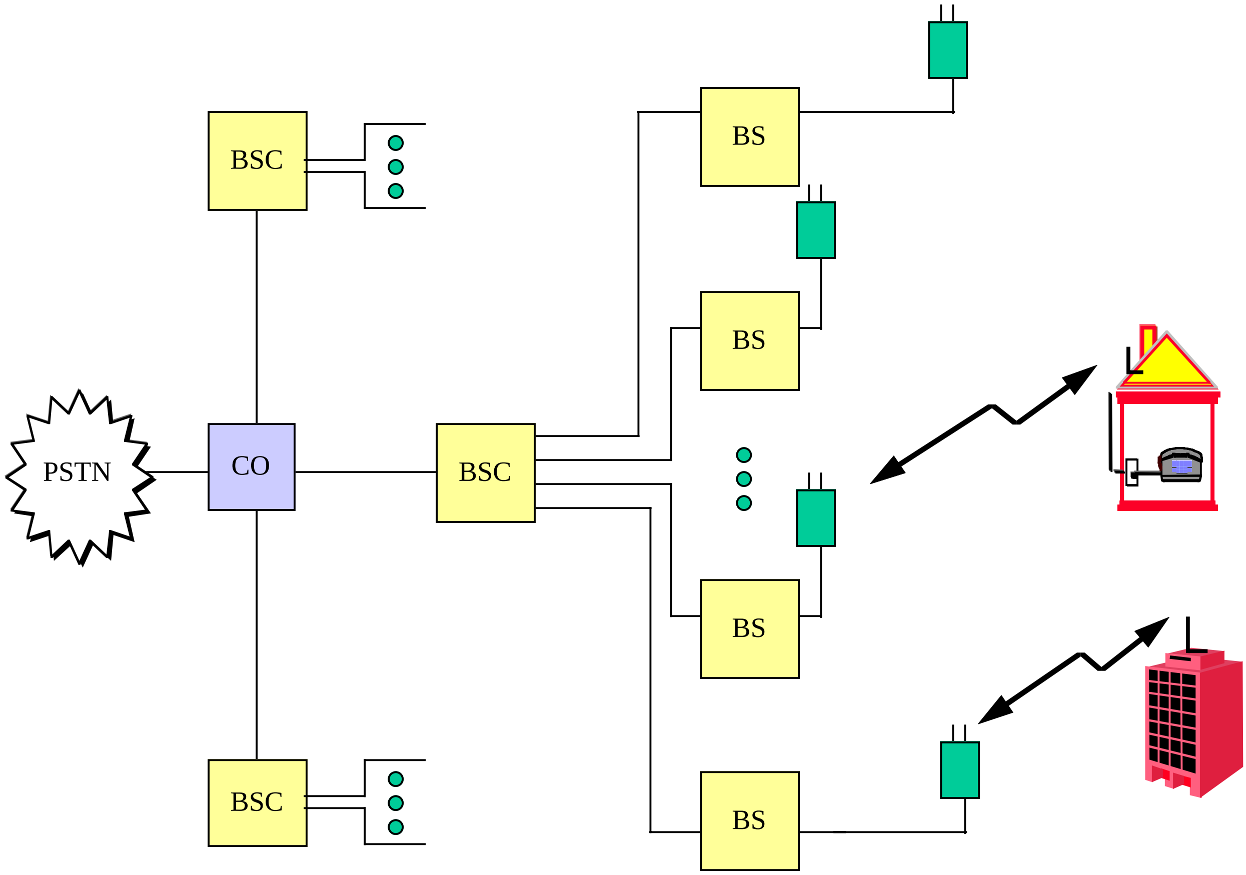


TABLE 8

Cost per Subscriber Versus Market Penetration

	5%	10%	20%	25%
Total No. Subscribers	5,000	10,000	20,000	25,000
Number of Calls	500	1,000	2,000	2,500
Number Calls/Sector	166	332	666	833
Number of BSs	1	1	2	2
BS Cost	$1,400K	$2,600K	$5,200K	$6,400K
BSC Cost	$600K	$900K	$1,500K	$1,800K
CPE Cost	$5,000K	$10,000K	$20,000K	$25,000K
Total Cost	$7,000K	$13,500K	$26,700K	$33,200K
Cost per Subscriber	$1,400	$1,350	$1,335	$1,328

3. quality of service requirements for voice and data

4. interface of vendor equipment to U.S. switches

5. availability of standard phone features such as dial-tone, CLASS services, etc.

6. customer need for high-speed data

The spectrum issue is key. If an operator can use spectrum for mobile service, where the customer pays for minutes of use, the attainable revenue is typically an order of magnitude higher than the corresponding revenue from a flat-rate WLL service. Many WLL technologies are proprietary and thus are not compatible with existing cellular standards and force the service provider to be captive to the selected vendor.

The quality of service expected on WLL connections varies widely. In locations where telephone service is available, cellular voice quality and low-speed data are likely to be satisfactory to customers. On the other hand, for capturing new customers or for displacing wireline connections held by new customers, high-quality voice, additional services such as high-speed data, and perhaps bundling of local and long-distance service are expected.

To date, vendor solutions have not addressed U.S. switch interface needs since there will be no strong driving force in the United States until such time as the FCC assigns dedicated spectrum to WLL. Dial-tone and CLASS services can be supported by many vendors and would be considered essential by most service providers.

The final question raised regarding the need for high-speed data is problematic. Perhaps asymmetric high-speed data is required for home and business Internet service. In general, it is expected that most residences would require much lower data rates than are needed for business use.

Conclusion

In this paper, WLL has been described as an alternative technology for subscriber voice and data access to the PSTN. The service provider considering deployment of WLL has a wide range of potential applications. In-franchise rural markets can utilize WLL where the cost of wireline installation is excessive. In adjacent out-of-franchise markets, WLL can be used to rapidly deploy local access, relying on existing infrastructure augmented by the wireless equipment to extend the market boundaries. As a result, the incumbent local exchange carrier can be bypassed and lucrative markets can be targeted. Due to spectrum limitations in the United States, international markets where frequencies have already been assigned for WLL currently represent the most attractive near-term business opportunities.

Several technologies have been identified including systems based on existing standards as well as proprietary designs. These technologies have been categorized as second- and third-generation cellular-based systems and broadband systems spanning bandwidths ranging from 5 MHz to 1 GHz. The efficiencies of the alternative categories, stated as Erlangs / cell / MHz, were examined for CDMA voice and data services. For voice services, the results show a distinct advantage for broadband systems. For data services, the broadband alternative permits higher data rates and also provides an efficiency advantage at comparable source data rates. The results also show that the spectral efficiencies are higher with reduced operating energy contrast ratios. A WLL architecture was presented along with estimated costs per subscriber at various levels of market penetration. The results clearly show that the customer premise equipment cost is a dominant element in the total cost per subscriber. Several outstanding issues were identified including the principal issue for U.S. operation, which is the lack of dedicated spectrum.

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TCP Performance in a Geostationary Satellite Environment

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Abstract

Geostationary satellite links have characteristics that can degrade the performance of TCP. The propagation time for a geostationary satellite link is on the order of 0.25 seconds. Thus, a satellite can add approximately 0.5 seconds to the round-trip time experienced by a TCP packet and the corresponding acknowledgement. This delay time is the primary cause of TCP inefficiency over satellites. There are some things that can be done to enable TCP to better utilize satellite channels. These practices include using the fast retransmit and fast recovery algorithms, the LFN extensions to TCP, and the use of selective acknowledgements. This paper briefly describes the satellite environment, the problems arising from that environment, and the best practices for mitigating the problems.

Introduction

A large portion of Internet traffic uses the transmission control protocol (TCP) for reliable data delivery. TCP is just one protocol in the family of Internet protocols known as the TCP/IP protocol suite maintained by the Internet Engineering Task Force (IETF). TCP is used by the File Transport Protocol (FTP) and for World Wide Web data transport. TCP started out as a research protocol in the early 1970s,[1] but has evolved substantially over the years. In October 1986, the Internet experienced congestion collapses and in response, several algorithms were developed to prevent or control network congestion.[2] These algorithms were introduced into the 4.3BSD (Berkeley software distribution) operating system and that version of TCP became known as Tahoe (after the name of the machine to which the 4.3BSD was being ported at the time). TCP-Reno was released in 1990 with additional changes and is the minimum benchmark for TCP today.

Users in remote areas, users in regions without well-developed terrestrial networks, and mobile users are all potential beneficiaries of satellite services. Given this environment, there has been a great deal of interest in getting the TCP/IP protocols, especially TCP, to work more efficiently over long delay paths. There are Internet services available over satellite today, so TCP obviously works over satellite, but efforts are underway to enable better utilization of satellite links.

The long propagation delay of a geosynchronous satellite path can be a fundamental problem for some applications. Interactive applications, such as a telnet session or a game of Quake, are frustrating for many satellite users. Even a basic TCP implementation will perform well for low-volume applications, including Web browsing, especially when the satellite link is shared among several users. On the other hand, high-volume data transfers such as medial images or large Web pages will require the implementation of high-performance TCP options as described in this paper.

Background

Communications satellites were developed in the 1960s to provide international telephone service. The geosynchronous orbit (GSO), at an altitude of 22,300 miles, allows ground station antennas to remain pointed in one direction. The resulting 250-ms delay because of the propagation time up and back proved not to be a problem for telephone conversations (once echo cancellation was introduced). In the 1970s, satellites were used primarily for telephony and for television program distribution. Today, 45-Mbps satellite services at bit-error rates of 1 in 107 are commercially available. Very small aperture terminal (VSAT) satellite systems provide 64-kbps or fractional-T1 data channels. Satellite frame relay services are also being offered.

New GSO satellite systems are being designed that will use higher frequencies (Ka-band) to offer services from low rates up to 18 Mbps at bit-error rates less than 1 in 1010. Low-earth orbit (LEO) satellite systems are also being built that will provide low data-rate services, but with delays comparable to, or less than, terrestrial systems. NASA's advanced communications technology satellite (ACTS) has pioneered the use of technologies that these systems will use. The concatenated error-correction coding used by ACTS has provided a link quality approaching fiber; that is, the link is either error-free or not available. As error-correction coding is used more frequently in satellite systems, the problems resulting from errors should be mitigated. However, there is a large installed base of satellite ground stations that do not use advanced error correction, many of which are in underdeveloped countries that might be slow to implement technology upgrades.

Future satellite systems are being designed that will provide personal communication services. There are LEO systems being designed and built that will offer mobile voice, messaging, and low-rate, remote Internet services. The LEO systems have low delay as well as lower power requirements compared to GSO systems, but require a larger number of spacecraft to provide coverage. Several new high-frequency (Ka-band) GSO satellite systems are scheduled for launch in the next few years. These systems will offer services at data rates from 16 kbps to nearly 20 Mbps.

Internet services are available to the end user today over satellite systems. Some of these are closed systems that can be designed for optimal transfer over high delay links and can take advantage of the asymmetric nature (that is, higher transfer rates in one direction than the other) of most Internet traffic. One satellite system is offering end users today a 400-kbps peak incoming data rate, which is much higher than the typical 28.8 kbps modem. In this paper, high data rate means over 1 Mbps.

TCP is a windowed protocol that uses acknowledgments from the receiver to clock the sender's output. New data cannot be introduced into the network until an acknowledgment has been received by the sender indicating that data has been removed from the network. The windows control the amount of data that can be transmitted at any particular time. A maximum window size (generally corresponding to the receiver's buffer size) is negotiated at the connection setup, and a congestion window is used to control the amount of data introduced into the network. Two algorithms, slow start and congestion avoidance, make TCP behave like a good neighbor and prevent data from being blasted out onto the network at the beginning of a connection or after a loss. These algorithms gently probe the network to find the proper level of data transmission. TCP assumes any loss is a result of congestion in the network and throttles back the transmission rate severely.

Advantages of Satellites

Satellites have not played a major role in the Internet up to this time, so one might question why any effort should be spent on making TCP work more efficiently over satellite. Satellites have some potential advantages that should be considered by architects of future networks. One advantage is that satellites, being wireless, do not require an infrastructure of cables and therefore can bring the network to hard-to-reach areas (e.g., in the middle of the ocean) or to economically disadvantaged areas that cannot afford a wired infrastructure. Another advantage is that a satellite is a natural for broadcasting the same data to many locations. There may be some future opportunities to take advantage of the natural broadcast characteristics of satellites to make multicast more efficient in the overall network.

Fooling TCP

It is possible to get around some of the inefficiencies of TCP by going around the protocol. This must be thought out carefully, because the congestion control in TCP is there for a reason. However, in some situations, such as at the edge of the network, it may be possible to translate to another protocol for a satellite hop or to spoof TCP by acknowledging packets before the satellite hop. It is possible to use multiple TCP connections to improve overall throughput. This can be done by splitting a large file up and sending the pieces over separate connections. It is also done by some browsers, but using multiple connections has been frowned on as an unfair practice by some computer scientists.

While bypassing TCP's slow start and congestion control algorithms might seem attractive in some cases, care must be taken to make sure that the network as a whole is not abused. This is most easily done at the edge of the network where the last leg of the connection is controlled. It might make sense in some cases to disable congestion control completely (for a deep space probe, for example, if it were using TCP for some reason). On the Internet, if one person disabled his congestion control, he might notice an improvement in performance, but if everyone disabled their congestion control, there would be no more Internet. In this paper, the concern is how to make TCP work better for everyone including satellites, not with satellite-specific solutions.

Satellite Link Characteristics

Satellite links have characteristics that can degrade the performance of TCP. These include:

- long delay paths (long feedback path)
- large delay x bandwidth product
- transmission errors (as opposed to congestion loss)
- limited bandwidth
- asymmetric use
- variable round-trip times (for some constellations)
- intermittent connectivity (handoffs and outages)

By far, the most common type of communications satellite today uses the geostationary orbit. Such satellites have an altitude of 22,300 nautical miles and orbit the earth once a day, thus appearing to be stationary in the sky. These satellites do not normally suffer from the listed disadvantages except for the final two. Asymmetric use is a result of the way satellite systems are typically configured for end users. The rest of this paper will concentrate on geostationary orbit satellites and the first three characteristics. The term "satellite" will be taken to mean "geostationary satellite" throughout.

Long Delay Path

The first characteristic, long delay path, is the primary problem addressed in this paper. It leads to the second, large delay x bandwidth product, even though satellites typically have limited bandwidth. It also exacerbates the problems arising from channel errors.

Because each satellite in the path will contribute about 0.5 seconds to the round-trip time (RTT), connection establishment will take longer over satellite. The use of TCP for transactions (T/TCP) can help make connection setup quicker by maintaining a connection for use by multiple transactions (request / response sequences).[3] HTTP1.1 should provide benefits for satellite channels for the same reason. Care should be taken in network design with regard to DNS server location to avoid DNS lookups over the satellite.

To avoid congestion in the network, TCP ramps up the connection rate using the "slow start" algorithm.[2] Because slow start is directly proportional to the RTT, the long RTT makes slow start over a satellite much slower than for terrestrial connections. Slow start time (the time to reach full connection speed after connection establishment in the absence of loss) is given by:

$$\textit{Slow Start Time} = RTT \log_2 (W)$$

Where W is the window size in packets.[2]

When using the delayed acknowledgements algorithm (which acknowledges two packets with one ACK), the slow start time increases to roughly:[4]

$$\textit{Slow Start Time} = RTT \log_{1.5} (W)$$

Thus, avoiding the use of delayed ACKs during slow start would appear to help in a satellite channel in the case of small file transfers (however, this requires further study). For large file transfers, delayed ACKs can help avoid congestion loss by controlling the burstiness from large bunches of ACKs and, therefore, is beneficial. Delayed ACKs may also be helpful in highly asymmetric channels where ACK bunching may occur that can lead to burstiness and congestion loss. However, delayed ACKs also cause slower congestion window growth during congestion avoidance. This is still a topic for research; however, it is clear that for small transfers delayed ACKs hurt, while for large transfers they can help. An obvious approach is to turn delayed ACKs on only after slow start has gotten the connection up to a reasonable rate. The use of selective acknowledgments (SACK) can allow better handling of the retransmission queue in the event of multiple packet losses in a single window.[5]

Large Delay x Bandwidth Product

The delay x bandwidth product is a measure of the capacity of a link in terms of the maximum amount of data that can be in flight at one time. This is a critical parameter in windowed protocols such as TCP. The window size must be equal to the delay x bandwidth product to utilize the channel at steady-state fully.

The largest window size in TCP without options is 65,535 bytes. For RTT = 0.5 seconds, this limits the throughput to around 1 Mbps per connection. To reach a steady-state condition where a large delay x bandwidth channel (such as one that includes a satellite) is utilized to its full potential, the use of long fat network (LFN) extensions is needed.[6] These options include window size scaling (or large windows), timestamps, and protection against wrapped sequence numbers.

Many computer scientists assume that the only thing to worry about on a satellite connection is using large windows. They assume the problem was solved many years ago (the large window option has been around since 1990).[7] Using LFN options is something that most users will have to do someday, but they are not a solution for all the problems faced by satellites. The large-windows option allows TCP to reach a steady state that uses the full bandwidth available, but does nothing for the long feedback path problems.

Table 1 shows the results of window-size calculations for selected data rates and round-trip times. Round-trip time for a coast-to-coast terrestrial network is represented by 0.1 seconds. A network including a single satellite link should come in under 1 second. Some remote sites (e.g., Alaska) may experience RTT of 2 seconds. Note that for a 2-second RTT, large windows are not necessary for a channel with bandwidth less than 262,140 bps. For a 0.1-second RTT, large windows will be necessary when the rate is a little greater than 5.2 Mbps. These numbers are for individual TCP connections. If multiple TCP connections are in use on the satellite link, each individual connection can utilize data rates up to the limit dictated by the window size; the utilization of the satellite link will be the sum of the individual connections. As stated

TABLE 1

Window Sizes for a Single TCP Connection

Rate (bps)	RTT (sec)	B*D (window) (bytes)	LFN needed? (Yes, No)
33.6 k	0.1	420	N
33.6 k	1	4200	N
33.6 k	2	8400	N
128 k	0.1	1600	N
128 k	1	16,000	N
128 k	2	32,000	N
1.55 M	0.1	19,375	N
1.55 M	1	193,750	Y
1.55 M	2	387,500	Y
10 M	0.1	125,000	Y
10 M	1	1,250,000	Y
10 M	2	2,500,000	Y
155 M	0.1	1,937,500	Y
155 M	1	19,375,000	Y
155 M	2	38,750,000	Y

TABLE 2

Round-Trip Times Corresponding to the Maximum Standard Window Size at Various Rates

Rate (bps)	RTT for 64 KB B*D (seconds)
33.6 k	15.6
128 k	4.096
1.55 M	0.340
10 M	0.050
155 M	0.003
622 M	0.0008

earlier, no action may be required if many users are sharing the circuit, and each user expects to use only a modest data rate. If a single TCP connection is expected to consume the available bandwidth, the considerations in this section apply.

Table 2 shows the results of a similar calculation in reverse, the RTT that gives a delay x bandwidth product equal to the largest possible window in TCP without using window scaling options. Note that a 12-kbps connection does not need large windows even for several satellite hops, while a 155-Mbps or 622-Mbps connection would need large windows routinely even for terrestrial channels. The low rate numbers in these tables may seem familiar today, but in a few years a reader might wonder why such ridiculously low rates are being examined. On the other hand, limits are being reached as to what can be done with the existing phone system, and cost/benefit considerations might keep many consumers using their current modems at home. As data rates increase, more connections will need LFN extensions even over terrestrial networks because of the growth in bandwidth.

Transmission Errors

The long feedback time discussed earlier also affects the response of congestion avoidance, which is an even slower growth phase than slow start. In congestion avoidance, the congestion window can be increased by no more than one segment per RTT (and when delayed ACKs are used, it has an increase rate of only one segment per two RTTs).

A loss event in TCP is always interpreted as an indication of congestion and causes TCP to enter congestion avoidance. If a loss occurs during slow start, then slow start is terminated and TCP enters congestion avoidance. Premature termination of slow start by losses other than congestion losses should be avoided because the congestion avoidance algorithm increases the transmission rate at a slower pace than slow start. A loss during steady-state operation will usually result in a drastic reduction of the effective window size at the sender, followed by congestion avoidance. Modern TCP implementations should use the techniques known as fast retransmission and fast recovery. The mechanisms attempt to recognize a case where a single TCP segment has been lost (often due to a transmission error); in this case TCP can bypass the congestion avoidance stage. To improve the handling of a loss of multiple TCP segments, the selective acknowledgment (SACK) option for TCP is needed. While this option and its performance characteristics have been extensively studied by network researchers, it is not yet widely available in end-user operating systems.

For TCP to operate efficiently, the channel characteristics should be such that all loss is due to network congestion. The use of forward error correction coding (FEC) on a satellite link should be used to bring the performance of the link to at least fiber quality. Because of the effect of long RTT, errors on a satellite link have more severe repercussions than on a lower RTT terrestrial channel, so an even better error performance is indicated, if possible.[4] There are some applications, such as military jamming, where FEC cannot be expected to solve the noise problem. Also, there may be a trade-off between coding complexity and delay.

Implementation Issues

Satellite users should keep abreast of updates to pertinent documents and ensure that the implementations they use are up-to-date.[8] They should also follow the efforts of groups such as TCP implementation working group. Efforts are currently underway to update RFC 1323 and RFC 2001. The TCP over satellite working group in the IETF has been working on identifying the problems with current versions of TCP and recommending the best common practices for satellites.

There is a large installed base of TCP that does not necessarily support the options that can improve performance over satellites. Different implementations also vary in the degree to which they follow the TCP specifications. These specifications can be difficult to understand because in the past they have not been clearly written or available in one place. The TCP implementation working group is correcting these problems.

There has been some talk about working on the next generation TCP or TCPng. A decision was made not to work on TCPng when work on Ipv6 was begun, but now there is growing interest in fixing TCP. TCP has evolved through the use of extensions that make use of the option field in the header. It may begin to make sense to migrate some of these optional extensions to a more regular position. Resistance to changing TCP could be due, in part, to a wish to avoid the congestion collapse of 1986. The Internet has become so complex that it is not possible to predict how it will react to a change in TCP.

Recommendations

Satellite users should make sure that the TCP implementation that they are using meets the Internet Standards for host requirements and for TCP.[8-10]

The TCP implementation should also meet the RFC for congestion control.[11] Specifically, a TCP implementation should include slow start, congestion avoidance, fast retransmit, and fast recovery.

Satellite users with a large delay x bandwidth product should also use implementations that include the proper options, known variously as LFN, high performance, or large windows.[6]

Satellite users should use selective acknowledgments (SACK).[5]

Satellite users should use HTTP 1.1 capable servers and browsers.[12]

Conclusions

It is important to remember that TCP works over satellite. There are several companies that offer Internet access over satellite today. TCP suffers from some inefficiencies over a long delay path, but it is not unworkable. There are efforts underway to make TCP work better, not only over satellite, but for all users. There are also efforts under way to improve the performance of TCP over satellite at high data rates. The performance issues described earlier are on a per-connection basis. Trunking TCP channels together does not affect the performance of TCP.

To utilize the available bandwidth fully it is necessary in some, but not all, cases to use the TCP large windows option. Although this solves the steady state condition, the dynamics of getting a connection up to speed or recovering after a loss is slow (proportional to the round-trip time) over satellites because of the long delay path. Efforts are underway to improve this situation.

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Deploying Enhanced Subscriber Services and IN: How and Why

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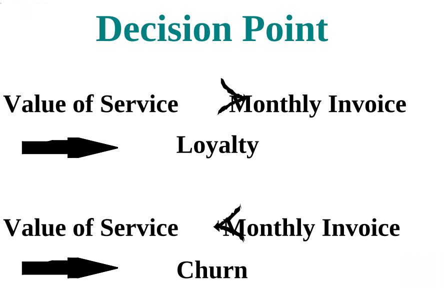
Whether due to increased competition among providers or increased sophistication among users, much focus is currently being placed on the provision of enhanced services. Enhanced services should not cannibalize or take over a network, but rather should enhance and complement what a network provider—wireless, wireline, international, or domestic—has as a core product offering. This paper will explore ways in which vendors can distribute valuable enhanced services to better serve their customers. It will outline the provision and value of several services at a high level, and examine, from a customer perspective, some of the issues faced in service deployment.

FIGURE 1
Decision Point



One of the most important matters for any provider to remember is that customers of communication services make a buying decision every month. Providers do not have the luxury of being as important as food, gasoline, clothing, or other essentials, so their services must really provide value to their customers. Certainly, wireline providers could argue that customers need telephone service, and that is true. Nevertheless, given some of the changes in the telecommunications bill and some of the new competitive factors, this may not be the case for long. Hence, it is important to focus on the customer in every possible way.

The services that providers are deploying must certainly be cutting edge, but they must also have value. It is important to remember that a provider will not simply be selling something and then walking away. Rather, there is an ongoing relationship with the customer. This must be cultivated and constantly updated with services that provide value. Generally, customers are not concerned with having advanced intelligent network (AIN) services per se, but rather with having services that allow them to communicate easily and effectively. Regardless of how services are designed from an engineering perspective, they should always be easy and convenient for carriers to deploy and customers to accept.

Value is a very intangible concept. A monthly invoice, however, is very tangible. The customer's decision point is simple. As can be seen in *Figure 1*, the value of the service in the customer's mind must be greater than the invoice. If customers see the value of that service as greater than the monthly invoice, then they may continue to retain that concept, creating a higher chance for customer loyalty. If, however, the perceived value of that service is less than the invoice, there will probably be a high churn rate. Enhanced services can increase perceived value and, hence, help in carrier differentiation and drive revenue.

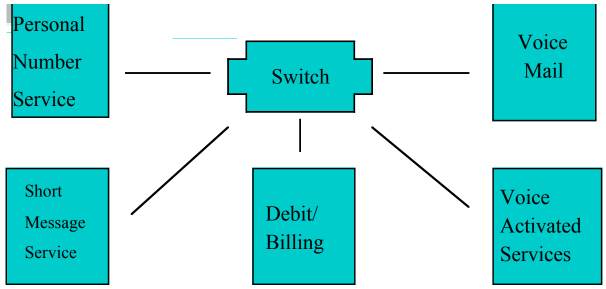
People today are communicating far more effectively than ever before. Almost every user can find a communications mechanism that suits his or her particular needs: cellular phone, pager, calling card, facsimile, etc. Each one, however, communicates individually. Enhanced services should facilitate network utilization through a particular carrier and drive as much revenue as possible. This can be done by integrating some of the networks that exist today.

The cellular switch can serve as a good example. As shown in *Figure 2*, a cellular switch can have a number of point solutions, including personal number services, short message service, voice mail, voice-activated services, and debit / billing. Having all of these point solutions, however, creates several network issues. For instance, there is no integration of services, which leads to both technical and marketing issues. There is also inefficient signaling and trunking in this scenario, as well as issues involving maintenance, training, and administration. There is a need for a reasonable integration solution—one that will provide a return on investment.

One solution could be an enhanced services platform, such as a service node (see *Figure 3*). In this scenario, carriers could customize service offerings including voice mail, outgoing calling, facsimile mail, personal number service, and voice-activated services, all of which could all exist on a single platform. The benefit to this scenario is that it is an integrated

FIGURE 2

Networks Today



service. There is a common end-user interface, a common technical interface, and a common provisioning interface. In addition, many technical and administrative issues are simplified: If something goes wrong, there is only one place to call. Using an enhanced services platform as a service node also decreases training requirements.

Enhanced services clearly have a major role in future wireless technology. They will attract a wider customer base, add subscriber value, reduce churn, and differentiate product offerings. Finally, enhanced services will drive easy revenue. Through the use of such services, companies will be able to generate revenue through their own networks. For example, the paging industry generates approximately $5 billion per year for interexchange carriers. If paging companies could figure out a way to integrate services, they could keep some of that automatic revenue.

Applications

There are many enhanced-services applications that can be deployed at a reasonable rate and generate a good return on investment. These include basic messaging, rapid response or automatic callback, voice dialing, facsimile messaging, and personal number service. Providing enhanced services is a good idea for many reasons. One of these is that once the decision is made to provide such services, product offerings can be integrated into a basic voice-mail service incrementally. Services should be cost-effective for subscribers to use and adopt.

Basic Messaging

Basic messaging is a very important entry-level service, particularly from a wireless carrier's perspective. Most personal communication service (PCS) carriers are marketing their PCS phones with voice mail, although many cellular carriers are not. Because of this, PCS carriers are able to immediately differentiate themselves.

With basic messaging, one party places a call. The end-services platform takes the call and notifies the subscriber through a short message service, pager, or other notification method. The subscriber then calls back and retrieves the message. This process is shown in *Figure 4*. This service is easy to implement, and there is no apparent change to the caller.

Rapid Response

A natural progression from basic messaging is rapid response, or automatic callback, shown in *Figure 5*. With this service, a call is placed, the subscriber is notified, and with a simple additional keystroke, the subscriber can reach the caller almost immediately. This is an attractive service from the subscriber's perspective, as it is extremely convenient and easy to use.

FIGURE 3

Enhanced Services Platform as a Service Node

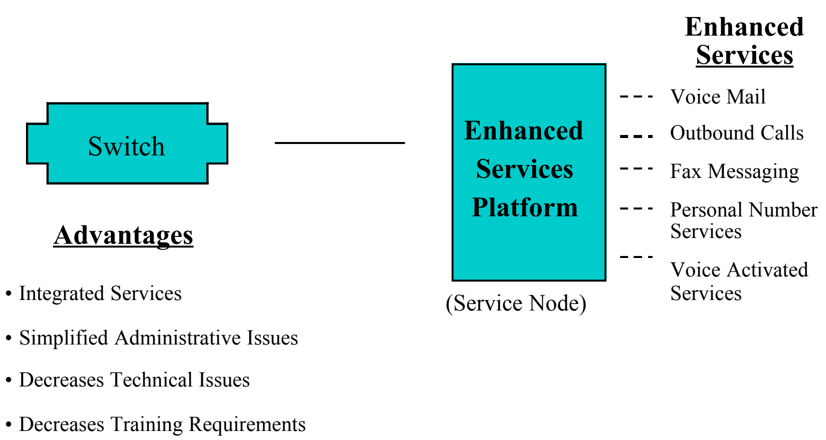
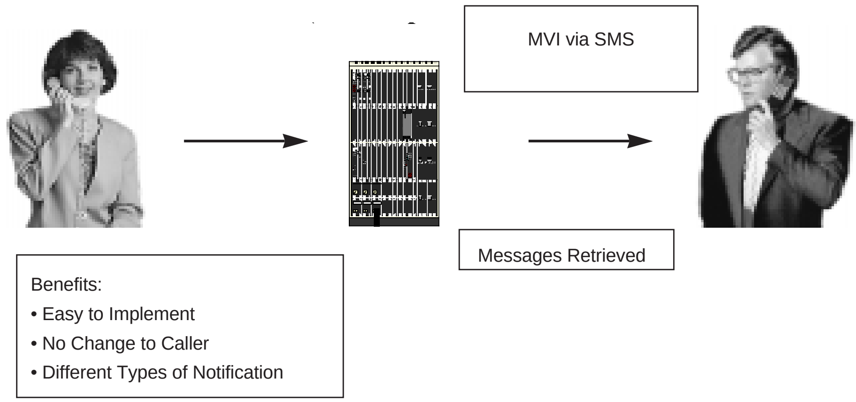


FIGURE 4
Basic Messaging



This is also a good service for providers, because the toll margins are very good. As mentioned above, one of the benefits of enhanced services is their ability to drive easy revenue. If it is possible to package a toll product with a messaging product, more revenue should be gathered than with a simple long-distance calling card service with competitive rates.

Voice Dial

In keeping with the concept of adding services that are easy to use and improve communications efficiency, providers could choose to offer voice-dialing capabilities. Certainly, pushing one button to place or return a call is very easy, but it would be even easier for users to return calls via voice. This might mean speaking phrases such as "call home," "call Jim Smith," or "dial 555-1234." In addition, the subscriber's personal directory is very secure. Finally, like rapid response, voice dialing is another service that can drive toll revenue for the provider.

While voice-dialing applications are certainly easy and convenient, they probably have a limited life in terms of being a stand-alone service. The more likely future of voice-activated services involves integration with the mailbox, allowing users to operate a mailbox with voice commands such as play, save, erase, delete, and so on. Nonetheless, voice dialing can be a very beneficial service offering for the present, although the technology is still imperfect.

One of the keys of voice dialing as an enhanced service offering is that the technology is being put on a service node-type of architecture rather than acting as a stand-alone point solution. This means that the capital cost can be leveraged over multiple revenue streams, which reduces the risk of deploying this type of service.

Facsimile Messaging

Facsimile messaging, shown in *Figure 6*, is a slightly different enhanced service. This involves being able to receive a facsimile message in the same mailbox as a voice message, using the same interface and capabilities to perform functions. The subscriber would be notified of having received a facsimile and would be able, with a few additional key presses, to print the facsimile.

This service adds another communication method for mobile subscribers. Most of these subscribers have already learned

FIGURE 5
Rapid Response: -Automatic Callback

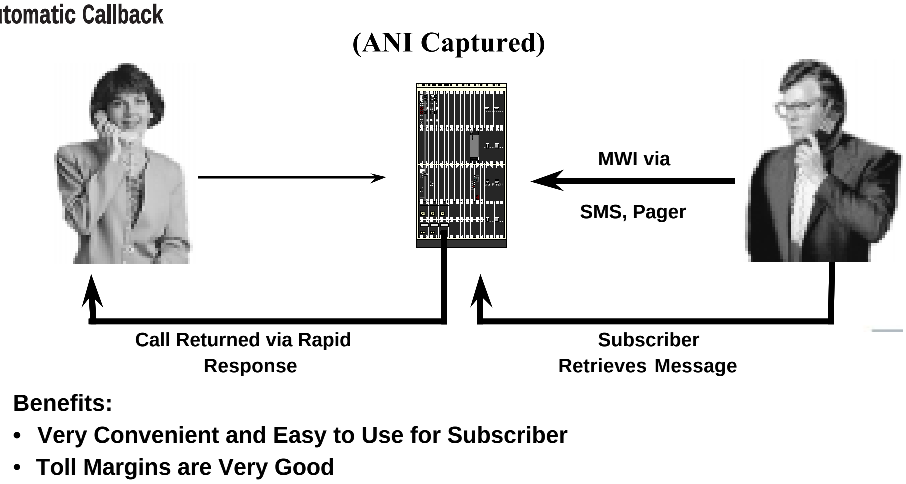
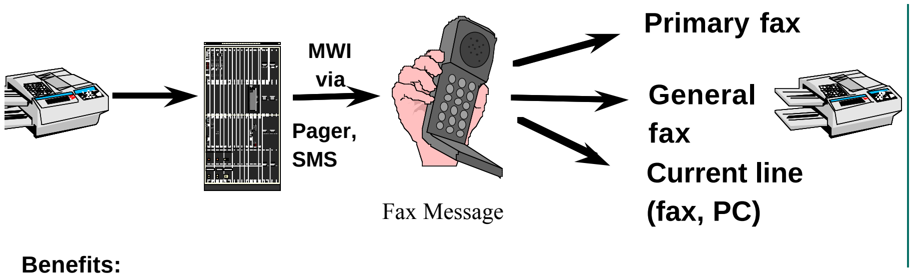


FIGURE 6
Fax Messaging



Benefits:
- **Adds Another Communication Method for Mobile Subscribers**
- **Premium Service, Drives Revenue**
- **Keeps Documents Confidential**

basic services and how they interact with the mailbox on a basic level. Facsimile messaging, then, would simply involve a small, incremental difference in function. As a premium service, facsimile messaging can drive revenue for the provider.

As yet, facsimile services have not been widely deployed in the wireless market by large carriers. This may be a distribution and focus issue, as some smaller providers are offering this service and finding it lucrative. There is a demand for this type of service, but many carriers with vertical markets have yet to take advantage of this demand. Enhanced service providers have been very focused on distribution channels, and they are able to get these types of messages very easily. Their customers are given the ability to receive a voice message, receive notification, make telephone calls, and receive facsimiles from a single unit.

This is wise on the part of service providers, because such companies are not counting on a single service to generate all their revenue. If, for instance, facsimiles become obsolete, then the enhanced service provider who has spread its investment over a number of points can still leverage costs and continue to draw revenue from other services.

Personal Number Service

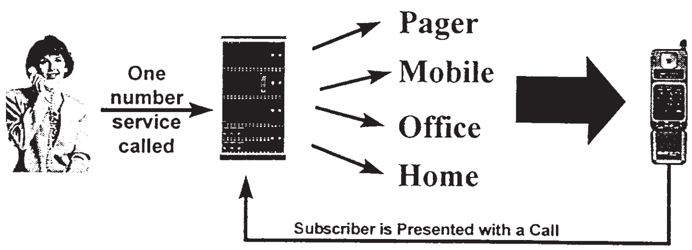
Much focus has been placed on a newer service offering—personal number service. This service allows subscribers to be reached at any location via a single number. In this scenario, a call is placed and the enhanced services platform answers the call, which connects to a series of personal communication devices and presents the call. The subscriber has several options: connect to the caller, forward the caller to voice mail, or redirect the caller to an assistant (see *Figure 7*).

Here again, if a provider were selling personal number services in a stand-alone environment without any relationship with customers, it might be difficult to explain how to use this type of service from the ground up. However, if the subscriber already has a mailbox and uses some enhanced services, personal number service is just another, incremental learning step. Another eight or ten new additional keystrokes will provide users with a powerful communications solution.

Building on Enhanced Services

Providers can significantly increase their marketability by offering some or all of these enhanced services. It is interesting to note how local number portability, now an FCC mandate, may affect the impact of enhanced services. While personal number service may be a good selling point at this time, there is a chance that it will no longer be valuable as a commodity when it becomes possible to transfer numbers between carriers. Nevertheless, this may not be such a major concern: Even if a competitor tries to lure customers from their original provider, the competitor may not be able to offer all of the enhanced services that these customers want. Even with number portability, then, providers who offer enhanced services will have an advantage.

FIGURE 7
Personal Number Service



Subscriber Options:
- Connects to caller
- Forward caller to voive mail
- Redirects caller to assistant

The key to building on enhanced service product lines is modularity. This provides both the provider and the subscriber with a great deal of flexibility. Indeed, many subscribers do not need all of the services mentioned above. Some may be satisfied with just voice messaging and direct dialing. Some may want direct dialing and personal number services, but not facsimile services. Others may want all of the available services. What is important to remember is that people differ in how they communicate. Being able to deploy these services effectively and easily in an incremental fashion should help to increase the penetration of some of these kinds of services. This is why deployment as a service node is recommended.

Carrier Issues

There are some significant areas to be addressed by wireless carriers, including billing, distribution, and focus. Deploying enhanced services requires a billing strategy. Generally, companies offering billing solutions do not like calls that originate from somewhere other than the mobile telephone switching office (MTSO). This can be problematic, since many enhanced services platforms initiate calls to locate someone on the personal number service, deliver a facsimile, or make an outbound call. This can be confusing to billing systems, which raises questions involving how to rate calls that come into the network from something other than the MTSO.

To solve this problem, carriers are exploring the possibility of debit and / or prepaid solutions. Debit and prepay are meter-type services not only for core services, but also for the outbound services that some customers may have relating to enhanced services. Switch-based billing is another option and would involve relaying calls back to the switch as though the mobile unit had made the telephone call. This would clarify things for the billing system, creating something that looked like a normal, switched-call detail record. This solution has yet to be refined and, again, requires a particular carrier strategy.

There is also pressure being placed on billing companies to offer more flexible, open types of billing systems. In the past, billing companies have actually impeded carriers, since some services were so complicated to bill that carriers simply could not offer them. Now, however, with increased competition and the value of enhanced service, carriers are pushing harder for flexible solutions that will allow them to offer more services and hence create a differentiation strategy.

Distribution is another critical issue, in terms of both core services and ancillary services. Many companies are not adequately encouraging their sales forces to concentrate on enhanced services. Many customers have not bought enhanced services because they have not been encouraged to do so. This is because representatives are paid a far smaller amount to sell a voice mailbox than to sell a new number.

If it is true that enhanced services and customer retention is the way of the future, then more attention must be paid to the way that distribution channels are compensated. There certainly needs to be new distribution channels, perhaps more related to telemarketing or other alternative distribution channels than to direct-agent sales. Many carriers have had success with specialized telemarketing or enhanced-services representatives who have received training in selling particular services. This type of training would probably be the responsibility of the vendor.

Finally, carriers must consider their focus. Many people consider enhanced services from a very high level, never reaching the market level in terms of how important these services can be. One way to change the focus is to make executives aware of the potentially powerful return on investment from deploying enhanced services. In general, if the people at the head of an organization understand the revenue-generation capabilities of a set of services, then their importance will be communicated throughout that organization. If everyone then understands the importance of enhanced services, the decision can be made to actively market them.

Conclusion

There are several important results of a successful enhanced-services product line. First, it will provide carriers with product differentiation and the ability to offer services that they know their customers need and want. Second, it will be possible to generate new and diverse revenue streams. Many of these revenue streams exist now, but through different networks. Finally, an enhanced-services product line will add subscriber value.

When considering enhanced services, providers should allow return on investment to drive their strategy. The provision of these services should be looked at it in its entirety rather than considering each point solution separately. This will allow costs to be leveraged and return to be gathered from different sources.

Multiple application platforms—that is, platforms deployed as service nodes—allow the most flexibility to deploy services, test new services, and solve administrative and technical issues. Overall, however, providers must remember that the focus should always be on the services. Services should be easy to accept, flexible, powerful, and cost-effective to deploy. By providing these type of services, carriers should be able to attract and maintain a larger customer base than companies who do not offer enhanced services, while at the same time drawing “easy” revenue.

Wireless Local Number Portability

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Motorola

Just as the wireline portion of the telecommunications industry is grappling with local number portability, so is the wireless part of the industry. From a standards perspective, many decisions remain regarding how Interim Specification 41 (IS-41) protocol implementation will support local number portability. The Cellular Telecommunications Industry Association (CTIA), specifically through the TR45.2 group, will outline particular protocol changes.

In addition to concentrating on the effects of local number portability (LNP) on IS-41, it is important to recognize similarities or differences that service providers who have implemented Global System for Mobile Communications (GSM) in the United States may encounter when implementing LNP in the wireless environment.

Overview of Cellular Networking

Figure 1 is a cellular network reference model. From its inception, cellular started as an intelligent network. In fact, cellular inherently operates according to geographic portability because a wireless terminal allows a user to roam anywhere.

The upper portion of *Figure 1* correlates to intelligent network (IN) applications in the wireline environment. This includes the visitor location register (VLR), the home location register (HLR), and the authentication center (AC). The HLR manages subscription and location information and is deployed either as a stand-alone element or integrated with the MSC. The AC manages authentication information and is usually integrated with the HLR. The visitor location register provides temporary subscription and authentication storage and is usually integrated with the MSC. Information from all of these control points is communicated to and from the MSC via either the IS-41 protocol or in GSM via the MAP protocol.

The MSC compares to a service switching point (SSP) in the wireline environment. It provides a call switching function between the public switched telephone network (PSTN) and the radio network and has at least two modes of operation: a serving and an originating mode. In the originating mode, the MSC receives a call entering the wireless network; in the serving mode, the MSC uses the base station controller (BSC) to allow the wireless subscriber communication. The BSC provides radio transport and cell-site control functions.

Numbering and Identification

To make a wireless network operate, numbering and identification terms have been created, and these must be understood in order to appreciate the impact of LNP on wireless. The first concept is a mobile directory number (MDN), which is essentially the subscriber's phone number. Depending on the network, it is either a 10-digit North American Numbering Plan (NANP) string, or a 15-digit E.164 format. IS-41 revisions A and B are NANP-specific, although Revision C and all GSM revisions support the E.164 format. The GSM term for mobile directory number is MS-ISDN or mobile station ISDN number.

The second dialed number in the network is a temporary local directory number (TLDN). This number is used for routing calls to mobile subscribers when they are roaming. It is a similar concept to a location routing number (LRN) and local number portability with the exception that these numbers are dynamically allocated on a per-call basis. As such, they are managed by the serving MSC.

There are two station identification numbers in existence. All the analog mobiles in the world today support a mobile identification number (MIN), which is a fixed 10-digit number. It was invented in the United States and is patterned after the NANP. International markets have developed ad hoc standards groups to create international numbering conventions for specific countries.

FIGURE 1

Network Reference Model

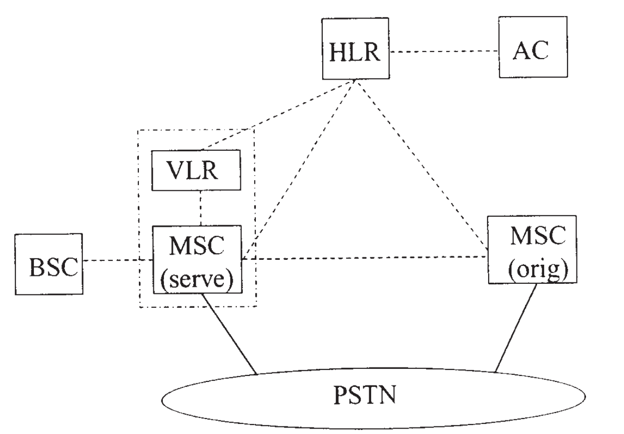


FIGURE 2

Registration Procedure

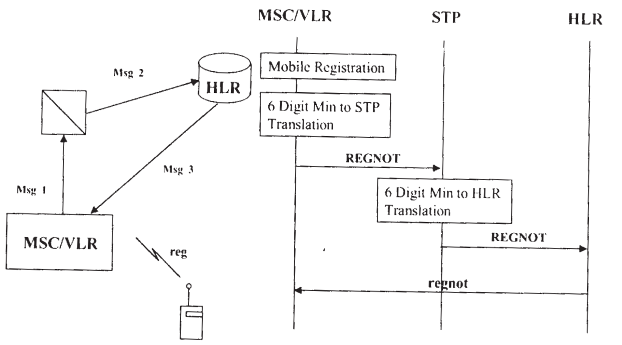
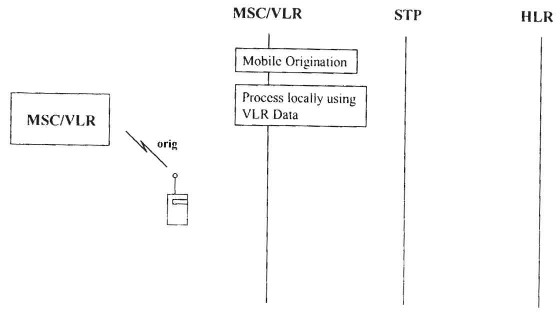


FIGURE 3

Origination Procedure



The second number, which offers a long-term solution, is the international mobile station identification (IMSI). This is a variable-length number that can be as many as 15 digits long. It contains a mobile country code and a mobile network code, and it is managed by the International Telecommunications Union (ITU). The newer digital protocols in the United States will support IMSI, and the GSM protocols will do the same.

There are a number of global title translations (GTTs) that occur within a cellular network. The first one is a MIN-to-HLR translation. Typically, this is implemented as a six-digit translation, and it is performed either in a serving MSC or in a signal transfer point (STP) somewhere in the network.

The second translation introduced by IS-41 revision C is an MDN-to-HLR translation. This is also a six-digit translation, and it is only performed within the originating MSC function in the network.

For systems that use IMSI, there is an IMSI-to-HLR translation that is supported in these networks. This translation is of variable length (3 to 6 digits) because of country codes, network codes, and construction of the IMSI. This is performed in a serving MSC or STP.

Registration Procedure

The registration procedure in a cellular network allows a cellular phone that is moved into a new market to communicate with the home system. That system has to send an indication to the user's home system so that it knows the user's current location. This is accomplished through registration.

The registration message flow requires the serving MSC to use the global title translation (GTT) capability within an STP to reach the home location register of the subscriber (see *Figure 2*). The serving MSC must first select the STP based upon a local analysis of the MIN. The STP will then perform a complete GTT and route the message to the subscriber's HLR. The HLR will update the location and issue a response back to the serving system containing the subscriber's profile. In most cases, the STP is part of the home network, serving as a gateway STP that allows the home network to move subscribers between HLRs without affecting translations in serving system markets.

The origination procedure in cellular is fairly simple (see *Figure 3*). Because a copy of the subscriber data was sent to the VLR during the registration transaction, the serving system can completely process call attempts by the subscriber without involving the HLR. This is designed to achieve efficiency in performance and increase the number of transactions on the network.

The termination procedure involves an originating MSC (see *Figure 4*). When a call comes in for a subscriber, the HLR is queried for the location. The HLR forwards a request to the serving system for a TLDN, which is subsequently returned to the originating switch. At that time, the call is routed using that TLDN from the originating switch to the serving switch using PSTN trunking.

The operations involved are called the location request, which is routed from the originating MSC to the HLR using the six-digit MDN-to-HLR translation. The HLR then formulates what is known as a routing request, which is sent from the HLR to the serving MSC where the temporary routing number is allocated.

Wireless Local Number Portability Architecture

There are many similarities between the wireless and wireline local number portability architectures. This is sensible be-

FIGURE 4

Termination Procedure

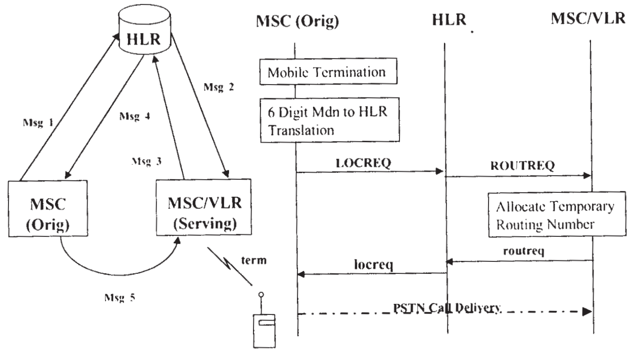
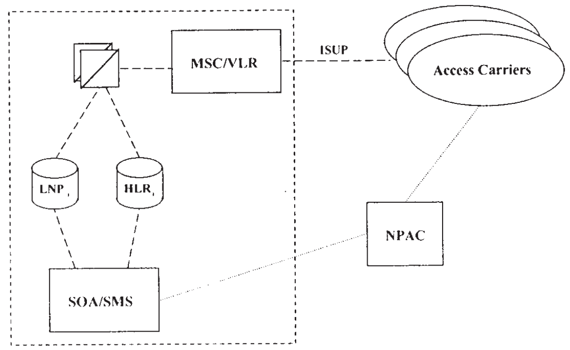


FIGURE 5
Termination Procedure



cause in terms of numbers, cellular phone numbers are still a subset of the total number of lines in the nation, and it would make the most sense to leverage as much of the wireline LNP work as possible.

The assumption is that the wireless carrier's network would contain a local service order administration or service management system. Within this wireless carrier's network, the HLR and an additional local number portability SCP function are included (see *Figure 5)*. This could be on a traditional SCP or it could be built within an STP. There are a number of ways in which these functions can be implemented. There is also the need for STPs within the wireless carrier's network as well as a requirement for ISDN user part (ISUP) connectivity between the wireless carrier and the other access carriers in a region.

Architectural Impacts of Wireless LNP

Wireless LNP requires the introduction of an LNP-SCP into the network. This LNP-SCP will need to support the wireline data model in order to maintain a single provisioning model for all types of carriers. In addition, the wireless LNP-SCP will need to support the trigger format from the wireless switches. Wireless switches—IS-41 switches, for example—generate IS-41 triggers; they do not generate advanced intelligent network (AIN) triggers.

The serving MSC function is also affected by LMP. The first factor is support for an office-based trigger similar to what is being added to the AIN implementation in wireline. There is also a need to support outbound LRN call generation. The originating MSC function must support the inbound LRN call because the originating MSC will potentially receive calls from ported numbers. In addition, the STP function in the network will now have to route queries to the LNP-SCP.

One of the main impacts of LNP on cellular is its effect on the registration scheme. The reason for this is the convention of using the MDN as the MIN assignment in analog phones. Virtually every analog phone in the United States today has the mobile directory number planted in the handset.

This creates a problem because the serving systems need to determine a user's home carrier when the phone is turned on outside the home serving area. The reason for this is that operators have multiple roaming and routing agreements for queries that are carrier-specific. LNP changes all the rules because it will be impossible to determine a home carrier based on the phone number alone. As a result, this will be the biggest factor to affect cellular.

Potential Solutions for Registration Issues

Three principal registration solutions are available. The first is mobile directory number-based, a solution that will allow the industry to keep the mobile directory number in the cellular phone as it is today. The second solution would involve a transition IMSI. The third solution is to use what has been the mobile directory number and change it into a logical identifier.

The mobile directory number–based approach involves a large amount of IN equipment (see *Figure 6*). Using this solution requires multiple translations to register a mobile unit because the serving system must query an LNP-SCP to retrieve the ten-digit translation of the mobile directory number so that the registration can be routed to the proper carrier and HLR.

Figure 7 shows MDN-based registration in IS-41 messages. When the registration occurs at the serving system, the visited serving system would generate a registration notification by employing mobile directory numbers. This would be routed to an STP located in that serving system's market. Part of the purpose of the STP is to support redundancy of the LNP-SCPs in the serving region. It is important for the architecture to support replication of these elements due to the number of transactions that will occur.

This STP essentially performs a partial GTT and routes it to one of the LNP-SCPs in the serving market. This LNP-SCP would need to use the MDN to determine the address of a gateway STP for that subscriber. Once this is determined, it can reroute the registration to the appropriate gateway STP, which would perform the final GTT and respond directly to the MSC-VLR in the serving region.

The obvious benefit is that this solution is currently compatible with IS-41 Revision B. There are no fundamental IS-41 changes required to support this. However, there are numer-

FIGURE 6
W-LNP Architecture

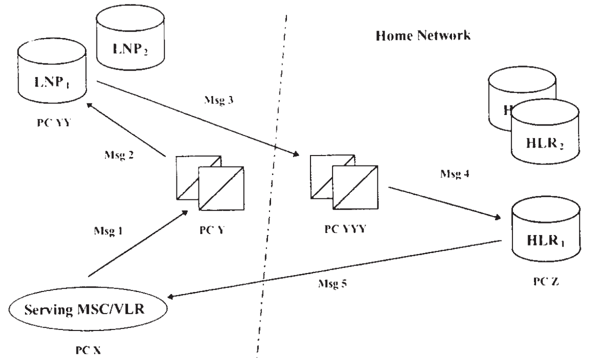


FIGURE 7

MDN-Based Registration

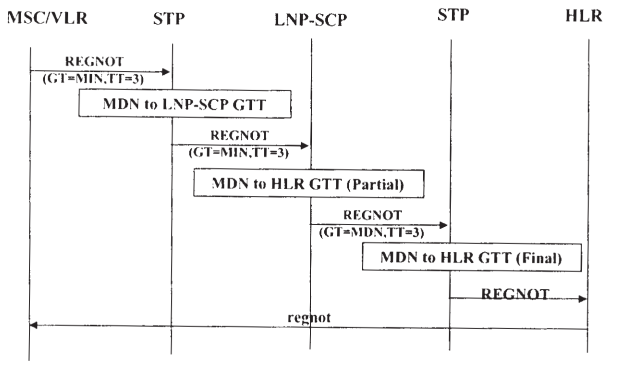
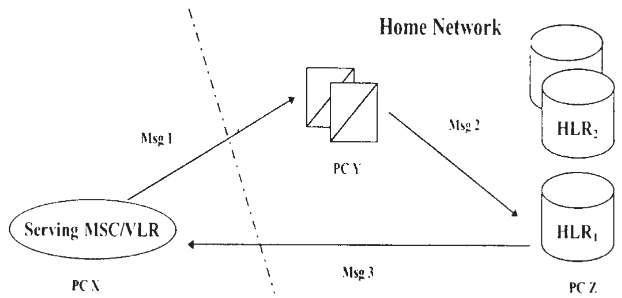


FIGURE 8

IMSI-Based Registration



ous drawbacks, the first of which is a nationwide database problem requiring MIN-to-HLR information to be propagated to every serving system in the United States. Currently, the LNP information is propagated within a rate center, but this would open it up to the whole country.

Another problem is the introduction of wireline NPAC incompatibility because of the added HLR address information. It also adds an LNP dip for registration. In cellular networks, registrations tend to be the largest transaction because of the rate at which people move around, meaning such a configuration would add even more overhead to the cellular network.

The second possible solution is IMSI-based registration (see *Figure 8*), which is much simpler. In new GSM systems, or the newer cellular systems, the IMSI has a separate numbering range from the MDN now in the mobile. Therefore, it is easy to program the IMSI to relay to the home network of the subscriber and allow registration to occur without introducing extra hardware and software into the network.

A translation protocol is defined in IS-41 for IMSI-to-HLR translations (see *Figure 9*). This serving system examines the mobile country code and mobile network code digits (generally the first five or six digits of the IMSI) to determine the gateway STP of the home carrier for that subscriber. This STP can do the final GTT and route the registration to the proper HLR, which will open a direct path back to the serving system when responding with profile information.

One benefit of using IMSI is the international numbering scheme, since the traditional ten-digit numbering system did not extend well into the international scheme. The IMSI fixes that problem by using a large, hierarchical numbering space. For example, just a few digits indicate the operator involved. In the United States, provisioning global title tables within cellular switches involves thousands of ranges that must be populated because of the layout of the NANP. The IMSI reduces this process to one range per operator.

A main disadvantage to this approach is that it requires IS-41 Revision D. Revision C has just come out, so it would be very doubtful that revision D could be finished, validated, and deployed in time to make the Federal Communications Commission dates for LNP. In addition, the ten to fifteen million analog cell stations in use will not support IMSI.

The final option for solving the registration problem is to retain the MIN, but not to encode the MDN in it (see *Figure 10*). The objective is to place another number in the MIN that can coexist with the currently assigned MDNs, but to allow the network to identify the home carrier more directly. With such an approach, the routing of the network becomes similar to the routing in IMSI, in which the serving system can route the records to gateway STPs in the home market for registration.

FIGURE 9

IMSI to HLR Translations

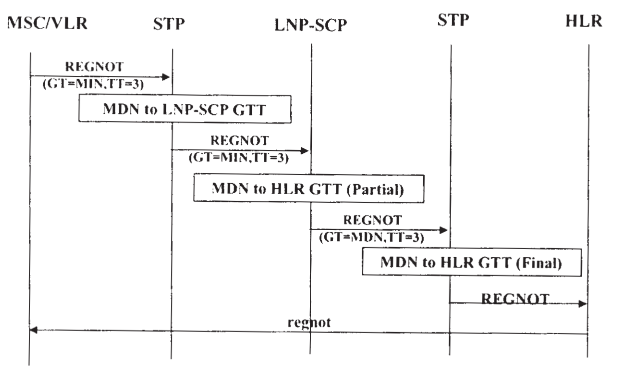


FIGURE 10

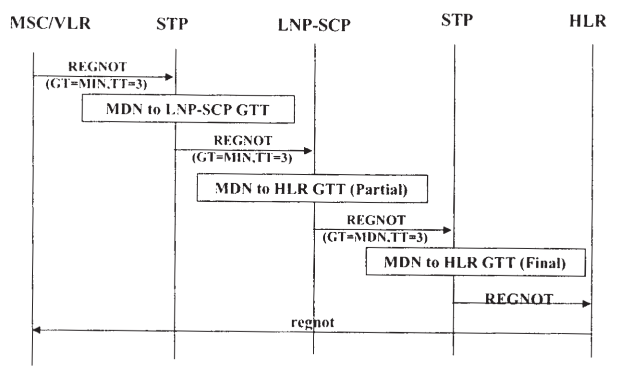


FIGURE 11

MTN-Based Registration

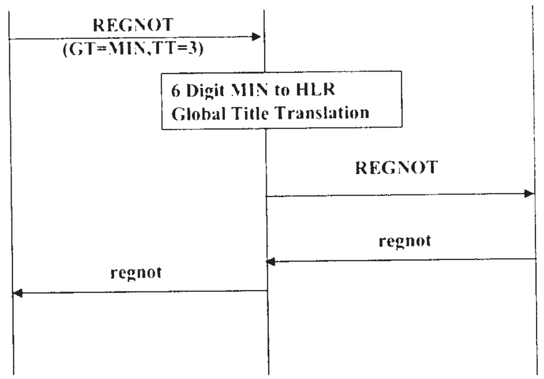


FIGURE 12

Mobile Organization

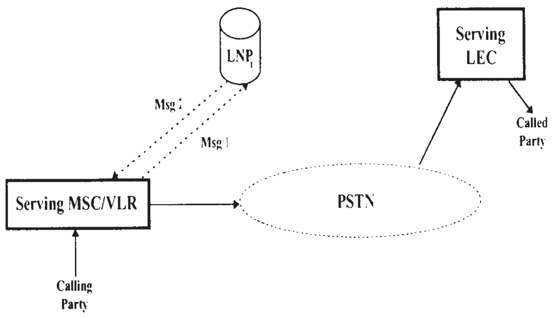


***Figure 12:** Mobile Organization*

From an IS-41 perspective, the MSC/VLR would be used in the registration notification (see *Figure 11*). Because this is not a true MDN, the six-digit analysis that occurs in this serving system can be used to determine the gateway STP for that home market. Once it is routed there, that STP would perform its normal six-digit final translation on the registration router and allow the registration to complete.

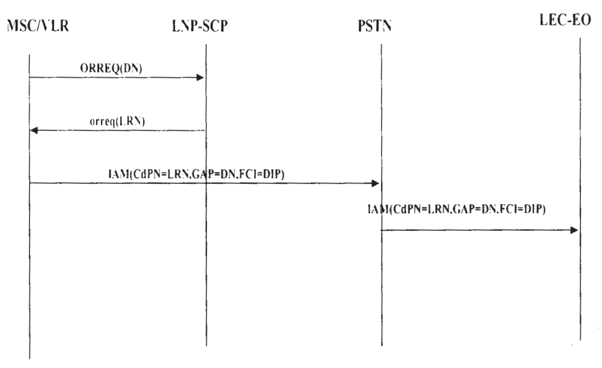
To make this work, the MDN must be returned to the serving system during registration because the MIN is no longer adequate for billing and calling line identification purposes. A new IS-41 parameter must exist to pass back the actual directory number during the registration process.

With this system, analog mobile stations can be supported without any change, which is a great benefit. Customers with existing units who want to port to another analog carrier will be able to do so. Debates within the CTIA ensue, however, so the proposed solution is still in flux.

This capability of passing back the MDN during registration is an IS-41 Revision C feature. Revision C has just finished its ballot, so a race to update U.S. carriers to Revision C functionality will have to take place, or else there must be other workarounds that will allow the installation of nonmobile directory numbers in phones.

FIGURE 13

Mobile Organization



Once again, international numbering conflicts have to be dealt with due to the analog problem. In addition, subscribers will have the added complication of the subscribing unit not knowing the MDN value anymore. A potential for confusing subscribers exists because the operation of a subscribing unit will change somewhat. This is similar to the registration story. Hence, using the base registration approach is really the only practical solution at present.

On the other hand, mobile origination is much simpler, because it uses straight mapping into the LRN method (see *Figure 12*). This requires the introduction of office-based triggers at the serving MSC. There must also be a way to inform the switch that it should generate the appropriate forward calling indicators and ISUP for gap parameter handling specified in the LRN method. These are issues that TR45.2 will consider as they develop IS-41 protocol support.

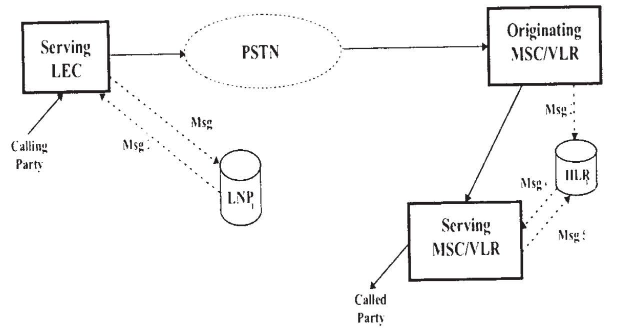
The Network Perspective

Although an STP is not shown in *Figure 13*, a local STP will distribute queries from the serving switch to the LNP database. When a call is made, a query is generated from a serving MSC to the LNP database. The SCP will determine the LRN associated with the called number and return this information to the serving MSC.

IS-41 has an existing trigger message called the origination request. Currently, the plan is for this message to be extended to support office-based triggers, providing the ability to specify that the LRN routing is being performed. Once that trigger response is received, the ISUP destination number will be assigned to the LRN, and the gap parameter will have the original directory number (DN). The forward calling indicator would show that the translation function had been performed already so that the call can be properly routed.

Figure 14 shows what happens on the mobile termination side. Because the MSC needs to recognize the reception of an inbound call from a ported number, it will use the gap parameter for the called-party address instead of the DN. There must be an option to generate a wireless LNP trigger if the call is not translated, and the MSC will need to have the ability to generate that trigger. If the call was translated, an IS-41 lo-

FIGURE 14
Mobile Termination



cation request is generated. Some work has to be done with TLDN-delivered calls to indicate that the call was translated. It is not efficient to route a call via TLDN and force the serving system to do an LRN dip, because it was just queried previously to acquire the number.

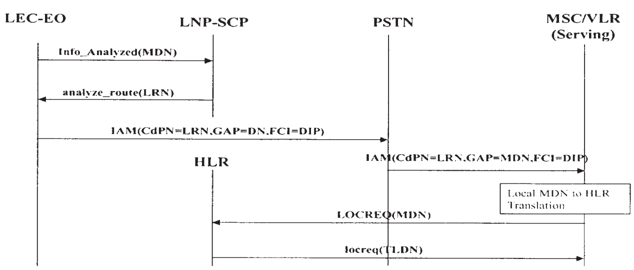
When the call enters the wireless network from the serving local exchange carrier (LEC), the LNP database would have been previously queried for an LRN (see *Figure 15*). The LRN call would be delivered to the MSC-VLR and the cellular network serving as the originating switch. This MSC-VLR will query the HLR for the routing information of the subscriber, and then route the call to the serving subscriber.

In terms of messaging, if a LEC were originating the call, an IAM message would go to what would presumably be another switch within the PSTN. When the call comes in from the PSTN, the initial address message (IAM) prompts the MDN-to-HLR translation in order to generate the location request, which is sent to the HLR. The serving MSC-VLR then receives back the TLDN for routing the call.

Other Issues

One issue of concern with the dawning of LNP is mobile-to-mobile call routing optimization, and another is number management within the HLR. *Figure 16* shows the routing flow in a mobile-to-mobile call. A serving MSC-VLR queries an LNP database, after which the call is sent across the PSTN to an originating MSC-VLR switch that happens to have the LRN

FIGURE 15
Mobile Termination



assignment. This originating switch will have to do a query once again from a serving switch.

One of the most obvious inefficiencies is routing the call through three switches that might be in the same carrier's network. Eliminating one of these switches from the route will reduce a carrier's operational expense. Work is needed to optimize the LRN procedure in order to prevent such occurrences. Furthermore, two database dips are happening. Every mobile-terminated call will hit an HLR and an LNP-SCP. In the wireless competitive market, it would be beneficial to minimize extra queries and call routes.

A possible solution is to combine the LNP query functionality into the location request query functionality, which makes sense for a wireless carrier when they use their original number blocks because fewer than one percent of mobiles may be ported out of those blocks.

Without integration between the location request and the LNP query, two messages are required. However, if the switch generates a location request for certain number blocks and handles ported numbers as an exception, 99 percent of subscribers could be terminated in a single query, which would be a fairly substantial cost benefit for operators.

HLR Number Management

An important issue in the area of HLR number management is MDN-to-HLR mapping. Over time, LNP will result in a very sparse mapping of MDNs to the HLR. Today, blocks of numbers are given to wireless carriers. The wireless carriers know that the entire block happens to be on an HLR, and LNP will make that mapping sparse. This creates problems for network planners. If a competitor goes out of business, or a successful marketing campaign attracts new subscribers who were using the competitor before, then a block which used to have one active number in it may now have a thousand. This creates havoc in terms of planning, because HLRs have finite transaction capacity, especially if they are switch-based.

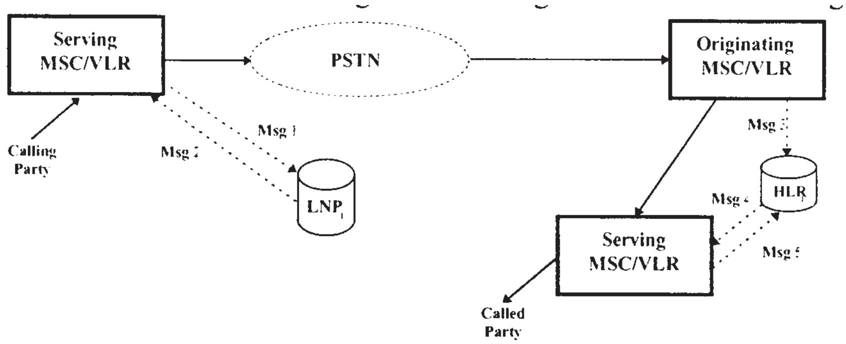
Additional issues with multiple MDNs exist as well. This is especially true with GSM, where there can be more than one directory number pointing to a subscriber, which may be supported by IS-41 as well. This creates more complex mapping due to the added possibility that two MDNs may need to point to the same subscriber, but their GSM global titles have been directed to two different HLRs. It seems the perfect solution is to use a ten-digit translation like an LNP-SCP approach to route the MDN to the serving HLR. There are cost issues associated with this, however, especially for smaller carriers. The most economical solution may be larger, centralized HLRs that allow for more number ranges to be concentrated in a single network element in order to help sites overcome such problems.

Summary

Wireless LNP is leveraging off the wireline architecture. In particular, the industry is leveraging off the SCP data model so that all the work being done on provisioning and by the

FIGURE 16

Mobile Origination (to Wireless)



local utility commissions does not have to be redone or modified for wireless. The ISUP LRN routing method makes sense because wireless numbers are a minority, so it is practical to conform to the practice of the wireline network with respect to call routing.

The CTIA has chosen the MIN-based registration method. Wireless LNP may turn out to be a killer application for large centralized HLR platforms, because as numbers become increasingly scattered, it may be more cost-effective to install a large, centralized platform that can handle more numbers than to perform increasingly complicated AIN routing.

The Business Case for Distributed Wireless Switching

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Over the last decade, the growth of wireless services worldwide has been strikingly high. This trend is likely to continue as more and more people in the world discover the benefits of wireless communications. Unfortunately, there are many areas in the world where it is not economical for wireless operators to deploy service using traditional switching architectures. In these areas, the required infrastructure, technical knowledge base and subscriber density is low. A potential solution to this dilemma lies with a concept called distributed wireless switching. This concept is based upom small, scalable, full-featured wireless switching platforms specifically designed for profitable use in rural and other low-traffic markets. This essay will discuss the target market for distributed wireless switching, compare and contrast it against traditional wireless architectures, and show how it can be applied specifically to a digital architecture such as global system for mobile communication (GSM).

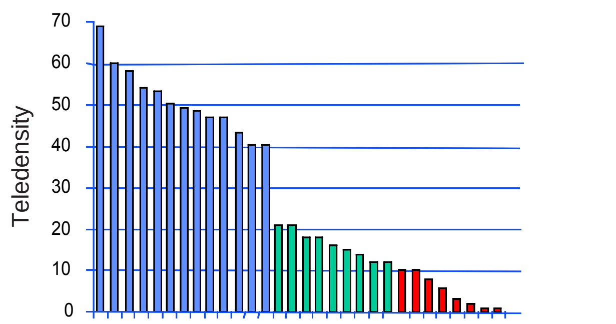
Distributed wireless switches are generally extremely small and can support approximately 15,000 to 20,000 subscribers. They are full-featured wireless switching platforms based on nonproprietary technology with an emphasis on the client/server concept. The switches tend to push intelligence and processing power closer to subscribers and end users, and they use off-the-shelf hardware, such as Intel processors. As a result, the switches themselves are extremely low-cost and follow the computer industry's cost curves (e.g., Moore's Law), where processing power continually doubles and prices are consistently cut in half. Most importantly, since they are small switches, interoperability with multiple vendors is a must. Therefore, distributed wireless switches are open and follow standard interfaces, wherever those standards are defined.

Market Characteristics

Distributed switches are specifically designed for low traffic density areas. A low-traffic density market is one with a teledensity (telephones per head) of 1 percent or less. Traditionally, these areas are not well served through standard wireline or wireless telecommunications. They have either extremely old public switched telephone networks (PSTNs) or no PSTNs at all. These are very dispersed areas, such as remote villages, towns, and small cities surrounding larger cities and areas with some form of geographic barrier. Poor infrastructure, no roads, and a lack of power facilities make the business case for installing telecommunications networks in these areas very difficult. These characteristics are not unique and tend to describe rural markets worldwide.

In the United States, wireless operators always build out their networks in large cities first. This makes sense in countries like the United States, where population is concentrated in cities. However, 70 percent of the world's land area and population are not in big cities. They live in low-traffic density areas (or rural areas) worldwide. Operator tendencies to concentrate primarily on cities has lead to the following startling statistic: Half of the world's population has never made a phone call and have no access to telecommunications. For example, 99 percent of the one billion people who live in India have no access to telecommunications. To compare this statistic to the United States, it would be necessary to look back to the 1920s. Even then, the general store in a small town had a pay phone and a private operator. This does not exist in India. In sub-Saharan Africa, 99.5 percent of the people have no access to telecommunications. When telecommunication services have been made available to these rural areas, especially wireless service, the market penetration rates exceeded those in larger metropolitan areas. The reason for this is that the population needed the ser-

FIGURE 1
Worldwide Teledensity

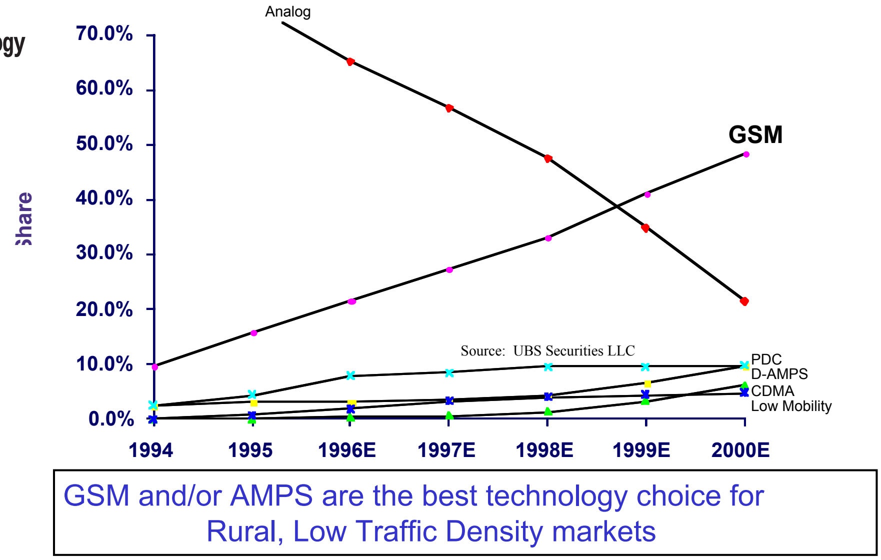


Complied by Bear Stearns

"The per capita GDP relationship between the Haves and Have Nots of Teledensity implies that the cost per line must decrease by 75% to 80% before emerging markets can fully be served." Montgomery Securities

FIGURE 2

Market Share by Wireless Technology

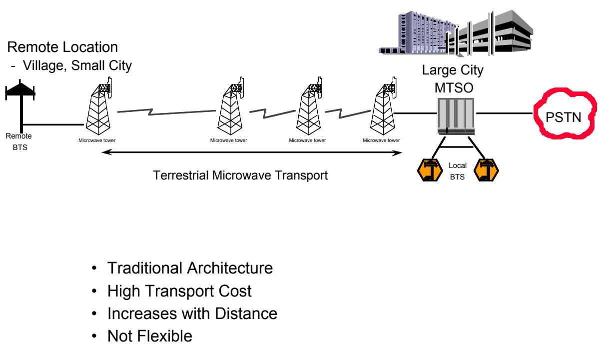


vices much more. They also needed wireless much more. In rural areas, people are not tethered to a specific location, such as an office. A farmer, for example, is out in the field with a tractor. The only way to reach him is through a cellular phone. Less-developed regions such as Latin America, Brazil, African countries, Southeast Asia, China, and India are the areas with the lowest levels of teledensity penetration (see *Figure 1*). Interestingly, Sweden—not the United States—is number one in teledensity.

The market requirements for low traffic density rural areas are different and much more stringent than for high traffic density areas. Because there is a very low initial subscriber base, start-up costs must be extremely low. The initial vendor equipment needed must be inexpensive. It also must be quickly and easily deployed in order to make the business case positive. Since low traffic density areas have little experience with telecommunications service, people will line up to get it once service is in place. Therefore, support for incremental network growth is important. The equipment must be optimized for low-traffic density areas and must be able to account for poor infrastructure, poor power facilities, and difficult terrain.

FIGURE 3

Traditional Approach for Serving Rural Areas–Backhaul



In addition, the network must be extremely easy to maintain and operate on a day-to-day basis. The switch itself has to be extremely easy to operate remotely without much training. The power requirements for a switch or a base station have to be similar. For instance, the switch might work off the same facilities as the base station being deployed so as to simplify colocation.

Proven technology must be used in order to keep the technology risk as low as possible. Any problems that require sending a person out to the site sacrifices profit because of the high travel costs to get to these areas. Proven technology that has progressed as far as possible down the experience curve and that has been reduced in cost because of mass deployments elsewhere is essential before entering a low traffic density market.

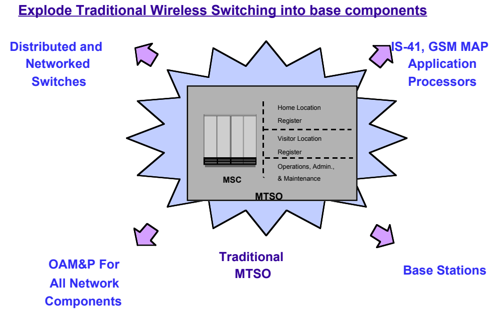
In light of these requirements, the best technologies to initially investigate for low traffic density markets today would be analog technologies such as advanced mobile phone service (AMPS) or digital technologies like GSM. For the near future, they will have the largest market share worldwide. AMPS or analog technology seems to be decreasing with the growth of digital technologies such as GSM and code division multiple access (CDMA) (see *Figure 2*). Again, the best choices are the ones that are already available and that have gone as far down the cost curves as possible.

Comparing Architectures

The traditional architecture used for wireless networks is a centralized switching system deployed in a major metropolitan area. Essentially a telephone company mainframe, it is an extremely high-cost, large, centralized system that is very reliable, but requires complex support to operate and maintain. It was not designed for low traffic density areas, but to serve a large number of people in metropolitan areas at a low subscriber cost. Such systems are not suitable for the majority of the world's land areas.

FIGURE 4

Distrinuted Switching

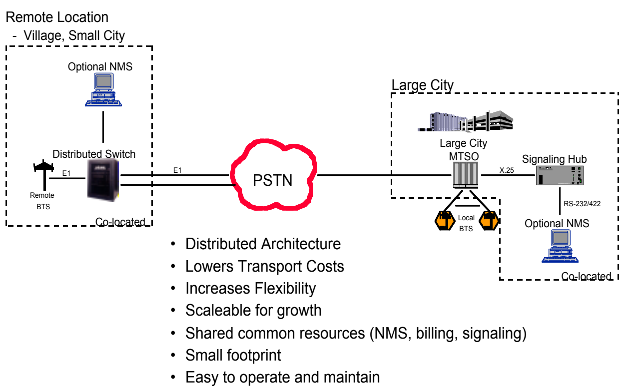


There are several different ways of deploying the traditional wireless architecture to serve large, low traffic density areas. The most common approach is called backhaul (see *Figure 3*). Essentially, a large mobile telephone switching office (MTSO) already deployed in a large city is connected to a remote base station placed out in a village or small town to cover that area, with some type of transport facilities between the two. Terrestrial microwave is by far the most common transport facility. The problem with this approach is the extremely high-cost of these long-length transport facilities. Also, the architecture is not very flexible. This approach serves two completely different markets with essentially the same software and the same feature set. The costs also increase dramatically with distance. For example, if a village is 50 or 60 miles outside of the large city MTSO, the terrestrial microwave backhaul may be much more expensive than installing a switch there. This situation highlights the case for distributed switching.

Distributed switching takes the traditional MTSO and explodes it into its different components (see *Figure 4*). The switching component is deployed close to the end user, pushing the intelligence of the switch close to the customer. The signaling components and the network management components can be shared across many different distributed switches. For instance, the IS-41 gateways or GSM map application can be shared across many different distributed switches. Operations, maintenance, administration, and provisioning (OMA&P) can be performed either through centralized locations or on an individual node basis. All this reduces costs and simplifies the equipment actually located near the customer.

FIGURE 5

Distinuted Wireless Switching Approach for Serving Rural Areas (BTS: Base Transceiver Station; NMS: Network Managenment System)



To use distributed wireless switching instead of the backhaul approach, a single base station is deployed along with a distributed switch out in a remote location (see *Figure 5*). This approach provides great flexibility. The public switched telephone network (PSTN) facilities can be used where they are available for backhaul and connectivity to the large city–based mobile telephone switching office (MTSO). Distributed wireless switching keeps local traffic local, so as not to place any burden on the large-city MTSO. This also reduces opportunity costs since large MTSO capacity is not used to serve remote locations and can be better used to serve more large-city customers. Common resources are shared, such as the signaling hub for roaming between distributed switches and the large city. The entire system can also be managed either from the large city or out in the remote location.

The space requirements for these small distributed switches are the same as the base stations. A distributed switch could fit easily in the same rack as a base station, or next to it. The power requirements are very low, so an existing power source that is already serving the base station can probably be used for the distributed switch as well without any additional upgrades. Distributed wireless switching is extremely scalable for growth. Additional base stations can be added to serve more subscribers out in the remote location, or another location can be added with a distributed switch and additional base stations. Importantly, these switches are extremely easy to operate. Their network management systems are based on a Windows 95 graphical user interface (GUI) as well as Internet browser technology, making them extremely easy to learn and use.

Comparing Cost

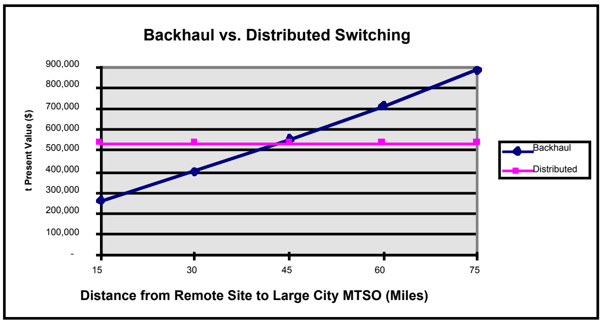
Microwave is the largest incremental cost component of the backhaul architecture. There is the microwave equipment cost, the cost for the microwave license if required, tower costs, and real estate costs for the towers. With a flat terrain and good weather conditions, the microwave cost may be modest; however, this cost quickly increases if the terrain includes jungle or mountains. For example, four or five microwave hops may be required to go around a mountain. Traffic engineering costs also must be considered. These are the opportunity costs of taking traffic capacity off the large-city MTSO and using it for a remote area. There also may be incremental PSTN costs or satellite interconnection costs due to the incremental traffic. Additionally, there are the costs of training workers on the new microwave facilities and making sure that the microwave link is continually up and running.

On the distributed switching side, the largest incremental costs are for the switching equipment, which includes network management and signaling for roaming. Network management and roaming can both be shared across numerous distributed switches, spreading out the cost across a larger subscriber base. There may be additional access fees for certain PSTN calls. These are the calls that normally would route through the large-city MTSO in a traditional architecture but are now sent directly to a PSTN connection by the distributed switch. This cost can be viewed as a revenue opportunity if such calls can be classified as long-distance to customers. Like the backhaul approach, incremental PSTN facilities are needed, along with data links to collect billing information and bring it back to a centralized site. Staffing and training costs to take care of the equipment will be extremely low because of the simple user interface for network management.

Figure 6 compares the cost of backhaul versus distributed switching. The break-even point is a 45-mile distance to the city, or about two to three microwave hops (depending upon the geography and terrain). This is a worst-case scenario, because with more than one base station there is a larger subscriber base. The cost for distributed switching is essentially flat, while for backhaul it increases with distance and the number of remote sites served.

FIGURE 6

Backhaul vs. Distributed Switching Results



- Worst case scenario: single remote BTS
- Cost to Backhaul increases significantly with distance
- Distributed switching costs are essentially constant
- Break-even at less than 45 mile distance to city (or 2-3 microwave hops)

Distributed Switching for GSM

GSM was standardized over a ten-year period and was designed specifically for western Europe. Before GSM, western Europe had cellular networks that did not communicate with each other. They had very poor roaming with different protocols for each country. GSM is a great success and solved these problems by standardizing everything. However, since it was meant for western Europe, which is a high traffic density area and GSM is also very expensive in its current form for deployment in a low traffic density area. The requirement for rural areas is to reduce backhaul by reducing all the different network components to just what is needed to serve the low traffic density market. The idea is therefore to take the intelligent network components, which for GSM are traditionally oversized for large cities, and scale them down appropriately for low traffic density areas. Instead of a home location register (HLR) that handles one

FIGURE 7

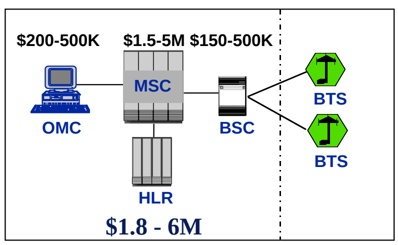
Distributed GSM Architecture for Rural Areas (PLMN: Public Land Mobile Network; SS7: Signaling System 7)

million subscribers, an HLR that handles 10,000 subscribers would be used. The platform requirements to run these components are drastically reduced. In the spirit of openness, GSM's common interfaces are preserved for growth and seamlessness.

Figure 7 illustrates one way of applying distributed switching technology to GSM. The original standard GSM architecture is in the box at the bottom. The base station controller (BSC) is combined with the mobile switching center (MSC) and the intelligent network databases, such as the HLR, the authentication center (AUC), the visitor location register (VLR), and the equipment identity register (EIR). In a low traffic density area there likely would not be a need for more than one BSC. Therefore, in a low traffic density area, the BSC function is redundant if run on a separate processor initially. The goal is to take all of the basic GSM functions (e.g., MSC, HLR, BSC, etc.) and run them on a single hardware platform, while preserving the common GSM interfaces that have been defined between the network elements. This will allow the GSM functions now running on the same hardware platform to be moved to separate hardware platforms any time in the future and as the market demands. This significantly lowers the cost of entry for GSM.

FIGURE 8

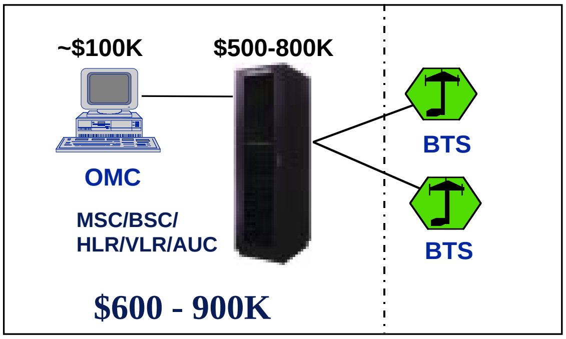
Traditional GSM Architecture



Optimized for large / high traffic-density such as major metro areas

FIGURE 9

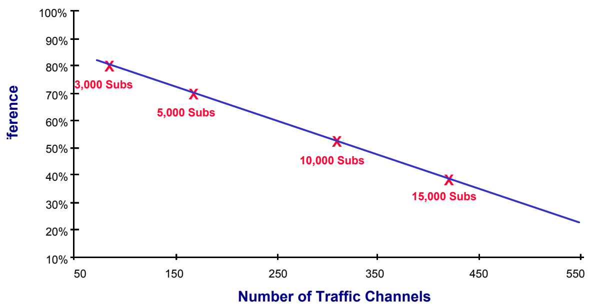
Distributed GSM Architecture



As *Figure 8* shows, a traditional GSM architecture optimized for high traffic density areas will range from $2 million to $6 million for an initial start-up configuration supporting a few thousand subscribers. A large percentage of that cost is in the switching component itself. With growth, the base stations will become a larger percentage of the cost. For a distributed GSM architecture (see *Figure 9*), all of the components are placed into a single platform, which makes for a much lower cost of entry. The radio frequency (RF) costs are about the same, but the overall cost savings for deploying and activating a network are approximately $1 million to $5 million. At 15,000 subscribers, the cost savings is approximately 30% to 40%, but at 3,000 subscribers it can be as high as 80% (see *Figure 10*). The smaller the number of subscribers, the greater the cost difference.

FIGURE 10

Distributed Architecture Price Advantage vs. Traditional Architecture

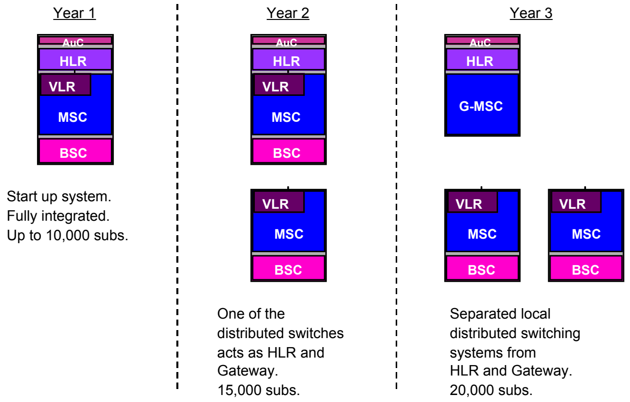


Comparison of sample average selling price based on equivalent network configuration

One of the most important aspects of applying distributed switching technology to GSM is that the architecture outlined above preserves the individual standard GSM functions. These functions exist as separate and distinct software entities running on a single hardware platform. They are completely modular and can be physically separated, which allows for incremental growth. When run on different platforms, they communicate with each other and with other GSM network components through well-defined, standard GSM interfaces. There is nothing proprietary in the network.

FIGURE 11

System Growth Plans



For example, consider an operator starting off at year one (see *Figure 11*). They buy an all-in-one system that contains an AUC, HLR, VLR, MSC, and BSC on one platform and which supports up to 10,000 subscribers. This system gets the operator past the incremental hurdle and begins to generate income and build a subscriber base. The operator keeps adding subscribers and can add another switch to increase capacity beyond 10,000 subscribers. When they do this, they can share the HLR and AUC facilities between the two different switches. As the operator grows to three switches, they can designate an MSC as a gateway switch, again sharing the HLR, AUC, and other intelligent network components between the different switches, with a capacity now of up to 20,000 subscribers.

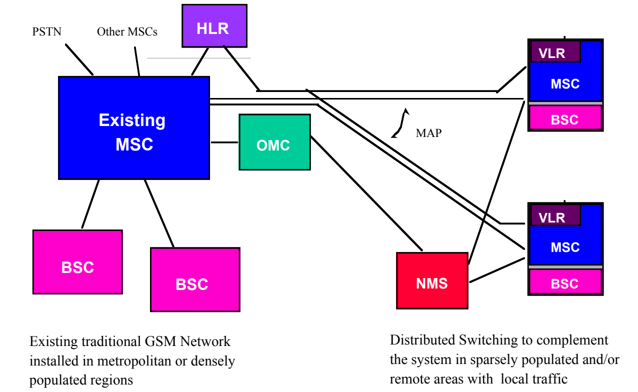
As another example, consider an operator who has a GSM network already in place with a traditional architecture. This network has an existing large-city MSC with base station controllers, but has coverage gaps in the network where subscriber density is low (see *Figure 12*). These low traffic density areas are not currently covered because they are not cost-effective to cover with the GSM traditional architecture. The operator can easily place a distributed switch out in these low traffic density areas and connect it back into the large-city MTSO via a mobile application protocol (MAP) link for roaming, if desired. This preserves the complete standardized GSM architecture. The operator can even manage the components centrally.

Network Design

Optimal network configurations are based on individual customer needs and applications. The design process for low traffic density areas is in most ways similar to larger metropolitan areas. However, some factors must be accounted for that are normally taken for granted in a large metropolitan area, such as where to put facilities and shelters. PSTN connectivity, calling patterns, power requirements, and traffic characteristics are important considerations and may drive decisions concerning low traffic density areas. These factors will help create the business case for which architecture the operator should actually use. Also to be considered is the normal RF coverage, number of cells, where to place the cells, where the switches can be placed within the cell sites, and the number of channels for each base station. Tower sizes and

FIGURE 12

Expansion of Existing Networks



transmitter power have to be considered as well. It is only through careful planning and foresight that an operator can ensure that a network design is optimal for the chosen subscriber base. This work is difficult and tedious and must be monitored closely to assure that vendors, contractors, and consultants address all factors important to the operator and potential subscribers.

Conclusion

In summary, rural areas are excellent opportunities for wireless operators, yet such opportunities must be approached with the right network architecture. The best technologies to use in these low traffic density areas are AMPS and/or GSM—at least initially—because they are the most proven technologies to date. Distributed switching provides a key to solving the entry cost problem to ensure a positive business case for these low traffic density areas. The small, scalable switches are specifically designed with the needs of low traffic density rural markets in mind. They allow for rapid deployment and rapid evolutionary growth in these markets, with low start-up costs. The operator can grow as the subscriber base grows and add components incrementally. Distributed wireless switching is extremely simple to operate and maintain. It takes only a couple of hours to learn how to operate the system. Distributed wireless switching is a better alternative in many cases to backhaul using traditional switching architectures and should be considered.

Wireless Enhanced 911

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Lucent Technologies

Of all the new technologies and services emerging in the wireless arena, the government-mandated ones do not seem to be the most exciting. They are, however, extremely important. This paper will focus on one of these: wireless enhanced 911 (E911). It will begin by offering some historical perspective and will then outline the FCC mandate for wireless E911. Finally, it will offer suggestions about the future of wireless E911.

Historical Perspective

Prior to the FCC mandate, wireless 911 services were sketchy at best. Wireless phone users could dial 911, press the send button, and sometimes, in certain areas, be connected to emergency services. In some places it was necessary to dial a different code such as *999 to be connected to an emergency service provider. With this basic 911 service, the caller had to provide all of the necessary information. A caller who could not provide a phone number or precise location was often not able to get assistance.

In the wireline arena, on the other hand, enhanced 911 service is provided to about 80% of wireline subscribers. With enhanced 911, the calling-party information is provided automatically. When a subscriber calls 911, the name, address, and phone number of the caller are displayed on the emergency services terminal. In some cases, emergency medical information may be displayed as well.

The dichotomy between wireless and wireline services was cause for concern. There were several reasons to focus on comparable wireless and wireline E911 service. One of these was the growing popularity of mobile communications. As more people got mobile phones either for their cars or for general personal use, wireless calls were making up 10% to 25% of all 911 calls. This was particularly high considering that about 25% of these callers could not identify their exact location, or at least not exactly enough to make their location known to the public safety answering point (PSAP).

A first attempt to improve wireless 911 service was cell site location–based routing; however, this was often geographically inaccurate. A user could dial the necessary emergency notification digits and be routed to public safety personnel based on the serving-cell location, but due to the idiosyncrasies of radio the serving cell may be far removed from the caller's location. This meant that users could be routed to a public safety person in another region of the country who might not know how to get to the caller, even if the caller could identify where he or she was. Obviously, this caused problems in trying to get assistance to the 911 caller.

A final area of concern was that even when a caller got through to the PSAP, the call-back number might not be known. When 911 is called from a mobile phone, emergency personnel may receive an indication that the call is coming from a mobile phone rather than the calling party number. Although wireless service has been improving consistently, it is still not unusual to be disconnected. Whether due to driving through a tunnel, losing radio, or simple static, many callers disconnect themselves or were disconnected. Since the number of the originating unit was unknown at the PSAP, personnel have no way of getting back to the caller. In some cases it was possible to provide a seven-digit automatic number identification (ANI), which may or may not be the seven-digit directory number for the caller's phone. However, even when this was possible the proliferation of area codes made a simple seven-digit number fairly ineffectual. It is essential to have 10 digits in order to get back to a caller, even when the call is being placed from a home environment.

The FCC Mandate

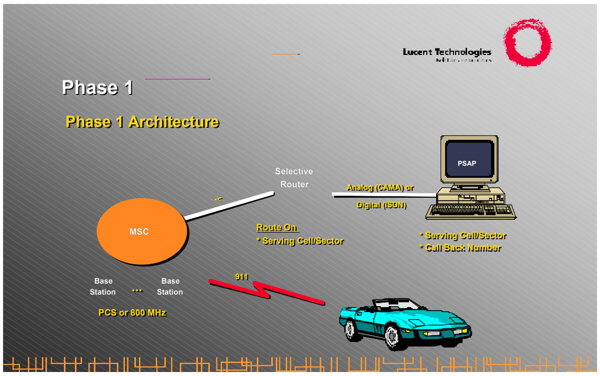
Realizing that something had to be done to better enable mobile subscribers to access emergency resources, in August 1994 a Joint Experts Meeting (JEM) was held concerning 911. This involved experts from the telecommunications industry, the FCC, wireless communications, and public safety personnel. The goal of this meeting was to discover what would be necessary in order to offer enhanced service—that is, the ability to provide information automatically—for 911 calls in a wireless environment.

One result of this meeting was a prioritized list of emergency services features. These included location-based routing, call-related information, and system-congestion control. With location-based routing, rather than routing on the serving cell which may not be in the same geographic location as the calling party, an attempt is made to pinpoint the location of the caller and route based on that location.

These features were then mapped to an evolutionary path. This was broken out into two phases of implementation, although some issues were left for the future. Information flows between the wireless system and the emergency services system were developed for both phases. The information to be conveyed includes the calling party's location and a full, 10-digit call back number. In addition, radio-based location tech-

FIGURE 1

Phase 1 Architecture



niques were studied to determine how they could be applied to 911 service.

In November 1994 the FCC came out with a Notice of Proposed Rulemaking. This notice was based on the output of the JEM and sent out to industry for comment. The Notice of Proposed Rulemaking was designed to cover both PBX and wireless E911 service, because even landline PBXs had some issues with 911 similar to those being encountered in the wireless industry. Basically, the notice was a call for comment on the proposed list of emergency service features, the location technologies, and the implementation schedule put forth by the JEM.

After going through some iterations with the proposals, September 1996 became the effective date of the final FCC ruling on wireless E911. Again, the objective was to provide wireless E911 service that would include automatic display of the calling party information. In the final order, the ruling applied to cellular, broadcast PCS, and special-radio mobile licensees. It expanded the original scope somewhat while also excluding landline PBXs that had significant differences despite the similarities.

The mandate specified two phases of deployment. The first was to be implemented within 18 months of the September 1996 date (that is, March 1998). After this date service providers are expected to deploy E911 capability within six months of receiving a request from the PSAP in their region, but vendors must have the capabilities available by March 1998. Service providers may have more time to actually deploy enhanced 911, since the public safety equipment must also be upgraded. Phase 2 was to be implemented within five years to allow the location technologies time to mature. Even though some good advances have been made, it was not felt that the technology would be ready for practical use until somewhere around 2001.

Phase 1

Phase 1 includes many important aspects. One of the requirements is that all 911 calls be supported, including calls from non-subscribers. Any cellular phone user dialing 911, even noncode identified mobile units, should be connected to a PSAP. In addition, a call-back number must be provided. It must be possible to transport through the network the full, 10-digit mobile directory number of the calling party to the PSAP.

The use of location-based routing is also mandatory. For Phase 1, since sophisticated location technology is as yet unavailable, every system must use a cell/sector routing mechanism, and each serving cell/sector will be associated with a specific PSAP. It should be noted that this solution does not provide the necessary granularity—there is still a chance that a caller might be directed to the wrong PSAP because of the idiosyncrasies of radio. Nevertheless, this solution does give a reasonable approximation of connecting the caller to the right PSAP. Finally, Phase 1 calls for support for TTY access.

Figure 1 provides an overview of the architecture in place for Phase 1. When mobile phone users call 911, they are served by a base station, and the information about this base station is used to route the call through a selective router and on to the PSAP. The serving cell/sector information is available because the calls went to a particular station and were being served off one of a limited number of cells or cell sectors. This will provide emergency personnel with some idea of the caller's location. Feature group D signaling might still be used, but there is a need to enhance it, use the full 10-digit call-back number, and ensure that number is delivered to the PSAP.

Despite the fact that the deadline is fast approaching, there are still some open issues for Phase 1. One of the most important of these is how to handle E911 for noncode identified mobiles. Even though it is a requirement in Phase 1, there is no call-back number available for such callers as of yet. The caller has no mobile directory number (MDN) because they do not subscribe for service. It may be possible to provide basic 911 services for these types of phones, but a solution that will allow E911 has not yet been discovered. Another open issue involves support for the TTY devices. Support for analog TTY devices is available, but support for digital TTY devices is still an emerging technology.

Phase 2

Phase 2, as mentioned above, is due to be implemented by October 2001 and mainly refines the location requirements. The location must include latitude and longitude, and it must be accurate to within 125 meters 67 percent of the time. Location-based routing must still be provided, and in this case it must be provided based on the location coordinates. Whereas in Phase 1 location-based routing will be performed based on the serving cell or sector, Phase 2 will require a routing mechanism that looks at the latitude/longitude coordinates and then routes to the PSAP nearest to those coordinates, regardless of the serving cell.

There are several additional feature candidates also included in Phase 2. In Phase 1, basic features involved allowing call delivery of 911 calls from any type of mobile phone, providing the call-back number, and using location-based routing. The additional features in Phase 2 may include call-attempt reporting, subscriber-information delivery, and congestion control. Call-attempt reporting means that all 911 call attempts must be reported in real time to the PSAP. If a caller dials 911 in an emergency and then disconnects, the 911 personnel, already having the caller information, will call back to ensure that the call was disconnected intentionally.

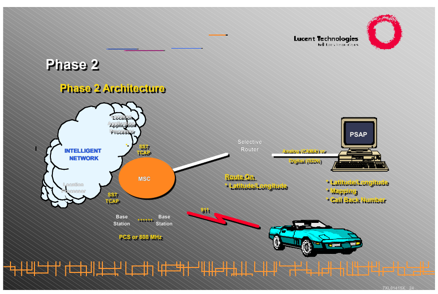
This process should be possible even for abandoned or blocked calls, which present a major technical challenge. What this means exactly must be clarified with the FCC and public safety groups. There are certain points at which a caller might be dialing a mobile phone, but no call events have yet occurred and so can not be reported. If a call is blocked or abandoned at certain points in call setup, there may or may not be sufficient information available to send a call-back number or the location information to the PSAP. For example, it may take a few seconds to calculate the latitude/longitude for a caller. If a user quickly hits the end button or powers off the mobile phone, there may not have been sufficient time to gather the essential information.

Subscriber-information delivery has created several issues. There was much discussion in the JEM and in successive meetings about what kind of information is useful when someone calls 911. Obviously, in landline situations the caller is at a fixed station. This makes information such as name, address, and phone number very useful. In the wireless arena, an address is obviously impossible to provide. On the other hand, it may be possible and helpful to provide a serving system ID, a subscriber identifier that could be the user's name or the name to which the mobile phone is registered, a mobile directory number, or the 10-digit call-back number. There may also be some value in knowing which phone made the call, which would require a mobile station identifier. There is ongoing discussion about appropriate information elements and how to make them available.

Once the essential information has been agreed upon, delivery options must be considered. There are two apparent approaches to delivery. One is to provide information on initial call setup. In this scenario, as much information as is available when a caller dials 911 and hits send is sent to the PSAP along with the call origination setup message. The other option is on-demand delivery. In this scenario, the system waits for a request from the PSAP for additional information about the caller. It may be that both of these approaches are used.

FIGURE 2

Phase 2 Architecture



Emergency system congestion control, specific to the wireless arena, is a particularly interesting challenge. In a possible scenario, the PSAP notifies a wireless system about multiple incident reports, where the number of calls about a single incident is overwhelming. After a broadcast message is sent from the PSAP to the wireless service provider, that provider might screen out duplicate requests. Repeat callers would be questioned as to the reason for their calls, and if the incident was a new one, the caller would be put through. Another scenario has the wireless system broadcast a message to mobile users notifying them that the situation has already been reported. This mechanism could also be used to notify mobile users of emergency conditions and, if necessary, suggest alternative routes.

A final congestion control mechanism is an emergency area congestion control, basically controlled by the wireless system. Whereas in the previous scenarios the control is initiated by the PSAP when it notifies the wireless system that it is experiencing congestion, in this case the wireless system would limit 911 calls from the same geographic area without having been notified by the PSAP. The number of emergency services trunks from a particular serving system to its PSAP may be a limiting factor. When those trunks are full, it is not possible to send more calls to 911, and calls may have to be dropped. It should be noted that this may not be a required service.

Figure 2 shows the architecture proposed for Phase 2. As the MSC processes the E911 call, it queries a location processor in the intelligent network to determine the geographic location of the phone. This requires a digital transmission method (i.e., ISDN) to carry the additional location information to a selective router. The router can then use that information to determine which PSAP should receive the call. This architecture uses the latitude/longitude information rather than the cell/sector information to route to a PSAP. An enhancement to PSAP equipment for this stage will be the ability to graphically represent the mobile location. For example, the latitude/longitude coordinates may be applied to a local street map to indicate the caller's location graphically rather than simply displaying the coordinates.

Geolocation

The geolocation technologies may well be the most exciting part of E911 services. One of these is direction of arrival (DOA) technology. DOA involves a number of antenna arrays communicating with a mobile phone; based on the line of bearing from the mobile, it is possible to calculate the caller's location relatively accurately. This approach is good because it works with unmodified mobile units. In many cases, it may be possible to have only two base stations involved in this triangulation. Also, due to a long integration period, this approach has a low signal-to-noise ratio. Unfortunately, DOA does require fairly large antenna arrays, and multipath degrades the accuracy. This means that in scenarios where more base stations are involved, accuracy will not be optimal. DOA is probably most useful in rural areas. Another approach that has been discussed a good deal is time difference of arrival (TDOA), which is somewhat similar to direction of arrival. TDOA can work in one of two ways: signals are sent either to a mobile unit or from a mobile unit to a receiving station, and the time difference of these various signals being received by the target is calculated to produce position coordinates. This technology also works with unmodified mobiles and may be able to use existing antennas. This solution requires at least three base stations for triangulation. Like DOA, however, TDOA's accuracy is degraded by multipath. Also, the base stations must be tightly synchronized. Intersystem timing issues may occur in border areas if timing is not synchronized between adjacent systems.

Another geolocation mechanism is ranging. Here, a signal is sent to or from the mobile unit and reflected back to the origination point. The position is calculated based on the round trip of that signal (e.g., from the mobile to the target and back again). This scenario may also use existing antennas and, again, a long integration period enables low signal-to-noise ratio operation. While the accuracy is fairly good, ranging requires some cooperation between mobile units and some enhancements to the units. As yet, there has been no protocol defined to support this. Ranging is not as fault tolerant as other methods and, again, has a problem with multipath.

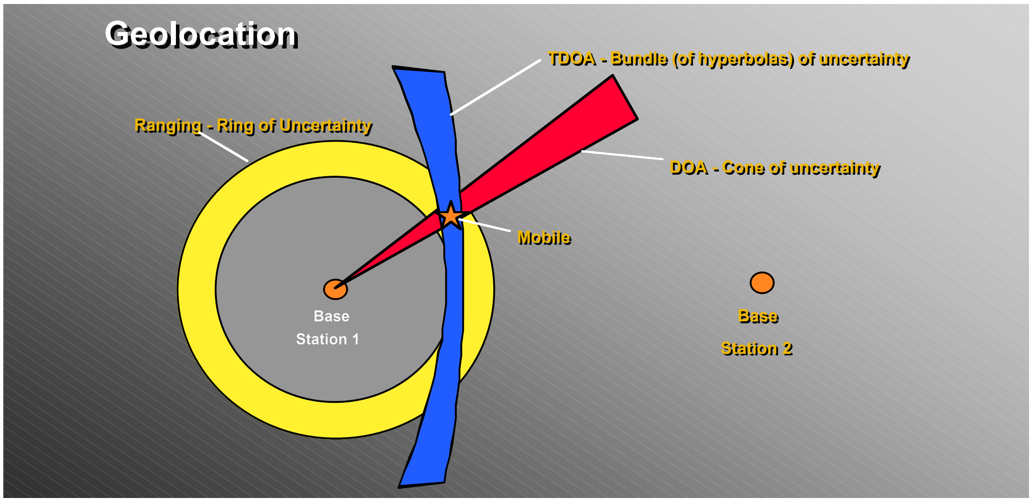
Figure 3 compares these three approaches. DOA results in a cone of uncertainty. Given that there are two base stations and one mobile unit involved, the caller is somewhere within this cone. TDOA provides a bundle of uncertainty based on a hyperbola; again, the mobile unit is somewhere in this range. Finally, ranging defines a ring of uncertainty encompassing the mobile's location.

The Future of E911

As mentioned above, the FCC has left several areas for future development and study. These include refining location requirements and interactions with priority services. There was much discussion about including altitude in Phase 2, but it was not done. Particularly in large metropolitan areas, however, altitude could be very helpful information. If there were an emergency in a skyscraper, for instance, simple latitude/longitude coordinates would not accurately pinpoint a caller. Increasing the location accuracy is also desired. Currently, the requirement is to be accurate within 125 meters 67 percent of the time. In the future, accuracy should be within 40 feet 90 percent of the time. Obviously, this will require much more precise location techniques.

Interactions with priority services are also essential. One type of priority access provides police or local government officials a higher priority for call delivery than regular subscribers in certain emergency situations. This could cause problems, however, since the occurrence of a major disaster will certainly not forestall other emergency situations—even something as serious as a bombing should not make a user unable to access emergency services in case of an accident.

FIGURE 3
Geolocation



Evolving the User Interface for Advanced Network Services

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Abstract

The realization of nomadic computing and communications is upon us. Innovations in wireless network technology as well as user-device software and hardware are increasing their utility for nomadic users. In addition, with the emergence of the Internet acting as a major catalyst, there is a strong consensus of converging wireless voice and data services in the future. A critical element of this paradigm shift is the recognition that users need to access information nomadically, and they face dramatic and sudden changes as they move from home to office to meeting rooms to airport to hotel, and so forth.

In order to provide a rich set of capabilities and easy-to-use services in a transparent form, providers must focus on key system parameters that are critical. These parameters include bandwidth, latency, reliability, processing power, interoperability, battery life, user interface, and cost. Specifically, solutions must include the fact that a user has only limited carrying capacity (i.e., minimum number and type of equipment and interfaces that they have to cope with). In this paper, some of the key system parameters needed to support nomadic computing and communications will be reviewed along with the technical challenges they present. A number of related, but parallel, technological evolutionary paths that are converging for resolution of these challenges are also shown.

The User's Landscape

The global market for wireless communication network and information services has enjoyed significant growth over the past decade. Wireless network technologies have evolved to support a much wider set of services for the user. Beyond traditional voice, these services include: voice-activated dialing (VAD), voice messaging, caller ID, short-messaging service (SMS), e-mail, and Internet access. Network access has also evolved to include both advanced analog and digital signaling. In addition, wireless phones and pagers have become common appliances in many countries.

Despite these advances, the interface between advanced services and its users remains stuck in the past. To use an advanced service, a user often has to put up with long and confusing sets of voice prompts to which the user must respond by inputting digits from a menu or digits that are committed to memory. The digits are often followed by more long and confusing sets of recorded voice prompts. This approach, called interactive voice response (IVR), evolved out of the need to accommodate the lowest common denominator in customer premises equipment (CPE) and network access technologies: dual tone multi-frequency (DTMF) capability.

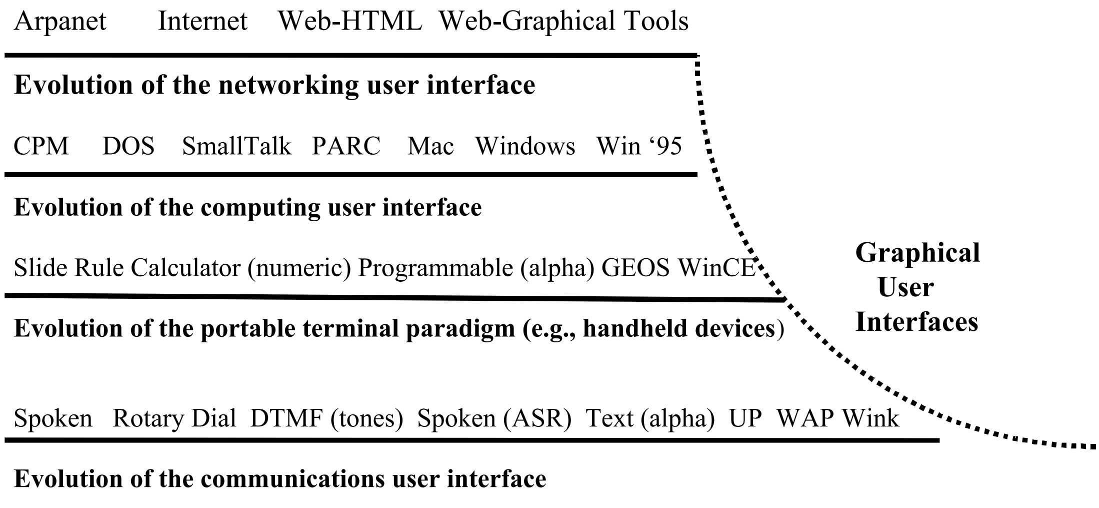
Today, the growing diversity of vertical voice services supported by evolving wireless intelligent networks (WINs) requires centralized servers, such as service control points (SCPs), intelligent peripherals (IPs), or service nodes (SNs) to engage subscribers in increasingly complex sequences of digit entries and voice prompts. For example, subscribers must enter an incredible amount of data to take advantage of robust mobility management or personal number services. Time-of-day routing, day-of-week options, location overrides, location-hunting sequences, screening and priority list administration, and the interaction of various feature options are only a few of the items users must juggle. Although personal number service is one of the most well-established IN services on the market, it requires even the novice user to administer in excess of 40 to 50 different parameters. One wonders how much more popular one-number services would be if the IVR interface to them were not so cumbersome.

Most users cannot recall what the options are at a given branch in the IVR tree, let alone how they got there or how to get out. What can a user do, except resort to writing things down on scraps of paper and trying to coordinate them with the IVR sequence? The limitations of IVR are not exclusive to complex services. Even basic features, such as voice dialing, can quickly build up unmanageable lists. If a user cannot remember which 50 people are on their current list, how will they know which ones to delete to make room for more? Carriers should consider leveraging the user-interface advantages supported by new CPE and access technologies, or it will become a limiting factor in the development, deployment, and acceptance of new services.

Increased competition is pushing service providers to seek new ways to enhance their services and differentiate their offerings from previous regulated services. To remain competitive, service providers must improve the ease-of-use and access to existing services while adding new capabilities, such as news, information, and data services to their portfolios.

FIGURE 1

Parallels in User Interface Evolution



The recent explosion in on-line services and World Wide Web access illustrates the growing demand for data services and electronic information. Web browsers and on-line services are rapidly evolving to exploit the computing resources of desktop PCs and to provide users with powerful graphical tools to present reams and reams of such data.

Parallels in User Interface Evolution

Figure 1 shows that when users grow accustomed to superior user interfaces offered by these technologies, their expectations of other communications offerings will grow accordingly. Unfortunately, the gap between desktop solutions and telecommunications devices is widening, not closing. Voice and information services require new interface technologies to keep pace with growing expectations of the user's view. *Figure 2* shows the relationship between three common devices used by nomadic users. The increasing cost for higher capability devices is paralleled by an increase in size. The overlapping areas indicate multi-functional devices, or areas where more than one device can provide a given function.

Note that the general direction of decreasing prices over time for consumer devices will force each of these device spaces into more overlap. Users will expect devices to do more for less, as technology improves over time. Users will also expect more portability in their devices (e.g., HPCs) and more consistency in their user interfaces (e.g., WinCE). It is likely that more multi-personality devices will be developed, and early versions of wireless computing, mobile Internet access, and voice adjuncts or services on data communications networks are already widely available.

Evolving Technologies

In parallel with the evolution of the user's expectations for graphical interfaces and programmable applications on mainstream wireless devices, a number of related technologies have been evolving steadily in the same direction(s). Whether this synchronicity was random luck or effective product management remains unclear. What is clear is that the wireless consumer immediately benefited from the evolution of:

- display technology
- data-compression technology
- client / server software technology
- digital wireless network infrastructures
- new standards in content format and storage

Figure 3 shows the progression of the user's interface experience and how it improves after each technical hurdle is passed.

Display Evolution

One of the most visible evolutions is that of the typical wireless handset's display, as shown in *Figure 4*. The type of display has evolved from a single-line light-emitting diode (LED) string capable of showing only digital information to a series of liquid crystal displays (LCDs). The initial LCDs not only added alphanumeric capabilities, but increased the number of lines of information that were available to the user over time. The next step was to add a row or two of icons that could be used to present essential graphical information to the user, usually the signal strength, battery condition, and presence of messages in a mailbox. Subsequently, the use of icons was accompanied by the need to display languages that are not character-based (e.g., Japanese, Korean, and so on).

Soon, it became more common to find bitmapped displays, where the entire set of pixels in the LCD could be used to form graphical images. As with the original alphanumeric displays, these started out with a small size and horizontal aspect ratio, and over time grew to have more pixels. About that time, the original smart phones started to appear, and the displays became some fraction of a variable graphics array (VGA) ratio (640 x 480) in order to display portions of a Web page more easily. The design issues therein are numerous, as the manufacturers have to trade off the desire for small form

FIGURE 2

Evolution of Consumer Device Characteristics

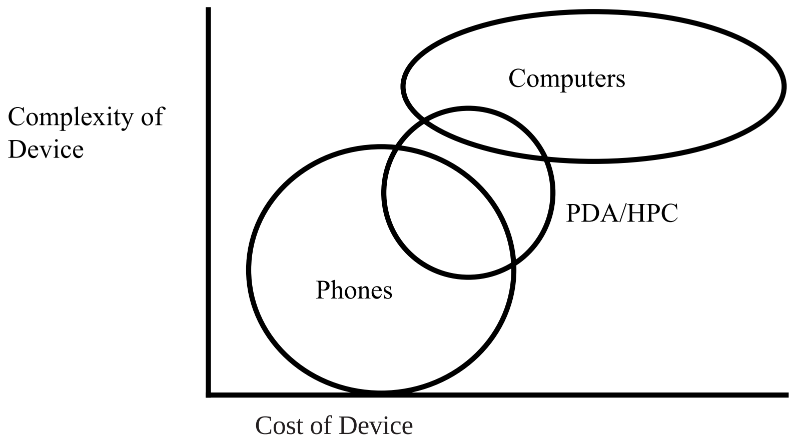


FIGURE 3

User Interface Perception Hurdles

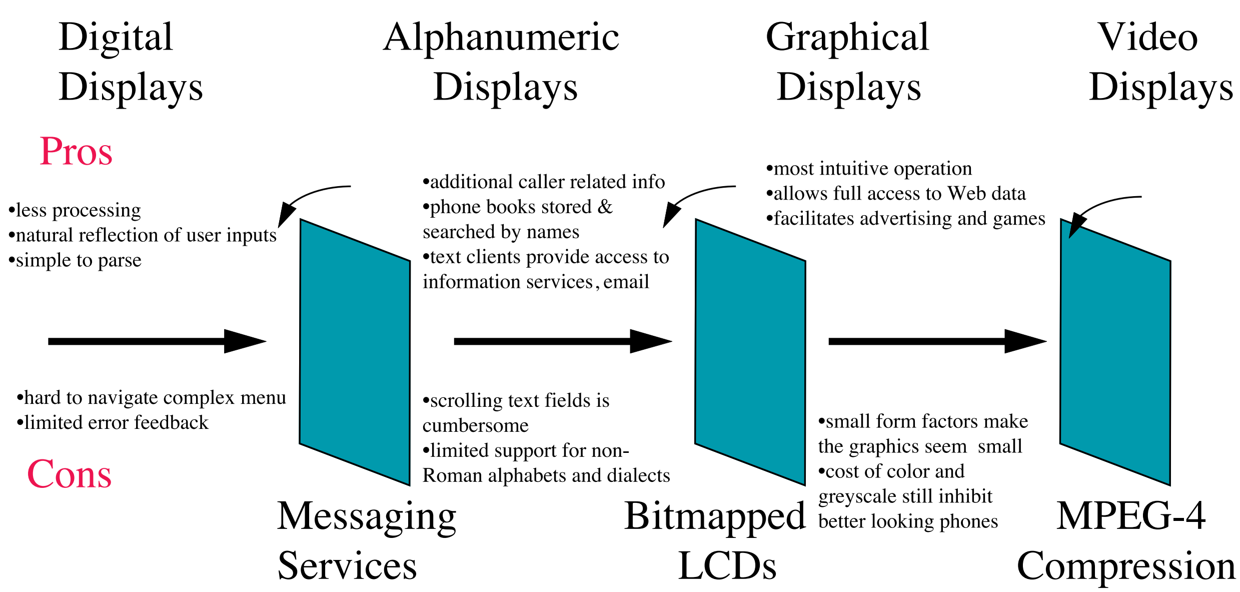
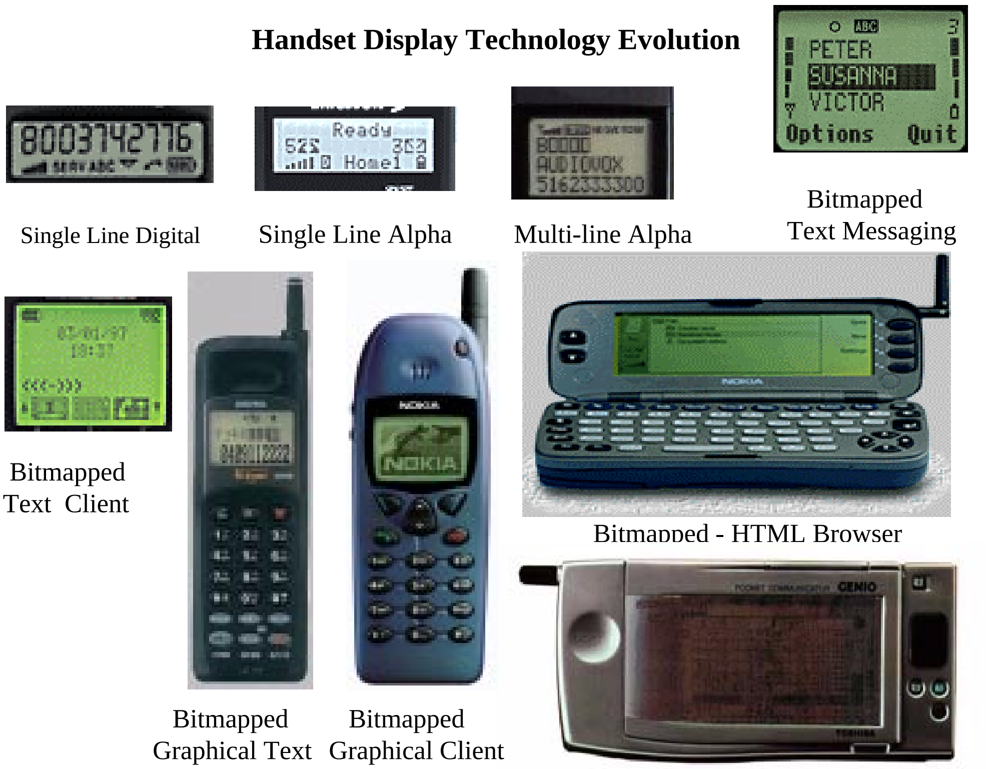


FIGURE 4
Handset Display Technology Evolution



factors with the constraints of the hypertext markup language (HTML) files and the visual ability of the typical user(s). Recently, manufacturers have been displaying LCDs that allow different levels of gray scale and even color. The current state of technology is being pushed by high-density displays with high color resolution that can be coupled with passive lenses to form virtual displays.

Data-Compression Technologies

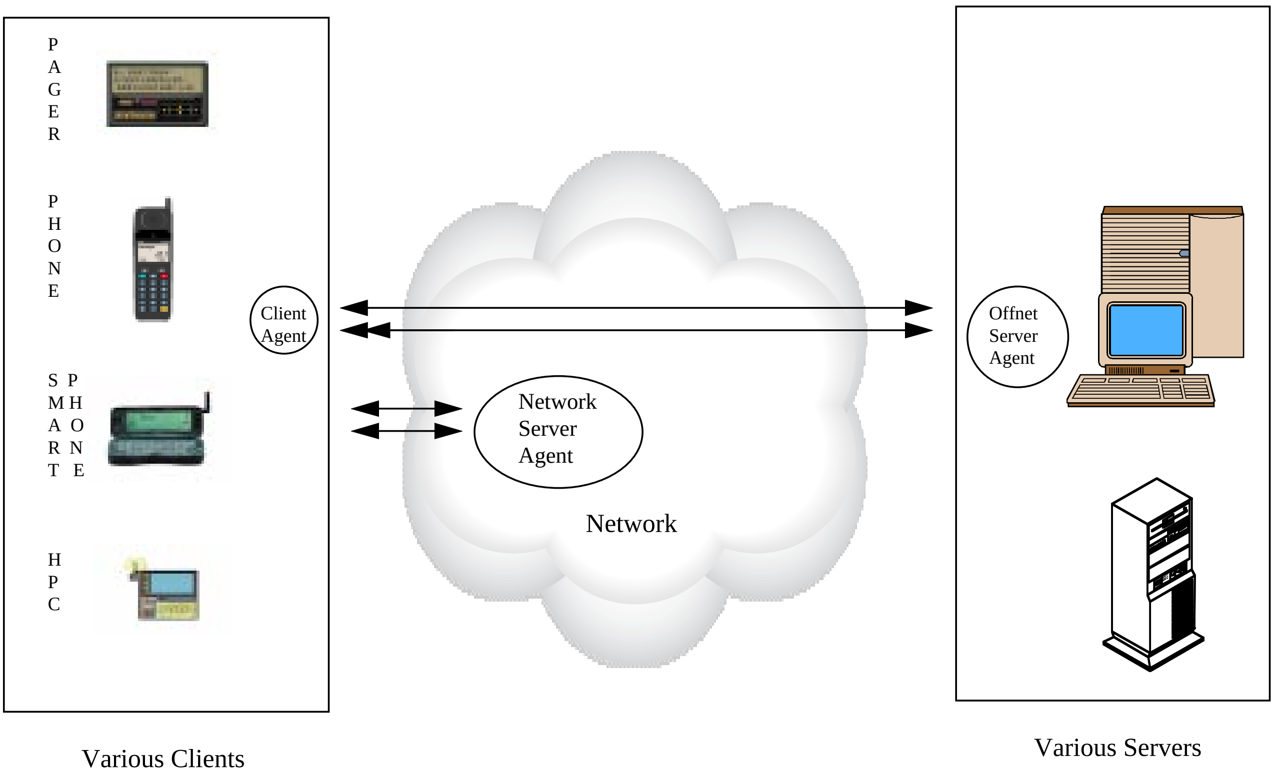
The growth of graphics and high-end desktop capabilities for the Web (e.g., video and GIF animation) has been so rapid that it quickly outpaced even the most optimistic projections for the abilities of constrained devices that a nomad is likely to carry. Both the bandwidth required for transmitting this information and the processing and memory necessary to take advantage of it on the nomad's primary communications device are prohibitive. Thus, an entire market niche has developed around the ability to intelligently strip out much of the information the Web author puts in and to convert the relevant parts back down to lower level information suitable for nomadic devices. The field of proxy servers has been extended to include these abilities, some driven by simple algorithms and the evolving ones using simple artificial intelligence. The results are impressive—typical factors of 90 percent reduction for fully graphical information and 50 percent to 66 percent for pages that include graphics plus text.

Client/Server Software Architectures

The evolution of client/server (C/S) architectures in the handset market allows the application developer to benefit from their traditional strengths. These include a degree of operating system (OS) independence and transport independence that reduces the dependency of an application on a specific design choice of different manufacturers or carriers, as shown in *Figure 5*. This provides the ability to reuse content across different manufacturers with different HW/FW/OS implementations, and the cross-platform ability for sending one application to many devices without having to know their unique nature or keep track of them in associated application subscription databases.

Another advantage of C/S architectures is the ability to distribute processing across either unit. In this context, it provides the ability for the nomad's device to do its own local processing within an application. Local processing reduces the necessary communications bandwidth and can greatly assist in session-level consistency during mobile transitions (e.g., hand-offs). The natural evolution of this distribution will be to have the client tell the server its capabilities and status as part of the session initialization sequence. The term microbrowser has been coined to represent this technology in the handset market, and over the past two years many vendors have offered possible solutions, including Unwired Planet, Wink Communications, JavaSoft, and so on. So many ven-

FIGURE 5
Wireless Client/Server Architectures



dors have offered alternatives that the ad hoc Wireless Applications Protocol Forum is defining a proposed standard to simplify the deployment of services across handsets from different vendors.

Digital Wireless Network Infrastructures

If the wireless device is to operate in the various client/server modes, it will be necessary to have a variety of data-transmission capabilities. Newer, digital network infrastructures provide messaging capabilities (short-message service) that can be used for pushing information, alerting, or silently downloading new services to the user. Their ability to eliminate the Personal Computer Memory Card International Association (PCMCIA) cards necessary for modem operation means that even the mainstream handset can be used as a data communications device, both for tethered operations and for on-board applications. It also means that the nomadic user can operate on the batteries of the handset, rather than having to power a separate modem from their device. Circuit-switched data provides a reasonable method for delivering larger applications and can be used in conjunction with the messaging capabilities to construct convenient service and feature combinations. Digital networks also provide an adequate transport level protocol for error correction and encryption, reducing the need for the applications to provide this overhead. Network-based interworking units/functions have evolved direct IP interfaces to reduce call set-up time, and eventually packet data transmission technology will further improve the client/server capabilities of the typical handset.

Standards for Content Format and Storage

Another key technology is, of course, the uniformity provided by the Internet as a transmission and storage media and the Web as the greatest single content resource. While early versions of HTML were suitable only for the desktop paradigm, the most recent specifications are broad enough to allow effective operation in consumer devices (e.g., wireless handsets, television displays, etc.). However, even with the improvements of HTML 4.0 (dynamic HTML), the nature of wireless networks required extensions for the nomadic user to effectively use these new application. Recent submittals to the World Wide Web Consortium (W3C) of the HDML and HDTP developed by Unwired Planet and the ad hoc development of the Wireless Applications Protocol by leading vendors have begun to extend the use of Web-based content more appropriately for the nomadic user. Another competing alternative submitted to the W3C is that of compact HTML.

In addition, the growing base of wireless subscribers has attracted the attention of different media organizations—many from a historically different market (i.e., television and the media). Examples of major players that are addressing wireless now include CNN and The Weather Channel, both of which are already distributed across a slew of access technologies beyond television. As the business grows, the mass-media market characteristics will come into play, including the use of advertising as a revenue source. Finally, the evolution of content includes the ability for third-party applications to extend to nomadic users on a greater scale. Early vertical adopters, such as the dispatch market or the sales force, will be followed by other casual users (e.g., White pages access, access to map databases, and so forth) as more and more content providers use common interfaces to their legacy systems.

As the sources of content proliferate, they also require increasing amounts of storage as they incorporate more graphical and interactive content. The constrained environment of the handsets, however, is evolving at a slower pace. Recently, the global system for mobile communications (GSM) specifications were expanded to allow for larger subscriber identity module (SIM) cards (16 KB) and for applications on SIM cards to access handset UIs (SIM toolkits). Even more recently, Siemens has led an effort to adopt the multimedia card (MMC) as a standard for adding off-board memory to wireless devices. The MMC promises 256 KB of space and has options for flash to allow writable persistent storage. The SIM cards are large enough for applications that want to count on resident micro-browsers, while the MMC cards can carry the entire client as well as a suite of applications.

User Interface Requirements and Directions

As discussed in the opening section, the wireless device user will grow more and more to expect their device to be a portal to many network and information services. As Vinton Cerf, Vice President of MCI's Internet Architecture, has said, "In years to come, the term 'smart phone' will seem as redundant as the term 'horseless carriage' does today." Each succeeding generation of device will add more display capabilities, better client/server software, and improved data-transmission capabilities as outlined in the technological evolution section. These combined forces will dictate user requirements that are increasingly:

- graphical user interfaces
- simple, intuitive, and fun to use
- adept at processing data locally (when disconnected or resident)
- able to reduce air costs and increase battery life
- able to interconnect easily with related devices (e.g., PDAs, input devices)
- useful for both work-related functions and personal features
- able to store and download multiple applications
- portable, pocket-sized form factors
- complementary to voice-controlled features and input
- simpler to input text for advanced services
- addressable in groups and used for bridged calls
- upgradeable via software updates after market

The user will seek out devices and network operators that complement their ever-growing experience with desktop and intelligent television services, and, in many cases, look for these devices to be companions to their other consumer devices.

A Wireless Local Loop Business Case

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This paper will provide a business perspective on fixed wireless in the local loop. The information presented comes from work done by Southwestern Bell Communications (SBC) in early 1996 and over the few preceding years as the company built up its strategies for the A and B PCS auctions, and eventually the D, E, and F auctions. In early 1996, the C auction was under way, and different strategies were being discussed. The company needed to make a decision about whether or not to participate in future auctions, and we also wanted to understand how a competitor could use the PCS spectrum to provide local telecommunication services. The thrust of this study is to look at the viability of using wireless local loop (WLL) as a so-called low-tier service to provide communication services to residential and small business customers.

In our analysis, we tried to take the perspective of a small business—the companies bidding in the C-block PCS auction —when evaluating the wireless business opportunity for this BTA. What would a small company need to do in order to enter this particular market and compete with the local exchange company? Did wireless local loop provide a competitive threat by providing a license holder the opportunity to provide high-quality local service? What were the priorities in terms of service and equipment?

We believed that providing wireline service and voice quality were high priorities, as well as the ability to reuse customers' inside wiring and equipment (which is important in early marketing). No one would expect the customer, if they chose another carrier, to throw away all of their handsets and other equipment in order to sign up with the new service provider. We thought that customers would want to be able to use everything that they already owned. Could wireless be used to cost-effectively meet these objectives? Since most homes are wired, SBC chose the fixed wireless local loop option whereby consumers could reuse their inside wire.

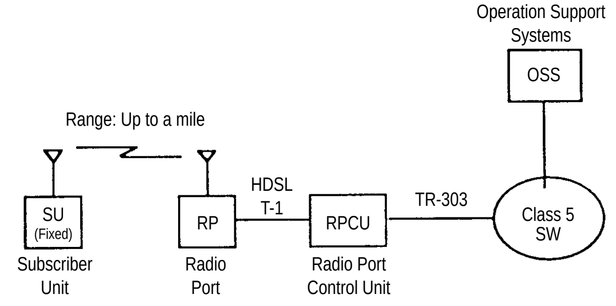
Eventually, we chose to base our analysis on personal access to communication systems (PACS). Initially, PACS provided a limited mobility service and, in our analysis, we thought the competitor would have to find a viable niche and not provide high-speed highway mobility. While vendors have tried to convince the public that PACS can do more, we believe this has taken away some of PACS effectiveness at addressing fixed wireless access. From our perspective, our competitor was interested in enabling people to take their phone from home and go to the ball park to watch their children or to the supermarket (essentially 1,000 feet to one mile). We were also concerned about the capital involved in deploying this network. The particular market being discussed here is a rural market, and our view was that the competitor did not want to provide service up and down the highways to cover pastures and other areas that would not be used; it wanted to focus on wireless local loop. Finally, because we were familiar with PACS technology and had an idea of its cost and deployment considerations, we chose to use PACS in our analysis.

Southwestern Bell has been successful at selling wireline vertical services in this market, and customers will expect such services from any competitor that comes into this market. The wireless technology adopted had to support the services that are available today as well as any new services that might come up. When third-world countries are being discussed with respect to telecommunications and wireless access, one major difference between those countries and the United States is not just the number of phones, but how they are used. American customers use the phone quite a bit, and the wireless network we designed would have to support that kind of usage. That has a big impact on the network design and capital.

The architecture of PACS is shown in *Figure 1*. The subscriber unit (that is, the fixed wireless access unit) is mounted either on the side of the house or inside the house and interconnects to the inside wire, allowing the existing telephones to be reused. There is also a radio port and backhaul facilities from the radio port to the radio port control unit. The radio port control unit is backhauled to the class 5 switch. As some of the numbers in the business case discussed later in the paper indicate, these backhaul facilities have a major impact on the

FIGURE 1

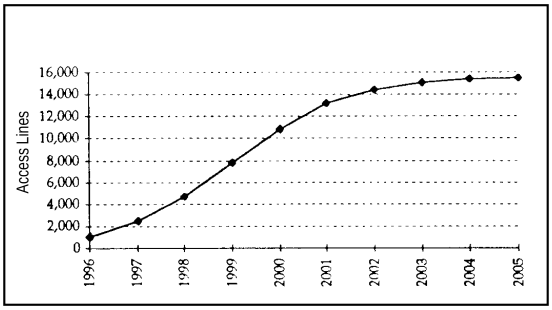
PACS Architecture—Fixed Wireless Access Application



PACS (Personal Access to Communication Systems)

FIGURE 2

Wireless Access Lines — 30% Penetration: 2005



financial viability of this business. It should be remembered that our goal in looking at this opportunity was not just to get a license and deploy capital and networks, but to develop a financially viable business.

Basic Network Assumptions

When looking at this type of business opportunity analysis, many assumptions must be made: network assumptions, subscriber assumptions, revenue assumptions, expense assumptions, and financial assumptions. We made our basic network assumptions first. In entering the particular BTA discussed here, we assumed that the competitor would have 30 MHz of spectrum to work with. The technologies involved will work on 10 MHz, but it costs a little bit more, and the capital involved tends to be higher with only 10 MHz. We toured the BTA and examined the facilities that were available in the area, such as telephone and power poles, building space, the topology of the land, and other various facilities. We assumed that the wireless competitor would be able to place the network radio ports in a one-mile grid, with an antenna height of 40 to 45 feet. This has an impact on the quality of service, because there needs to be some radio coverage overlap in order to ensure good quality service; nevertheless, since the ultimate goal was to have a financially viable business, we chose to deploy using the one-mile grid. The particular town in this example is in tornado alley, so it has many new, tall telephone poles.

The wireless network was designed to accommodate up to a 40 percent access line penetration rate over a 10-year period. Whether or not that level of penetration could be achieved was unknown, but we looked at business-plan sensitivities for various penetration levels. It was assumed that maintenance and installation expense is driven by penetration, network deployment, and in taking the perspective of a small business we sought to keep these costs down. The wireless local loop equipment costs in this business model are based on quotes provided by equipment vendors.

Other basic network assumptions involved backhaul facilities. We looked at both leased and owned backhaul facilities to interconnect wireless components. Leased facilities were available from the LEC or other providers, and tariff prices for T-1s and DS-3s were used in our analysis. We also looked at building the backhaul network using existing poles where possible, 19- and 22-gauge cable to connect the RPs to the RPCUs, and fiber to connect the RPCUs to the switch.

Subscriber Assumptions

Next, subscriber assumptions were assessed. In the BTA being discussed, there were about 200,000 people, 80,000 households, and 6,000 businesses. We thought the competitor would choose not to address this entire market: there are one or two cities within the BTA that are dense, and the rest of the population is in small towns that we thought a small company entering this market might choose not to address. Of the 200,000 population base, we decided to address about 120,000 people, 43,000 households, and about 3,300 businesses—overall, just over half of the entire market. The residential local and toll minutes of use per month totaled about 1,300 minutes, while business local and toll came to about 1,350 minutes per month. We assumed that 54 percent of the minutes of use were originating minutes, and also assumed the presence of 1.2 access lines per household and business. Four different levels of customer penetration were examined.

Revenue Assumptions

In laying out its revenue assumptions, we were able to perform sensitivity analysis and therefore, we did not spend much time discussing what the numbers would be. We as-

TABLE 1

Capital Investment/Access Line

Total Capital per Subscriber (Lease)										
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
10%	8,415	3,993	2,384	1,590	1,261	1,110	1,079	1,061	1,066	1,069
20%	4,436	2,182	1,360	989	833	754	735	735	740	743
30%	3,075	1,598	1,043	799	697	643	629	626	630	633

Total Capital per Subscriber (Build)										
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
10%	8,961	4,273	2,550	1,694	1,347	1,195	1,171	1,162	1,181	1,196
20%	4,707	2,324	1,444	1,041	886	809	797	806	822	835
30%	3,253	1,694	1,101	839	740	689	679	685	697	709

TABLE 2

Wireless Access Lines - 30% Penetration: 2005

30% Penetration Lease Interconnect

Monthly Revenue and Expense Ratios	1996	2000	2005
Subscribers	1,113	10,909	15,574
Local Service Revenue/Average Subscriber	13.46	13.12	12.71
Vertical Service Revenue/Average Subscriber	4.92	6.00	7.68
Long-Distance Revenue/Average Subscriber	12.51	12.47	12.41
Switched Access Revenue/Average Subscriber	6.65	6.63	6.60
Term Local Interconnect Revenue/Average Subscriber	9.48	7.44	5.99
Monthly Revenue/Average Subscriber	*47.02*	*45.66*	*45.38*
Customer Care Expense/Average Subscriber	6.19	2.80	2.12
Marketing Expense/Average Subscriber	18.33	1.09	0.66
Sales Expense/Average Subscriber	18.75	5.46	2.83
G&A Expense/Average Subscriber	5.64	5.02	4.99
Leased Facility Expense/Average Subscriber	*100.16*	*14.11*	*10.52*
Network Maintenance Expense/Average Subscriber	78.75	7.07	3.09
Local Interconnect Expense/Average Subscriber	11.12	8.74	7.03
Long-Distance Expense/Average Subscriber	6.26	7.04	8.16
Total Operating Expense/Average Subscriber	*245.20*	*51.33*	*39.39*

sumed that calls terminating on the competitor's network would yield 1.8 cents per minute. At the time of the study in the particular market under consideration in this analysis, Southwestern Bell basic residential telephone service cost about $14.00, and we assumed a competitor would try to come in below that price. Our pricing assumption was that residential service would be priced at $12.50 per month. Essentially, this would put service at about one cent per minute in terms of usage. The residential average vertical service was about $5.00. The business flat rate was settled at $25.00 per month, and business average vertical service was $4.00. The new company also planned to be in the long-distance business, reselling another firm's long-distance service for 16 cents per minute, in addition to providing access to some of the other exchange carriers for 5 cents a minute.

Expense and Financial Assumptions

We assumed that local interconnect charges would be 1.8 cents per minute while wholesale long-distance cost would be 8 cents per minute, creating a 50 percent margin. Billing costs would be $2 per subscriber per month, and advertising would have a fairly small budget, about one dollar per pop. G&A would be 12 percent of revenues, which is a reasonable number. The PCS C block license cost about $4 million for this BTA, but, taking into account the discounts and the financing that the FCC gives small businesses, that $4 million can be reduced to $2 million (if the present value of $4 million is spread out over a 10-year financing period, and the discount is taken into consideration).

Finally, we assumed the cost of capital to be 11.5 percent. This may not be high enough, depending on the financials of the small business. We assumed the debt ratio was 46 percent. Some small businesses will have to assume a much higher ratio than this, and that impacts the evaluation. There would also be an 8.25 percent interest expense and a 10-year time period for equipment depreciation.

The Business Case

Wireless Access Lines

Figure 2 provides an example of how the market develops. At the 30 percent penetration level, the competitor would start with a few thousand customers in the first year, and by the end of the 10-year period, the company should have a little more than 15,000 customers. A 10 percent penetration rate follows this same kind of curve, but has 5,000 customers at the end of 10 years.

Capital Investment Per Access Line

Capital investment for assets is important. Although many in the industry say that wireless service can be provided more cheaply than wireline, it is only possible with the right kind of penetration rates, usage patterns, network design, and customers. *Table 1* provides an idea of the capital investment required per access line for penetration levels of 10 percent, 20 percent, and 30 percent if the facilities are leased (top) or built (bottom). Assuming 30 percent penetration and $633 per subscriber, around $10 million in capital is being spent by leasing and $11 million by using built facilities.

Monthly Revenue and Expense

Table 2 shows the revenues and expenses for the situation in which the backhaul network facilities are leased from the local telephone company. The section at the top is the average revenue per subscriber per month for the years 1996, 2000, and 2005, assuming a 30 percent penetration rate. Below the revenue ratios are the total operating expenses per average subscriber. In looking at the first column, it does not take a great deal of math to realize that if $47 per month is being made per subscriber while $245 is being spent, there is no

TABLE 3

Build Backhaul Network Option

30% Penetration Build Interconnect

Monthly Revenue and Expense Ratios	1996	2000	2005
Subscribers	1,113	10,909	15,574
Local Service Revenue/Average Subscriber	13.46	13.12	12.71
Vertical Service Revenue/Average Subscriber	4.92	6.00	7.68
Long-Distance Revenue/Average Subscriber	12.51	12.47	12.41
Switched Access Revenue/Average Subscriber	6.65	6.63	6.60
Term Local Interconnect Revenue/Average Subscriber	9.48	7.44	5.99
Monthly Revenue/Average Subscriber	*47.02*	*45.66*	*45.38*
Customer Care Expense/Average Subscriber	6.19	2.80	2.12
Marketing Expense/Average Subscriber	18.33	1.09	0.66
Sales Expense/Average Subscriber	18.75	5.46	2.83
G&A Expense/Average Subscriber	5.64	5.02	4.99
Leased Facility Expense/Average Subscriber	*7.89*	*0.47*	*0.28*
Network Maintenance Expense/Average Subscriber	87.13	7.57	3.39
Local Interconnect Expense/Average Subscriber	11.12	8.74	7.03
Long-Distance Expense/Average Subscriber	6.26	7.04	8.16
Total Operating Expense/Average Subscriber	*161.31*	*38.19*	*29.46*

profit. One of the big expense items is the leased backhaul facility cost per subscriber. There are many radio ports that take T-1s back to some point, and leasing these lines has a big impact on the business case. When the lines are loaded up, then the cost per subscriber comes down.

Table 3 shows what the revenues and expenses are like when the backhaul facilities are built—it is a very different picture. There are still some leased facilities being used, but these are the telephone poles and equipment that have to be attached, as well as some right-of-way expenses. The leased facility expense essentially goes away, and the picture starts looking better. In analyzing business cases for PCS and wireless, it is common for the provider to spend a great deal of money in the early years, so cash flows look negative for the first few years. However, these start becoming positive by years five and six, and this example is not much different.

Net Income

Net income projections for the leased and built backhaul network options are shown in *Figures 3* and *4*, respectively. For the leased option at 10 percent, 20 percent, or 30 percent penetration, net income never becomes positive. However, if the wireless competitor were to build its own network, partner with another firm, or negotiate a different leasing rate, then there are some net income curves that look better (*Figure 4*). These curves are typical of the situation for PCS providers; the magnitude of the numbers are smaller because the example under consideration is a small market. In a large market such as Dallas or Chicago, a lot of money is being spent. The magnitude might change, but the shape of the curves are pretty much the same. In *Figure 5*, the three bars on the right represent the net present value (NPV) of the cash flows for the backhaul lease option, and the three on the left are for the backhaul build option. At 20 percent penetration in the build option, the NPV is almost zero; this could turn to about $3 million positive NPV given 30 percent penetration.

FIGURE 3

Net Income: Lease Backhaul Network Option

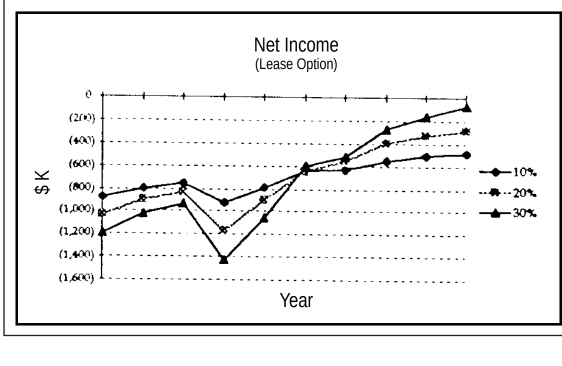


FIGURE 4

Net Income: Build Backhaul Network Option

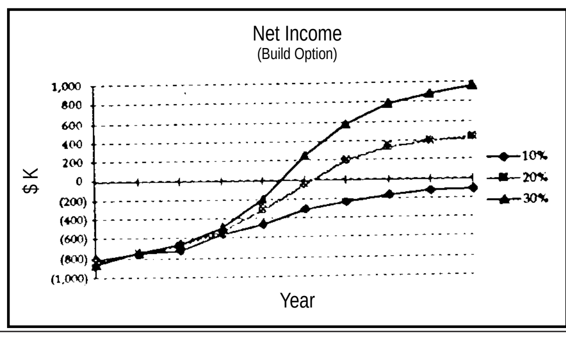
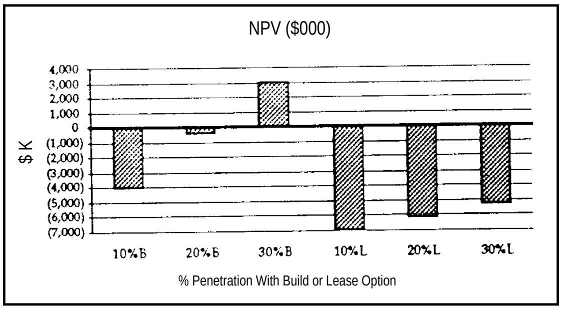


FIGURE 5

Business Case Net Present Value



It is important to remember that this particular company picked one specific market to pursue for a number of reasons. That may not be the type of market another company wants to go after, since there are many factors that impact the business case. *Figure 6* is a "tornado chart"—a way of evaluating the relative importance of various factors to NPV. The horizontal line in the middle represents the $3 million positive NPV mark for the 30 percent penetration case, and we call it the base case. Each variable (penetration rate, local rates, sales cost, etc.) has been changed plus or minus 50 percent. For example, the intersection of the horizontal "base case" line and the vertical penetration line represents $3 million NPV at 30 percent penetration. If 45 percent penetration can be achieved, then the business case looks good (over $8 million NPV).

The next vertical line represents the percentage of originating calls; if more calls could be terminated on the new company's network, NPV would improve. Right now, companies are giving away free minutes for incoming calls in an attempt to have users give out their wireless numbers. The intended result is that more calls will terminate on the company's network in the long run. The next line in *Figure 6* represents local rates, plus or minus 50 percent. If one could charge $20 a month rather than the $12.50 mentioned previously, this would have a big impact on NPV. It would also have a big impact on customer penetration as well. Many people in the industry dwell on the factor of capital which is important because it involves a great deal of up-front money. However, capital expense is not the key driver in the business case. Earlier, it was mentioned that the competitive company spends about $10 million (plus or minus $5 million) as shown in *Figure 6*, and it does not have that much of an impact because of depreciation and other issues. Other factors represented in *Figure 6* follow the same pattern.

Conclusions

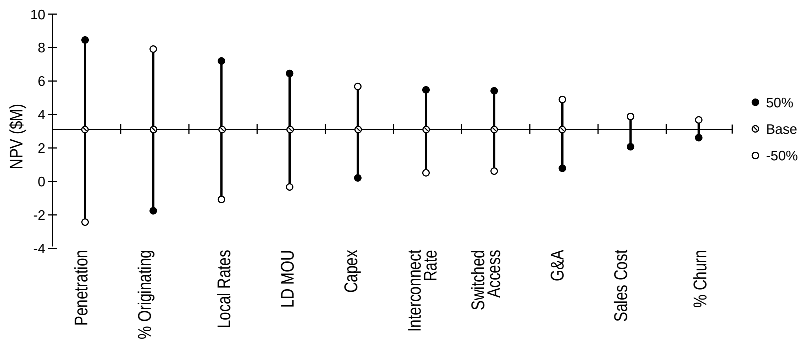
The business case discussed in this paper was for a domestic application of wireless local loop, and it should be remembered that the international arena is different. This application is a risky opportunity involving a lot of money up-front. By offering a limited-mobility service, can a market penetration in excess of 20% be garnered by charging a little bit less than the incumbent telephone carrier? This is the key question that must be answered.

Many companies that are considering going into the wireless business are looking at attracting the second-line business. In making such a move, a potential carrier must examine the mechanics of the business case, the existing competitor, the infrastructure, and costs involved. Wireless local loop is not just a simple yes or no solution. It requires a great deal of analysis and the right set of strategies, vertical services, and so on. The right kind of partners associated in a project can prove to be one of its biggest assets in terms of addressing backhaul options, obtaining cell sites, setting up structures, and mitigating costs.

Issues associated with interconnection and switched access rates will be important for the wireless loop business. In addition, companies must ask themselves how they plan to differentiate their service. Limited mobility will help, but there must be more than that. Strong penetration rates are required for success. Application of wireless local loop overseas could be a much different option. Foreign markets are being entered that have no telephone service today, and once subscribers start using it, they may use very few minutes per month. That has a big impact on network design and cost. The case discussed in this paper is not intended to apply to international applications. The scenario we looked at was local bypass of the incumbent LEC using wireless local loop.

FIGURE 6

Sensitivity Analysis



Wireless Technologies in the Local Loop: The Case for PACS

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Within the telecommunications industry, wireline and wireless technologies are merging into a single set of services. Wireline services offer zero mobility and a low cost of $15 to $18 per month for 700 to 800 minutes of use in the local calling area. Cellular wireless provides mobility, but it costs much more, anywhere from 25 to 30 cents per minute. Customers are willing to pay 10 to 20 times more on a per-minute basis for mobility because it seems to add value. Now, the industry is saying that since billions of dollars are invested in the wireline side and billions are invested in the wireless side, these technologies should merge into a service that offers local loop cordless, mobile data, and wireless video. PCS is all about bringing these technologies together. The Federal Communications Commission (FCC) is in the process of auctioning off personal communication services (PCS) frequencies. This essay will discuss how those frequencies can be used to offer local loop service or local loop plus some mobility as an integrated service offering.

The FCC is allocating six sets of frequencies in the United States, labeled A through F. These licenses are defined as metropolitan trading area (MTA) licenses and basic trading area (BTA) licenses. They total 2,074 licenses within the frequency band of 1850–1990 MHz. This is the operating frequency for PCS. These licenses have to be purchased; the FCC set up franchises so that taxpayers can get some revenue for the public use of the airwaves. The A- and the B-block licenses, which are the MTA licenses, sold for about $7.5 billion. The C-block licenses sold for almost $10 billion. The D, E, and F licensing process is underway, and they might sell for another $2.5 to $3 billion.

Options for Wireless Technologies

The companies who own the licenses have to figure out what sort of service to offer. Wireless local loop, PCS services, wireless data, wireless video, and other wireless services are among the different technology choices. *Table 1* lists a number of different options for license holders. Digital European cordless telephone (DECT), which has been renamed digital enhanced cordless telephone, is a European standard that is being deployed in many parts of the world outside Europe. Personal handiphone system (PHS) is a Japanese standard, but it is also growing within Southeast Asia, China, and Latin America.

PCS 1900 is based on the global system for mobile communications (GSM) standard. It was a European standard, but has been accepted in many countries around the world. IS-136 is a time division multiple access (TDMA) digital cellular standard being used for mobile cellular applications. IS-95 is a code division multiple access (CDMA) standard. These technologies are all ways of providing wireless services.

The first three technologies listed in *Table 1* are low-tier or microcellular technologies. They provide coverage anywhere from 100 to 1,000 meters away from the cell site or radio site. Although many sites are needed, low-tier technologies have several advantages. They provide wireline voice quality and they can offer 80 to 100 milli-Erlangs of traffic (800 to 1000 minutes of use) to every customer. The next three technologies are considered high-tier. A 100-foot tower outfitted with antennas transmit over a three- to five-mile radius and provide 100 to 150 minutes of mobile cellular service to every subscriber, or typically 10 to 15 milli-Erlangs of traffic.

Several other ways of differentiating between the technologies are listed in *Table 1*. Operational availability refers to whether the technology has been extensively tested and / or is ready for commercial deployment. Cost and service expectations are the other differentiating characteristics. The first three systems are designed to offer little or no mobility (although PACS–based systems can also support full highway–speed mobility). Zero mobility means wireless local loop, and more mobility means neighborhood PCS. A portable device would work in and around a neighborhood or in the car along the highway. The other three systems, PCS-1900 (GSM), IS-136 (TDMA), and IS-95 (CDMA), are designed primarily to offer mobile cellular service.

Differentiating PACS from Cellular Service

In choosing personal access communication system (PACS) technology, will carriers make money? Will subscribers use the system? The answers to these questions lie in the factors that differentiate PACS from other wireless systems.

PACS technology is very simple. It is not the same as CDMA. Millions of dollars are not needed to bring it to market. PACS is based on TDMA, a technology that has been used in the satellite business and the wireless industry for 30

TABLE 1

PCS Technology Options

Air Interface	Operational Availability	Service Quality	Cost	Primary Service Expectation
PACS PCS[1]	✓	✓	✓	• Mobility • WLL • High traffic usage • WCTX/WPBX • High-speed data
DECT	✓	✓		• Cordless telephony
PHS	✓	✓		• Pedestrian telephony
PCS-1900 (GSM)	✓			• Mobile cellular[2]
IS-136 TDMA	✓			• Mobile cellular[2]
IS-95 CDMA				• Mobile cellular[2]
Omni Point		✓		• Mobile cellular[2]

1 PACS Service: Wireline voice quality, 1% GOS, 80 to 100 me traffic/subscriber, 97% coverage
2 Mobile cellular: Mobile voice quality, 3 to 5% GOS, 10 to 15 me traffic/subscriber, 90% coverage

years. It is designed to minimize network equipment and subscriber costs.

PACS is a standard that many different companies are involved in promoting. There is a users' forum that promotes the benefits of PACS, with member companies including Hughes, Siemens, Bellcore, Panasonic, NEC, Motorola, Lucent, and others. PACS is a well-rounded, open-interface standard that many companies can use to build equipment.

The first uniqueness of PACS is in its area of usage. With PACS, carriers can provide a wireless local loop equivalent to the wireline usage rate of 800 to 1,200 minutes per month for a residential line. A cellular system is designed for an average usage of 100 to 150 minutes per month. The estimated monthly fee is linked to usage. PACS access for the local loop can be priced anywhere from $20 to $30 per month, which is in line with what wireline telephone companies charge for local access. Compare this PACS-based WLL service to cellular where the average bill is about $50 per month (for about 100 minutes of use), so cellular customers pay twice as much as PACS but receive 10 times fewer minutes of use! This cost comparison provides a big differentiation between PACS wireless local loop and cellular.

In terms of mobility, a microcellular system will have a range of 100 meters to 1,000 meters. PACS has a range of almost 1,600 meters. These microcellular systems can be installed exactly where the customers are and therefore can be deployed in a well-focused strategy. In contrast, a cellular system can put up one tower and cover a large area of geography, but cannot focus the coverage where the WLL subscribers are likely to be located.

PACS was designed by Bellcore and originally was called wireless access communication system (WACS). It was designed specifically for wireless local loop, and in that formulation there was a limitation of 25 to 35 miles per hour on traffic speed, just as with the personal handiphone system and the DECT system. The standards committees realized that if wireline voice quality was possible using wireless, then there should not be a limitation on whether the phone could be used on the highway. When the system specifications were changed to evolve WACS to PACS, improvements were made in the standard to allow for a highway speed of 65 to 70 miles per hour.

The first handsets for PACS will be single-mode at a cost of around $200. Eventually, a dual-mode handset will be needed with a default mobile use for national roaming through the use of analog cellular. In Europe, the standard used for mobile cellular will be GSM, and PACS will face an uphill battle in Europe because DECT is already there.

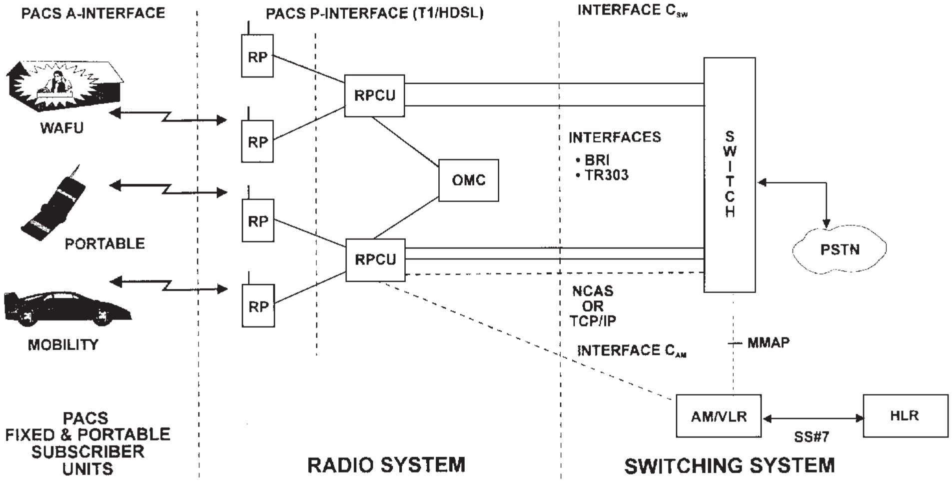
When a wireless local loop system is installed in the home, a wireless access fixed unit (WAFU) is used to connect all the existing telephones in the house to PACS. It has an RJ11 interface, so all the telephones connect normally, but the transport is wireless via a PACS system. The WAFU would have a telephone number, and all the existing telephones would connect through that device. The voice quality is equivalent to wireline quality because PACS uses a very good voice coder: 32 kbps adaptive differential pulse code modulation (ADPCM).

PACS is wireless wireline service. Wireline voice quality, very high coverage, and 1 percent grade of service differentiate PACS from cellular service. When trying to make a cellular call during rush hour, the call is often blocked because the systems are designed for 3 percent to 5 percent blocking. PACS is designed for 1 percent blocking and hence would allow many more users to access the network.

Wireless will probably not be able to provide broad bandwidth. To provide 1.5 Mbps using wireless would be very ex-

FIGURE 1

PACS PCS System Architecture



pensive, but providing 28.8 kbps or 64 kbps is probably a very good application, and there is a good market for it. For example, students on campus could have laptops with wireless modems to access the university database or the Internet.

In a PACS network, a number of different radio ports provide a number of different services. Radio ports can be deployed in the neighborhood to provide wireless local access, but PACS does not stop there. Higher-speed data and wireless centralized exchange service (Centrex) are other PACS applications. In urban areas, PACS can be used for personal mobility, and the same system and equipment can be used along highways. Carriers can start off with a local loop system and then add these different applications with few if any incremental costs.

PACS is designed to support 80 to 100 Erlangs of traffic per subscriber, 10 times more traffic than is carried today by cellular. With analog cellular systems, there is a lack of privacy and security. With PACS, all transmissions are encrypted, so people cannot easily listen to a radio channel and eavesdrop. Before a user makes a PACS call, the system asks for specific information for an authentication algorithm. This security system minimizes fraud, which is a big problem in the wireless industry today.

PACS has a built-in short-messaging service, so customers do not have to carry both a PACS phone and a pager. The pager functionality becomes part of the phone. The advanced intelligent network (AIN) functionality of the wireline network comes through to the wireless user for the most part because PACS is based on simple technology and a simple interface to a class 5 switch. In fact, PACS interfaces using the integrated services digital network (ISDN) to existing end office switches. All the investments in the wireline network can be used in a wireless local loop application that uses PACS, which results in lower costs: leveraging existing transport facilities, existing AIN functions, and existing switches minimizes expense.

PACS is environmentally friendly. Hundred-foot towers and big shelters are unnecessary for the service. Instead of buying land to put up a tower, PACS equipment can be put on a telephone pole, a street lamp, or on the side of a building. The radio port equipment is the size of a laptop computer.

On the network side, the voice coding for PACS has a delay of only five milliseconds one-way, or 10 milliseconds round trip, so echo cancellation in the network is not needed. This serves to reduce network cost. In CDMA, there is about 150 milliseconds delay one-way, and it is like talking on a satellite system. The delay in CDMA and GSM systems require echo cancellers.

PACS allows for reuse of a transport network and the T1 facilities already installed by the telephone companies. AIN, the switching system, and class-5 end offices all can be reused. In the PACS 16-cell reuse pattern, the first 16 cells take up all the frequencies of a 10 megahertz license. The 17th cell reuses the first frequency, the 18th cell the second frequency, and so on through the 32nd frequency. The 33rd frequency is on the first channel again.

The frequency planning aspect of PACS is also important. In existing cellular systems and some PCS systems, extensive frequency planning is required. PACS uses an automated algorithm designed by Bellcore called quasi-static automatic frequency assignment (Q-SAFA). All the radio ports monitor all the known channels in the network and then make a list of the observed signal level on each channel. The system then rank-orders the channels from “no signal” status to “some signal” status. When a channel has no signal, it is free and a radio port can use it. Each one of the radio ports does this automatically, eliminating the need for a staff of people to count all the different channels in the network.

PACS Architecture

The frequency range that PACS covers is the band from 1,850 MHz to 1,990 MHz. The radio frequency (RF) channels are small, taking up about 300 kHz of spacing. PACS uses 32 kilobits ADPCM with a frame duration of 2.5 milliseconds.

TABLE 2

PACS Traffic Capacity

PCS Spectrum	RF Channels/RP	32-kbps Channels VCs	32-kbps Channels Erls at 1%	16-kbps Channels VCs	16-kbps Channels Erls at 1%
5 + 5	1	7	2.5	15	8.1
10 + 10	2	15	8.1	31	21.2
15 + 15	3	23	14.5	47	35.2

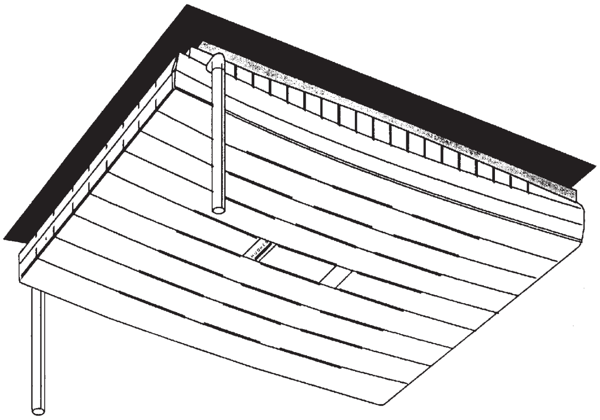
Handoff in the system occurs at high speed, even at 65 to 75 miles per hour, from radio port to radio port.

The transmit power for the portable and radio port equipment is less than one watt. CDMA, GSM, and IS-136 cellular systems use anywhere from 20 to 45 watts of radio power. The lower the power, the less costly the service will be. Low power lessens the range but allows for smaller equipment and minimizes the fear people have of developing cancer from the use of portable phones. The 200-milliwatt subscriber transmission power of PACS is among the lowest power systems available today. Existing cellular phones use 600 milliwatts, and GSM uses up to 1.5 watts; these higher power levels tend to use up the battery. In addition, the 200-milliwatt power level of PACS is adaptive; the farther away the user is from a radio port, the higher the power level. The closer the person is to the radio port, the lower the power transmitted. This adaptation improves talk time.

As a TDMA system, PACS uses a frame with specific slots to transmit voice or data. PACS frames have eight slots: one is used as a control channel, and seven are used for traffic. Hence, seven simultaneous calls can be on the radio port on the base station. Each frame is 2.5 milliseconds, so there are 400 in one second. A short frame is good for propagation purposes, because if a frame is lost through interference, it can be thrown away by muting the audio for 2.5 milliseconds. The human ear cannot hear a gap in a conversation of less than 15 to 20 milliseconds so the loss of a few frames will not even be noticed. Even if five to six of these frames are lost, the customer will not notice it. DECT has a 10 millisecond frame, and PHS has a five millisecond frame. In those cases, the loss of two or three frames is noticeable. The longer the frame length, the greater the likelihood of degraded quality in an interfering environment.

FIGURE 2

Indoor RP (Ceiling Mounted)



The PCS spectrum is divided between 10-MHz and 30-MHz allocations, between MTAs and BTAs. The A, B, and C licenses are 30 MHz; the D, E, and F licenses will be 10 MHz. A 10-MHz licensee could have one radio channel at each radio port (see *Table 2*). The voice channels per radio port would be seven, allowing for 2.5 Erlangs of traffic in that radio port. Assuming typical WLL subscribers have a traffic load of 80 to 100 milli-Erlangs, an RP can support anywhere from 25 to 30 subscribers.

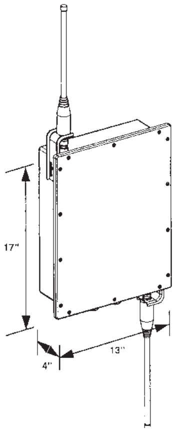
There are three ways to increase capacity. One is to add more radio ports, which allows for more subscribers. The second way is to cut the voice coding rate in half to 16-kbps voice coding, which increases traffic capacity at each radio port by 2.5 to 3 times. Half-rate voice coding frees up the frame to allow for fifteen voice channels instead of seven with 32 kbps. The third method of increasing capacity is to add more frequency. For example, by using 10 + 10 MHz spectrum, 2RF channels can be used at each RP, and with 15 + 15 MHz, 3 channels can be used.

The PACS PCS architecture is illustrated in *Figure 1*. Subscriber units are portable units used by a pedestrian or in a car. The wireless access fixed unit (WAFU) would be used in a local loop environment. The subscriber units communicate through a common air interface to radio ports that connect to radio port controller units (RPCUs) through a T1 or high-speed digital subscriber loop (HDSL) facility. The radio port controllers talk to existing class 5 switches. The switch requires an ISDN interface and an AIN generic 0.1 interface. With those in place, existing class 5 switches can be used. In PACS, mobility management functions are offloaded from the switch into peripherals called access manager/visitor location register (AM/VLR) and home location register (HLR). These are intelligent peripherals that manage the mobility aspects of the system and communicate with the switch by signaling system 7 (SS7). This radio system can be dropped in place in an existing telephone company's network.

Figure 2 depicts an indoor radio port. It has 20 milliwatts of transmit power and is 9 by 12 by 2.5 inches, or about the size of a laptop computer. It weighs only four pounds. The port plugs into the wall for AC power, and with a T1 facility, it provides the capability to serve 2.5 Erlangs of traffic. Normally this unit would be used in an office environment.

FIGURE 3

Outdoor Radio Port



- RF power output: 800 mW
- Outdoor enclosure
- Employs spatial antenna diversity
- Network interface DS1 (T1/HDSL)
- Powering options: AC with battery backup or battery feed from plant
- Environmentally friendly
- Size: 13" x 17" x 4" (884 cubic inches)
- Weight: approximately 18 lbs.
- Operating temperature: -40° C to +50° C

Depending on the traffic, 30 to 100 subscribers could be served per radio port. The range of the unit covers one floor of a building as well as the floor above and below it.

Outside traffic is handed off to an outdoor radio port, which is more rugged. It has an outdoor enclosure and built-in antennas (see *Figure 3*). It is about 13 by 17 by 4 inches and weighs about 18 pounds. These units can be equipped with battery backup. If the power goes out, the battery provides four to six hours of operation. The radio power is up to 800 milliwatts and the only external connections are AC power and either an HDSL or T1 line for transport. One of the interesting things about HDSL is that it provides both the transport facility and DC power. The outdoor port can operate at temperatures from negative 40 to positive 50 Celsius. The range from the outdoor radio port is up to one mile, or 1,600 meters.

The radio port controller unit is a large rack of equipment. One rack of two RPCUs will handle up to 336 radio ports. The whole system is controlled by an operations and maintenance center. The center is connected to each radio port controller with an Ethernet connection to the RPCUs (see *Figure 4*). The RPCUs control the outdoor and indoor radio ports. The function of the operations and maintenance center is to keep track of the radio network, which includes fault isolation and diagnosis, alarm monitoring, performance monitoring and logging, configuration management, radio element management and control, and testing.

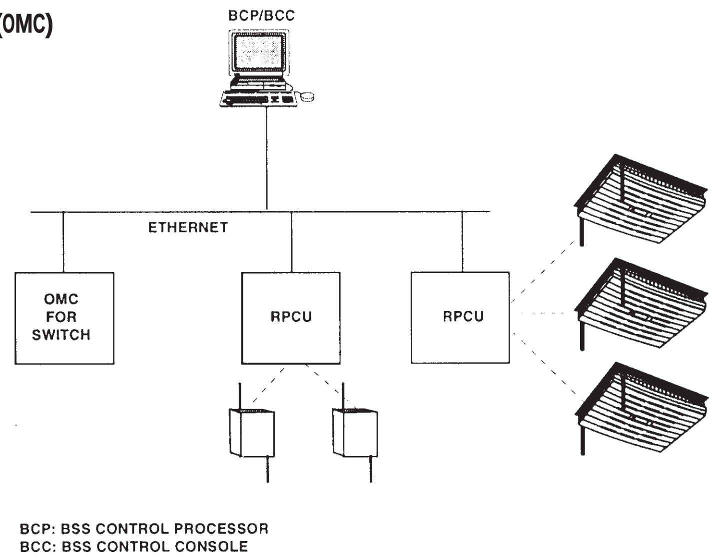
The PACS portable handset unit has indicators for roaming, a short message service, receive signal strength, battery, and other functions. The talk time is about four hours, and standby time is 168 hours, which is four to five times longer than the typical cellular phone today. The longer battery life is due to the 200 milliwatts maximum power, power adaptation, a sleep mode, and the simplicity of the technology. To perform 32 kilobits ADPCM, only one bank of digital signal processors is needed. With GSM, CDMA, and IS-136 systems, more processing power is needed, and processing power cuts down the battery life. PACS requires very little processing in the portable unit.

Implementing PACS in the Local Loop

When wiring a neighborhood for PACS, radio ports can be installed on existing facilities such as telephone poles. The radio ports allow wireless access by the wireless access fixed units (WAFU) installed in a house or office building. A typical customer premise equipment installation would involve a wireless access fixed unit that would be installed in a house and plugged into the wall for AC power. It has an RJ11 connection to plug in existing telephones. More than one phone can

FIGURE 4

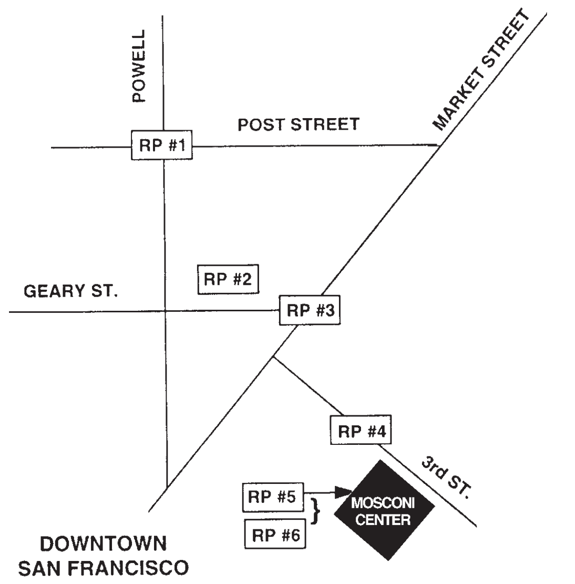
Operations and Maintenance Center (OMC)



- Fault isolation and diagnosis
- Alarm monitoring
- Performance monitoring and logging
- Configuration management
- Radio element management and control
- Testing

FIGURE 5

PacBell PACS Technology Trial



be connected because the unit will drive up to three ringer equivalents (REN). The WAFU has a built-in tool to help locate the optimal placement for the best signal. Total set-up time should be no more than 15 minutes.

Some clients have had concerns about not getting enough subscribers. In a suburban area, a radio port mounted on a telephone pole will cover about 1.2 square miles or 768 acres, which equals about 1,000 to 1,500 homes. Given that one radio port supports 2.5 Erlangs in a 10-MHz allocation and that about 30 subscribers can be supported at 0.08 Erlangs each, only a 2% penetration, or 20 to 30 homes, is needed to load one radio port. The issue will not be whether there are enough subscribers for the radio port, but whether there are enough radio ports for the subscribers.

The operating environment for PACS could be urban, suburban, or rural. The radio port can be mounted 8 to 16 meters above the ground, and the expected cell radius would be 300 to 1,600 meters, depending on how high the radio port is mounted and the type of environment.

PACS Technology Trials

The most recent PACS technology trial was carried out by Pacific Bell in San Francisco. Pacific Bell had the back-haul (T1 facilities) and the switches. The company wanted to demonstrate a wireline voice quality system and achieve mobility in a microcellular PCS environment. It also wanted to show how PACS could integrate into the company's DMS-100 class 5 switch. As it turned out, the most important issue was local zoning in San Francisco. Local ordinances prohibited more antennas in view. However, PACS is so small that it could be placed inside of a building against a window.

The trial was a six–radio port installation. Two were installed in Moscone Center and four outside (see *Figure 5*). The system provided continuous coverage from inside Moscone Center, where the PCS show was being held, to throughout the area shown in *Figure 5*. The system was installed and commissioned in less than four weeks, including identifying the sites and ordering the T1s. The environment was downtown San Francisco, which contained numerous high-rise buildings. The voice quality was excellent, and handoff between radio ports was demonstrated. The two indoor radio ports covered the entire Moscone Center. The PACS range in an urban environment was confirmed to be 300 to 400 meters. PACS successfully interfaced with a DMS-100 using two basic rate interface (BRI) lines.

At the April 1996 CTIA show in Dallas, PACS' ability to connect to an off-the-shelf fax-phone machine was demonstrated. The machine was connected to a PACS subscriber unit and the telephone system using the PACS interface. With the radio interface into the controller and with a BRI connection into a class 5 switch (an AT&T 5ESS, the demonstrator picked up the handset and successfully made a call. A fax was sent in the fax machine at 9,600 bps. In this case, the environment was very stable (the radio port had a line of sight to the subscriber unit) and 9,600 bps delivery was possible. Note that PACS guarantees 4,800 because of the 32-kbps ADPCM. The test showed that 9,600 bps can be accomplished with a clear line of sight or an adequate fade margin in the radio paths.

Another demonstration was done in September 1995 in Orlando. The purpose was to show the capability of PACS to provide high-speed wireless data service. The demonstration combined two slots on the air and put a laptop with a 28.8 modem on it. As mentioned previously, the TDMA frame has eight slots. By combining two slots and using 64-kbps pulse code modulation (PCM) coding a clean channel was available on the air. The laptop was then able to dial up on a 28.8 kbps wireless data line through the system. With a leased analog line from BellSouth and an account with an Internet service provider, 28.8 kilobit wireless Internet access was accomplished using PACS. At the time, no other wireless system could do that. After the demonstration, GSM and PHS started to tout this capability. Moving forward with PACS, all seven slots can be combined for high-speed packet data delivery on the order of 200 kbps packet data. The basic platform allows for that capability.

The earliest demonstration of PACS put to rest the notion that PACS could work only at pedestrian speed. In 1995, Bell Atlantic installed telephone poles for mounting four radio ports. The ports were brought back to an RPCU and connected to a 5ESS end-office switch using BRI lines. Demonstrators drove up and down a road at up to 60 miles per hour. The demonstration showed that communication was possible at 60 miles per hour with PACS. Handoff was accomplished and wireline voice quality was maintained at that speed.

PACS has been demonstrated in various applications: wireless local loop, wireless Internet, as well as for high-speed mobility. It also has the ability to work in an urban environment such as San Francisco. PACS is a next-generation PCS technology that offers highway-speed mobility with handoff. Higher-speed data transmission is possible through slot aggregation. There are standard interfaces to the switch, so the existing PSTN network can be reused, and the low complexity and low-power equipment make for easy installations and low cost to the operator. Finally, deploying PACS does not require much spectrum. It works with 10 MHz, which makes PACS available to the D, E, and F PCS operators as well as the A, B, and C operators. The A, B, and C operators have 30 MHz and could use 20 MHz for CDMA, GSM, or IS-136 and 10 MHz for PACS. This strategy will catch on as more companies discover the benefits of PACS and examine its capabilities.

In terms of current PACS deployments, GCI bought a B-block PCS license for Alaska, and the company will deploy PACS. 21st Century Telesis is a C-block winner. This company has 17 markets in the PCS band covering 4 million people, and it has committed to using PACS. Windkeeper Communications is the U.S. Virgin Islands winner for C-block, and it will be using PACS as well.

Third-Generation Wireless Systems: TDMA vs. CDMA Revisited

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Abstract

Wireless networks are growing rapidly around the world, and the projected demand for higher capacity, coverage, data rate, and flexibility and range of services motivates the need to develop a new generation mobile standard. The International Telecommunications Union (ITU) has been coordinating the standardization of the future land mobile telephone system (FPLMTS), which it recently renamed international mobile telephone-2000 (IMT-2000). The IMT-2000 system is promoted as a truly global, third-generation mobile-network standard that will eventually replace current disparate second-generation standards. The service initiation goal for IMT-2000 is the year 2000. Japanese, American, and European companies and standards bodies are currently finalizing candidate standards for the IMT-2000. A key decision in a mobile standard is the multiple-access system since it strongly influences the implementation of many other system features. The leading contenders for multiple-access schemes are TDMA and CDMA. This paper explores the comparative advantages and disadvantages of these two approaches for IMT-2000.

Introduction

ITU-R (Task Group 8/1) has been studying IMT-2000 standardization as a global wireless access standard to serve an estimated one billion users early in the 21st century. The key goals of IMT-2000 can be summarized as follows:

- Multi-rate services: A minimum of 2 Mbps indoor, 384 kbps pedestrian outdoor, 144 kbps mobile outdoors.

- Multicell, multi-mobility, and multi-density capability: Seamless coverage across pico, micro, and macro cells supporting different mobilities and user densities using terrestrial networks and global coverage with satellite networks. Also proposed are tandem links for relay services within trains and aircraft.

- Multi-operator capabilities: Easy sharing of frequency band across operators with the lowest degree of granularity.

- High spectrum efficiency: Maximum b/s/Hz per base station.

- Multiple quality of service (QoS): BER target of 10-3 for voice to 10-6 for data, maximum delay of 50 ms for voice (radio access) to variable delay limits for data.

- High communications security: For voice and data.

- Low granularity and high flexibility: In service buildout and provisioning.

The minimum performance capabilities for IMT-2000 are listed in *Table 1*. The IMT-2000 specification is driven by the philosophy of a horizontally layered architecture with well-separated modular functions and clearly defined interfunction interfaces. Moreover, it emphasizes the maximum independence of the air interface. The radio is defined through a set of generic radio bearers, each with specified data rates and QoS, thus allowing flexible evolution of the standard. The ITU is currently in the phase of accepting proposals from regional standards bodies. It is expected to evalu-

TABLE 1

Minimum Performance Capabilities for IMT-2000 Candidate Radio Transmissions Technologies

Test Environments	Indoor Office	Outdoor to Indoor and Pedestrian	Vehicular
Mobility	Low	Medium	High
Handover	Required	Required	Required
Packet Data	Required	Required	Required
Asym. Service	Required	Required	Required
Multimedia	Required	Required	Required
Var. Bit Rate	Required	Required	Required
Min. Data Rate	2048 Kbps	384 Kbps	144 Kbps

ate these proposals in 1998, and after a phase of consensus building, it will embark on the specifications phase in 1999 with the expectation of completing this by the year 2000.

Three major mobile radio standards bodies are expected to make proposals to the ITU; these are Japan's ARIB, Europe's ETSI, and the United States' TIA. ARIB is likely to propose a wideband CDMA (W-CDMA) system developed under the leadership of NTTDoCoMo. ETSI is currently considering six multiple-access schemes. One leading contender is an advanced TDMA (A-TDMA) proposal backed by Siemens, Nortel-Matra, and Alcatel, among others. This proposal has some degree of backward compatibility with GSM, a leading second-generation TDMA system. The other contender is W-CDMA, which was proposed by several companies including Ericsson and Nokia. This has a slightly different flavor from the ARIB version of W-CDMA, but the two can be harmonized if ETSI adopts W-CDMA. The U.S. proposal is likely to be yet another version of W-CDMA, motivated by backward compatibility with IS-95, a second-generation narrowband CDMA standard.

This paper studies the trade-offs of the two leading multiple-access schemes, namely, A-TDMA and W-CDMA. For TDMA, a baseline system proposed under the FRAMES project in Europe is used here. For W-CDMA, a generic version that incorporates baseline features of all three CDMA proposals is adopted in this paper. These two multiple-access systems are compared from two points of view: spectrum efficiency and flexibility / ease of implementation.

First, one basic difference between the two multiple access methods must be addressed. In TDMA, the spectrum is divided into frequencies and time slots yielding a finite set of fully orthogonal channels that do not interfere with each other. In CDMA, the use of quasi-orthogonal cover codes over orthogonal or quasi-orthogonal code sets yields an effectively infinite channel set in which each channel is quasi-orthogonal to every other channel (possibly orthogonal within a subset). This means that every user in the CDMA network can have a unique channel with which all the other channels interfere weakly. In TDMA, since there is a finite but orthogonal set, the same channel must be reused, and physical separation must be employed between reuse cells to keep interference manageable. Of course, if frequency channelization is used in CDMA, channels in a given frequency set remain orthogonal to those from another frequency. This difference in orthogonality and in the number of channels has a strong influence on the performance variances between the two multiple-access schemes.

Points of Comparison

In this section, the generic factors that influence spectrum efficiency and flexibility / ease of implementation are addressed as a prelude to the discussions of the two multiple access schemes later in the paper. Spectrum efficiency is of critical importance in IMT-2000 and is traditionally the main battleground for competing multiple-access schemes. The main factor driving spectrum efficiency is the degree of reuse that can be sustained in the network. This leads to the fundamental metric of spectrum efficiency—keeping the mean and standard deviation of signal to interference ratio (SIR) for each user as low as possible and consistent with the required BER. As the standard deviation of SIR increases, however, the SIR mean has to be increased to maintain required BER. Also, if the SIR is sustained above the minimum necessary value, the excess transmitted power increases interference to other users, which reduces spectrum efficiency.

A number of approaches used to improve spectrum efficiency will be described below. Fundamentally these seek to minimize the STD of the signal and the interference power while reducing the mean transmit power to meet minimum performance thresholds.

- *Signal diversity:* Diversity plays a central role since it can mitigate fading, a significant cause of SIR fluctuation. Diversity significantly reduces the required mean SIR to meet the target BER.

- *Power control:* Since the signal and interference power in a wireless network fluctuate continuously, power control ensures that each link has just enough transmit power, no more and no less, to be consistent with the target BER. Power control can be used in both forward and reverse links.

- *Channel allocation:* Channel allocation ensures that each user is allocated a channel for setting up a radio link to the fixed infrastructure that needs the lowest transmit power in order to meet the target BER.

- *Channel estimation:* In order to mitigate multipath and co-channel interference and to demodulate symbols effectively, the receive or transmit channels must be estimated.

- *Interference grouping:* This is related to channel allocation and relates to coordination of channel allocation within and between cells such that SIR for all the users is maximally equalized (i.e., strong users are matched with strong co-channel interferers).

- *Interference cancellation:* This technique uses spatial and temporal differences in the user-signal signatures to reduce interference prior to demodulation. Clearly the ability to mitigate interference can improve spectrum efficiency.

- *Interference diversity:* This is analogous to signal diversity and minimizes the interference power fluctuation by averaging over multiple interferers.

Both TDMA and CDMA offer different advantages with respect to each of these spectrum efficiency-enhancing factors, which will be discussed later in the paper. IMT-2000 will be substantially more flexible in services and operations than the current second-generation systems, as was previously discussed. Both TDMA and CDMA offer different advantages in this respect, which will be addressed as well.

Spectrum Efficiency

This section examines factors that enhance spectrum efficiency and discusses how TDMA and CDMA differ in spectrum efficiency. Features that are common to both schemes, however, are not discussed; only points of difference will be explored. Also, note that the forward link is usually the limiting link for spectrum efficiency. Therefore, the following discussion will focus on the forward-link problem.

Signal Diversity

TDMA can use frequency hopping (FH) to capture frequency diversity across the entire operating band by using interleaving and forward error correction (I/FEC). FH is not readily feasible in W-CDMA due to problems with power control.

Multipath propagation also offers (path) diversity for both systems. TDMA captures this in the equalizer and CDMA through the RAKE receiver. Since the CDMA operates with a wider bandwidth, the number of resolvable paths can expect to be larger and offer higher diversity. In TDMA, the Viterbi equalizer grows exponentially in complexity with channel length (delay spread), whereas the RAKE grows linearly in complexity.

Both TDMA and CDMA can use soft handover to realize macro diversity gain. Two or more base stations transmit the same information signal so as to arrive closely time-aligned at the subscriber unit. The equalizer in TDMA and the RAKE in CDMA combine such multiple-base station signals to effect data detection. In TDMA, any differential delay between the arriving signal bursts will appear as delay spread and therefore exponentially increase the equalizer complexity. In CDMA, the RAKE handles this with linear complexity. Since accurate timing synchronization will not be possible in large cells, due to differential transmission delays, macro diversity is complicated in TDMA. Therefore, TDMA systems employ hard handoff, which, if done instantaneously, can provide macro diversity gain comparable to that of soft handoff. However, hard handoff needs adjacent cell carrier measurements and control signaling, which take one to two seconds, and frequent ping-pong handoffs are not desirable. Therefore, a three to four dB hysteresis threshold is often employed to reduce this ping-pong effect, which reduces macro diversity gain from hard handoffs in TDMA.

Power Control

Tight power control is difficult to implement on the forward link in TDMA because the mobile receives and transmits in different slots and cannot return received signal-power information. Similarly, on the reverse link, the base is unable to measure mobile power levels continuously and cannot implement tight power control. TDMA systems can be designed to cope with little or no power control by using higher reuse factor. Nevertheless, poor power control translates to the loss of spectrum efficiency.

In CDMA, power control is essential to system performance unless sophisticated multiuser detection (MUD) is employed. However, since both links are continuously active for every user, it is possible to implement tight power control on each link. The availability of better signal and interference diversity in CDMA also makes SIR fluctuations smaller, improving power control performance. In large cells, slow-moving subscribers at the edge of the cell that are not in soft handoff, could need high transmit power during deep fades to sustain BER performance. This can result in amplifier saturation (clipping), causing poor power control and/or an outage.

Channel Allocation

Channel allocation performance is best deployed if there are a large number of channels or channel pools from which to choose. In TDMA, it is possible for the base station and subscriber unit to scan these channels during slow periods and choose the best channel. In TDMA, if the reuse factor is small, there are large numbers of channels available in each cell. In CDMA, typically only one carrier may be available for each operator in a cell. Moreover, the subscriber unit cannot scan other carriers to check for good channels. Unlike TDMA, all channels (codes) within a carrier have the same SIR performance, diminishing the value of channel grouping.

Channel Estimation

In TDMA, the response of the channel to a single symbol must be estimated, and the total channel length is the sum of the delay spread and the symbol duration. Such a response can be estimated by transmitting a training sequence that must be about three to four times the channel length. If the channel is time varying, it must be tracked by frequent retraining. Moreover, if interference cancellation is used, further estimation and tracking of the interference channel is necessary. In unsynchronized networks or synchronized macrocells, the signal and interference slot may be misaligned, which causes sudden change in the interference channel during a slot. These factors make channel estimation and tracking expensive in TDMA.

In CDMA, the use of unique spreading sequences directly offers a training resource. Estimation of channel parameters such as path delays can be done without explicit training signals. Moreover, paths separated by more than one chip are quasi-orthogonal and do not interact; the channel of a path is described by a single tap (complex scalar). Therefore, the channel can be estimated using one or two training symbols. Also, in CDMA, signals flow continuously, which avoids problems associated with slotted operation in TDMA. This makes channel estimation easier in CDMA.

Interference Grouping

In TDMA, the ability to scan across all the channels makes it easy to group users with channels such that the SIRs are maximally equalized. Use of tiered cells and different reuse factors are examples of this flexibility. In CDMA, such grouping is not possible. A strong interferer can reduce performance or even shut down the network by interfering with all channels. In addition, grouping across frequency channels is not possible since the subscriber unit does not have cross-frequency visibility.

Interference Cancellation

In TDMA, the interference pattern is typically characterized by, at most, one or two strong interferers. Spectrum efficiency can be bought by reducing interference power by spatial processing and can use a better reuse factor. This requires the ability to null interference, which, in turn, requires accurate channel knowledge. Interference cancellation in the temporal domain is not practical in TDMA unless MUD is employed. Even so, this requires accurate channel estimation for desired and interfering signals, which is hard to achieve.

In CDMA, temporal interference cancellation is possible since signals have inherent signature waveform differences and channel estimation is easier. Moreover, spatial interference reduction is easier since, in CDMA, the interference pattern is a large number of weak interferers. Therefore, a simple robust beamforming rather than the less robust interference nulling is needed in TDMA.

Interference Diversity

In TDMA, interference diversity is obtained through random frequency and time hopping and is extracted through I/FEC. Since the desired signal "sees" a different interferer in every frame, the I/FEC can correct situations when one frame has an exceptionally poor SIR. However, since the interleaver depth is limited by the delay tolerance, the available interference diversity is also limited. In CDMA, interference diversity is available at symbol level, since all the interferers are active and contribute to the SIR at each symbol. The degree of averaging is much higher particularly for W-CDMA.

Summary

Clearly both CDMA and TDMA have advantages and disadvantages for maximizing spectrum efficiency. While this paper does not attempt a quantitative analysis of these tradeoffs, the results of a quick study show that wideband CDMA has, on balance, an advantage over TDMA through its advantages in signal and interference diversity and tight power control.

Flexibility and Implementation

This section examines the differences between TDMA and CDMA in flexibility and ease of implementation.

Multi-Rate Services

TDMA supports this via multi-slot (M-SL) and multi-carrier (M-CA) methods. Multi-slot methods aggregate a number of slots to provide the necessary data rate. If M-SL is not sufficient, M-CA aggregation can be added. Use of M-SL and M-CA techniques reduce the possibility for signal and interference diversity via frequency and time hopping. CDMA supports multi-rate services by multi-spreading factor (M-SF), multi-code (M-CO), and perhaps also M-CA. M-SF adjusts the spreading factor to support different rates, and M-CO supports higher rates by aggregating multiple code channels. M-CO requires a RAKE receiver for each code channel increasing hardware complexity compared to M-SF. However, as the spreading factor reduces, inter-symbol interference—normally absent in CDMA—can become a problem.

Multicell, Multi-Mobility, and Multi-Density Operations

TDMA and CDMA do not have strong differentiation in multi-mobility and multi-density operations. In multicell operations, TDMA has an advantage since different cells are strictly orthogonal to each other—despite their disparate power levels—as long as they are assigned different channels. In CDMA, code channels are quasi-orthogonal and therefore the cells cannot be adequately isolated from each other. This causes several difficulties in deployment.

Multi-Quality-of-Service (QoS)

In TDMA, the slotted operation makes it less flexible to provision different QoS services because power control cannot be used for establishing different BER. In CDMA, continuous bearers make this easier.

Multi-Operator Services

In TDMA, use of narrower channel bandwidths allow multiple frequency channels, which can be shared among carriers. In CDMA, use of wide bandwidths reduces this flexibility. A more interesting opportunity for multi-operator services is sharing at a much lower granularity such as time slot or code. Here, TDMA, with orthogonal channels, offers easier coordination.

Power Amplifier Design

In TDMA, the peak amplifier power is equal to Ns times the average power level, where Ns is the number of slots per frame. In A-TDMA, Ns is high due to multi-rate services, and the peak power becomes very high, which results in higher costs and amplifier pulsing along with attendant EMC problems. CDMA uses continuous transmission and can, therefore, work with lower peak power, which makes for electromagnetic, interference-friendly amplifiers.

Control Channels

In TDMA, logical channels are mapped to slotted physical channels. This sometimes complicates the control flexibility in TDMA. For example, in TDMA, forward power control is difficult to implement since the subscriber unit needs to listen to slots—other than its own traffic-bearing slot—for control information access or the unit needs look-ahead antenna diversity. This makes it imperative to transmit all slots at full power to make them visible to all subscriber units. CDMA uses continuous bearers and, therefore, offers natural advantages.

Frequency Planning

TDMA requires channel reuse factors ranging from 3 to 9. This requires careful frequency planning to reflect propagation and traffic density variations. In CDMA, the reuse factor is one and, as a result, this effort is unnecessary. However, both multiple schemes still need considerable network planning to decide base station location, antenna height and down tilt, and beacon power level.

Conclusions

This paper has presented a qualitative discussion of TDMA vs. CDMA. A quantitative discussion is beyond the scope of this paper. On the balance, W-CDMA has a higher spectrum efficiency, while TDMA has advantages in deployment flexibility. The final choice of multiple access scheme will also have to keep backward compatibility issues in mind, which could undermine the ITU goal of one world standard and lead to multiple (possibly three) standards for the IMT-2000.

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Satellites to Beat Wired Networks at their Own Games

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For three decades, communication satellite systems have played a key role in international and long-distance telecommunications services. This role, however, has largely been that of a support facility rather than a primary system. Satellites were always well removed from the end user. Consumers received their bills from the telephone companies, cable-television provider, cellular phone company, or a software company. Satellites were trapped well down the value-added ladder and were often owned and controlled by monopoly telephone providers. Space activities, including space telecommunications, were small industries in comparison to transportation, energy, insurance, banking, or the broad fields of telecommunications and information.

In the coming decade, however, new types of "direct access" satellite systems will be making a bid to play center-stage roles. There is approximately a decade-long window of opportunity for direct-to-the-consumer satellite services to grow to a global scale and play a major role, along with fiber-optic cable and wireless communication systems in a hybrid or merged information market. This new merged market, which some have called the global information highway or the global information infrastructure (GII), will be huge.

By the year 2001, global information and computer services will represent nearly $2 trillion (U.S.), and global telecommunications services will represent close to $1 trillion. This means that about one out of every $15 spent on the entire planet would be in this sector of the economy. This would make information and telecommunications the largest part of the world economy—larger than energy, transportation, or agriculture.

The Dynamic Tension Between Satellite and Fiber-Optic Networks in the Age of Multimedia

The dominant pattern in telecommunications, at least in the industrial countries, has been the widespread deployment of terrestrial networks of copper wire, coax, and fiber-optic systems, especially in connecting to the end user. Suddenly, the options for providing telecommunications to the local loop—the so-called last mile—have changed. Now, new types of satellite networks can provide comprehensive communications solutions that reach all the way to the consumer with new economic strength and service flexibility.

In particular, high-tech providers of new micro-terminals that can receive television directly from the satellite and return a digital pathway to the satellite are promising a revolution. This evolving type of satellite service that does not yet exist as an operational service is called "interactive direct broadcast satellite (DBS)" in this report. This service can evolve from the next generation of DBS satellites or the new Ka-band multimedia high data-rate satellites. (In fact, a review of filings made with the FCC and the International Telecommunication Union (ITU) suggests that both types of satellite systems would intend to provide video entertainment and interactive telecommunications services).

If organizations such as Motorola, Hughes Network Services, NEC, Ericsson, or even new players such as LG (Goldstar of Korea) or Nokia can deliver interactive micro-terminals and sell these products for under $1,000 around the years 2000-2001, there is a real potential for a satellite revolution in telecommunications as we enter the next century.

Terabits for Sale

Today, some 50 satellite carriers have deployed some 200 GHz of capacity in earth orbit. Within the decade, based on specific filings for new satellite systems, there could be two to three times as many satellite carriers and up to 2,000 GHz of capacity in low-earth orbit (LEO), medium-earth orbit (MEO), and GEO orbits. This is sufficient capacity to deliver over four terabits per second of capacity anytime and anywhere on earth. This is the amount of capacity needed to make satellites capable of entering new multimedia and broader-band services. These are not your father's satellites. These are a whole new breed of "smart" and broadband satellites with manyfold frequency re-use that can provide prodigious amounts of capacity anytime and anyplace.

This satellite revolution arises out of three key sources. These causes are converging in a powerful way. These sources are new satellite and ground-terminal technologies, the restructured and competitive telecommunications markets, and new regulatory processes that allow a bypass of traditional telecommunications networks. This process is now at work in the United States and many of the industrialized countries of the world.

The Satellite Revolution Can Happen In Any Country—Developed or Developing

Satellite communications in developing countries and rural and remote areas are different, but a revolution will happen here as well. The use of the new satellite technologies appears to make a great deal of sense in areas where traditional telecommunications networks are lacking. This, in fact, tends to give satellites more of an edge, but regulatory constraints in some of the countries can slow satellite growth.

The truth is that the satellite revolution can happen in any country at any level of economic development. It is surprising that new and highly efficient satellites that are designed to provide mass-consumer services can begin to challenge fiber-optic networks even in urban environments. In many ways, this trend is parallel to the emergence of plans to use wireless networks to penetrate to the home in the U.S. telecommunications market by AT&T and Sprint Spectrum. The same type of logic suggests that satellites, such as terrestrial wireless, can also provide a new form of direct access. For a cost similar to that of the installation of a cable TV system in the greater New York area, a national direct broadcast satellite system for the continental United States can be deployed. Furthermore, new customers can be activated one at a time anywhere in the entire service area without installing new infrastructure beyond the customer buying or leasing a small and easy-to-install dish.

The Move to Truly Mass Markets

As the next century quickly approaches, a new and dynamic role for satellite systems seems to be quickly emerging. New, direct broadcast satellite systems and mobile satellite networks are increasingly providing mass-market services directly to pizza pan-sized micro-terminals and hand-held transceivers. Although broadcast satellites and mobile satellite systems first defined this trend toward direct consumer access, there will likely be an expanding circle of mass-market satellite services in the next century that, in some cases, will bypass conventional telecommunications networks. This, in fact, is the economic key to satellite's 21st-century success. These new systems can and will bypass the traditional wire-based and static terrestrial systems of the past.

Regulatory Barriers and Constraints of Trade Will Hold Back New and Innovative Satellite Services

The major barrier for satellite systems to overcome in the coming decade is not in implementing new technology (although clear technical challenges do exist). The real test will be successfully surmounting the regulatory barriers that prevent satellite systems from bypassing the established terrestrial networks and skipping over the traditional carriers. Records of the European Commission Directorates IV, XII, and XIII, for instance, reveal how new carriers seeking to enter the telecommunications market have filed dozens of complaints against established carriers and the roadblocks they can deploy to block new entry and bypass of their terrestrial networks. Particularly in countries where telecommunications monopolies still exist, direct-to-the-consumer satellite systems will be slowed. Even those countries participating in the World Trade Organizations' GBN agreements to open their national markets to competition face numerous loopholes that can block new satellite entry.

The Power of Digital Convergence

The next wave of the direct-to-the-consumer satellite revolution will likely come from the new Ka-band multimedia high data-rate satellite systems. These innovative new satellite systems with a broad block of spectrum to use for broadband services promise to push this direct-to-the consumer revolution to new levels. If these trends continue, satellites will move dynamically forward, exploding into a wide range of telecommunications, entertainment, information, and navigational services. These new satellites seem optimized for the era of digital service convergence and the new integrated offerings of the so-called ICE age of information, communications, and entertainment. The forces of this revolution come from several key sources, which can be summarized as shown in *Table 1.*

The Local Loop: The Achilles' Heel of Traditional Telecom Systems

There are fundamental forces of technology and market at work here. First, satellites (as well as wireless systems) are a powerful way to bypass existing terrestrial networks. This is

TABLE 1

Traditional Hierarchical Telecommunications Network Architecture

- Globalization, privatization, and competitive telecommunication markets
- Mobile anytime and anywhere services
- Personalization and customization of information services
- Digitalization and the rapid convergence of information, communications, and entertainment into a unified digital market
- Direct-to-end-user services and bypass of conventional terrestrial networks
- Seamless interconnection of hybrid systems of fiber, coax, wireless

key because the shift in the market (i.e., the bypass of the local loop) suddenly allows satellite and wireless systems to compete economically with fiber.

This is perhaps the most important point. Wireless bypass of the "wired" local loop means that fiber does not automatically win. A satellite system that connects directly to the consumer can deliver service at the critical threshold of under $1,000 per household. The copper wire-based local loop at the end of fiber networks remains the Achilles' heel of traditional telecommunications carriers.

Thus, new competitive systems will frequently use wireless rather than wired access. This is because they will typically be unwilling to invest in a complete, expensive, and slower to install fiber network. Second, in the new globally restructured market, it may well be ironically true that a new competitive entrant in one new market is, in fact, the established dominant carrier in another. AT&T and Sprint are the major new entrants using wireless technology to seek local access in the U.S. market. Because of their enormous expense, if Ka-band multimedia satellites are to succeed, they will need to attract large amounts of capital from dominant carriers.

New Patterns of Globalization of Satellite Systems and Services

Clear-cut examples are Korea Telecom's decision to invest in the ICO mobile satellite system and also their probable backing of Lockheed Martin's Astrolink. Furthermore, AT&T has invested in Teledesic and DirecTV and almost made a multibillion dollar commitment to a Ka-band VoiceSpan system before getting cold feet, withdrawing from the field, and selling off the Telstar system to Space System Loral. In the coming months, dozens of similar examples will abound as now confidential negotiations are completed and announced. Players will likely include MCI, Telecom Italia, France Telecom, and Global One.

For the previous reasons and more, this study concludes that the new mass-market-oriented satellite services will claim more customers, generate more revenues, and utilize more spectrum over the next decade. Overall, the new types of satellite systems will stake out an increasing portion of the trillion-dollar pie represented by the rapidly expanding global telecommunications market. Satellites will, in short, succeed, grow, and reach increasingly toward end-user customers. To put this projected success of the satellite industry in perspective, the satellite share of the market will remain well behind fiber and wireless systems. Nevertheless, by 2005, it could claim some 10 percent of the global total of the telecommunications market.

In parallel with these trends, there is also the spread of the satellite communications market across the global economy—both as a key telecommunications service and an expanding industrial market. A current study conducted by NASA and the National Science Foundation concludes that there is growing capability, investment, and operational participation in satellite communications on a global basis. In addition to the United States, Europe, Russia, and Japan, there are new design, space, and ground-system manufacturing and telecommunications services emerging in Brazil, Canada, China, India, Israel, and South Korea.

Some of these countries, such as the Republic of Korea, are making multi-billion dollar investments in new international and regional satellite systems, creating sophisticated clean rooms and high bay-area test and integration facilities, which equal the most sophisticated in the world and reflect sincere intentions to be serious competitors in the world space market. Other countries such as China, India, Indonesia, and Brazil, with nearly 40 percent of the world's population, are committed to the deployment of satellite systems to meet a significant portion of their future telecommunications needs. These new industrializing giants are rapidly developing satellite communications capabilities in partnership with high-technology partners such as the United States, Japan, Russia, and Europe. Overall, satellite systems will grow rapidly across the globe.

Satellites can become an important part of the so-called national information infrastructure (NII) in the United States and likewise constitute a key part of the global information infrastructure (GII) on a worldwide basis. The so-called coming satellite revolution has several interlinked parts.

The Direct Broadcast Satellite or Direct-to-the-Home Satellite Revolution

In the early part of 1995, officials of TCI, the largest cable television MSO, reached an agreement to purchase the so-called fourth direct broadcast satellite (DBS) license, which was then in jeopardy of default for non-performance. The negotiated price was a healthy $34 million. The FCC considered this pending transaction and declared it null and void. They not only declared the license in default but also proceeded to hold an open auction to determine the final price. When MCI ended up bidding an astonishing $654 million for this national direct broadcast license, it established two things. First, it showed that the FCC's financial judgment in this matter was pretty sound. Second, it clearly signaled the beginning of a new age. A vibrant and commercially expansive stage for the satellite industry had clearly begun.

In the U.S. market, DirecTV has over two million subscribers and is growing strong with ownership now extending beyond the original GM / Hughes Communications Corporation to include Microsoft and AT&T. Soon, this same technology will be beamed by Hughes's Japanese partner Satellite Communications Corporation (SCC). This will begin with the provision of 100 compressed digital channels to Japanese consumers in competition with other new digital DBS systems that will also begin in 1998 in Japan.

There is already strong competition in the United States' direct-to-the-home television market. This comes from Hubbard Broadcasting's USSB system, the Primestar network backed by TCI (and perhaps soon also in partnership with the News Corporation and the Fox network), and the recently deployed Echostar and the incipient MCI DBS system. Echostar, although deployed only some months ago at the "Dish

Network," already has several hundred thousand subscribers. With all of these DBS systems, it appears that 10 million or more subscribers to satellite television can be achieved in two years from the current base of over seven million DTH and conventional satellite-TV subscribers. (This figure divides about five million DTH / DBS subscribers and two million conventional backyard satellite systems).

In Japan, there are already over 10 million analog DBS subscribers. The next stage is now just beginning. Digital subscribers on the Japanese Perfect TV (via JCSAT) and the DirecTV offering via the SCC Supersat systems are expected to rocket upward when service begins in earnest in 1998.

In Europe and Asia, there are also now millions of DBS / DTH subscribers on systems such as Astra, British Sky Broadcasting, TV-Sat, TDF, AsiaSat, Apstar, and the already-cited JCSAT and SCC. In short, this revolution is now going into full swing on a global basis. The first digital satellite television service delivered through JCSAT is known under the trademark "Perfect TV," and so far these systems have indeed performed flawlessly in both a technical and market sense. Part of this story is that satellites are now attracting extensive capital investment from financial markets, and international participation by the dominant players in the world of global telecommunications are crisscrossing global boundaries with ease and regularity.

Satellites can no longer be considered a minor adjunct to the overall field of modern telecommunications but a key force in the overall wireless revolution that has become a major theme of the 1990s. In this regard, DBS is leading the way in making satellites a direct-to-mass-consumer market. On a global basis, with lightening-like speed, the News Corporation has managed to move toward a nearly global direct-to-the-home capability via a network of different direct broadcasting systems. These include British Sky Broadcasting in Europe, plus AsiaSat on the Asia mainland, and now a pending merger in the United States. (This was first to have been with Echostar and when this went awry negotiations began with Primestar.) Finally, to cover Latin America, the News Corporation has leased capacity on Intelsat 8 and 8A satellites for additional DBS coverage.

The DBS / DTH service is clearly the most rapidly growing satellite telecommunications offering. The DBS / DTH industry now represents at least 25 million subscribers at some $9 billion in annual revenues on a global basis. These numbers could increase by a factor of more than two times in terms of subscribers and revenues. It is growing faster than cable television, personal communication services, paging, or any other major telecom service. Furthermore, the next generation of DBS / DTH satellites will be offering more than just video entertainment. Instead, a host of interactive capabilities will be offered by these flexible, multi-purpose systems.

The Mobile Satellite Communications Revolution?

This revolution is still in its infancy, and some doubt it will ever duplicate the force and velocity of the direct broadcast satellite revolution. It will be another three to five years before the jury of consumer opinion will definitely be in on mobile satellite services. The current generations of mobile satellite systems such as those represented by the International Maritime Satellite Organization (Inmarsat), the American Mobile Satellite Corporation (AMSC), the Hughes-led consortium that serves the North American market, and the Telesat Mobile Incorporated (TMI) are not "revolutionary" in their volume of traffic or market impact. To date, revenues and market growth for these services are disappointing.

Inmarsat has an established maritime and moderately growing aeronautical base of customers. Nevertheless, its potential for rapid expansion over the next decade is limited. AMSC and TMI are desperately trying ways to find a "convincing and viable" customer base for land-mobile services, including the offering of promotional rates for multimedia mobile services.

On the horizon are a half a dozen new satellite systems that are poised to offer truly personal mobile communications to individual consumers with hand-held phones (but still fairly large and heavy cell phones) at rates ranging from $1 to $3 per minute. It is clearly a radical breakthrough in terms of exotic new technology, but "gee-whiz" technology is not enough. Exotic marvels do not necessarily pay the bills. The market success must still be demonstrated. Already, the Motorola Iridium system has deployed the first phase of its 66-satellite network in bid to be first into this market, and Globalstar and ICO are not far behind. Many market analysts believe that most of the profits in land-mobile satellite services will come from the sale of ground equipment rather than from the sales of satellite service.

Before the year 2000, there are likely to be three or four of these new low- and medium-earth orbit constellations in actual operation and actively seeking customers. It is not clear whether there is sufficient market for other systems that may follow. In short, while the direct-to-the-home / DBS satellite systems have huge potential and great market performance to date, the mobile satellite market seems much more uncertain.

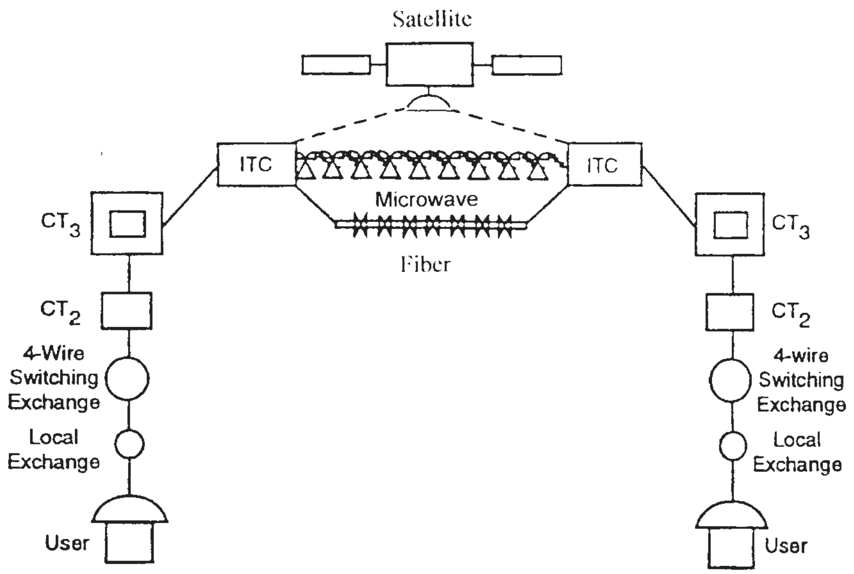
The Ultimate Satellite "Bypass Revolution"—The Broadband Direct-to-the-Consumer Challenge

The re-emergence of satellite communications as a force in the rapidly expanding global information systems of the 21st century will not come from a single source but from several of them combined. As noted in *Table 1,* it is a combination of new technologies, market convergence, competitive regulatory environments, demand for mobile, digital, and flexible services, and standards allowing terrestrial and space networks to link together that are all a part of the recipe for change and innovation in the new world of satellite telecommunications.

Overall, this satellite revolution (and the wireless telecommunications revolution along with it) does have one common denominator. It is the move from large, hierarchical, and monopoly-oriented satellite systems to new competitive space networks that deliver mass-consumer-oriented services directly to end users in the home and office.

FIGURE 1

Traditional Hierarchical Telecommunications Network Architecture



As shown in *Figure 1,* traditional telecommunications have tended to concentrate into a vertical hierarchy. This concentrated traffic is then routed via high-capacity broadband links such as fiber-optic cable to connect major nodes together. At the other end, the traffic is deconcentrated and routed to the end user through the local loop. Because of their ability to directly link many points to other points through wireless local loops, satellites can follow a much different network architecture. They are most efficient as a mesh or horizontal network, as shown in *Figure 2.*

This "democratic" networking capability of satellites is why bypass economics suddenly seem so attractive. This satellite revolution certainly has more to it than technology and new types of network architecture. Equally, it has a great deal to do with law, the national licensing of satellite systems (sometimes call landing rights), regulatory policy, trade regulations, frequency allocation, and partnerships with local carriers. It is still too early to tell how successful new global systems such as Teledesic, Hughes Spaceway, and others will be in providing cheap "bypass" services to business users if they cannot obtain easy and non-restrictive access directly to their customers. Many of these new systems are technologically brilliant, but the challenge is indeed regulatory.

In many ways, the power of the Internet revolution derives from the Internet's non-hierarchical structure and its flexible, almost random way of interconnecting. The power of the consumer-oriented satellite networks and its new flexible architecture are remarkably parallel.

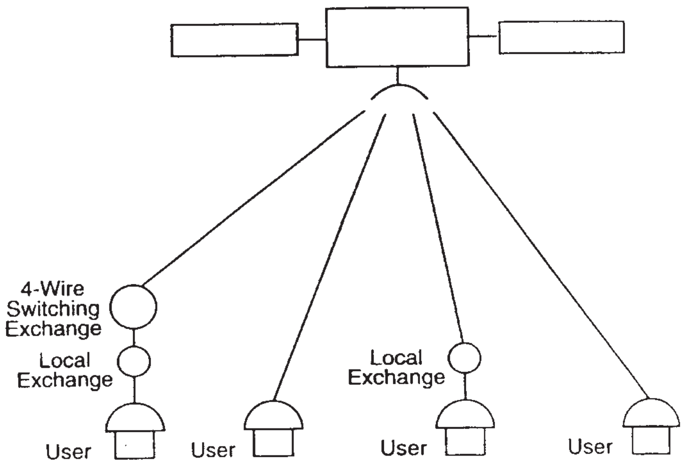
The next step in the evolving satellite revolution is the most critical. The challenge is to develop broadband high data-rate satellites that can deliver any and all services to business and home consumers. New high-capacity, high-power, high data-rate satellites will test whether satellite systems can truly aspire to compete with fiber-optic networks head to head. Already, conventional satellites can deliver all types of services from low-rate data service to micro-terminals at 1.2 kbps to high data-rate services at 155.5 Mbps through 72-MHz transponders. The next steps will be to have the system capacity and onboard processing capacity provide cost-effective interactive multimedia services. The most advanced designs of Teledesic, Spaceway, Astrolink, and M-Star seem to promise cost-effective space segment capacity. The development of the cost-effective ground segment (of under $1,000 per interactive micro-terminal) is the element that is most in doubt.

In short, the broadband, direct-to-the-consumer satellite revolution is increasingly real. The most critical test in this regard will come from the broadband personal mobile communications satellites where billions of dollars in new investment have been boldly proposed. This new "revolution" is no less than an attempt to establish parity between satellite and fiber-optic cable networks.

When the September 29, 1996, Ka-band filings with the FCC for new high data-rate or multimedia satellites systems were complete, it was clear that the telecommunications revolution of the 1990s was truly firing its guns into space. When the smoke had cleared, there were a total of 15 Ka-band satellite systems on file with the FCC, with five of these for domestic U.S. service and ten for global coverage. In addition, Intelsat has indicated that it will deploy Ka-band satellite systems for global services. Furthermore, the Alcatel-backed Skybridge satellite system will also vie for this market when it is consolidated with Cyberstar. Recently, on Friday, June 13, 1997, Motorola filed a new Ka-band system called Celestri that will directly compete with Teledesic for spectrum and market. Clearly, the established Intelsat system is in for a major challenge that goes well beyond that posed by today's competitors.

FIGURE 2

Horizontal or Mesh Networks of Satellite Systems



Even more significantly, these new systems are not just a series of systems planning to compete with the Intelsat global satellite network. These new high data-rate satellite systems are aimed at competing with ground-based broadband fiber networks. These satellite systems are aimed at competing with the mainstream terrestrial telecommunication systems and are targeted to go directly to business offices and the home. The bypass revolution cited previously will be fought with these innovative high data-rate satellites that require only small low-cost micro-terminals no more than 50 to 65 centimeters in size.

If they are all built, only the proposed capital investment in these new Ka-band satellites and launch services will exceed $50 billion. *Table 2* summarizes the key features of these proposed new satellite systems, which collectively suggest an almost complete change in the landscape of the satellite industry. The true meaning and implications of the 19 systems summarized in *Table 2* must be put in perspective. On the basis of past experience with FCC-competitive satellite filings, it seems likely that at best only a third to half of these systems will actually be built and deployed. Indeed, the consolidation and withdrawal process has already begun. Yet, even if a greatly reduced number of these systems were actually placed in service, it still implies a huge investment and a sea change in the way satellite telecommunications are offered to the end users.

Huge Capital Investments in New Satellite Systems

The total proposed investment is nearly twice the total amount of investment in all cellular telephone systems in the United States since the start of these new mobile services in 1984. Even if the proposed investments were reduced to a third of the initial filings, it still means new capital commitments equivalent to U.S. investments in wireless and satellite systems through 1995.

Satellites can no longer be considered an obscure telecommunications footnote. Along with wireless terrestrial, satellite telecommunications mobile services are likely to have the greatest percentage growth of any new telecommunications service over the next decade including fiber-optic systems. Satellites have now become a very big business.

TABLE 2.1

Key Satellite System Features

Operator-Name	Orbit	# Satellites	Services	Estimated Cost	Deployment Dates
Alcatel - Skybridge (Ku-band-noninterfering w/GEO (SATIVOD)	LEO	To be decided (after being merged with Cyberstar)	Voice, data, and multimedia	*	2001 or later
Alenia - Euroskyway (Ka-band)	GEO	4	Voice, data, and multimedia	$800 million	2001/2
AT&T – Voicespan (Ka-band-Canceled)	GEO	18	Voice, data, and multimedia	Proposal withdrawn	Filing withdrawn
Echostar (18/12 GHz)	GEO	2 + spare	Direct broadcast (U.S. system) plus interactive multimedia	$340 million	1997-1999
GE – GE*STAR (Ka-band)	GEO	9	Broadcast TV, voice, data, and multimedia	*	2002 or later
Hughes – Spaceway (Ka-band)	GEO	20	Voice, data, multimedia, and broadcast TV	$5.2 billion	2000
INTELSAT – IS 9/10 Ku- and Ka-band	GEO	N/A	Voice, data, multimedia, broadcast TV	*	mid- to late 2000s
Lockheed-Martin Astrolink (Ka-band)	GEO	9	Voice, data, multimedia, and broadcast TV	$4.2 billion	2001 or later

TABLE 2.2

Operator-Name	Orbit	# Satellites	Services	Estimated Cost	Deployment Dates
Loral – Cyberstar (Ka-band)	GEO	3+ spare	Voice, data, multimedia, and broadcast TV	$6.2 million	1999 or later
Matra – Marconi East and West Systems	GEO/ MEO	At least 14 Satellites	Voice, data, multimedia, and broadcast TV	$2 billion+	2001/2
Morning Star (start-up venture)	GEO	4	Voice, data, and multimedia	$936 million	2000
Motorola – Celestri	LEO	66-72	Multimedia, mobile, data, and voice	$4 billion	2002/3
Motorola – M-Star (43.47 GHz)	LEO	72	Multimedia, mobile, data, voice	$1.1 billion	2004 or later
Motorola/Comm Inc. – Millenium (Ka-band)	GEO	4+ spare	Video, data, broadcast TV, and multimedia	$2.3 billion	2002 or later
Orion	GEO	6	Video, data, and multimedia	$1.6 billion	2000
NetSat – Start-Up	GEO	1+ spare	Video, data, and multimedia	$250 million	2000
Panamsat	GEO	2 + spare	Video, data, and multimedia	$409 million	Will likely be consolidated with Hughes Spaceway
Teledesic (includes AT&T, Boeing, and Microsoft investment) (Ka-band)	LEO	280 + spares (1st phase) 840 + spares (Final phase)	Voice, data, multimedia, rural, supercomputer connect	$4-6 billion (1st phase) $12 billion+ (Final phase)	2002 or later
Visionstar	GEO	1	Video	$208 million	2000

An Overview of Smart Antenna Technology: The Next Wave in Wireless Communications

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Abstract

Space is truly one of the "final frontiers" when it comes to next-generation wireless communication systems. Large-scale penetration of such systems into our daily lives will require significant reductions in cost and increases in capacity that only spatial dimension can hope to offer. This is attested to by the fact that a significant number of companies have recently been formed to bring products based on such concepts to the wireless marketplace. Approaches range from "switched-beam" to "fully adaptive" with benefits provided by various approaches differing accordingly.

At one end of the spectrum is spatial division multiple access (SDMA) technology, a technology with roots in various defense-related development programs, which ArrayComm is currently incorporating in its IntelliCell™ line of products. SDMA technology employs antenna arrays and multi-dimensional nonlinear signal-processing techniques to provide significant increases in capacity and quality of many wireless communication systems. It is especially well suited to the current and next-generation cellular systems termed personal communications service (PCS) and to provisioning of first-mile access using wireless local loop (WLL) systems. Antenna arrays coupled with adaptive signal-processing techniques employed at base stations improve coverage, capacity, and trunking efficiency, allowing lower-cost deployments with cells of moderate to large size.

Introduction

In a majority of currently deployed wireless telecommunication systems, the objective is to sell a product at a fair price, the product being information transmission from one or more locations to one or more locations. From a technical standpoint, information transmission requires resources in the form of power and bandwidth. Generally, increased transmission rates require increased power and / or bandwidth independent of the medium. While transmission over wired segments of the links could generally be performed independently for each link (ignoring cross-talk in land lines), this is not the case for wireless segments. While wires (fibers) are excellent at confining most of the useful information / energy to a small region in space (the wire), wireless transmission is much less efficient. Reliable transmission over relatively short distances in space has traditionally required a large amount of transmitted energy, spread over large regions of space, only a very small portion of which is actually received by the intended user. Most of the energy is considered interference to other potential users of the system (frequency reuse). It is precisely this aspect of wireless communication inefficiency that SDMA technology addresses.

Somewhat simplistically, the maximum range of such systems is determined by the amount of power that can be transmitted (and therefore received), and the capacity is determined by the amount of spectrum (bandwidth) available. For a given amount of power (constrained by regulation or practical considerations for example) and a fixed amount of bandwidth (the amount one can afford to buy at auction these days), there is a finite (small) amount of capacity (bits / sec / Hz / unit-area, really per unit-volume) that operators can sell to their customers and a limited range over which customers can be served from any given location. Thus, the two basic problems that arise in such systems are: 1) how to acquire more capacity so that a larger number of customers can be served at lower costs in areas where demand is large, and 2) how to obtain greater coverage areas to reduce infrastructure and maintenance costs in areas where demand is relatively small.

Background

As its name implies, SDMA technology exploits information collected in the spatial dimension in addition to the temporal dimension to obtain significant improvements in wireless information transmission. Spatially selective transmission and reception of RF energy provides substantial increases in wireless system capacity, coverage, and quality. Various approaches to exploiting the spatial dimension have been attempted in the past, including finely sectorized systems and microcellular techniques. As the issue of trunking efficiency has become more pronounced, focus has recently shifted to more advanced techniques ranging from switched-beam to fully adaptive, uplink-only to uplink and downlink, with benefits provided by various approaches differing accordingly. Clearly, as one of Qualcomm's founders Andrew Viterbi stated, "Spatial processing remains as the most promising, if not the last frontier, in the evolution of multiple access systems."

Switched Diversity Technology

One of the earlier attempts at addressing the difficulties of the mobile RF environment was to employ two antennas separated by several wavelengths, each instrumented with conventional receivers. The basic principle underlying such designs is that in complex RF environments, there is sufficient scattering of the RF fields to practically decorrelate signals received from antennas sufficiently far apart. The import of this is that the probability of the signals in both of the antennas becoming extremely weak at the same time is small, and selection of the stronger signal will always improve matters. While these techniques are still in widespread use today, they do not increase range or capacity. However, they do address an important problem facing mobile systems today, that of fading (uplink signal quality) in complex RF (dense urban) environments.

Switched-Beam Technology

In what could be thought of as a shape-transformation applied to microcellular concepts, switched-beam technology is being investigated as a method of increasing range and capacity. The design of such systems involves high-gain, narrow azimuthal beamwidth antenna elements (using conventional or Butler matrix array technology), and RF and/or baseband digital signal-processing hardware and software to select which beam or sector to use in communicating with each user. In order to overcome the well-known trunking efficiency problem of small cells, pooling of radio resources is being investigated by several proponents of this technology. Additionally, many of the system-related issues dealing with access and control channels require some special care, and there are certainly interesting challenges to be faced concerning the downlink in such systems. While previous unsuccessful attempts at such solutions date back to the 1970s when six-sectored systems were tested as improvements over three-sector technology, advances in DSP technology may provide solutions to the challenges faced by highly restricted fields-of-view in rapidly changing mobile environments.

Intelligent Antenna Technology

Truly opening up this new dimension in wireless communications is spatial division multiple access technology, employing antenna arrays, standard RF and digital components, and multidimensional nonlinear signal-processing techniques to provide significant increases in capacity and quality of many wireless communication systems in a manner compatible with all currently deployed air interfaces.

A combination of antenna arrays and adaptive digital signal-processing techniques bring the fourth dimension to the three-dimensional world of wireless communications. Employed at base stations, SDMA technology improves coverage, capacity, and trunking efficiency, allowing for lower-cost deployments with reduced maintenance costs. In addition to these immediate benefits, the flexibility of the technology also allows for the creation of new value-added services that can provide a significant competitive advantage to operators offering these services. SDMA is not restricted to any particular modulation format or air-interface protocol and is compatible with all currently deployed air interfaces.

SDMA is a fully adaptive approach, combining antenna arrays, analog radio frequency (RF) and digital electronics, estimation and detection techniques, and resource allocation algorithms to affect efficient use of system resources. This technology is embodied in ArrayComm's IntelliCell line of products. *Figure 1* shows a block diagram of a typical intelligent antenna system configuration. With this basic configuration, the issues of capacity and coverage can be addressed with a common architecture. Optimal processing of the outputs of multiple antennas (see *Figure 2*) at a base station yields significant improvements in signal quality through increasing desired signal strength and reducing levels of interference (i.e., increased SINR). While the details of the algorithms employed depend on various factors, including the temporal modulation format and the complexity of the RF environment, the objective of maximizing capacity and quality remains the same. It is a goal that is achieved through appropriately analyzing the RF environment and using the information collected to receive and transmit signals selectively.

In the uplink direction, multiple receivers are used to selectively receive information from one or more users on the same channel at the same time, reducing the total amount of received noise and interference power while increasing the desired signal power. In the downlink direction, multiple low-power transmitters are used to selectively transmit information to one or more users on the same channel at the same time, reducing the total amount of transmitted power required (interference to other users in other cells). These

FIGURE 1

Typical Intelligent Antenna System Configuration

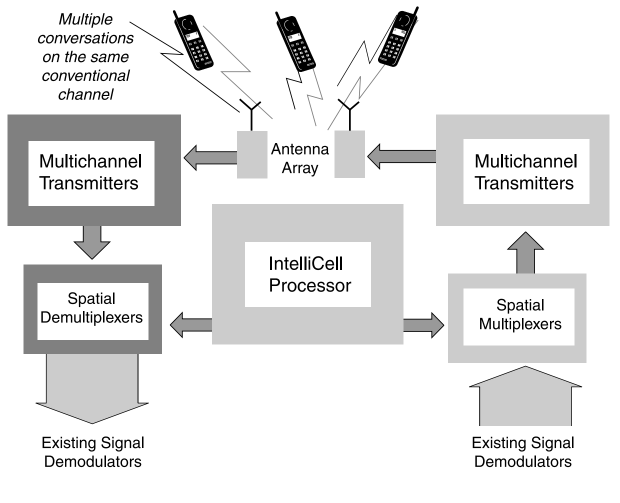


FIGURE 2

12-Element 1900 MHz WLL Antenna Array

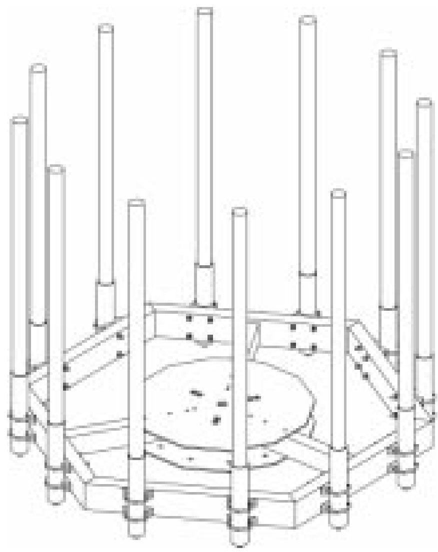
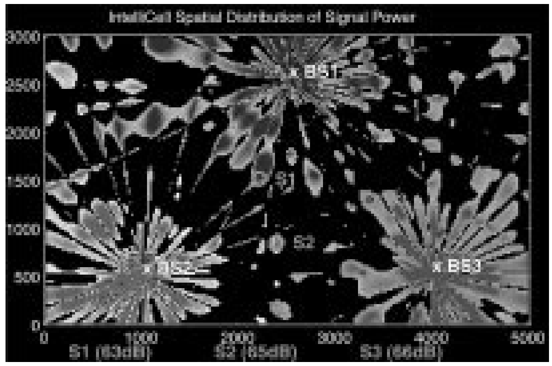


FIGURE 4

Downlink Power Distribution of Three Co-channel IntelliCell WLL Base Stations with 8 500 mW Power Amplifiers Each



fundamental capabilities come about through efficient exploitation of the spatial dimension and provide for significant increases in capacity and range.

To illustrate this, a graphical comparison of a conventional WLL omni-system deployment in a suburban area with a corresponding IntelliCell deployment is given. *Figure 3* shows the coverage areas of three conventional omni-cell sites (BSs), assuming that all three were attempting to establish links with subscriber units (SUs) on the same time slot on the same carrier at the same time. A 10 W power amplifier is deployed at each site, and the COST-231 propagation model is used to determine the requisite path loss as a function of SU location. Under the assumptions made, the nominal range of one of the cells in the absence of neighboring interference is somewhere between 2 km and 4 km. While the locations of the SUs were such that in the absence of the other SUs, each link could have been established, successful establishment of all links simultaneously from the corresponding BSs was not possible due to interference. The signal-to-interference plus noise ratios (SINRs) measured by each of the SUs were all significantly below the threshold necessary to establish a clear traffic channel (TCH) connection.

The dramatic effect that intelligent antenna array processing has in this deployment is shown in *Figure 4.* Therein, multiple elements spatially sample the incoming RF fields, identify the necessary parameters of the RF environment, selectively receive multiple co-channel signals of interest, and distribute energy "optimally" so as to allow the successful establishment of all three links. The quality of links is directly measured by SINR and is given in the figure for each of the SUs. Whereas the conventional system could not establish links successfully with 10 W power amplifiers, the IntelliCell system is capable of simultaneously establishing three high-quality links with significantly less transmitted power—in this case several orders of magnitude less power.

Summary of IntelliCell WLL Benefits

To quantify the system-level benefits of intelligent antenna technology, *Table 1* provides typical examples of the improve-

FIGURE 3

Downlink Power Distribution of Three Co-channel Single Sector WLL Base Stations with One 10 W Power Amplifier Each

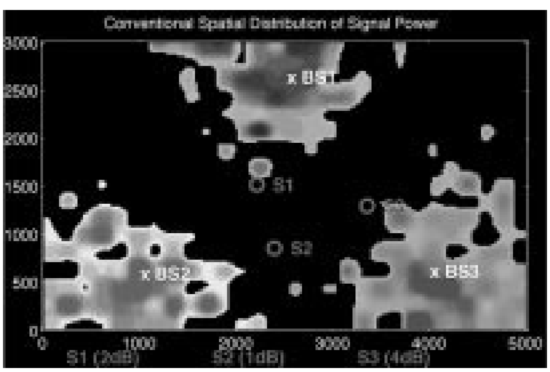


TABLE 1

Typical 12-Element IntelliCell WLL Performance Improvements (g=3.5)

Uplink Related	
* SNR Improvement	10 dB
* Range (Area) Increase	1.9 (3.7)
* SINR Improvement	>25 dB
Uplink & Downlink Related	
* DL Tx Power Reduction	90%
* Real Capacity Increase	> 2

ment that can be expected deploying a 12-element array assuming R3.5 range-dependent attenuation in a suburban environment. Note that for SINR improvements in excess of the stated SNR improvement, there must be the requisite amount of interference present. Also, the reduction in base station emissions relates to traffic channels and does not account for broadcast channel requirements associated with many mobile system protocols. In this light, it is interesting to reflect on the possible impact of intelligent antenna technology on the development of standards for future wireless telecommunication systems.

Conclusions

There is a growing need for improvements that increase coverage, capacity, and quality in many wireless communication systems. Optimal exploitation of new dimensions through intelligent antenna technology has the potential to meet these needs while providing operators the ability to offer new value-added services to their customers. Successful field tests have been and continue to be conducted demonstrating that SDMA / IntelliCell technology in particular can deliver the improvements wireless operators are seeking. These improvement promise to provide high-quality, low-cost wireless communications for developing nations around the world where basic communication services for a large number of the world's citizens are sorely needed.

Works Cited

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2 Stanford University, Third Workshop on Smart Antennas in Wireless Mobile Communications, Stanford University, Stanford, CA, July 1996.

License-Free Wireless Operation Under FCC Part 15 Rules

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There is a vast number of wireless devices and opportunities beyond the high profile personal communications services (PCS) and cellular. Federal Communications Commission (FCC) Part 15 rules permit low power wireless operation without a license. The devices that operate under Part 15 are already ubiquitous as garage door openers, keyless entry, radio-controlled toys, and cordless phones. Sophisticated wireless local area networks and spread spectrum devices that operate under Part 15 are beginning to emerge. This paper will explore the frequencies, power levels, and applications that govern Part 15 devices. While no license is required, Part 15 rules do require device authorization. Basic authorization issues will be addressed.

Introduction

The cellular and PCS market has gotten the lion's share of the publicity in the wireless revolution. This is rightly so because of the money invested in these services. However, there is a wireless revolution much closer to home. The cordless telephone has become ubiquitous along with radio controlled toys, garage door openers, and home automation and security devices, to name just a few. Wireless local area networks are now available. Most of these devices have one thing in common: they operate under the FCC Part 15 rules1 and they require no license.

Part 15 devices have a wide range of applications:

- automotive keyless entry and security devices
- residential home automation, security, and communications devices such as cordless phones and "baby monitors." High-speed wireless home communications is on the horizon.
- entertainment wireless and remote-controlled games and toys
- commercial radio frequency (RF) tags, remote data collection, point of sale devices, local area networking devices
- embedded radio radio links used to replace a wired connection in an existing system

An interesting exercise is for an individual to identify the short-range wireless devices in use around him or her. Such devices are surprisingly ubiquitous and almost all of them operate under Part 15 rules. A highly desirable feature of Part 15 devices is that they require no license. While they require no license, they do require FCC certification before sale.

Part 15 devices tend to be simple, low power, short-range systems. The keyless entry devices popular with new cars have a range in the order of meters, and the transmitter and its power supply are simple enough to fit into the key chain fob. There are exceptions. The IEEE 802.11 networking standard allows sophisticated computer networking with Part 15 radio systems. It is also possible to operate point-to-point microwave systems with tens of kilometer range under Part 15 rules.

Spectrum Sharing and Part 15 Devices

Part 15 rules define three types of devices: intentional, unintentional, and incidental radiators. An intentional radiator intentionally generates RF energy and emits it either by radiation or induction in the course of its operation. This is a "transmitter" regardless of the frequency or power level. An unintentional radiator also generates RF energy, but it is for use within the device with no intention that it be radiated. Examples are microwave ovens and TV receiver local oscillators. Incidental radiators generate RF energy only as a byproduct of operation. Some types of motors are incidental radiators. This paper will deal primarily with intentional radiators.

A basic principle of operation under Part 15 rules is spectrum sharing. Operation of any Part 15 device is subject to the condition that it causes no harmful interference. In addition, it must accept interference from any other source including other Part 15 devices. This means that Part 15 devices are at the bottom of the radio hierarchy. Because Part 15 devices must accept interference from any source, it is impossible to guarantee a particular level of performance.

This will become more of a problem as these devices proliferate. The non-interference requirement may be difficult to appreciate when that new $300 wireless widget does not work due to interference. This has been the object of some controversy as not-so-close neighbors' phone calls and bills have become scrambled due to wireless telephones. The amateur radio operator next door may interfere with your wireless stereo speakers. Amateur radio is a licensed service and as such it enjoys protection from Part 15 devices. The requirement that Part 15 devices share spectrum on a non-interference basis generally limits their power and effective range.

Part 15 Frequencies

A wide range of frequencies is available for Part 15 operation. Tables 1-4 list some of the frequency bands that are available for Part 15 operation. A complete catalog is also provided.*2* There are frequencies available for Part 15 operation from the kilohertz region to millimeter waves. Power levels and applications are specified for each range of frequencies. In addition to application specific frequencies, there are forbidden bands. Intentional radiators are not permitted in these bands and spurious emissions such as harmonics from Part 15 devices are limited to very low levels.

Part 15 applications are divided into three broad categories:

1. Continuous or "any" radiators transmit continuously or for long periods of time. Given the principles of spectrum sharing, continuous radiators are the most limited in power.

2. Periodic radiators devices transmit at a regular interval. They may operate at higher power levels but their on time is limited. These devices may transmit up to 1 second, but they must be off for a minimum of 30 times their on time with a minimum silent period of 10 seconds, as outlined in Paragraph 15.231 of the FCC Part 15 rules.[1]

3. Intermittent radiators are permitted additional power because they transmit only occasionally. It is intended for alarm systems, remote control switches, or door openers. Transmission at regular intervals is not permitted, but polling is possible if transmission does not exceed more than one second per hour. Manually or automatically activated transmitters must be automatically deactivated after 5 seconds, as outlined in Paragraph 15.231 of the FCC Part 15 rules.[1]

There are "forbidden" frequencies where intentional radiators are prohibited and only very low levels of spurious emissions are permitted[2]. An example of a forbidden band can be found in *Table 1*. The forbidden frequencies listed are the television broadcast bands. This prevents television interference.

In addition to limiting intentional transmission in a forbidden band, spurious emissions are limited. One forbidden band is 2655 - 2900 MHz2. The maximum allowable field strength in this band is 500 microvolts / m @ 3 meters. The third harmonic of devices operating in 902 - 928 MHz falls in this band. This harmonic must be 40 dB below the field strength allowed for 902 - 928 MHz non-spread spectrum devices in order to comply with the allowable radiation in the 2655 - 2900 MHz band. This may be very difficult to obtain with simple wireless devices. Those devices that operate from main power have limitations on conducted emissions as well as radiated emissions.

Power Levels

The power levels for many of the frequencies are listed as field strengths. At first, this may seem like an overly complex method of specifying power, but the field strength is a function of both the antenna and the transmitter power output.

If only transmitter power output is specified, then there is no reason why a very low power transmitter could not be used with a very high gain antenna. This would increase system performance, but it would also increase the possibility of harmful interference. Since the maximum field strength is specified, the transmitter and its antenna are considered as a unit. Part 15 rules (Paragraph 15.203) specify that a device must have either a permanently attached antenna or an antenna with a "non-standard connector."[1]

It is not difficult to obtain a simple relation between field strength, antenna gain, and transmitter power. The power

TABLE 1

Field Strength for Continuous Radiators

Frequency	Field Strength μV/m @ 3m	Transmission Prohibited See bulletin[2] for additional bands
9-490 kHz	2400/F(kHz) μV/m @ 300m	
490-1705 kHz	24000/F(kHz) μV/m @ 30m	
1.705-30.0 MHz	30 μV/m @ 3m	
30-88 MHz	100 μV/m @ 3m	54-72 MHz, 76-88 MHz
88-216 MHz	150 μV/m @ 3m	174-216 MHz
216-960 MHz	200 μV/m @ 3m	470-806 MHz
> 960 MHz	500 μV/m @ 3m	

TABLE 2

Field Strength for Periodic and Intermittent Radiators

	Periodic Radiators		Intermittent Radiators	
Frequency	Field Strength μV/m @ 3 m	Max Spurious Emission μV/m @ 3 m	Field Strength μV/m @ 3 m	Max Spurious Emission μV/m @ 3 m
40.66-40.7 MHz	1000	100	2250	225
70-130 MHz	500	50	1250	1250
130-174 MHz	500-1500[1]	50-150[1]	1250-3750[1]	125-375[1]
174-260 MHz	1500	150	3750	75
260-470 MHz	1500-5000[1]	150-500[1]	3750-12500[1]	375-1250[1]
> 470 MHz	5000	500	12500	1250

[1]Linear interpolation See bulletin[2] for forbidden bands

flux density in space is given by:

•EMBED "Equation" * mergeformat watts/m2 (1)

where h is the impedance of free space (120p) and E is the field strength in volts/meter. The power required to create this flux is:

•EMBED "Equation" * mergeformat (2)

where EIRP is the effective isotropic radiated power and D is the distance from the radiator. The 4pD2 factor is the spherical spreading loss as the wave propagates out into space. EIRP can be obtained by:

•EMBED "Equation" * mergeformat (3)

where Pt is the transmitter power and Gt is the transmitter antenna gain. Combining (1), (2), and (3) results in:

•EMBED "Equation" * mergeformat watts (4)

If the antenna gain is 1 and the measurement distance is 3 meters, (4) results in:

•EMBED "Equation" * mergeformat watts (5)

There are two notable exceptions to this philosophy of setting field strength. The first is specifying the transmitter power and antenna size at very low frequencies. In the 160 - 190 kHz band, the wavelength is approximately 1.7 km. Part 15 rules (Paragraph 15.217)1 limits the antenna, transmission line, and ground lead to maximum length of 15 meters. It is extremely difficult to make an efficient antenna this short at this wavelength. Interestingly, hobbyists have occupied this band and produced some stunning results even under the Part 15 limitations. They have communicated up to several hundred kilo-

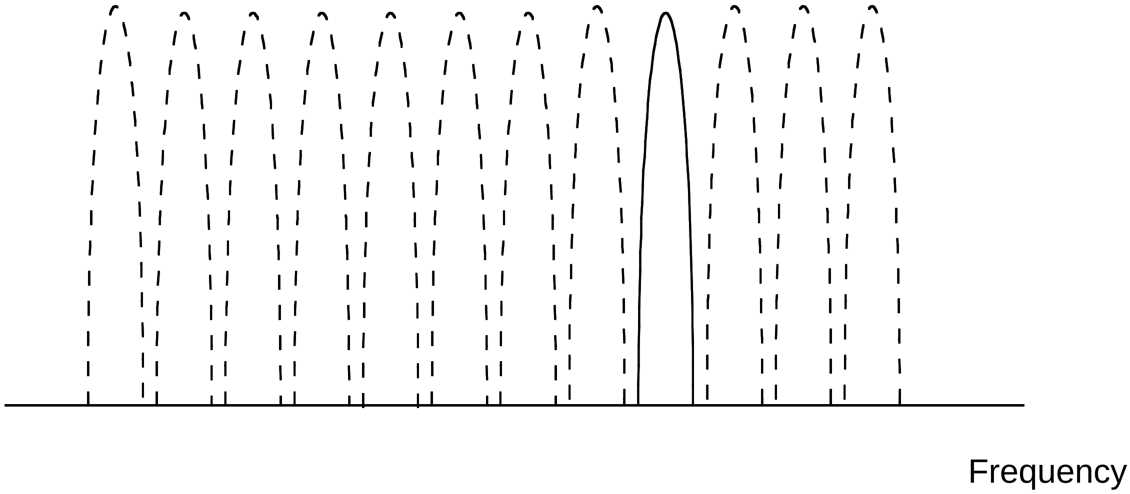
TABLE 3

Industrial, Scientific, Medical (ISM) Band Part 15 Radiators

Frequency	Field Strength or Power	Application	Paragraph[1]
902 - 928 MHz	1 watt (EIRP < 6 dBW)	spread spectrum	15.247
	50,000 μV/m @ 3 m	any	15.249
2.40 - 2.4835 GHz	1 watt (1 dB tx pwr reduction for each 3 dB increase in antenna gain above EIRP 6 dBW)	spread spectrum	15.247
	50,000 μV/m @ 3 m	any	15.249
5.725 - 5.850 GHz	1 watt (no EIRP limit)	spread spectrum	15.247

FIGURE 1

Frequency Hopping Spread Spectrum



meters. More mundane applications are carrier current devices such as intercoms.

The second exception is the 1 watt transmitter power permitted in the 902 - 928, 2400 - 2483.5, and 5725 - 5850 MHz bands for spread spectrum devices. These bands are referred to as the industrial, scientific, medical (ISM) bands. The ISM bands are listed in Table 3. So many services occupy the 902 - 928 MHz allocation that it has been referred to as the "kitchen sink" band.3 Common microwave ovens operate at 2450 MHz under ISM rules. A number of manufacturers are now making chip sets that are aimed at the relatively high power limits for unspread operation in the ISM band.4

Since Part 15 rules effectively limit transmitter field strength, the only way to improve system performance is by improving the performance of the receiving system. There is no limit on receiver sensitivity or receiver antenna gain. However, the greatest cost in most simple systems is in the receiver.

Spread Spectrum

High power spread spectrum is permitted in the ISM bands because spread spectrum is intended to minimize interference by reducing energy density. Paragraph 15.4271 limits spread spectrum devices to either frequency hoppers or direct sequence devices. A good introduction to spread spectrum techniques is provided by Robert C. Dixon.5

Frequency hopping spread spectrum (FHSS) is shown in *Figure 1*. It transmits for a short period of time on each of a number of carrier frequencies chosen pseudorandomly. The hopper transmits for only a short period on any one frequency thus reducing the possibility of interference.

For FHSS, a minimum of 25 kHz or the 20-dB bandwidth of each channel, whichever is greater, must separate the carrier frequencies. For 902 MHz systems, when the maximum 20-dB channel bandwidth is 250 kHz or less, a minimum of 50 hopping frequencies is required. The average dwell time on any one frequency cannot exceed 0.4 seconds in 20 seconds. This is an average of 2.5 hops per second, which is considered a

FIGURE 2

Conventional, Direct Sequence Spread Spectrum, UWB Transmitters

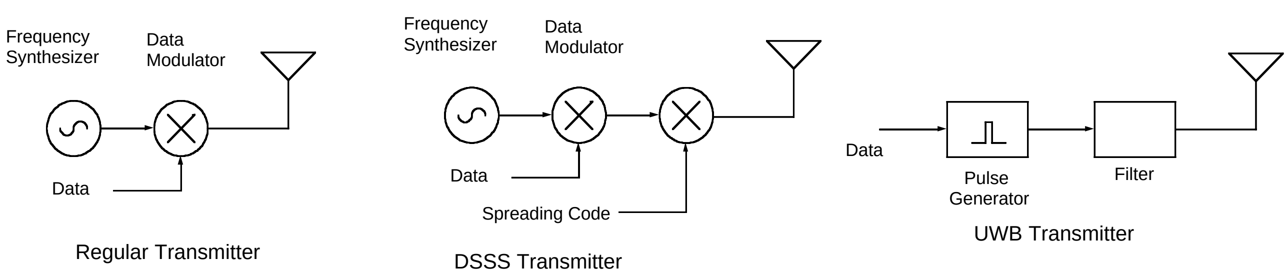
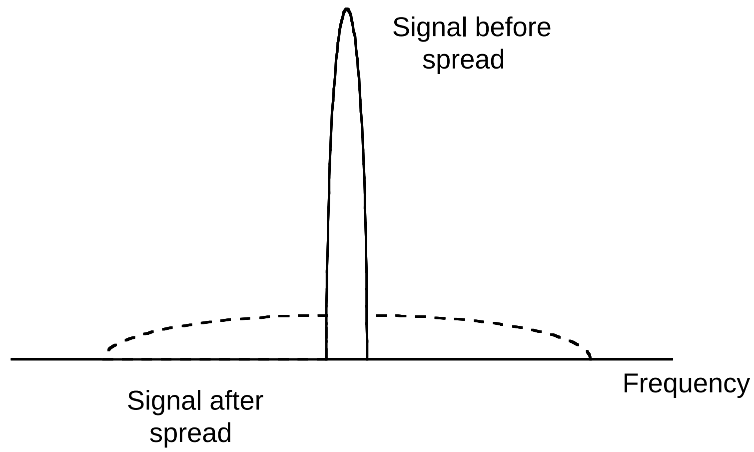


FIGURE 3

Direct Sequence Spread Spectrum



slow hop system [5]. If the 20-dB channel bandwidth is greater than 250 kHz, a minimum of 25 hopping frequencies is allowed. The average dwell is limited to 0.4 seconds in a 10-second period. The maximum 20-dB bandwidth for 902-MHz systems is 500 kHz.

Power levels up to 1 watt are permitted for 902 MHz systems with 50 or more frequency hops. The maximum EIRP (product of antenna gain and transmitter power) is 6 dBW (4 watts). Systems using less than 50 hops are limited to 0.25 watts or 0 dBW EIRP.

Frequency hoppers for 2400 and 5725 MHz can operate with 20 dB channel bandwidths up to 1 MHz, but they must hop to a minimum of 75 different frequencies. The average dwell time must be 0.4 seconds or less in a 30-second period.
Direct sequence spread spectrum (DSSS) is created by modulating a signal with pseudorandom spreading code. The spreading code has the correlation properties of white noise, but the code repeats periodically. *Figure 2* contains a block diagram for a DSSS transmitter.

Figure 3 shows the spectrum of a DSSS signal. The signal before and after spreading contains the same energy. The spreading causes the signal to occupy a greater bandwidth so it has lower energy in a given bandwidth. This reduces the potential for interference. The ratio of the spread bandwidth to baseband bandwidth is the processing gain.

Part 15 specifies that the minimum processing gain for a DSSS signal must be 10 dB. In addition, the minimum spread bandwidth between 6 dB points on the transmitted spectrum is 500 kHz.

DSSS 902 MHz systems are limited to 1 watt of transmitter power or the EIRP must be less than 6 dBW (4 watts), which ever is greater. FHSS and DSSS systems at 2400 MHz are also limited to 1-watt maximum transmitter power, but higher EIRPs are permitted. The transmitter power must be reduced by 1 dB for every 3 dB of additional antenna gain that results in an EIRP greater than 6 dBW. For example, a 0.1-watt transmitter could operate with a 36-dB antenna. This antenna would result in an EIRP 30 dB greater than 6dBW; therefore,

FIGURE 4

Effect of Spread Spectrum and UWB Transmission of a Signal

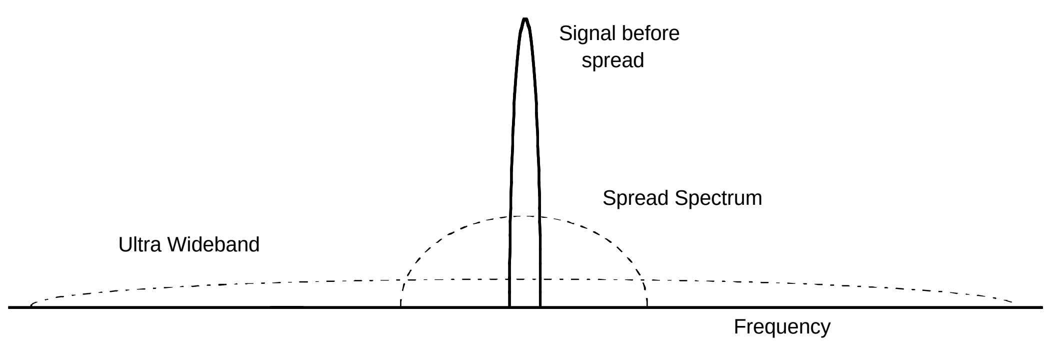


TABLE 4

Miscellaneous Radiators

Frequency	Field Strength or Power	Application	Paragraph[1]
160 - 190 kHz	1 watt input (limited antenna)	any	15.217
510 - 1705 kHz	0.1 watt input (limited antenna)	any	15.219
26.96 - 27.28 MHz	10000 µV/m @ 3 m	any	15.227
43.71 - 44.49 MHz 46.60 - 46.98 MHz 48.75 - 49.51 MHz 49.66 - 49.82 MHz 49.90 - 50.00 MHz	10000 µV/m @ 3 m	cordless phones	15.233
49.82 - 49.90 MHz	10000 µV/m @ 3 m	cordless phone or any	15.233

the transmitter must be reduced 10 dB to 0.1 watt. The combination of a 36-dB antenna and the 0.1-watt transmitter results in an EIRP of 26 dBW. There is no EIRP limit in the 5725 - 5850 MHz band. These relatively high power limits permit systems that rival point-to-point microwave to operate under Part 15 rules.

The higher power permitted under the spread spectrum rules offers the potential for long range systems. The major limitation on spread spectrum is its complexity.

Unlicensed Personal Communications Service (PCS) and National Information Infrastructure (NII) Devices

Two new unlicensed services are now permitted under Part 15 rules. The first is unlicensed personal communications service (PCS) devices. These devices are intended to provide a wide range of mobile and fixed communications services to individuals and businesses.

Unlicensed PCS operates in the 1910-1930 MHz and the 2390-2400 MHz bands. Currently, 1910-1930 MHz is occupied by the private operational-fixed microwave service (OFS). OFS is slated to be moved from this band to make space for unlicensed PCS.

Unlicensed PCS is intended primarily as a digital medium and it has a spectrum sharing etiquette to minimize interference. The Part 15 outline of this etiquette is beyond the scope of this paper, but it can be found in Paragraph 15.301-15.323.

The second new service is the unlicensed National Information Infrastructure (U-NII) operating in the 5.15-5.35 GHz and 5.725-5.825 GHz bands. These devices are intended to provide high data rate digital communications for individuals, businesses, and institutions. The salient features of U-NII devices are listed in *Table 5*.

TABLE 5

U-NII Transmitters

Frequency	Maximum Peak Power	Max Spectral Density	Maximum EIRP	Comment
5.15-5.25 GHz	50 mW	2.5 mW/MHz	23 dBm (200 mW)	Indoor operation only
5.25-5.35 GHz	250 mW	12.5 mW/MHz	30 dBm (1 watt)	
5.725-5.825 GHz	1 watt	50 mW/MHz	6 dBW (4 watts)	

Transmission must cease in the absence of information to transmit or in the event of operational failure.

Ultra Wide Band

Ultra wide band (UWB) is an emerging technology that has potential for short-range high data rate systems. UWB may be viewed as a kind of "super" spread spectrum. The function of the spread in spread spectrum is to lower the energy density. The ultra wide bandwidth of UWB results in very low energy density. This low energy density reduces its interference potential and makes it relatively immune to frequency selective or multipath fading. Figure 4 provides an example of a UWB spectrum.

UWB cannot operate under current Part 15 rules. It is difficult to restrict the bandwidth of UWB so it does not transmit in the forbidden bands. While UWB emissions may be low enough to meet emission limits in the forbidden bands, UWB is an intentional radiator. Intentional radiators are not permitted in the forbidden bands. The FCC is being lobbied to permit UWB because of its low power and spectrum sharing properties

UWB is defined as any signal whose fractional bandwidth is greater than 0.25:5

Fractional Bandwidth EMBED "Equation" * mergeformat (6)

where EMBED "Equation" * mergeformat is the highest frequency of the UWB spectrum and EMBED "Equation" * mergeformat is the lowest frequency in the UWB spectrum. There is no defined center frequency. UWB is also referred to as baseband, impulse, or non-sinusoidal radio.

Although UWB was referred to as "super" spread spectrum, it is not truly a spread spectrum signal. Spread spectrum signals are generated by taking a narrow band signal and broadening it either by frequency hopping or by direct sequence modulation. Spread spectrum signals have a defined center frequency, and they generally do not fit the fractional bandwidth definition of UWB. The bandwidth of the UWB signal is inherent to its process of generation.

This difference can be seen in *Figure 2*, which shows block diagrams for conventional, DSSS, and UWB transmitters. In the conventional and DSSS transmitters, information is modulated onto a carrier frequency. The UWB transmitter employs a fast rise time pulse generator. Rise times are generally less than 1 nsec. The result is a broad flat spectrum that has special lines at the data rate. The filter defines the signal bandwidth.

The transmitted signal is a small number of cycles at the filter center frequency. The limiting case is where the signal is a single cycle, thus its description as impulse or non-sinusoidal. Modulation is accomplished by pulse position modulation (PPM), and spectral lines can be removed by psuedonoise coding the input data stream.[6]

The UWB transmitter is a direct conversion from data to RF. While the peak power of the pulses may be very high, the average power is low. These two factors result in a simple low power transmitter with the potential for high data rates. UWB receivers employ high speed samplers, tunnel diodes, or avalanche transistor pulse detectors.5 Conventional synthesizers, mixers, and intermediate amplifiers are not needed. UWB transmitters, receivers, and antennas are a fruitful area for development.

Authorization

No license is required for devices that operate under Part 15 rules, but these devices must be authorized before they can be legally sold in the United States. There are various authorization procedures:[7] verification; notification; certification; type acceptance, and registration. Additionally, there are labeling requirements for each of these authorization procedures.

For verification, a manufacturer or importer of a device must have measurements performed to insure the technical compliance of the device. A measurement report must be retained and the FCC may request that the report be submitted. Verification is a self-authorizing process. Business computer equipment and TV/FM receivers fall in this category.

Notification requires that an application for authorization be submitted to the FCC. A measurement report must be retained and submitted on request. Point-to-point microwave and broadcast transmitters require notification.

Certification requires the submission to the FCC of a technical description of the device and a report that shows its compliance with technical standards. This is the most involved of the authorization processes. All Part 15 intentional radiators as well as some unintentional radiators require certification. Among unintentional radiators requiring certification are superregenerative detectors. Such detectors are often used in garage door openers, radio controlled toys, and other low cost wireless applications, but they can be potent radiators if not properly designed.

Type acceptance is similar to certification, but it applies to transmitters for licensed services such as the citizen's band or land mobile equipment, including cellular telephones. Registration applies to telephone equipment that is connected to the public switched telephone network.

The FCC does not perform the testing required for authorization, and it does not approve testing labs. However, labs that do compliance testing must file a description of their measurement facilities with the FCC. The FCC maintains a list of these labs.

Conclusions

The applications for Part 15 unlicensed wireless devices are limited only by the imagination. Current rules in the United States allow a wide choice of frequencies for these applications, but there are significant limitations on power so that these devices will produce a minimum of interference to licensed services. The significant power permitted spread spectrum devices opens a whole range of medium range applications such as wireless local area networks.

While no license is required for Part 15 operation, Part 15 devices must be certified for technical compliance before sale. The complexity of this process may represent a significant obstacle for low volume applications.

This paper is intended as an introduction to Part 15 devices. The regulatory environment is continually changing, and the requirements and procedures outlined.[1,7] These must be carefully studied and observed before a Part 15 device can be marketed.

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Over-the-Air Service Provisioning

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Over-the-air service provisioning (OTASP) is a capability that allows permanent memory in a mobile unit to be programmed "over-the-air" by the service provider via automated processing. This automated processing means that none of the traditional manual processing techniques, such as using a keypad on the handset or using a handset cradle application, need to be performed. This obviously has many benefits for the service provider. One is that it does not require an authorized dealer or any third party to distribute handsets. Essentially, the mobile units come from the handset provider to the service provider with nothing preprogrammed except an equipment serial number (ESN). Associated with that ESN are some other pieces of data like a subscriber provisioning code (which is a lock on that handset) and possibly an authentication key (A-Key) that validates the handset to the network. These are the only pieces of information that must be recorded when units are received from the handset manufacturer. The total programming process, programming the handset as well as doing subscriber provisioning on the network, can be completely controlled by the service provider in an automated manner, without manual intervention.

Figure 1 shows a reference model for a typical architecture to support the OTASP feature. IS-41, revision D is the interface that is currently being used most, and there are some vendor proprietary issues in terms of interfacing from the OTA function (OTAF) box to the customer service center as well as from the home location register (HLR) based on the network equipment that is chosen for specific functions within a network. This will, though, be the reference model that will be used to outline a typical call-flow scenario in support of an OTASP activation call.

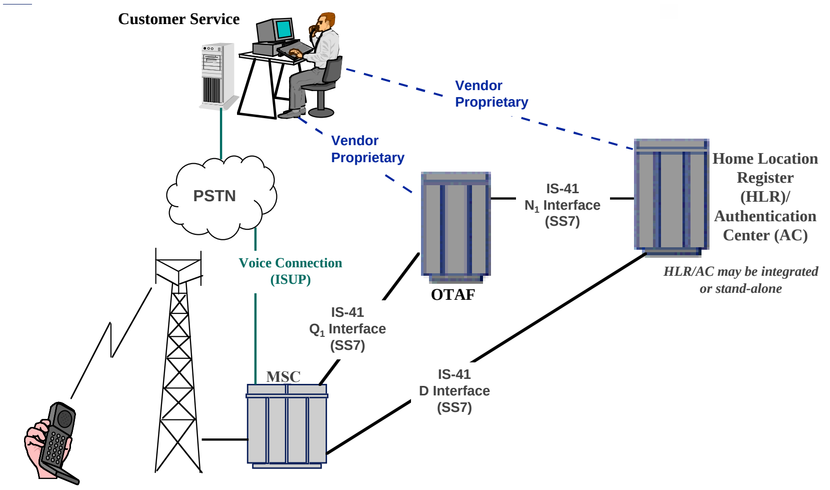
Network Components

There are five basic OTASP network components, each with their own functions. The customer service center (CSC) provides an operator with voice communication with the mobile subscriber. It also controls the provisioning actions via communications with the OTAF and provides an interface to the HLR for subscriber record manipulations. This is where the billing system would be located. It would include pieces within the front end of a call flow like the call distributor, the computer telephony integration (CTI) component which is required to support an OTA call, and the software within the call center that enables the customer service representative to communicate through the OTAF box to the handset.

The second component is the OTAF, which handles network communication to the HLR / AC and mobile switching center (MSC) and / or visitor's location register (VLR). The OTAF also formats OTASP messages for the mobile station. Essentially, it is brokering the data feed to the handset. The serving MSC / VLR, then, controls the voice communications between the mobile subscriber and the CSC as well as provid-

FIGURE 1

OTASP Reference Model



ing the data connection path between the OTAF and the mobile station. The fourth component, the HLR and authentication center (AC) stores subscriber records and authentication keys. This area also communicates with the OTAF during A-Key exchange procedures. Finally, the mobile station (MS) is the handset being provisioned for service. The MS sends current contents of its permanent memory when requested by the OTAF and loads the contents of its temporary memory when received from the OTAF, as well as committing temporary memory to permanent memory as directed by the OTAF.

Standards Status

As with many other areas of telecommunications, the standards for OTASP are undergoing constant review and occasional change. OTASP is currently in beta testing at two customer sites, and will be operational by the end of 1997, which means that initial standards are still evolving. As of June 1997, the standards were as follows:

- Code division multiple access (CDMA) IS-95A / PCS J-STD-008—Air Interface Specifications state that there are no changes necessary to support OTASP.

- IS-683—OTASP Air Interface Specification was approved and published in February of 1997, but did not include programming lock and enhanced roaming. There is currently a "Revision A" in progress to address these areas.

- IS-41—Network Interface Specification is being worked on by an OTASP focus group formed by TR45.2 in March of 1996. One of the things that they have produced is the PN-3769, which describes changes and additions to IS-41-C for OTASP, and which was approved for publication by TR45.2 in May of 1997.

Procedures and Benefits

Over-the-air service provisioning is composed of many features, and has several attractive benefits. The procedures included in the feature are as follows:

- call origination, which includes attachment and protocol capability request
- subscriber programming code (SPC) violation
- MS data upload
- A-Key exchange
- SSD update
- re-authentication
- MS data download
- roaming list download
- MS data commit
- call release

All of these represent, at a high level, some of the call-flow stages that occur during an OTASP call. There are two basic types of activities—new service activation and provisioning, and provisioning to change the service of an existing customer. The OTASP is not only for new call origination or new call activation, but can also support new service feature changes to existing accounts.

The three main benefits or features within OTASP are programming lock, enhanced roaming, and A-Key exchange. Programming lock, also referred to as subsidy lock, protects the carriers' investments in mobile phones. It may be that a service provider is selling handsets that are subsidized (i.e., below cost) as a part of a marketing or subscription plan. This provider would want to guarantee that the handset being sold off the shelf could only be provisioned with its service. With the ESN that is sent by the manufacturer, the provider can also get a subscriber provisioning code which has a specific lock associated with that handset. When this is done, only the person or service provider that ordered that handset knows the lock code and, therefore, only their service can be provisioned onto that handset.

This is important, as the sales of handsets have increased so much that suggestions have been made to provide them via new distribution outlets such as in vending machines, on home shopping networks, as business promotions, in department stores, and other places not normally associated with wireless service. These will now be viable distribution media for any service provider, because they no longer have to go

FIGURE 2
OTASP Call Flow (Origination)

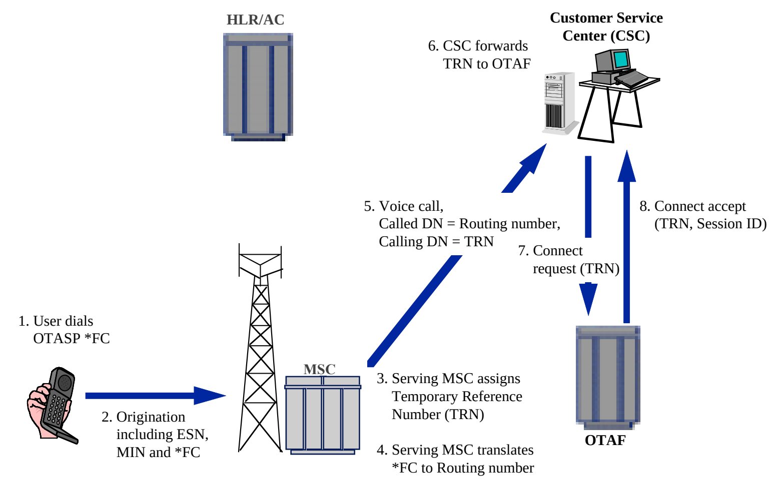
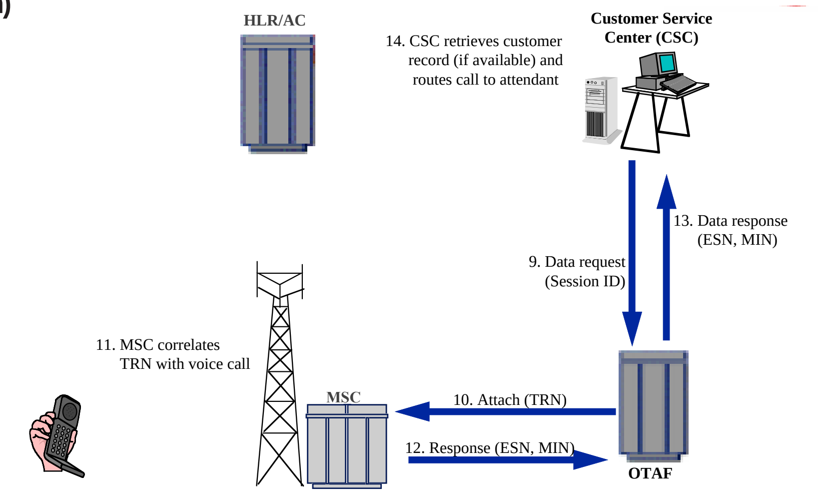


FIGURE 3

OTASP Call Flow (Data Connection)



through the traditional handset provisioning processes nor will they have to engage in costly "authorized dealer" compensation agreements. But if all of these places are offering retail handsets at low costs, they are obviously hoping to make up the profits in service sales. Hence, the programming lock provided through OTASP is essential. Using this, the mobile's memory must be unlocked before programming by providing the SPC to the mobile, which is only known to the provider that ordered the units. The lock applies to all programming methods, including OTASP, keypad, and cradles. Two things should be noted relative to programming lock: the initial OTASP implementation provides SPC validation only, and implementation is manufacturer-specific, although it is available to any vendor.

Enhanced roaming is another benefit to OTASP, which selects a preferred service provider when roaming. This works by the customer indicating preferences for service providers during roaming arrangements and the mobile phone downloading preferred roaming information during an OTASP session. When roaming, the unit uses this information to select the appropriate service provider. Once again, implementation is manufacturer-specific, but available to any vendor.

Finally, the A-key exchange is a mechanism by which, in a current process, the handsets have a default authentication key. In the future, it may be possible to assign a unique A-key that would be programmable over the air using the OTASP function. In either scenario, the A-key is programmed into both the mobile and the AC during the OTASP call, and the A-Key information remains secure. In an A-Key exchange, the OTAF facilitates communicate between the AC and the handset. It uses a Diffie-Hellman algorithm where the AC and the unit exchange parameter value and generate the A-Key. The option does exist to preprogram the A-Key, but this requires a certain amount of administrative overhead and creates a potential security risk.

New Activation

There are nine steps involved in a simple new service activation scenario:

1. The customer purchases a handset at almost any retail source deemed viable by the service provider.

2. The directions on the box will indicate a star OTASP feature code (FC). At this point, there are only two numbers that the customer is capable of dialing—911 service and the FC. That feature code would be unique to the service provider and would indicate the number that the handset owner should dial to initiate activation of the handset provisioning. This process will also put the subscriber on the network, a process that includes setting up the account, the account profile, initiating billing, and provisioning the HLR or other service nodes that may exist.

3. The voice call based on the number dialed is routed to the CSC.

4. A virtual data connection is established from the CSC to the mobile unit via the OTAF and the MSC, even before a representative answers the call. At this point, the incoming call from the MSC to the CSC only includes a temporary reference number (TRN). The TRN comes from a pool of reference numbers that the MSC allocates to calls, and is the number by which the CSC routes through the OTAF and sets up a data link to the handset. Once the handset link has been established, it is possible to retrieve information from that handset like the ESN, model number, and firmware version.

5. The programming lock code may be validated via command to the OTAF, and the mobile unit is "unlocked."

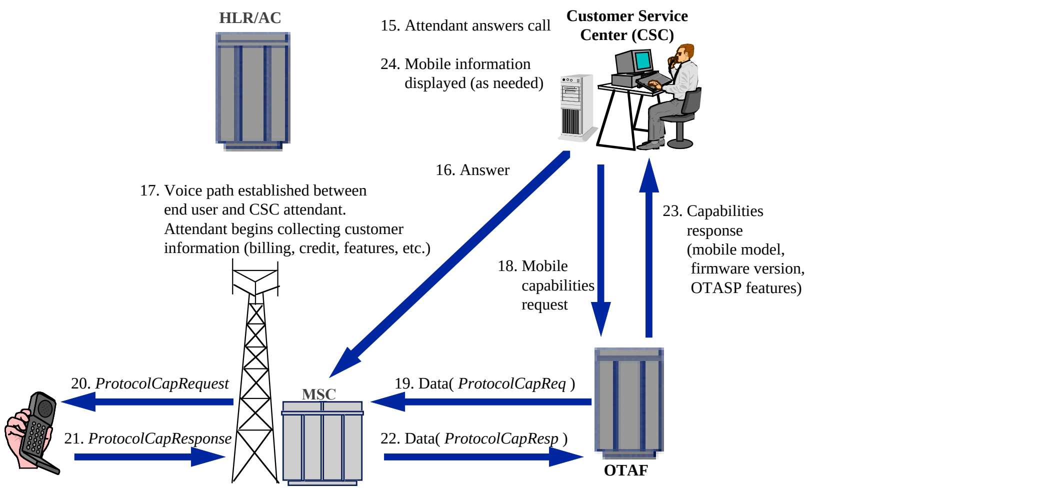
6. The customer service representative (CSR) collects information from the new subscriber about credit, billing, feature choices, and so on.

7. The mobile phone is programmed via commands to the OTAF.

8. The CSR has the option to continue or disconnect the voice call. Typically, the call will continue to assign and

FIGURE 4

OTASP Call Flow (Mobile Capabilities



program the mobile identification number (MIN) as well as enhanced roaming information.

9. The CSC uses a provisioning management system to enter the subscription information and the subscriber record in the HLR, billing database, and voice mail / short message service databases if necessary.

Together, these steps represent a high-level activation flow, and *Figures 2* through *10* will provide more detail about the processes involved. *Figures 2* and *3* show the OTASP call-flow origination and data connection, where a temporary reference number (TRN) is assigned by the MSC and sent to the CSC. The CSC software will then establish a data link to the handset. That data link, a mechanism by which the data is programmed into the handset itself, goes to the OTAF box. The response back from the handset will include an ESN and an MIN. In a new service activation, the MIN being sent is a default MIN, which is mainly a selection of zeros. If the call were from an existing account, the assigned MIN would be sent and the CSC would have the ability to dip into their billing system or customer database and actually have the customer profile available for review. All of this activity has occurred before the CSR even answered the phone. In total, there are around sixteen data interchanges which can occur within the network in about four to six seconds.

At this point, the attendant would answer the phone call and the mobile capabilities would be established, as shown in *Figure 4*. Information is simultaneously moving back and forth between the handset, the CSC, the OTAF, and the MSC. This is the time when the CSR would start negotiation with the subscriber, getting an account profile set up, doing a credit validation check, deciding which services and features were desired, and then validating those requested services and features against the handset information being passed back from the OTAF box. The link to the handset is in use throughout the call-flow process until the call release occurs. As mentioned above, the subscriber provisioning code (SPC), or the subscriber lock would usually be retrieved by the CSC from the billing center where the ESN information is stored. Hence, that is where the associated provisioning lock code

FIGURE 5

OTASP Call Flow (SPC Validation)

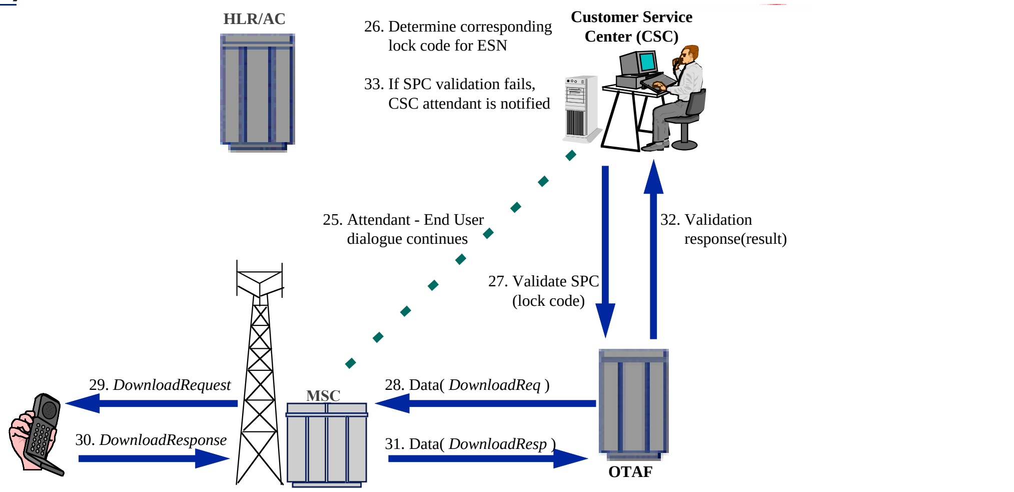
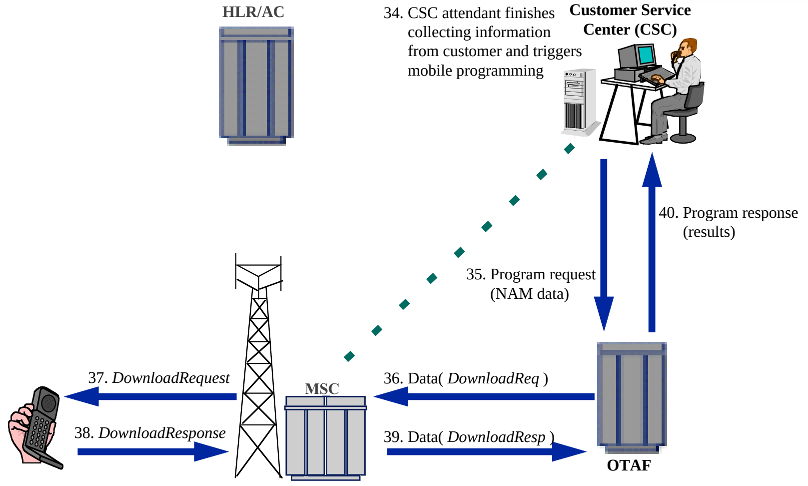


FIGURE 6

OTASP Call Flow (Mobile Programming)



would be stored for that handset, and so the billing center is accessed to validate the SPC. This process is shown in *Figure 5*. When validation has been completed, the mobile programming can take place, as shown in *Figure 6*. This process involves a series of requests and responses between the handset, the MSC, the OTAF box, and the CSC. When basic programming is finished, the roaming list may be downloaded, as shown in *Figure 7*. The final stage of this part of the call flow is the data commit, shown in *Figure 8*, which confirms the fact that all of the necessary provisioning activities have occurred within the handset, and that the handset has been provisioned with the requested features and information. Call release, shown in *Figure 9*, is simply the process by which the session with the handset would be ended after all provisioning has been acknowledged.

As can be seen in these figures, there are roughly 58 steps involved in getting to this point, and all that has been done is the provisioning of a handset—only a piece of the subscriber provisioning process. Part of the solution within a CSC, then, is to manage the provisioning of the subscriber on the actual network. The most important parts of this activation, as shown in *Figure 10*, are provisioning the subscriber administration on the HLR, getting information to the billing database, and updating the message center, voice mail server, or even paging services.

In fact, there is only one piece of software within the CSC that is managing this whole set of events. That piece of software must have the ability to understand the sequence of the call flow specifically as well as the steps that must occur to get from a beginning to an end in general. Perhaps the most important thing that the software must do is know what to do if things go wrong. Obviously, there is a great deal of software functionality built into the CSC from a work-flow perspective. If a customer is calling from a car and goes under a tunnel, losing the OTAF connection in the middle of the provisioning process, the software must be able to recover. It must be able to know the proper steps to take when the HLR has been updated but the billing database has not. Robust software intelligence is required within that CSC to pull all of those pieces together and support the OTAF process where

FIGURE 7

OTASP Call Flow (Roaming List Download)

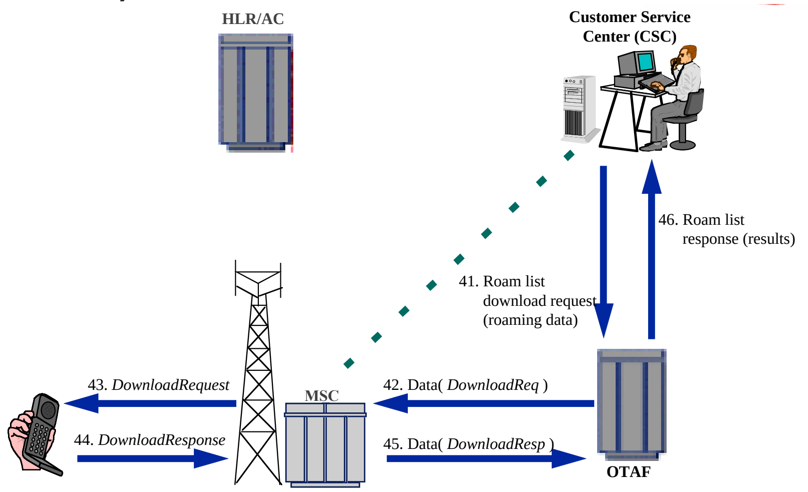
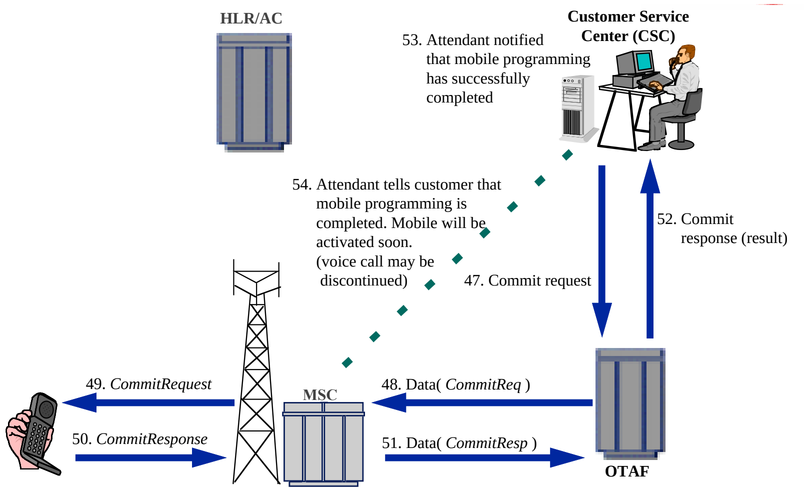


FIGURE 8

OTASP Call Flow (Data Commit)



all provisioning activities are automated for true "flow through" activation.

Business Drivers

Although over-the-air service provisioning is by no means a very simple process, there are a number of business drivers, for both the service provider and the subscriber. For the provider, it is difficult to quantify the savings exactly, but it should be possible to figure the cost of individually manually programming a handset and multiply that number by the number of handsets issued. This, then, is the figure that could be saved. There are other significant benefits to the provider as well. One of these is the wider range of distribution outlets, which could be anything from retail stores to kiosks to home shopping networks. There are also reduced distribution costs since handsets no longer have to be preprogrammed. Nor are dealers required for handset sales. The costs of typical handset provisioning, either through a keypad or through some type of handset cradle application, are also minimized. OTASP streamlines customer care as well, because new service activation is automated in many ways that it was not before, and also includes feature and service updates or enhancements re-

FIGURE 9

OTASP Call Flow (Call Release)

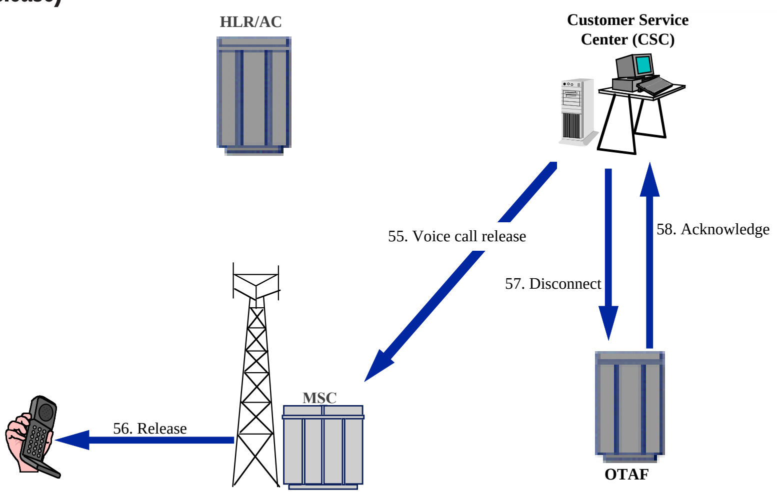
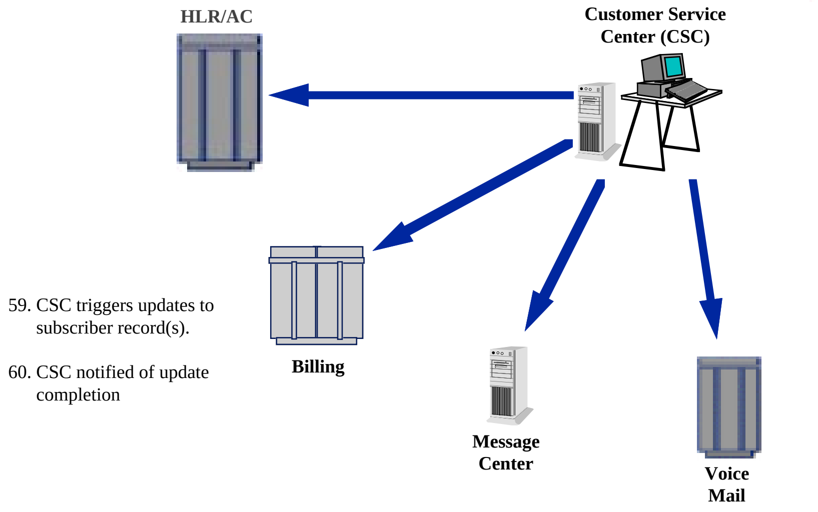


FIGURE 10

OTASP Call Flow (Subscriber Activation)



quested by an established customer. OTASP is even being used as a marketing vehicle—it is new, extremely convenient, does not require authorized dealers for activation, and supports unique and desirable features like programming lock, enhanced roaming lists, and A-Key exchange.

Of course, there are benefits to the subscriber as well. First, they do not need to go to a specialty store, but can purchase a handset almost anywhere. Second, they do not need to undergo a lengthy, in-house provisioning process. Rather, through OTASP, provisioning can occur anywhere from home, car, or the store itself, to an office. It would even be possible to buy and provision a handset from anywhere they were offered, even if the customer was away from home. Finally, the use of OTASP offers the customer immediate service and feature activation. The entire process of activating the handset plus doing the subscriber administration on the HLR and updating billing takes somewhere from ten to twenty minutes, only a portion of that requires the customer's on-line participation. Obviously, the convenience is exceptional.

In summary, over-the-air service provisioning is an exciting concept, for suppliers and customers alike. It is still in the definition stages, and standards have yet to be fully developed. There are also serious considerations about the technology necessary for the customer service centers. All of these problems are far from insurmountable, however, and the new features being introduced through this service, A-Key, programming lock, and enhanced roaming lists, are exciting in and of themselves. As the marketplace grows and as deployment grows, there should be many more enhanced features that could be supported through OTASP.

Wireless Web Access Technologies

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Wireless web access technology is a field that combines two very interesting industries—wireless and the Internet—both of which have had very high growth rates in the past few years. In the last decade when cellular phones first became available, many people thought they were a niche market for business executives who needed to stay in touch at all times. Many people overlooked the potential of this technology. Today, many individuals use cellular phones for diverse reasons—to stay in touch, for emergencies, and so on. In comparison with cellular telephony technology, wireless data communication is still at an early stage of growth, but there is much room for innovation as well as market expansion.

This paper will provide an overview of the trends not only in wireless data, but also in the wireless industry in general. It will then examine some of the current wireless systems that can provide data communications, including wireless wide-area and local-area networks, satellite, and local multipoint distribution systems (LMDS). Finally, emerging technologies and future trends in wireless communications will be outlined.

Why Wireless?

It may well be asked why anybody would choose a wireless solution when there are, in fact, wireline solutions that can provide a great deal of bandwidth. In the case of World Wide Web access, this may indeed be the most important consideration. There are, however, other features that wireless offers which wireline service does not. For example, wireless solutions have a low infrastructure cost, are attractive for low take-rate scenarios, and can offer fast initial deployment. These three attributes may be more important for the service provider than for the subscriber. However, from the user's point of view, wireless offers mobility—a very important feature that wireline communications cannot provide. Additionally, wireless has There are other advantages, as well, including the ability to provide high bandwidth and the integratione of other broadband services such as digital video broadcast. Finally, satellite wireless communications can offer delivery costs independent of transmission distance.

There are several ways to compare different wireless systems. The most important of these are spectrum, bandwidth, and mobility. Spectrum, which can be licensed or unlicensed, is a very valuable resource in connection to wireless communications. Bandwidth, as mentioned above, is essential for Internet access and is how the performance of different systems is measured. High bandwidth can be either symmetric or asymmetric. Finally, mobility is an advantage offered solely by wireless technology. There are fixed wireless systems that do not provide mobility, systems that provide limited mobility (local area), and systems that provide mobility over within a wide area.

Wireless Technology Spectrum and Industry Alignment

It is possible to isolate some differences in the way that the industry is changing. Cellular communications are primarily transmitting voice signals. New applications, though, are opening the doors to data and even video transmissions. One of the primary concerns in the case of wireless communications is the integrity of the transmitted ssion signal. Signal Ffading is one of the biggest still a problems in wireless communications. Signal fading can cause small interruptions and, therefore, the loss of information. This is not a major limitation forduring some voice communication;, howevertransmissions, and it is a problem that can not be afforded in the case of data communications. In data communications, Iit is necessary to provide a system that transmits information between two points in a reliable manner. Another concern is increasing changing bandwidth requirements. Most of the current systems provide low bandwidth, and as technology improves there will be more applications that demand higher bandwidth.

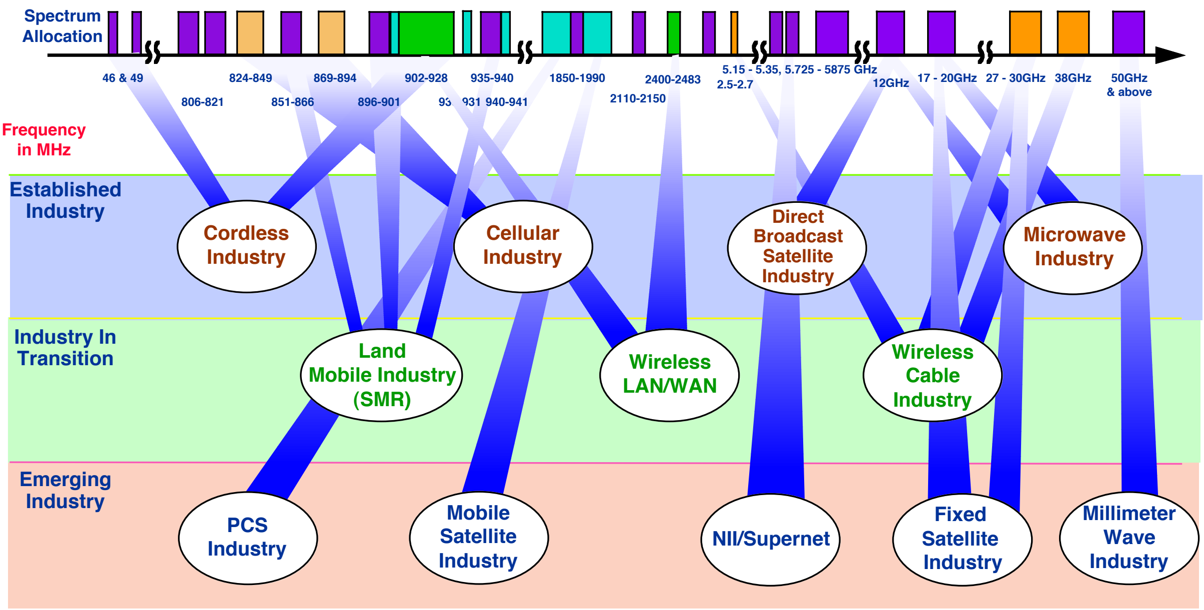
Spectrum

Of the differentiators listed above, spectrum may be the most valuable resource for wireless communications. *Figure 1* provides a limited list of established, transitioning, and emerging industries and their location in the spectrum. Established industries include cordless telephones, cellular telephones, direct broadcast satellites (DBS), and microwave point-to-point systems. The part of the industry that is in transition includes wireless cable, which accounts for local multipoint distribution systems (LMDS) and microwave multipoint distribution systems (MMDS). Other groups that are in transition include wireless LAN / WAN using one of the unlicensed parts of the spectrum, and the land mobile industry (SMR).

When considering spectrum, it is important to understand the characteristics of different frequency bands. As can be seen, all of the industry groups in the established and emerging sectors, as well as those in transition, use different frequency

FIGURE 1

Wireless Technology Spectrum and Industry Alignment



bandsies. The higher the frequency, the higher the attenuation due to rain and other propagation effectsfactors, and the more difficult it is to provide mobility. Also, the higher the frequency, the higher the bandwidth that is available. Obviously, this creates an interesting challenge, since ideally it will be possible to have high bandwidth as well as mobility. In the lower part of the spectrum, then, there is very limited bandwidth available. For this reason, applications that require higher bandwidth must move to higher frequency ranges, that require more complex technology and for which components are technology is not as advanced and equipment is more expensive.

Many countries are dealing with these same challenges in similar ways, and some are choosing different areas of focus. For instance, countries such as Canada have been far more aggressive about issuing LMDS licenses and will probably deploy this technology before the United States. One strong trend in the United States is toward the flexible utilization of spectrum. This means moving from the fixed narrowband channelization of spectrum and modulation schemes, standards, and technology mandated by FCC rules (e.g., AM and FM radio) to flexible broadband spectrum licenses, unrestricted channelization and modulation schemes, voluntary standards, and the use of emerging technologies (e.g., PCS and LMDS).

FIGURE 2

Trends in Wireless Communications Technology

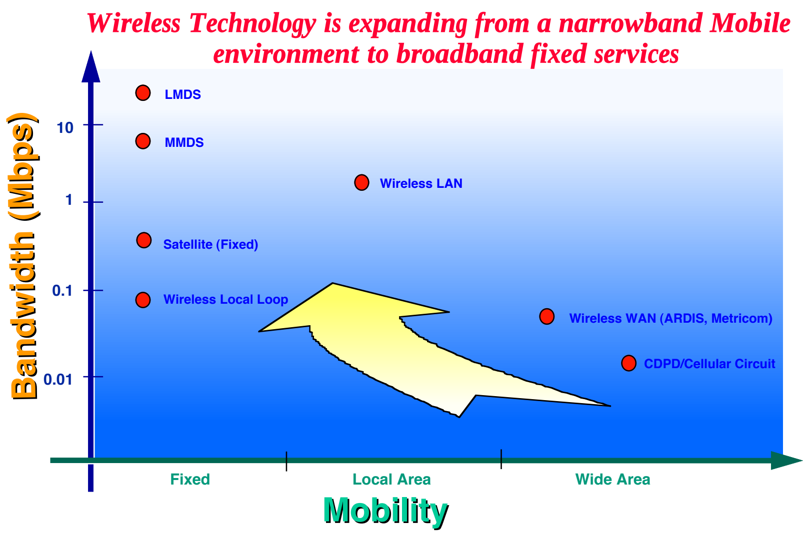
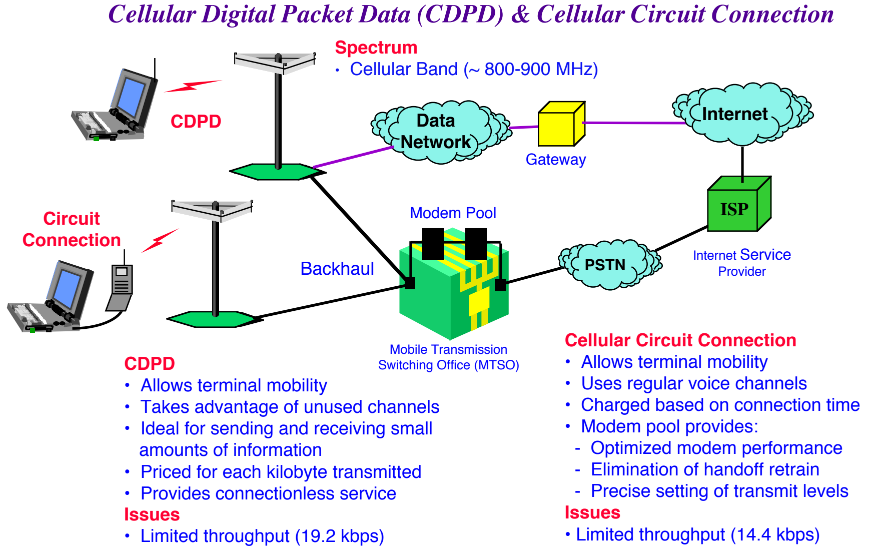


FIGURE 3

Wireless Wire Area Network (WAN)



This could involve going from the primary use of radio at 10 kHz AM and 200 kHz FM, television at 6 MHz VSB, and cellular at 30 kHz to the more common use of LMDS at 500 MHz or 1000 MHz and personal communications systems (PCS) at 5, 15, or 20 MHz. Not only should this trend increase transmission possibilities, but it should also foster the generation and use of new technology.

Another important trend in wireless data communications is the expansion from a narrowband mobile environment to broadband fixed services (see *Figure 2*). The first systems available provided a lot of mobility via cellular digital packet data (CDPD), but could only handle small data rates over a wide area. Now wireless technology is expanding from a narrowband mobile environment to broadband fixed services. Systems such as LMDS, MMDS, and digital satellite technologies are more common.

Wireless Wide Area Networks

There is a great need in the case of wireless wide area networks (WAN) for mobility, and optimally there should also be high bandwidth as well, but the current systems are very limited. *Figure 3* shows two of the available technologies, cellular digital packet data (CDPD) and cellular circuit connection, both based in the cellular network. CDPD is a system based on packet switching packet switched–type of system that provides connectionless service. This means that it is possible to leave a laptop computer with a CDPD modem on all the time, andbut it will only transmit or receive information when it is requested to do so. or is receiving information. This is important, because charges for CDPD use are incurred per kilobit of information transmitted / -received. CDPD, then, allows terminal mobility, takes advantage of unused channels, and is ideal for sending and receiving small amounts of infor-

FIGURE 4

Wireless Wide Area Network (WAN)

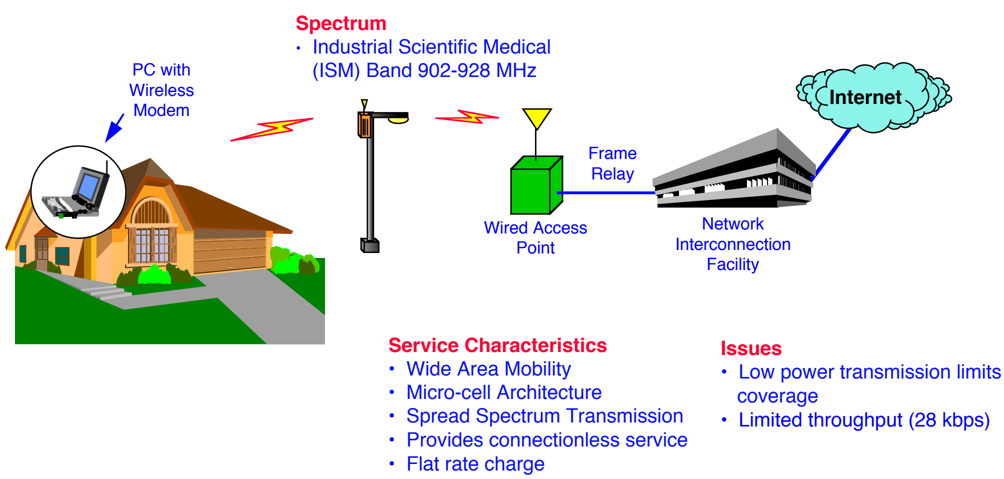


TABLE 1

Summary of Wireless WAN Technologies

	CDPD	RAM Mobile (Mobitex)	ARDIS (KDT)	Ricochet
Data Rate	19.2 Kbps	8 kbps (19.2 Kbps)	4.8 kbps (19.2 Kbps)	~ 28 kbps
Modulation	GMSK	GMSK	GMSK	GMSK
Frequency	~ 800 MHz	~ 900 MHz (SMR)	~ 800 MHz (SMR)	~ 915 MHz (902 - 928)
Chan. Spacing	30 KHz	12.5 KHz	25 KHz	160 KHz
Status	In Service	In Service	In Service	In Service
Access Method	Unused AMPS Channels	Slotted Aloha CSMA		FH SS (ISM band)
Transmit Power			40 Watt	1 Watt
Product Company	Lucent, Nortel, Ericsson, etc.	Ericsson Mobitex	Motorola	Metricom

Operations Characteristics
- High mobility & wide range
- Low data rate

mation. The major limitation associated with CDPD is that it involves a limited throughput of up to 19.2 kbps.

Cellular circuit connection, on the other hand, involves a wireless modem connected to a cellular phone. A connection is established between the wireless modem andThis is connected to a modem pool that is located in the mobile transmission switching office (MTSO). In this case, the modem pool provides some protocol conversion to optimize the transmission in the wireless part of the link. Then from that modem pool it connects to the rest of the telephony network. Cellular circuit connection also allows for terminal mobility, uses regular cellularvoice channels, and is charged based on connection time. The modem pool provides optimized modem performance, elimination of handoff retrain, and precise setting of transmit levels. Here again, the limitation involves bandwidth, with a throughput of up to 14.4 kbps.

Figure 4 provides another example of a wireless WAN—a license-free system, such as that provided by Metricom. This company is currently providing this service in several cities, includingin the San Francisco Bay area and Seattle among others. This technology differs from the two mentioned above in that it involves more of a micro-cellular environment. The tendency to move to smaller cells is valid for many different applications. The purpose of such a system is to increase capacity by reducing the size of the cell. It is important to note that this system uses one of the license-free parts of the spectrum, the industrial scientific medical (ISM) band (902–928 MHz). This type of system also offers connectionless service and is charged at a flat rate. One of the disadvantages here is

FIGURE 5

Wireless Local Area Network (LAN)

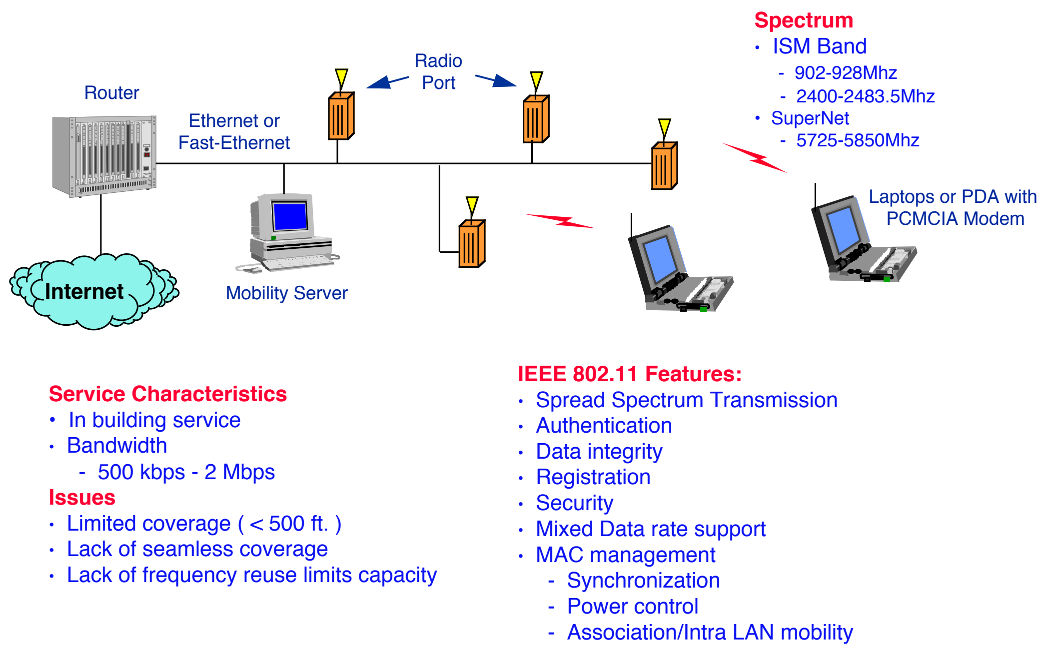
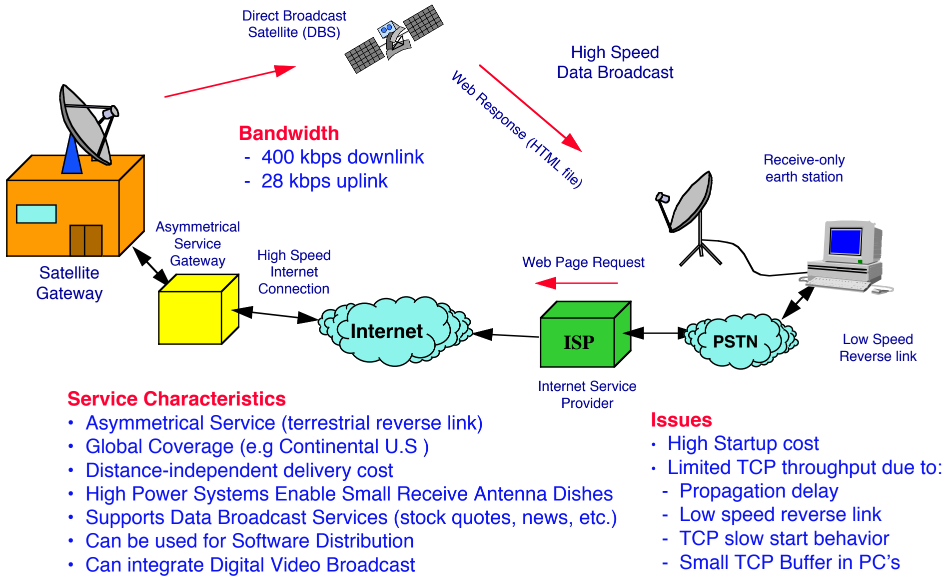


FIGURE 6

Asymmetrical High-Speed Digital Satellite (e.g., DirecPC)



that the allowed transmit power transmission is low, which limits coverage, and the throughput is currently limited to approx. (28 kbps).

There are other wireless data systems that currently provide service, being researched, such as RAM Mobile and , ARDIS, and Ricochet. These are systems that have been available for some time and were originally used for applications like credit- card request in a mobile environment. All of these systems share the operations characteristics of offering high mobility over a wide areaand a wide range, and they are useful for low–data rate transmissions. *Table 1* summarizes the characteristics of several of these systems.

Wireless Local Area Networks

Another important category of wireless access technology is the wireless local area network (W-LAN), an example of which is shown in *Figure 5*. This is still not a mature technology, although there have been some products available for some time. The most common standard is IEEE 802.11, which provides features such as spread spectrum transmission, user authentication, data integrity, registration, security, mixed data rate support, and moves, adds, and changes (MAC) management (i.e., in the areas of synchronization and, power control), and association/intra-LAN mobility. Security is a particularly important issue in wireless communications, because these networks use a medium that is shared and available to anyone with an antenna. In the case of wireless LAN, the data rates range fromare 500 kbps to 2 Mbps—significantly higher than with wireless WAN. Several vendors are working on solutions that may accommodate rates of up to 10 Mbps. Some infrared systems are also becoming available.

802.11 uses spread spectrum transmission, which has the advantages of providing some level of security and being resistant to interference from other systems and users. Wireless LAN also has some drawbacks associated with it; the coverage is limited to 500 feet or less and roaming may not be seamless. In addition, the lack of frequency reuse limits capacity. As with wireless WAN, the goal of wireless LAN is to have a laptop computer or a personal digital assistant (PDA) with a modem that connects to radio ports.

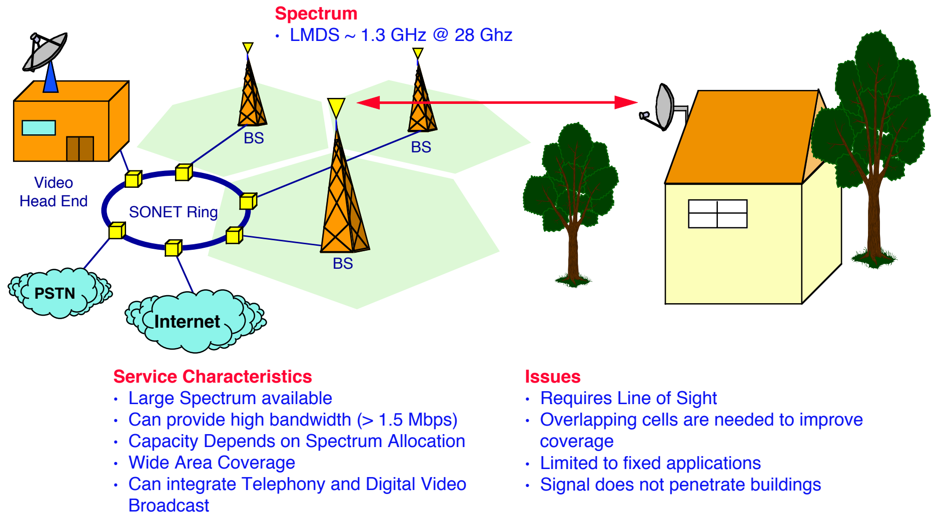
Asymmetrical High-Speed Digital Satellite

Another wireless technology that is available is asymmetrical high-speed digital satellite (e.g., DirecPC). This system uses a satellite to send information downstream. ,A and an example is shown in *Figure 6*. One important characteristicthing about this system is that it provides asymmetrical service, whereby requests are sent through a plain old telephone service (POTS)typical (plain old telephone service) telephone line with a regular with a plain old telephone service (POTS) modem, over the PSTN and the returned information is sent back through the satellite. This system takes advantage of some of the important features of satellite communications, such as the capacity to broadcast large amounts of information and cover a wide area , (i.e., such as an entire country). Asymmetrical high-speed digital satellite systems offer distance-independent delivery cost and support- data broadcast services such as stock quotes, news, and so on. The high-power systems allow for the use of small receiving antenna dishes. and can be used for software distribution. The system can even also integrate digital video broadcast.

Of course, there are also several technical issues with this type of system because of the asymmetrical transmission. First, since the goal is to deploy a higher-bandwidth communication that utilizes up to 400 kbps in the downlink, the acknowledgments requests that are sent back through the telephone line may exceed the capacity of that line. Hence, it becomes necessary to use different types of techniques, such as selective acknowledgment, to overcome the problem. Another very important problem in with satellite communi-

FIGURE 7

Local Multipoint Distribution System (LNDS)



cations is the propagation delay. Because the satellite is located 22,000 miles above the earth, the signal delay is about one quarter of a second. While one-fourth of a second may not seem too important, in the case of computer protocols, it greatly reduces the throughput of the transmission control protocol (TCP) connection. Limited TCP throughput is also caused by the low-speed reverse link, TCP slow-start behavior, and small TCP buffers in PCs.

Local Multipoint Distribution System

As mentioned above, there are other systems that provide higher bandwidth, such as local multipoint distribution system (LMDS). This technology is shown in *Figure 7*. These types of systems are migrating from digital or analog video broadcast (VB) to providing two-way communications or digital services. MMDS is very similar to LMDS but operates at a different frequency with more limited bandwidth. One of the advantages of LMDS is that, depending on the country, there is a large great dealamount of bandwidth or spectrum available. In the case of the United States, 1.3 GHz is available, which can accommodate high–data rate services. Essentially, the total capacity will be determined by the amount of spectrum available. Some of the other positive aspects of LMDS are that it can offer wide area coverage and integrate telephony and digital VBvideo broadcast.

There are also limitations associated with LMDS. Because of the high frequencies being used (in this case, 28 GHz), line-of-sight transmission is required. This means that there must be an antenna that is capable of "looking at" the transmitter, and the signal is greatly attenuated at these frequencies. This can be overcome by using directional antennas and having higher power in the transmit end, but in order to provide a higher percentage of coverage there is a need for a cellular type of architecture. Since the signal does not penetrate buildings, there must be several transmitter stations that can reach the same user from different points. Even in these conditions, coverage will only reach about 80 percent of the total number of users.

TABLE 2

Local Access Technology Assessment

Local Access Technology (Segmentation Group)		Bandwidth Supported: Kbps								Mbps							Gbps	
		4.8	19.2	28.8	64	128	144	384	640	1.5	2.0	6.1	10	30	45	155	1.2	10
Metallic Access	Twisted Pair (POTS)			□	▲													
	Twisted Pair (ISDN)					▲	□											
	ADSL				▲	▲			○			●						
	HDSL				▲	▲					□							
	SDSL				▲	▲					□							
Coax Access	Two-Way Coax												○	●				
	Cable Modem									○				●				
Fiber Access	Fiber to the Home																□	
	Fiber to the Curb																□	
Licensed Spectrum	Cellular/CDPD		□															
	Fixed Wireless					▲□												
	Wireless Cable (MMDS,2.5GHz)									□								
	Wireless Cable (LMDS, 28MHz)															□		
Unlicensed Spectrum	ISM (0.9, 2.4 GHz)					▲				□								
	SuperNet (5.1,5.7 GHz)												□					
Satellite	Direct Broadcast																●	
	Mobile Satellite Services	□																
	Fixed Satellite Services				▲	▲		□										

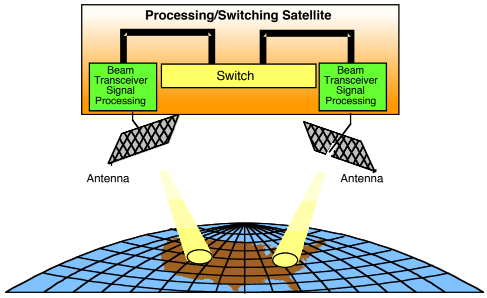
● Downstream Data ○ Upstream Data □ Symmetric Data ▲ Voice

FIGURE 8

Emerging Trends in Wireless Communications Technology: Digital Satellites

Features
- Two-way communications
- Voice, Data and Video services
- Higher Data rates
- Higher capacity
- Higher Frequency operation (e.g. Ka Band)

Key Technologies
- Higher Solar Array Power
- Larger Satellites
- On-board processing
- Use of spot beam antennas
- Higher Frequency operation (e.g. Ka Band)
- New channel coding and error correction schemes
- Higher order modulation schemes



Potential Issues
- Multiple Contenders for Attractive Slots
- Inter-working with Terrestrial Wireless
- High Startup cost
- Worldwide regulatory approval

Table 2 provides a basic summary of some of the technologies discussed above, comparing them to wireline technologies such as asymmetrical digital subscriber line (ADSL), high–bit rate digital subscriber line (HDSL), cable modems, fiber, and so on. Within the area of wireless communications there are a variety of applications that range from very limited bandwidth to bandwidth that is on the order of several megabits per second.

Emerging Trends

There are several technologies that are critical for wireless communications. As mentioned above, the higher the frequency, the more complex and expensive the equipment is. This means that there is a need for low-cost, high-frequency devices. The industry is also looking for low-power transceivers and pico- cellular technology. Effort should also be focused on developing systems that make more efficient use of the spectrum. This means more advanced channel modulation schemes and signal/channel processing. Other key enabling technologies include smart antennas, digital radios, self-adapting networks, and distributed processing and switching.

Digital Satellite Services

There are a number of digital satellite services that are currently being created that will provide two-way communications as opposed to the asymmetrical solutions mentioned above. They will offer voice, data, and video services; higher data rates; higher capacity; and higher frequency operation. This type of system is shown in *Figure 8*. There are several technologies that are key to these types of services, including the following:

- higher solar array power
- larger satellites
- on-board processing
- the use of spot beam antennas
- higher frequency operation (e.g., Ka band)
- new channel coding and error correction schemes
- higher-order modulation schemes

The advantage of spot-beam antennas is that they cover a very limited area. Hence, it is possible to employ frequency reuse—the basic concept of cellular communications—to provide higher capacity. On-board processing is also essential. Most of the current satellites are only "bent pipe"–type devices; that is, repeaters in the sky. They receive the signal and send it back to the earth. With on-board processing, it is possible to recover the signal through modulation and do things like switching in the sky.

Potential drawbacks to this type of satellite system includes the issue of power, since the power that is available in the satellite is very limited. In addition, there will probably be multiple service providers contending for the attractive slots available. This type of technology also involves a high startup cost and may have difficulty interworking with terrestrial wireless technologies. Finally, systems such as these have has yet to meet with worldwide regulatory approval.

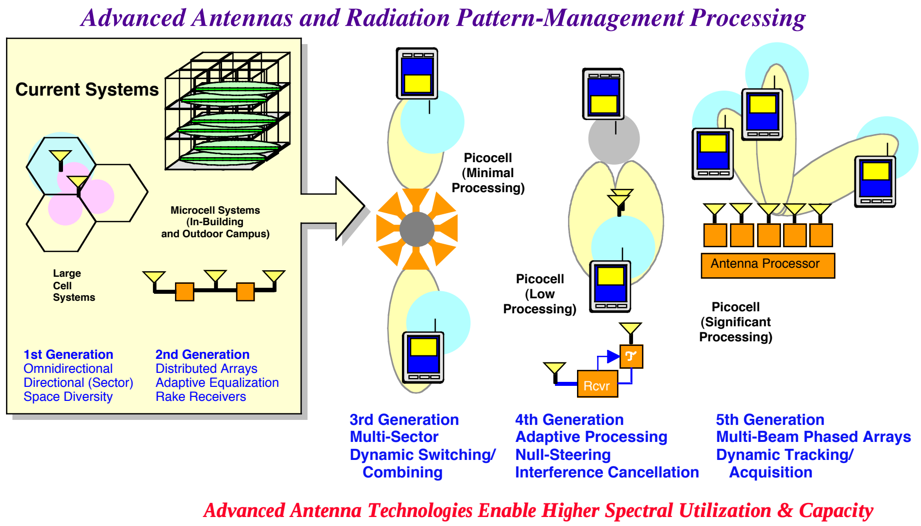
Merging of Data Networking and Mobility Applications

Another trend in wireless communications is the merging of data networking and mobility applications. The goal is to provide higher data rates for wireless LAN communications and mobility similar to systems such as CDPD. With regard to LAN applications, using wireless transmission would reduce costs, since there would be no need to install wire or fiber. Also, the networking complexity using combinations of wired systems is too high. In the case of high-mobility applications, using wireless transmission would meet the need to communicate while in motion, allowing a large roaming area. As yet, there are no wired systems available to answer these needs.

As mentioned above, one disadvantage of wireless LANs today is that they are basically isolated into "cells" and user groups. They do not provide roaming capabilities or a wide area of coverage. They have a small user population, offer non-contiguous coverage, and operate almost solely indoors. Finally, current wireless LANs are slower than Ethernet and accommodate mostly asynchronous traffic. In the future, with wireless data network services, there should be a larger user

FIGURE 9

Emerging Trends in Wireless Communications Technology



population utilizing Internet/intranet connectivity, with contiguous coverage available in dense areas and in a wider area that provides roaming capability similar to what is available for cellular phones. Wireless data network services will utilize a mix of asynchronous and isochronous traffic and achieve Ethernet-compatible speeds.

Advanced Antennas and Radiation Pattern-Management Processing

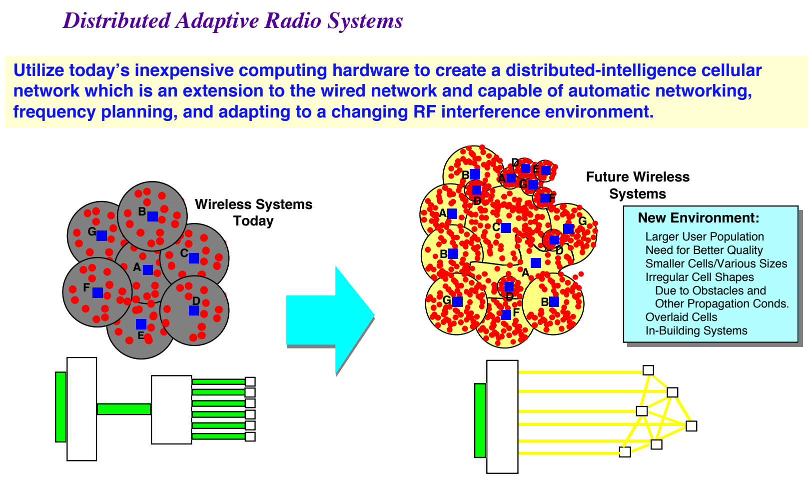
Another new technology in wireless communications involves advanced antennas and radiation pattern-management processing. This type of system is shown in *Figure 9.* Current cellular networks have different base stations distributed over large cells. There is currently a movement toward a second generation of microcell systems, where the goal is to increase the capacity inside onea building or in a campus by usingand provide a smaller area of cells. The third generation is multi-sector antennas, where the signals received from different antennas are combined and switched to increase capacity. The fourth generation would involve some adaptive processing of the signal-receive antenna. In this case, the mode of the antenna pattern can be steered to reduce or cancel interference caused by users and, again, increase the capacity. Finally, the fifth generation would involve multi-beam phased arrays and dynamic tracking and acquisition. This would allow for higher processing of the signal as well as actually steering the gain of the antennas in different directions to point at different users, once again increasing capacity.

Distributed Adaptive Radio Systems

A final important trend in wireless communications technology is the use of distributed adaptive radio systems. This concept is shown in *Figure 10.* Such a system will utilize today's inexpensive computing hardware to create a distributed-intelligence cellular network that is an extension to the wired network and capable of automatic networking, frequency planning, and adapting to a changing RF interference environment. It would make it possible to move from a central-

FIGURE 10

Emerging Trends in Wireless Communications Technology: Distributive Adaptive Radio Systems



ized system to more a distributed system, where each cell has some intelligence.

Summary

Wireless WAN systems can provide low–data rate mobile connectivity to the Web. When higher bandwidth is necessary, fixed wireless systems can be used. These are capable of providing data rates that are comparable to or even higher than those available through technologies such as ADSL and cable modems. In terms of providing both mobility and high bandwidth, the solution seems to lie in wireless data communications, which are still at an early stage of growth. Fortunately, advances in technology are making possible low-cost, high-performance solutions. Ideally, these will be focused on the eventual full development of wireless data communications systems.

The industry faces many challenges in the drive to increase system performance and make wireless services comparable to wireline service. There is a need to reduce cost, both in terms of operations and service provisioning. Ideally, it will also be possible to increase capacity through emerging radio technologies that increase system capacity, such as smart antennas, advanced modulation techniques, and microcellular technology. Another essential objective for wireless access technologies is future proofing—chosen technologies must involve a robust and flexible network architecture. Finally, and perhaps obviously, everyone involved would like to see more revenue growth. Hopefully, enhanced services will leverage emerging technologies, and wireless access technologies will reach their full potential, both in terms of services offered and financial return.