

Wireless Systems and Technologies: An Overview

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The wondrous inventions of Marconi brought about the first wireless revolution, which dramatically transformed the ways people worked and played. The telecommunications industry is now in the midst of a second wireless revolution, which is projected to have an impact as large as that of the original. The current revolution began with the invention of cellular communications technology. As new discoveries were made and cellular technology advanced, another generation of wireless applications has emerged during the past decade. Recent developments, including AT&T's proposed \$12.6 billion merger with McCaw Cellular Communications Inc., whose network now spans nearly one-third of the United States, provide overwhelming proof of the tremendous potential of these technologies. Future applications will make it easier than ever for people to avail themselves of anywhere, anytime voice, data, and messaging services through the telecommunications network. This paper discusses the development of current cellular applications and technologies, and also explores the expanding wireless telecommunications network of the future.

Introduction

The vision of a "seamless" wireless network is not just some distant dream of high technologists. It is the demand of today's communications-centered marketplace. Already, cordless telephones are providing instant communications mobility in our homes and offices, and wireless local area networks (LANs) are being used for high-speed data networking inside buildings. Cellular service and paging systems provide communications coverage virtually everywhere in between the home and office. And there are innumerable wireless remote-control devices that make our lives easier and more fun. In the not-too-distant future, people will find it quite ordinary to:

- Pay highway tolls on the way to work by means of a wireless, electronic toll-collection system
- Carry a notebook, or palm-sized personal digital assistant, with a wireless interface that provides access to a range of personal information and messaging services

- Place and receive calls throughout the day on portable, personal telephones that access either an office wireless network, when inside an office building, or a public, personal communications network (PCN) when outside an office building.

Emerging wireless systems and services will provide the technology to allow people and machines to communicate anytime, anywhere using voice, data, and messaging services through telecommunications.

This issue of the *AT&T Technical Journal* provides a snapshot of wireless systems and technologies. It covers the key technologies and innovations at AT&T for emerging digital cellular systems; describes advanced signal-processing technologies, which hold promise of further increasing the quality and capability of digital wireless systems; describes speech-coding techniques that address the impairments found in indoor wireless environments; and reviews the technical requirements and solutions of a high-speed, wireless LAN.

Cellular: Going Digital

The current wireless revolution is being fueled by the rapid growth of cellular-based services and the technology advances associated with that growth. The cellular concept was first developed and implemented in the United States in the late-1970s and early 1980s.¹ Prior to cellular technology, mobile radio systems were single-cell systems. In other words, a fixed number of radio channels was used for transmitting and receiving information over a single geographic service area; the service area was limited by the range of the base transmitting antenna. If a channel was in use, it could not be used by any other user in that service area. The overall capacity of the single-cell system was limited by the number of radio channels allocated to it.

The cellular concept called for dividing a service area into a number of small cells, and only using a subset of the radio channels in any given cell. Radio channels could be reused in cells that were far enough apart, which kept co-channel interference below acceptable levels (see Figure 1). For a fixed amount of spectrum, system capacity could then be increased by reducing the size of the cells, thereby increasing the number of times a radio channel could be reused.²

While the concept was simple, the implementation was both a regulatory and technical challenge. First, spectrum had to be made available and operator licenses awarded. These were not simple tasks, given that:

- There was no spectrum available in the most desirable frequency bands.
- Seeing the large market opportunity, virtually everyone in (and out of) the communications business wanted the opportunity to obtain a license.

The regulatory issue was solved in the United States by making available 50 megahertz (MHz) of spectrum (previously allocated for UHF television), and awarding two licenses (25 MHz each) in each service area. (Cellular was initially allocated 40 MHz, with an additional 10 MHz allocated a few years later.)

Second, a system had to be developed that could track mobile units as they moved from cell to cell. This meant delivering calls to a unit, wherever it happened to be, and maintaining a connection as a unit moved within a cell and from one cell to the next. These technical issues were solved in the United States by the advanced mobile phone service (AMPS)³. Similar systems were later developed in other countries. The AMPS system

Panel 1. Abbreviations, Acronyms, and Terms

AMPS—advanced mobile phone service
CCITT—Consultative Committee for International Telephone and Telegraph
CDMA—code-division multiple access, a radio-access technology
co-channel interference—distortion of a system's radio signal by other nearby systems using the same frequencies
CRC—cycle redundancy check, a technique used to minimize channel errors in a radio system
CT-2—cordless telephone 2, a second-generation digital cordless system
diversity—a technique by which radio signals are received over two or more independent channels in order to mitigate fading and increase capacity
DQPSK—differential quadrature phase-shift keying, a modulation technique
FCC—Federal Communications Commission
FEC—forward error correction
FSK—frequency shift keying, a modulation technique
GMSK—Gaussian minimum shift key, a modulation technique
GSM—Global System for Mobile Communications
IC—integrated circuit
ISDN—integrated services digital network
ISM bands—industrial, scientific and medical bands allocated by the FCC that are often used by unlicensed (e.g., cordless) systems
LAN—local area network
multipath interference—reflection of radio waves off buildings or other structures, causing a single signal to arrive at the receiving antenna as multiple signals at slightly different times
PCN—personal communications network
service zone—categorization of end-user environments used to manage the appropriate wireless architectures and plan the evolution of technology
spectrum—the entire band of available radio frequencies for a given application, authorized for use by the FCC
TDMA—time-division multiple access, a radio-access technology
UHF—ultra high frequency
VHF—very high frequency

used sophisticated signaling, between mobile units and mobile switching centers, to track and monitor mobile units, control the radio transmission link, and perform real-time hand-offs from one cell to another. ("Hand-off" is the term used to describe how cellular systems

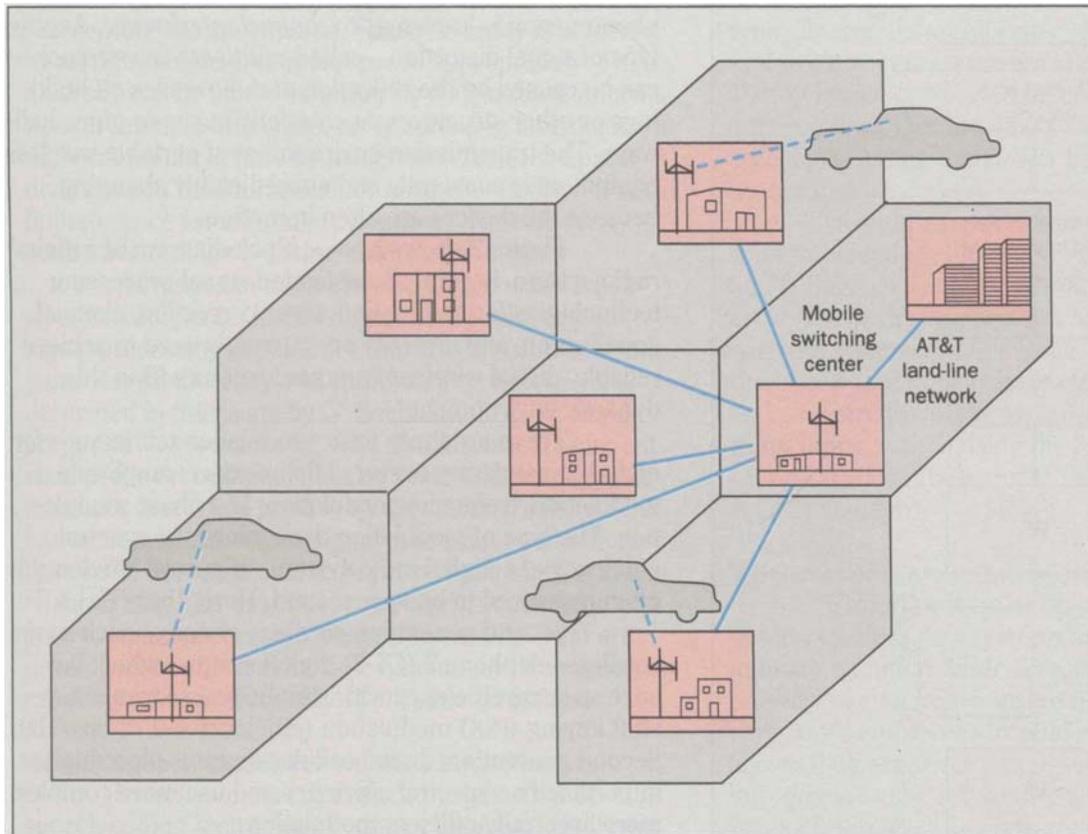


Figure 1. A wireless system divides service areas into a number of small cells, using only a subset of the radio channels in any given cell. Channels can be reused in cells that are far enough apart, which keeps co-channel interference within acceptable limits.

transfer a call between radio channels in different cells.) With a mere 50 MHz of spectrum, there are now over 11 million subscribers to cellular service in the United States, and the number is growing rapidly.

Current, first-generation cellular systems are based on analog FM radio technology. With the objective of improving quality and increasing capacity, second-generation cellular systems—based on digital radio technology and advanced networking principles—are now being developed and deployed worldwide. Radio-access technology determines the quality and network capacity of a system. These second-generation systems use either time-division multiple access (TDMA) or code-division multiple access (CDMA) technology to increase overall system capacity by a factor of three to ten over existing analog cellular systems. These second-generation systems also use principles derived from integrated services digital network (ISDN) and intelligent networks to provide end-users with “seamless” roaming and access to a wider range of telecommunications services.

In this issue, T. P. Bursh Jr., et al., describe and explain the most popular digital cellular systems, specific Autoplex[®] system implementations, and future trends.⁴ Also in this issue, M. A. Gauldin, et al., describe how the AT&T 5ESS[®] digital switch is being used as the next-generation mobile switching center, through the re-use of existing hardware and incremental extensions of the existing software architecture.⁵

Wireless Signal-Processing Technologies

Maximizing spectral efficiency—while maintaining a high-quality communications channel under sometimes harsh and unpredictable conditions—could be the largest technical challenge the wireless industry faces. Unlike physical media, such as copper or fiber, which provide a somewhat predictable and controlled transmission environment, the free-space environment for wireless systems is constantly changing.^{6,7}

Radio signals, for example, can be distorted by other nearby systems using the same frequencies. This

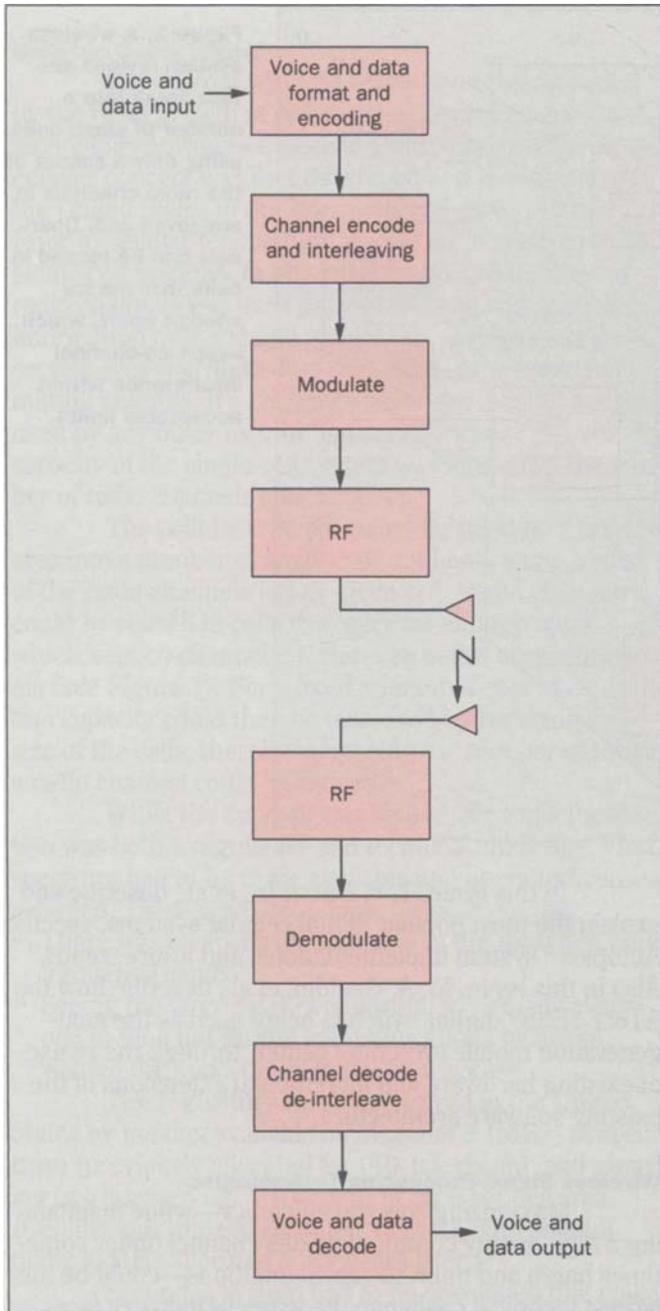


Figure 2. A digital radio system operates in a dynamic environment. In order to achieve reliable, digital wireless communications, several sophisticated signal-processing technologies for modulation, error correction, channel equalization, and diversity are used.

phenomenon is known as *co-channel interference*. Another type of signal distortion—called *multipath interference*—can be caused by the reflection of radio waves off buildings or other structures, such as city buses or office hallways. The transmission environment of portable wireless equipment is constantly and unpredictably changing, because the devices are often in motion.

Figure 2 shows a basic block diagram of a digital radio system. Several sophisticated signal-processing technologies for modulation, error correction, channel equalization, and diversity are currently used to achieve reliable, digital wireless communications within this dynamic environment.

There are three basic modulation techniques for digital transmission over a radio interface: amplitude modulation, frequency modulation, and phase modulation. The type of modulation determines the spectral efficiency of a digital radio system. (Spectral efficiency is often measured in bits-per-second/Hertz [bps/Hz].)

Second-generation cordless systems, such as the cordless telephone 2 (CT-2) digital system, which balance spectral efficiency with simplicity, use frequency shift keying (FSK) modulation (efficiency = 0.72 bps/Hz). Second-generation, digital cellular systems place higher importance on spectral efficiency and use more complex, more spectrally efficient modulation.

The pan-European Global System for Mobile Communications standard (GSM) uses Gaussian minimum shift key (GMSK) modulation, which provides a spectral efficiency of 1.35 bps/Hz. The North American digital cellular standard (IS54) uses differential quadrature phase-shift keying (DQPSK) modulation, with a spectral efficiency of 1.62 bps/Hz.

Convolutional channel coding determines how information is reliably transmitted over the modulated channel. Channel coding with forward error correction (FEC) is essential for reliable digital radio transmission. In fact, convolutional channel coding is used in all of the current digital cellular systems. Systems designed to the IS54 standard use convolutional channel coding, cycle redundancy check (CRC) codes, and interleaving to minimize channel errors.

A number of *diversity techniques* can be used to mitigate fading and increase capacity.⁸ The principle behind diversity is that the transmitted information is received over two or more independent channels. Several combining techniques can then be used to

reassemble the information. Space diversity is achieved by using multiple antennas, spaced appropriately. Time diversity can be achieved either by transmitting information on multiple time slots, or by receiving information at different points in time by using *rake receivers*. Space diversity can be impractical for portable telephones with limited space for antennae placement. Time diversity is ineffective for slowly fading indoor channels.

Advances in the technology have made it possible to incorporate increasingly more sophisticated signal-processing capabilities into small, portable terminals. Several diversity and combining techniques are described in this issue by N. Seshadri, C. E. W. Sundberg, and V. Weerackody, who also discuss the current state-of-the-art of digital cellular systems and technology advances that could provide quality comparable to wireline systems.⁹ Advanced signal-processing technologies have been demonstrated to improve the quality of radio-channel links (for example, CDMA and TDMA). As low-power, signal-processing integrated circuits (ICs) are developed, complex electronic functions will be incorporated into compact, hand-held portable terminals.

Robust Speech Coding for Wireless Environments

In terms of overall impact, the selection of speech-coding technology is one of the most significant engineering choices for wireless voice systems. Consider that the speech coder affects system capacity, link quality, delay, power requirements, and terminal size, as well as the overall system cost. While a low-bit-rate coder may provide increased system capacity, it may result in lowering speech quality. A higher bit-rate coder may improve speech quality—but it may be less spectrally efficient if the same modulation scheme is used.

Choosing the proper speech coder for a wireless voice system requires the careful balancing of a number of important factors. They include spectral efficiency, performance under impaired conditions, delay, power consumption, memory requirements, and cost.

The industry trend for cellular systems is toward maximizing capacity while maintaining quality. The pan-European GSM system employs a 13 kbits/s coder. The North American IS54 standard employs an 8 kbits/s coder. Both systems are planned to evolve to half-rate coders (6–4 kbits/s).

Systems designed exclusively for short-range or indoor applications, such as wireless PBX installations,

typically use higher bit-rate coders. The European CT-2 and DECT systems, as well as the Japanese Personal Handy Phone (PHP) system, employ 32 kbits/s ADPCM voice coding. The 32 kbits/s ADPCM coder requires less signal processing than lower bit-rate coders, but utilizes more radio bandwidth.

Given the variety of impairments that can affect a communications link, such as co-channel interference and fading, a speech coder that performs well in an error-free environment is not necessarily the best one for wireless systems. In this issue, K. Gould, et al., discuss the effects that impairments can have on speech quality, and compare the performance of alternate methods of transcoding speech using the 32 kbit ADPCM Consultative Committee for International Telephone and Telegraph (CCITT) standard.¹⁰

Wireless Local Area Networking

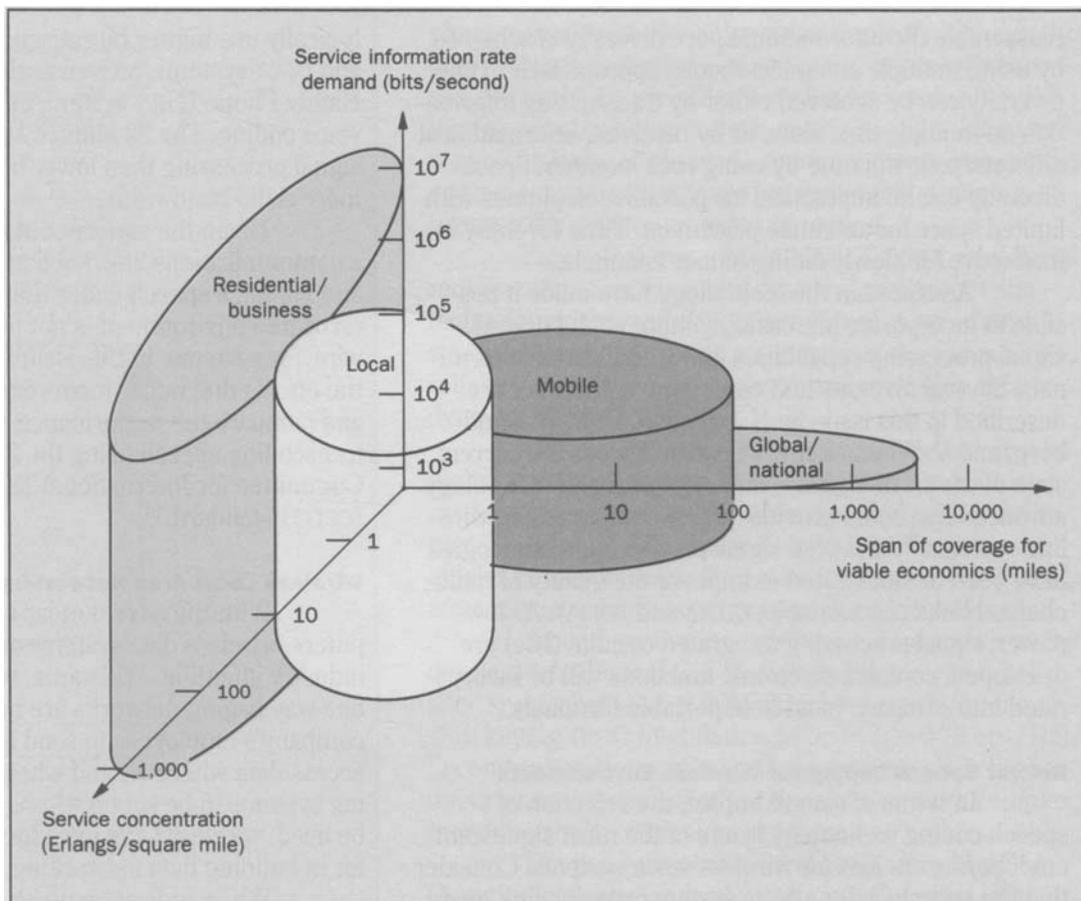
With the advent of lap-top and palm-top computers, wireless data systems are receiving increased industry attention. Wide-area, two-way packet radio and one-way paging networks are making it possible for a company's employees to send and receive messages and access data wherever and whenever required. By allowing systems to be set up where traditional wiring cannot be used, wireless LANs introduce a new level of freedom for in-building data networking.

While wide-area, wireless data networks provide relatively narrow bandwidth (typically less than 9.6 kbits/s), indoor wireless LANs can operate at much higher speeds. The NCR WaveLAN[®] system is an indoor, wireless LAN that achieves a raw data rate of 2 Mbits/s using 12 MHz of bandwidth. The LAN operates in the 900 MHz industrial, scientific and medical (ISM) band under Federal Communications Commission (FCC) spread-spectrum regulations. B. Tuch describes the design philosophy and technical tradeoffs encountered in the development of this high-speed, ISM-band wireless LAN.¹¹

The Future Is "Seamless"

Currently, there is no wireless technology or system that will support all applications and end-user needs. There is a versatile and expanding set of systems and technologies that comprise the wireless universe, ranging from narrow-band cordless systems and wide-band wireless LANs, to advanced digital cellular technology. Researchers and system architects are developing

Figure 3. Researchers and system architects are developing methods to support wireless applications “seamlessly” across varying environments. Four service zones can be used to categorize end-user environments, manage the appropriate architectures, and plan the evolution of technology.



methods to support applications “seamlessly” across varying environments and technologies.¹² *Service zones* can be used to categorize end-user environments, manage the appropriate wireless architectures, and plan the evolution of technology. The four basic service zones are described, and illustrated in Figure 3:

- The *global/national service zone* is characterized by: ubiquitous radio coverage throughout a region, country, or the entire globe (even in the most remote areas); low user densities; and minimal bandwidth requirements. Wireless service in this service zone is typically provided by satellite systems having megacell coverage areas and radii of hundreds of miles. These satellite systems can be either the geosynchronous or low-earth-orbit types. While satellite systems provide maximum coverage, they are typically limited in capacity, because their frequencies cannot be reused as often.
- The *mobile service zone* is characterized by radio coverage in urban, suburban, and populated rural areas, such as villages and small communities along highways. This environment is characterized by medium to high user densities, low to medium bandwidth requirements (tens of kbits/s) and high-speed vehicular service. Service in this zone is typically provided by terrestrial-based macro-cells, coverage areas with radii of one to 20 miles, and relatively high-powered transmission. The North American AMPS system is a good example of a system designed for the mobile environment.
- The *local/micro service zone* is characterized by radio coverage in densely populated urban areas, shopping malls, and transportation centers, such as train stations. This environment is characterized by high end-user densities, medium bandwidth requirements, hand-held portable terminals, and low-speed mobility (less than ten miles per hour). Service in this zone is

Panel 2. Electromagnetic Spectrum

The lifeblood of all wireless systems is electromagnetic spectrum. There is only a fixed amount of usable spectrum and—in the United States—it is already allocated for one or another application. Commercial television and radio, communication satellites, point-to-point microwave transmission equipment, private mobile radios, paging devices, cordless telephones, and countless other systems compete for spectrum. For example, North American cellular systems have 50 MHz of spectrum allocated to them. The 12 VHF television channels require 72 MHz of spectrum. The NCR WaveLAN system uses 12 MHz of spectrum. And current-generation analog cordless telephones operate in approximately 1 MHz of spectrum.

New applications, such as wireless PBX systems and PCNs, require the allocation of even more spectrum. The international standards body that develops radio standards, CCIR, has estimated that over 200 MHz of spectrum is required for the operation of future public land mobile telecommunications systems. The lack of available spectrum is often the single largest impediment to the development and introduction of a new wireless product or service. The challenge to the wireless industry is to find ways to eliminate this bottleneck to make way for a new generation of products

and services that will meet emerging needs.

There is a regulatory solution to this challenge: spectrum reallocation. In other words, current allocations can be identified and moved (or “grandfathered”). Then, through rule making, the new applications are allowed to begin using the spectrum. This is what the FCC did in the 1970s to create the cellular bands, and what it is currently doing to make spectrum available for PCNs in the 1850–1990 MHz emerging-technologies band. Unfortunately, the regulatory deliberations can be slow, and the rule-making process can take years to complete. The reasons for this include the need to be fair to incumbent spectrum users, and dealing with the administrative issues to guide the new industry in the right direction.

There are also technical solutions to spectrum shortage. These include the development of new, more spectrally efficient technologies, such as the emerging digital cellular systems, and technologies that push out the boundary of usable spectrum. AT&T is conducting research to determine whether higher, less congested 6 GHz frequencies can be used for commercial service. Of late—and at the encouragement of the FCC—there has been significant activity in the industry to develop technical spectrum-shortage solutions.

typically provided by terrestrial-based systems having microcell coverage areas with radii of less than one mile. By their very nature, microcellular systems are high in capacity, because spectrum can be reused often. They can also operate on low-power, uncomplicated radio interfaces, providing the benefits of long battery life and small terminal size. Microcellular systems are suited for both mobile and local applications.

- The *indoor/pico service zone* is characterized by in-building radio coverage, low to high user densities, medium to high bandwidth requirements (Mbits/s), and very low mobility. Service in this zone is typically provided by pico-cellular systems, with cell size measured in hundreds of feet. The small cell sizes of pico-cellular systems provide the opportunity for high-bandwidth systems that can support high-speed data systems, and even multimedia applications.

The wireless vision calls for the capability of using a single voice or data terminal, even as an end-user

moves from one wireless environment to the next. International and regional standards bodies are considering how to develop standards that will allow for “seamless” service across all environments. These considerations range from a single, all-purpose radio interface, to a family of modular interfaces built from readily available components.

With progress continuing in technology, standards establishment, and regulatory rule making, the vision of “seamless,” end-to-end global wireless service could become a reality within the next decade.

Conclusion

Rapid progress in digital wireless technology promises to make voice, data, and video services available anytime, anyplace. Ready access to needed information can often make the difference between success and failure. In the business world, a company having the capability to remain in constant contact with its field

service technicians—in real time—will have more highly satisfied customers, a more productive work force, and a distinct competitive edge.

Information access on demand can also improve the quality of one's personal life. It can mean the difference between frustration and delight, or even life and death. Whether handling an emergency or just a simple change in plans, wireless communications can help bring people together and make their lives much easier.

As you will see in reading this issue of the *AT&T Technical Journal*, wireless technology is rapidly evolving to support this exciting new world of anytime, anywhere communications.

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(Manuscript approved September 1993)

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