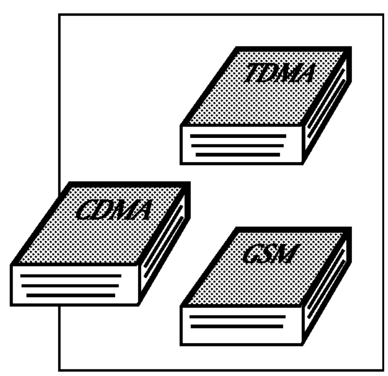
Part C: Issues and Implications

As wireless technologies and systems are deployed, a host of technical, legal, and social issues will need to be addressed. Some will be amenable to marketplace solutions; others will not and will require a policy response. The policymakers task is complicated because the implications of ubiquitous wireless information services are poorly understood due to uncertainties in technology, user demand, and regulation. The greatest unknown in the rollout of the National Information Infrastructure (NH) and wireless services is what type of implications the NII generally, and wireless technologies specifically, will have for people and businesses. In addition to the technical problems associated with the wide–scale use of radio-based communications, there are also likely to be a host of administrative and social problems associated with wireless that must be addressed. Chapters 6 through 12 survey the various issues and implications associated with the widespread use of wireless technologies.

- Standards and Interoperability
- Regulation of Interconnection
- Zoning Regulations and Antenna Siting
- Wireless Technologies and Universal Service
- Privacy, Security, and Fraud
- Health Issues
- Electromagnetic Interference and Wireless Devices

Standards and Interoperability 6

Today's telecommunications and information infrastructure consists of many independently operated networks and systems, including the telephone network, cellular systems, cable television systems, broadcast radio and television networks, and various satellite and data communications systems. Some of these can connect and exchange information, while others cannot. The National Information Infrastructure (NII) initiative was designed to bring together these various networks—and a variety of new services—into a seamless network of networks that would allow users to send information across systems easily and efficiently.[1] In order for this to happen, different networks must be interconnected and interoperable. Standardized interfaces and connections will be critical in bringing this about and allowing the NII to develop. This chapter describes the technological requirements for building a seamless and integrated infrastructure that includes both wireless and wireline networks.



FINDINGS

- **A proliferation of wireless voice technologies and standards is leading to a patchwork of potentially incompatible systems that may make it more difficult for some mobile telephone users to "roam" outside their home system, or to easily switch service providers.** Until the early 1980s, the Federal Communications Commission (FCC) played an active

[1] U.S. Department of Commerce, Information Infrastructure Task Force, "The National Information Infrastructure: Agenda for Action," Sept. 15, 1993, p. 7.

role in standards-setting, specifying the technologies that licensees were required to use. For example, all cellular licensees were required to use a technology called Advanced Mobile Phone Service (AMPS). During the past decade, however, the FCC has largely withdrawn from standards-setting for wireless communications. Today, the FCC usually leaves it to industry to decide whether there will be a standard and which technology will be chosen as the standard. The FCC is following this approach for Personal Communications Services (PCS) and digital cellular air interface standards.

Various industry groups tried to settle on a single standard for PCS and digital cellular services, but were unable to reach agreement. Individual carriers are now choosing the technology standard/system they will deploy from among several contenders. Many cellular carriers have announced their technology choice, but most PCS carriers have not. Among the carriers that have announced which technology they will use, there is no consensus; two different cellular technologies will be deployed, and it appears that at least three different PCS technologies will be used. As a result, there is a danger that incompatible systems will make it more difficult or impossible for some users to make and receive calls as they travel from city to city.

The final impact on customers of the deployment of multiple standards is not yet clear. To some extent, carriers are coordinating their technology choices with carriers in other regions. Carriers are also acquiring additional licenses to enlarge their service areas, allowing them to provide expanded roaming without the need to coordinate technology choices with other carriers. At least three carriers plan to provide near-nationwide service to their customers. Consumers and businesses will have to shop carefully for the next generation of mobile services.

- **Technical challenges and incompatibilities may slow the integration of wireless systems into the NII, but pose no insurmountable obstacles.** Wireless carriers have a clear incentive to ensure that their networks are interoperable with wireline networks because their customers want to be able to call users of the landline network, access the Internet, and download information from online services. If wireless users were unable to communicate with the much larger number of wireline users, wireless networks would not survive in the marketplace. However, there are technical challenges that must be overcome. Most of today's networking protocols were developed for wireline networks and do not work well in the more challenging radio environment. Because it is often necessary to use specialized protocols in wireless networks, interoperability cannot be achieved unless the wireless carrier makes provision for a translation between wireless and wireline protocols to occur at the interface.

Options

In order to encourage the more orderly integration of wireless technologies into the NII, Congress has several broad options. One is for Congress to encourage the FCC to play a more active role in ensuring that cellular and PCS carriers do not deploy multiple technologies. However, the FCC's current approach allows considerable flexibility in the service offerings of carriers and spurs a continuing competition among technologies. It is consistent with the trend toward deregulation and competition that individual carriers be allowed to choose the technology that they believe will give them a competitive edge. Moreover, it would be difficult for the FCC to reverse course at this time. Manufacturers have invested in developing their systems and service providers have begun making their technology choices.

Congress may still wish to hold hearings and monitor the process closely. The technology selection process for digital cellular and PCS can be viewed as an experiment that will show whether interoperability can be achieved in the decentralized and competitive telecommunications industry of the future. Moreover, the federal government, as a user, may want to ensure that seamless nationwide services are available to support its activities. Through their procurement decisions, federal agencies may be able to encourage carriers to coordinate their technology choices and create a seamless network.

THE WIRELESS STANDARDS-SETTING PROCESS

In wireless networks, as in all networks, there are many pieces that must work together to ensure seamless communications. From the user's perspective, the most important connection is the radio link between the service provider's transmitter and the user. The user's equipment must be able to understand the radio signals transmitted by the service provider's network, and vice versa. For example, televisions must be able to decode the signals broadcast from television stations and cellular phones must be able to send signals through the air in a format that the cellular network understands.

It is sometimes sufficient that user equipment work with only one service provider's network. For example, wireless data users can obtain nationwide coverage from a single carrier—they may have no need for a modem that works with several carriers' networks. For other services, however, users may want to be able to access different networks with the same device. For example, cellular users can use cellular systems all over the country because their phone is interoperable with the visited carrier's network. Television sets can receive signals from different stations as well as from cable and satellite services.

One way to guarantee that user equipment will operate with several service providers' systems is to develop an industry standard—a common technology that all service providers agree to deploy. In the past, because of the value to consumers of interoperability, the FCC played a major role in ensuring that wireless network operators deployed a standard technology for the radio link between the network and the user.[2] However, a new model has emerged in which government leaves it to "the market" to decide whether a standard technology is required and what it will be.

The FCC Standards Process

Until the early 1980s, it was generally accepted that FCC involvement in wireless standards-setting was in the interest of the public and the industry.[3] The alternative—the deployment of different technologies by different service providers—was considered too chaotic, and there was a fear that technology development would be slowed if consumers were uncertain about which of many competing technologies to buy. Setting a standard was also thought to create the certainty that the industry needed before it would make the potentially large investment in manufacturing and deploying a new technology.[4] FCC-selected standard technologies are still used in many segments of the wireless communications industry, including radio, broadcast television, and cellular telephony.

In setting a standard, manufacturers would propose different technologies for adoption, and the FCC would compare them—often by means of a competition. The FCC would then select the "best" technology and designate it as the standard that had to be used by all service providers. Much of the actual work involved in testing and comparing the candidate systems was done by committees established by the FCC, but the ultimate decision was made by the FCC itself.

[2] U.S. Congress, Office of Technology Assessment, *Global Standards: Building Blocks for the Future,* OTA-TCT-512 (Washington, DC: U.S. Government Printing Office, March 1992).

[3] Mark J. Braun, *AM Stereo and the FCC* (Norwood, NJ: Ablex, 1994), p. 10.

[4] In its proceeding on high definition television (HDTV), the FCC observed that "establishing a standard may overcome audiences' and broadcasters' reluctance to invest in ATV technology by increasing the amount of programming available to audiences and ensuring that receivers will be compatible with broadcast signals." Federal Communications Commission, *Tentative Decision and Further Notice of Inquiry, Advanced Television Systems and Their Impact on the Existing Television Broadcast Service,* 3 FCC Rcd 6535 (1988).

An important benefit of FCC standards-setting was that the chosen technology had to be licensed on equitable terms to other manufacturers, allowing competition in the manufacture of equipment to develop. Furthermore, the standard created a large national market, attracted competitors, and created manufacturing economies of scale. This competition also led to significant innovations in equipment and services. For example, competition among the many manufacturers building to today's AMPS standard has led to cellular phones that are dramatically smaller and less expensive than those available when cellular service began.

Beginning in the early 1980s, however, the FCC has withdrawn from most standards-setting activities. The Commission will not, for example, select a standard for the next generation of cellular telephones or for PCS. This change in direction is part of the trend towards deregulation in the 1980s. One component of telecommunications deregulation is giving service providers the freedom to select the technology that they believe will attract the most customers. According to proponents of this approach, consumers benefit from having a range of technology choices and also benefit from service providers' flexibility to introduce new technologies as they become available.

But the FCC withdrawal from standards-setting is also the result of practical considerations. In many cases, it was difficult for the Commission to determine which of the contenders had developed the "best" technology. The process was often long and contentious because the contending technologies were often quite similar in their performance, making it difficult to assemble a rationale for the choice that was sufficiently solid to preempt lengthy litigation by the losing proponents. With AM stereo, the first technology for which the FCC left standards-setting to the market, the Commission had first tried unsuccessfully to set the standard itself.[5]

The notable exception to the FCC's new policy of leaving technology choices to the market is High Definition Television (HDTV), for which the FCC followed the old model of establishing an advisory committee and organizing a competition between proponent technologies. There are several reasons why the FCC may have decided to play a more active role with HDTV. First, there was great political pressure to develop a national champion technology that could compete with systems developed in Japan and Europe.[6] Second, there was no interest on the part of broadcasters in deploying anything other than a standard technology. Third, there were severe constraints on the freedom that designers could be allowed, given the need to squeeze the HDTV signal into unused channels. Fourth, pressure from Congress to avoid multiple standards may have played a role in preventing the FCC from leaving the choice to the market.[7] The HDTV standards process is described in more detail in chapter 5 and in box 6-1.

The Marketplace Approach

If the government does not set a standard, then the private sector decides whether there will be a standard and which technology will be chosen. The telecommunications industry often uses standards committees to determine a common technology. Committee-developed standards have many of the same advantages as a government-selected standard. For example, network operators all deploy the same technology, reducing confusion for consumers. In addition, as with government-selected standards, a committee-developed standard is not proprietary. All manufacturers are free to build to the specification contained in publicly available standards documents. Companies par-

[5] Braun, op. cit., footnote 3.

[6] See, for example, William D. Marbach et al., "Super Television," *BusinessWeek,* No. 3089, Jan. 30, 1989, pp. 56- 63.

[7] Braun, op. cit., footnote 3.

BOX 6-1: Interoperability of Video Services

One issue that has attracted considerable attention is the interoperability of video services. There is growing recognition that video is no longer synonymous with broadcast television, but is an important component of many industries and can be delivered by a variety of media, both wired and wireless. Interoperability, in this context, means the ability to use the same video equipment and standards for as many of these applications and media as possible.[1] This lowers the cost of equipment and makes it possible for users to receive information from a variety of sources.

Government plays a special role in ensuring video interoperability because the FCC is leading the selection of a High Definition Television (HDTV) standard. While the FCC will only mandate a standard for broadcasters, the Commission has recognized that the selection of an HDTV standard will have significant implications for other industries. Through the committee structure that was established by the FCC, computer, cable, and other industries have attempted to push the broadcasters toward a technology that takes their needs into account. In fact, the HDTV system under development is compatible with the international MPEG-2 framework,[2] which has been adopted by the new DBS services, the LECs for their new video dial-tone networks, and many players in the cable industry.

A remaining issue is whether the broadcast industry should be required to broadcast programming in interlace mode or progressive mode. Current televisions display in interlace mode, in which alternate lines of the screen are scanned in each frame. Progressive mode, in which each line is scanned every frame, is considered by many to be more suitable for display on computer monitors. The computer industry has campaigned for the inclusion of this capability in the terrestrial broadcast system for HDTV While it now appears that the standard will permit progressive-scan broadcasts, the FCC still has to determine whether broadcasters will be required to use this capability (see chapter 5).

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[1] For a discussion of video and the Nil, see Technology Policy Working Group, Committee on Applications and Technology, Information Infrastructure Task Force, "Advanced Digital Video and the National Information Infrastructure," Feb. 15, 1995

[2] MPEG is the Motion Picture Experts Group, an international standards committee that is developing standards for video compression,

SOURCE: Office of Technology Assessment, 1995.

ticipating in the activities of a standards committee usually have to agree to license, on reasonable and nondiscriminatory terms, any of their technology that is included in the standard.

However, the participants in industry standards committees do not always agree on which technology should be the standard. Manufacturers work to promote the technologies that they have developed, and campaign against those that other companies have developed. There is no mechanism for ensuring that agreement will be reached quickly or at all, and the process of developing and agreeing to a standard can often take many years. Moreover, the existence of a committee-developed standard does not guarantee that it will be the only technology that is deployed. In contrast to an FCC-selected standard, a committee-developed standard is voluntary. Manufacturers may choose to sell, and service providers may choose to deploy, a different, proprietary technology. Finally, it is possible that different standards committees will produce contending standards.

If standards committees fail and multiple technologies are manufactured, the market still has an opportunity to create a de facto standard. Service providers and others who are responsible for choosing from among the contending technologies may eventually converge on a single technology. This is what happened with videocassette recorders, as the VHS technology gradually

BOX 6-2: Proprietary Interfaces and Lock-in

In the cellular systems deployed in the United States, the interface between cellular switches and base stations is proprietary. Switches only work with base stations built by the same manufacturer. If network operators choose to change suppliers for one component of their network, either the switch or base stations, they have to rebuild the whole system. This tying was of concern to the Department of Justice (DOJ) when it evaluated AT&T's acquisition of McCaw. Because cellular companies that used AT&T equipment were to a certain extent locked in, the DOJ felt there was a risk that AT&T could hurt a competing carrier by delaying development or delivery of equipment or software, and imposed several safeguards.[1]

By contrast, in the European cellular standard, GSM, the switch to base station interface is not proprietary-base stations and switches from different manufacturers can work together. In fact, the use of open interfaces is a basic principle of GSM. The GSM standards committee unbundled all important network functions and defined open interfaces between them. Because of the number of interfaces involved, the GSM specification is over 5,000 pages long.

[1] U.S. Department of Justice, "Proposed Final Judgment and Competitive Impact Statement; *United States of America v. AT&T Corp. and McCaw Cellular Communications, Inc. ,"* notice, *Federal Register* 59(165):44158, Aug. 26, 1994 at 44168, 44172.

SOURCE: Office of Technology Assessment, 1995.

took over the market.[8] Although in the early stages of the marketplace process, limited interoperability and customer confusion may slow the convergence to a single standard; because interoperability is so valuable to users, situations in which multiple incompatible technologies are marketed are often transient.

In addition, it is possible that the de facto standard will be a proprietary technology, limiting competition among manufacturers and keeping equipment prices high. Proprietary interface standards enable manufacturers to lock in future sales in an adjacent market: if an interface is proprietary, equipment can often connect only to other equipment made by the same manufacturer. For example, the subscriber equipment that works with the new high-powered DBS service is currently only available from one manufacturer and cellular base stations usually work only with switches made by the same manufacturer (see box 6-2).

Europe and Japan have not followed the new U.S. model of standards-setting. They also rely on standards committees, but their governments do not permit the deployment of multiple technologies. This creates an incentive for committees to come to agreement. In Europe, strong centralized standards-setting is viewed as essential to knitting together disparate national networks. In the first generation of analog cellular service, different technologies were deployed in different parts of Europe, and some technologies were deployed in only one country. It was impossible for a user to roam outside their home country and difficult to achieve economies of scale in the manufacture of cellular phones. To avoid a recurrence of this problem, the European Union launched a coordinated effort to develop a European standard for

[8] For an economic analysis of this phenomenon, see Michael L. Katz and Carl Shapiro, "Technology Adoption in the Presence of Network Externalities,' 'Journal *of Political Economy,* vol. *94, No. 4, 1994,* pp. 822-841.

[9] After the first million units are sold, however, a second company will begin selling equipment.

next-generation digital cellular. This system, the Global System for Mobile Communications (GSM), is now being deployed across Europe and in many other countries.

CELLULAR AND PERSONAL COMMUNICATIONS SERVICE STANDARDS

The development of digital cellular and PCS technologies is a prime example of how the marketplace tries to set standards. It shows the tension between giving competing service providers the freedom to choose their own technologies and the desire for nationwide interoperability. The advantage of the marketplace approach is that it allows carriers considerable flexibility in choosing the services they offer. Moreover, by fostering a competition among technologies, the less rigid U.S. standards-development process may ultimately lead to a better technology choice than the European approach, which is now locked in to a single technology, GSM. But there is a real danger that different technologies will be deployed in different cities, limiting the possibilities for seamless nationwide roaming. Users may find that they are unable to use their phones when away from their home city, contrary to the vision of "anytime, anywhere" mobile telephone service.

The problem is, in fact, a combination of "no standards" and the FCC's decision to divide the nation into many license areas. In developing the cellular licensing plan, for example, the FCC created 734 cellular license areas—with two licensees per area. Although some cellular carriers now operate across several areas, the wireless industry remains fragmented. With so many companies, establishing seamless nationwide service requires that many carriers across the nation deploy the same technology. When cellular service began in the early 1980s, the FCC solved this coordination problem by requiring all carriers to use the AMPS standard. For the next generation of digital cellular, however, the FCC did not specify a standard, preferring to let industry committees settle the issue. They could not, and two standards—TDMA and CDMA—will be deployed (see below).

In the PCS industry the situation is much the same. The licensing plan for PCS established two licenses in each of 51 Major Trading Areas (MTAs) and four licenses in each of 493 Basic Trading Areas (BTAs)—MTAs and BTAs overlap, meaning that each local area could have up to six PCS carriers. PCS industry committees also could not agree on a standard, and several technologies are being developed. In both digital cellular and PCS, individual companies will have to decide which technology is best for them. Because each carrier has different business priorities, different companies are likely to initially select different standards, making the coordination problem potentially quite formidable.

Multiple Air Interface Standards

Today's cellular phones use AMPS for the *air interface*—the radio link between the phone and the base station. Two incompatible digital air interface technologies have been proposed as a replacement for AMPS, one based on Time Division Multiple Access (TDMA) and the other based on Code Division Multiple Access (CDMA) (see box 3-3). In the late 1980s and early 1990s, the cellular industry attempted to choose between the two technologies but was unable to reach a consensus (see box 6-3). As a result, some carriers are deploying the TDMA system, while others will deploy the CDMA system.

PCS operators have also been unable to agree on a standard. A standards committee established to determine which air interface technology would be used in the PCS band only managed to reduce the number of contenders from 16 to seven (see box 6-4). Two of the proposed PCS technologies are based on the cellular CDMA and TDMA systems, but modified to work at the higher PCS-band frequencies. A third PCS technology is based on the European GSM cellular system, but modified to work at the U.S. PCS frequencies and renamed DCS-1900. The four other technologies were developed specifically for the new PCS band.

While the digital cellular and PCS standards committees were unable to reach agreement, they

BOX 6-3: Cellular Standards

The development of digital cellular standards is the responsibility of a committee of the Telecommunications Industry Association (TIA) called TR45. In the late 1980s, it appeared that the industry would be able to agree on a single digital cellular system, based on a technology called Time Division Multiple Access (TDMA).[1] But in 1990, Qualcomm, a company based in San Diego, CA, proposed that a second technology, called Code Division Multiple Access (CDMA), be used instead.[2] This proposal was supported by some cellular carriers, and, in 1992, the cellular industry's trade association, the Cellular Telecommunications Industry Association, abandoned the idea of selecting a single technology as a U.S. standard and asked that TR45 establish a new subcommittee to work on a CDMA system.[3]

TR45 has developed two U.S. "standards," the TDMA-based system, referred to as IS-54, and the CDMA-based system, referred to as IS-95. These are standards in the sense that TR45 has written publicly available specifications that any manufacturer can use to build a conforming system. However, neither IS-54 nor IS-95 is a national standard in the way that the current analog cellular system, the Advanced Mobile Phone Service (AMPS), is a standard: a single specification that all manufacturers and cellular service providers have agreed to adhere to.

[1] Steven Titch, "The Digital Dilemma," *Telephony,* Oct. 14, 1991, pp. 33-36.
[2] Steven Titch and Charles F. Mason, "Digital Cellular: What Now?" *Telephony,* Feb. 10, 1992, pp. 30-36
[3] Charles F. Mason, "CTIA Approves CDMA Standards Setting," *Telephony* June 15, 1992, p. 3.

SOURCE: Office of Technology Assessment, 1995.

will publish specifications for each of the proposed systems. Manufacturers will be able to use these specifications to build any of the proposed systems, although they may have to obtain licenses to any patented technology that the systems incorporate. It does not appear that manufacturers will try to sell proprietary equipment that is not based on one of the published air interface specifications. Carriers would be unlikely to choose a proprietary air interface technology because they would not have as wide a choice of manufacturers and the future development of their technology would be in the hands of a single company.

In part, the wireless industry was unable to agree on a single technology for either the cellular or PCS bands because it was difficult to assess the strengths and weaknesses of the newly developed systems before large-scale deployment. System proponents argued at length about the relative performance and technical feasibility of the proposed technologies. But these arguments were based largely on theoretical calculations, simulations, and small-scale tests. None of the proposed systerns had been tested with real world traffic at the time that the standards committees were deliberating. There was no conclusive way to evaluate the claims made by system proponents.

Another significant cause of the industry's failure to agree on a single technology was the competitive nature of the wireless equipment industry. Standards-setting requires compromise; however, manufacturers who had invested in the development of prototype systems and owned intellectual property rights to the technologies they had developed tried to prevent rival technologies from being chosen as a national standard. Although cellular and PCS service providers played a less active role in the standards committees, they also differed in their perception of the features that they thought their customers would value and in their evaluation of the contending technologies.

Because the standards committees were unable to reach consensus, some analysts have suggested that the FCC should have acted as an arbiter and selected a standard. However, it is doubtful that an

BOX 6-4: Personal Communications Services (PCS) Standards

The standards controversies in the 2 gigahertz PCS band are even more complex than those in the cellular band. At first, two different committees, a new Telecommunications Industry Association (TIA) committee known as TR46, and T1P1, sponsored by the Alliance of Telecommunications Industry Solutions (ATIS), were working on PCS standards. ATIS historically has worked on wireline standards for the public switched telephone network (PSTN), not wireless standards. Its involvement in the development of PCS standards reflects the fact that PCS was initially viewed as a *low tier* service that would be integrated to a greater extent with the PSTN than had been the case for cellular. In 1992, the two committees recognized the overlap in their work and formed a joint committee, the "Joint Technical Committee on Wireless Access" (JTC).

A total of 16 technologies were proposed to the JTC for consideration as a U.S. PCS standard. The committee was only able to reduce the number of contenders to seven; subcommittees are writing standards for each of these technologies.[1] One of the main reasons that there are so many more contenders in the 2 GHz band is that there are different conceptions of what this band is to be used for. Originally, the PCS band was thought to be for a new kind of wireless technology that would be different from cellular, Compared to cellular, PCS was supposed to be simpler, use smaller cells and lower power handsets, and be aimed more at pedestrian than vehicular use. However, many carriers have since come to believe that the PCS band will be used in much the same way as the cellular band. The diversity of views has made it even more difficult to agree on a single standard.[2]

[1] Charles I. Cook, "Development of Air Interface Standards for PCS," *IEEE Personal Communications,* vol. 1, No. 4, Fourth Quarter 1994, p. 30.

[2] "The ideal goal of the [committee] would be to arrive at a single air interface that meets the needs of everyone. However, the wide diversity of potential service providers has caused this to become an unrealistic goal. " Ibid., p. 31.

SOURCE: Office of Technology Assessment, 1995.

FCC-led competition between the proposed systerns could have resolved the issue sooner, if at all. The same technological uncertainties and competitive factors that made it impossible for the industry standards committees to select a single system would also have made it difficult for the FCC.

It is now too late for the FCC to take any action that could force agreement on a single digital cellular or PCS standard. Manufacturers have begun to build equipment, and service providers have begun to make their technology choices. If government is going to be involved in standards-setting, it cannot easily step in at the last minute; instead, it must act early in the process to establish the expectation that a single technology will be chosen. In Europe, the development of GSM followed from a clear objective to create a single standard that would tie the formerly incompatible national cellular networks together into a continent-wide system. Furthermore, the GSM project began at an early stage in the development of digital cellular, before manufacturers had a vested interest in any particular approach.

Mobility Management Systems

In addition to the problem of incompatible air interfaces, a second standards problem—incompatible *mobility management* technology-maybe a greater challenge. Cellular and PCS networks use mobility management technology to connect systems and exchange information about roamers. For example, a cellular system can send messages to a roamer's home system, informing it of its customer's current location so that any incoming calls can be forwarded. The switches and other network equipment that use a particular air interface also come with a particular mobility management technology—when carriers choose their air interface technology, they are also choosing a mobility management technology.

Fortunately, all of the cellular air interface technologies and most of the PCS-band air interface technologies are usually sold with switches that use the same mobility management technology, known as IS-41. Users could roam between IS-41-based systems as long as they had multimode phones to overcome any air interface incompatibilities. However, the European DCS-1900 system is sold with a mobility management system that is not compatible with IS-41. Therefore, users could not roam between DCS-1900 systems and IS-41-based systems, even though it is possible to build a multimode phone that incorporates both the DCS-1900 air interface and a second air interface. This may dissuade some carriers from choosing DCS-1900, although some manufacturers are trying to make it possible for the two mobility management systems to work together.

Carrier Technology Choices and Interoperability

Because the industry has failed to agree on an air interface standard, carriers have been evaluating the contending systems and trying to determine which technology to deploy. There are significant risks associated with their technology choice because the construction of a digital cellular or PCS network requires the investment of millions of dollars and the wrong choice could leave a carrier at a competitive disadvantage. Among the factors of concern to carriers are coverage, capacity, and voice quality. The most important consideration is the per-user cost of building and operating the network, because this factor most directly affects a carrier's ability to compete with its rivals.

Carriers are also concerned with the technological maturity of the contending systems. For example, some cellular carriers have chosen TDMA because it is commercially available and they have an immediate need for the greater system capacity afforded by digital technology. Other carriers will wait for CDMA, which is still being tested. The maturity of the technology is given special weight by the new PCS entrants because delays caused by unforeseen problems with a new technology would give cellular carriers even more of a head start in the market. One of the selling points of the DCS-1900 system is that its GSM and DCS-1800 cousins have been in commercial service in Europe for several years. American Personal Communications, one of the "pioneer's preference" winners, has selected DCS-1900 for this reason.

Because of uncertainties about the contending systems' capabilities and because of differences in their business plans, different carriers are choosing different technologies. Most cellular carriers have announced their technology choices; Bell Atlantic Mobile, NYNEX Mobile, and AirTouch plan to deploy CDMA, while AT&T (formerly McCaw) and Southwestern Bell Mobile Systems are deploying TDMA. Among the carriers with PCS licenses, most have not yet announced their technology choices. However, it appears that two technologies, the U.S. CDMA system and the European DCS-1900 system, are attracting the most interest.

Because there is no clear favorite among the technologies at this time, there is a risk that a patchwork of technologies will be deployed, making it difficult for users to roam in all cities. The impact of multiple standards on roaming depends not on how many technologies are deployed, but the pattern in which they are deployed. Some major players in the wireless industry intend to build networks with near-nationwide coverage through acquisitions of other carriers, mergers, and alliances (see chapter 3). Other carriers are working to coordinate their technology choice with carriers in neighboring regions. These companies or alliances could then guarantee seamless roaming by deploying a single technology throughout their license areas. In addition, the technology choices of these major players will influence the choices of smaller carriers and thereby determine which of the contending technologies will survive in the marketplace.

Technological Solutions to Interoperability

To a certain extent, there may be technological solutions to the multiple-standard problem.[10] It may be possible to use *multimode* phones that work with more than one type of air interface. However, a multimode phone built with today's technology requires additional circuitry that increases the cost and weight of the phone. In the future, it may be possible to minimize this penalty by implementing most of the phone's functions in software.[11] This approach is the focus of research sponsored by the Advanced Research Projects Agency,[12] but the required signal processing technologies are still several years away from commercialization.

Dual-mode phones will indirectly allow interoperability between cellular companies that deploy different digital technologies. These phones will not be TDMA/CDMA phones; instead, they will incorporate AMPS and one of the digital technologies. The AMPS capability is being included with all digital phones mainly because it allows users to make calls in areas where digital has not yet been deployed—all cellular carriers will continue to support AMPS until most of their customers own digital phones. However, users who roam into an area that does not employ the digital technology the user has will be able to fall back on AMPS to complete their calls. Falling back to analog incurs a significant performance penalty; when operating in analog mode, phones deplete their batteries at least twice as quickly. In addition, the continued use of AMPS to support roamers could slow the transition to more efficient all-digital networks.

Because there is no existing common technology in the PCS band, PCS carriers would have to either use phones that incorporate multiple PCS technologies or *dual-band* phones that incorporate both a PCS air interface and an analog or digital cellular air interface. These dual- or multimode phones would be more expensive to design and build than a single-mode phone, and would take longer to develop. The added cost would depend in part on the degree of similarity between the air interface technologies combined in the phone. It would also depend on manufacturing volumes; the price of a multimode phone would only be reasonable if it could be sold in large quantities. Manufacturers are trying to determine which air interface combinations the market will demand, if any.

Coordinated Technology Choices

Although multimode technology may provide a partial solution to the multiple-standard problem, several carriers are taking more direct action to ensure that roaming is possible. They recognize that nationwide roaming is of value to users and that they will have a competitive advantage if they can offer nationwide roaming. They are working to coordinate their technology choices with carriers in other regions. In several cases, a group of carriers has established an alliance whose members agree to deploy a common technology.[13] For example, US West New Vector, AirTouch, Bell Atlantic Mobile, and NYNEX Mobile have formed an alliance that is committed to CDMA.

Carriers are also working to expand the area that they are licensed to serve, reducing the need to

[10] "On the other hand, the next generation of mobile radio may well be 'computers with an RF front end' with the capability of performing many signal processing functions. Perhaps different format translations and emulations will be performed by the mobile unit itself so that it can operate in different modes. Perhaps the mobile unit will be able to be updated to perform new capabilities in the same way that computers today are updated with new software, expansion boards, and the like." Federal Communications Commission, *Notice of Inquiry, Advanced Technologies for the Public Radio Services,* FCC Gen. Docket No. 88-441, Dec. 11, 1989.

[11] Joe Mitola, "Software Radios," *IEEE Communications,* vol. 33, No. 5, May 1995, p. 24.

[12] Robert J. Bonometti, "Integration of Space and Terrestrial PCS in the Information Infrastructure," *Proceedings of the 1994 Third Annual International Conference on Universal Personal Communications* (Piscataway, NJ: IEEE, 1994), p. 455.

[13] Gutam Naik, "Alliance Planned for National Wireless System," *The Wall Street Journal,* Nov. 7, 1994, p. A3.

coordinate with other carriers. One strategy is to acquire other carriers; there is a clear trend toward consolidation in the wireless industry. Another strategy for building nationwide coverage was afforded by the FCC's design of the PCS auctions. The licenses in all regions are being auctioned simultaneously, allowing a carrier to bid for contiguous license areas. In theory, it would be possible to assemble a nationwide system by winning all of the available licenses. While this did not occur in the first round of auctions, several companies assembled licenses covering very large areas. For example, one consortium won licenses with a total of 182.5 million potential customers.[14]

Some of the biggest winners in the first round of PCS auctions were cellular companies who will use their new PCS spectrum to fill in the gaps between their cellular properties.[15] In order to knit their cellular and PCS licenses together into a nationwide service, these companies' customers will have to use dual-band phones that work in both the 800 MHz cellular band and the 2 GHz PCS band. It is possible that these will be *dual-band, dual-mode* phones that would use a different air interface technology depending on whether they were operating in the PCS or cellular band. But phones that used the same air interface technology in both bands would be simpler and less expensive. Two of the proposed PCS technologies are simply *upbanded* versions of the cellular CDMA and TDMA systems, facilitating this dual-band strategy. To some extent, the technologies deployed in the PCS band will be determined by the technologies deployed in the cellular band. For example, the alliance of US West New Vector, AirTouch, Bell Atlantic Mobile, and NYNEX Mobile plans to use CDMA in both its cellular and PCS properties.

Alliances and consolidation represent the industry's attempt to overcome the FCC's decision to divide the wireless service map into a large number of license areas. Almost every other country grants licenses on a nationwide basis to begin with, guaranteeing nationwide roaming. When there are nationwide networks, the deployment of multiple technologies would only be of concern to users if they decided to switch carriers, in which case they might have to buy a new phone. The lack of a national standard would not limit roaming. While the FCC has withdrawn from standards setting, it should be recognized that its decisions about the structure of the wireless industry critically affect the pattern in which technologies are deployed.

Narrowing the Choices

The technology choices of the larger PCS carriers and alliances will begin the process of reducing the number of contending PCS technologies from seven to, most likely, two or three. The larger carriers will be looking for partners in the regions where they do not have roaming agreements. As a result, many mid-sized and smaller operators will follow the lead of the larger carriers and alliances. For example, if a high percentage of a small operator's customers were roamers from a large city, it would likely follow the lead of the larger operator. The technologies that receive only limited initial support may not survive long in the marketplace. Manufacturers would be less likely to build to these standards, and the price of the phones would not benefit from economies of scale.

Over time, the number of incompatible air interface technologies in the market is likely to be further reduced. Although it is costly to do so, carriers may switch technologies as more is learned about the performance of the competing systems or about the choices of competitors and alliance partners. Carriers may choose to deploy a more mature technology today, knowing that in a few years they will exchange it for a better technology. For example, some carriers believe that CDMA may prove to be a better technology in the long

[14] "Broadband PCS Auction Nets $7.7 Billion," *Telecommunications Reports,* vol. 61, No. 11, Mar. 20, 1995, p. 3.

[15] Ibid.

run, but that TDMA is the best technology for solving immediate capacity problems. Some manufacturers support this strategy by designing their products so that much of the equipment purchased for a TDMA rollout can later be used for CDMA.

Effect of PCS and Cellular Standards on Trade

One side effect of the U.S. approach to standards-setting is that it has left the United States without a national champion technology to sell in other countries. The worldwide market for cellular telephone equipment is large, especially when the possibilities for wireless local loop applications are considered. Because the battles over standards in the United States have slowed the commercialization of U.S. digital cellular, more and more countries are adopting GSM. GSM has a significant head start, with 1.8 million phones in service worldwide in mid-1994 compared to 100,000 U.S. digital phones.[16] It has been adopted by 78 network operators in 59 countries.[17] Outside of the European Union, GSM has been selected by carriers in China, Australia, New Zealand, Russia, and Hong Kong, for example.[18]

The openness of the U.S. technology selection process creates other imbalances. Because Europe and Japan have specified the technology that all licensees must use, these markets are closed to the U.S.-developed technologies. For example, even if the U.S. CDMA system does turn out to offer significant advantages, service providers in Europe would not be able to adopt it in place of GSM. At the same time, however, the technology-neutral U.S. licensing process allows PCS carriers to adopt the European DCS-1900 technology. The real effect on U.S. manufacturers is unclear, however. The largest suppliers of GSM equipment are all European companies,[19] but U.S. companies build GSM and DCS-1900 equipment and are selling it around the world.

INTEROPERABILITY OF WIRELESS AND WIRELINE NETWORKS

The first section of this chapter discussed the radio link standards that enable interoperability between a user's phone or other wireless device and a service provider's network. But it is equally important that different networks be interoperable with each other, allowing their users to exchange information with users of other networks. The future NII is often envisioned as a network of networks—a diverse collection of networks that are independently operated but still interoperable. Therefore, it is necessary that the wide variety of wireless networks currently being deployed—PCS, cellular, wireless data networks, and others—be interoperable with wireline networks as well as with each other.

Although there are technical challenges that need to be overcome to ensure wireless-wireline interoperability, it is unlikely that the infrastructure will be segmented into separate wireless and wireline worlds. There are clear incentives for the operators of wireless networks to ensure that there is interoperability between wireless and wireline networks. Wireless carriers know that their customers want to be able to talk to wireline users of the public switched network, exchange e-mail with users of the Internet, and retrieve information from their companies' computer networks. Wireless networks would not survive in the marketplace if their users were limited to isolated islands, unable to communicate with the far larger number of wireline-connected users.

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[16] Gail Edmondson, "Wireless Terriers," *BusinessWeek*, May 23, 1994.

[17] Mark Newman, "GSM Takes On the World," *CommunicationsWeek International*, Issue 133, Oct. 24, 1994, p. 1.

[18] "GSM Gold Mine," table in *CommunicationsWeek International*, Issue 132, Oct. 10, 1994, p. 26.

[19] Ibid. A table lists the four largest suppliers of GSM equipment as Ericsson, Siemens, Nokia, and Alcatel. Motorola and AT&T appear on the list, but sales volumes are considerably smaller. For example, according to the table, AT&T has sold four GSM switches, Ericsson 33, Siemens 30, Nokia 15, and Alcatel 14.

Wireless-wireline interoperability also allows for communication between disparate wireless networks. Because most wireless networks act as an extension to a larger wireline network, the wireline network can serve as a common core through which incompatible wireless networks exchange traffic. For voice or fax traffic, this common core would be the public switched telephone network; for data, it might be the Internet. For example, the fact that both CDMA and TDMA cellular networks are designed to interoperate with the public switched telephone network (PSTN) will also allow them to interoperate with each other. The wireline standards can act as a common language, allowing users of incompatible wireless networks to communicate.

Translation of Protocols

Despite the incentives for wireline-wireless interoperability, it is not always easily or inexpensively achieved. It would be easier to achieve if wireless and wireline systems could use the same protocols—the rules and formats that govern how communication occurs. But many wireline protocols do not work well over wireless links, because wireless links are noisier, have less bandwidth, and may have a long transmission delay. Therefore, it is often necessary to use specialized wireless protocols.[20] Because these protocols are incompatible with their wireline counterparts, interoperability requires that there be some type of translation or "gateway" at the interface between wireless and wireline networks.

For example, interconnection of digital cellular networks to the public switched network requires that the voice signals be translated from the wireless to the wireline format—wireless networks have to use a much lower bit rate because of the limited bandwidth available. Cellular carriers also need to install "modem pools" at their switches to translate between ordinary wireline modem standards and special modem protocols that work better over a noisy wireless link. Operators of wireless packet data networks need to translate the specialized protocols that they use into the protocols used in the Internet or in corporate data networks. E-mail may have to be translated from a wireline format into the format used by paging networks, permitting instantaneous delivery of e-mail from wireline users to alphanumeric pagers or laptop computers equipped with paging receivers.

Because different types of services require separate translation schemes, it is often the case that services that have the most commercial value are supported first. For example, the new digital cellular services will support the interoperability of voice services from the beginning because voice is considered to be the core service. But interoperability of fax and data services will not be supported until the appropriate *interworking* equipment is installed. More specialized services, such as secure voice services, which have only a limited market, may have to wait even longer. Where these services are essential to the mission of a government agency, the agency will have to get involved with industry groups and standards committees to ensure that the services are available.

Most of the cost of ensuring interoperability falls on wireless network operators because wireless networks are newer and have fewer users. For the most part, wireline protocols have been developed without regard to the needs of wireless. Satellite operators, in particular, have complained that wireline protocols were developed and standardized based on assumptions about short transmission delays that do not hold true for satellite services.[21] Many of the technical issues of integrating wireless access with Asynchronous Trans-

[20] John A. Kilpatrick and Mobeen Khan, "MOBITEX and Mobile Data Standards," *IEEE Communications,* vol. 33, No. 3, March 1995, p. 96.

[21] It takes about half a second for a signal transmitted to a geosynchronous satellite to reach its destination.

fer Mode (ATM) networks, which are expected to play a key role in the future wireline infrastructure, still have to be addressed.[22] In the future, however, the increasing interest in wireless may mean that network designers will use a more integrated approach that takes both wireless and wireline into account. Government can reinforce this direction by supporting testbeds and demonstration projects that include both wireless and wireline components.

Wireline Networks and Mobility

Another challenge to integrating wireless and wireline networks is that existing wireline networks, such as the PSTN and the Internet, do not recognize that users can be mobile. They associate a telephone number, for example, with a fixed location. As a result, wireless operators have had to develop their own specialized call routing procedures. For example, the cellular industry's IS-41 mobility management system, used to forward calls to a user's cellular phone as they travel, operates separately from the wireline network's call-routing mechanism.

The lack of integration between wireless and wireline call routing mechanisms causes inefficiencies.[23] With IS-41, for example, calls are first delivered to the user's home system and then forwarded to the city where the user is currently located. In fact, the called user could be in the next room, but the call would still be routed all the way to the user's home city and then back again, requiring two long distance calls and turning an inexpensive call into a very expensive call. More efficient call routing would send the call directly to the user's current location. For this to be possible, however, the LEC or long distance carrier at the originating end of the call would have to have to be able to recognize that the number belonged to a mobile user, look up the user's current location in a database, and then route the call appropriately.

As more and more users become mobile, wireline networks will have to begin to recognize the concept of mobility. The first step toward incorporating mobility concepts into the landline network is now being taken with the assignment of special "500" numbers. If this nongeographic prefix is used in place of an area code (e.g., (500) 123-4567), it indicates to wireline switches that the user could be mobile. Wireline carriers are currently using "500" numbers for an advanced call-forwarding service. Customers use a touch-tone phone to update a database that records the phone number to which calls should be forwarded. However, with current technology, it is not possible for a wireless network to automatically update this location database as a customer moves from city to city. True integration will require that the wireless industry's mobility management technology work with the wireline industry "Intelligent Network" call routing technology, which is only now becoming possible.[24] It will also require business arrangements that permit wireline and wireless carriers to have access to each other's location databases (see chapter 7).

[22] "News from JSAC," *IEEE Communications*, vol. 33, No. 5, May 1995, p. 12.

[23] See discussion in National Regulatory Research Institute (NRRI), *Competition and Interconnection: The Case of Personal Communications Services*, July 1994, Columbus, Ohio, pp. 20-24.

[24] Brenda E. Edwards and Paul B. Passero, "Testing PCS in Pittsburgh," *Bellcore Exchange*, September 1993, p. 14.