CHAPTER 17.5
WIRELESS NETWORKS

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The recent past has seen fast-moving developments in the field of telecommunications. Wireless communications in particular continue to experience growth at an unprecedented rate. This is partly caused by our growing dependence on computer, cellular phone, pagers, fax machines, e-mail, and the Internet. The demand for real-time information exchange is being made on an increasingly mobile workforce. Many jobs require workers to be mobile, e.g., inventory clerks, healthcare workers, policemen, and emergency care specialists. It is estimated that roughly 48 million U.S. workers cannot do without one form of tetherless communication. Their work tools must be mobile.

Wireless refers to any communication that uses electromagnetic or acoustic waves as a medium, rather than a wire connection. It could be the technology that allows seamless and instant access to information across any number of devices and platforms. Wireless technologies are targeted to meeting certain needs, which include:

- Bypass physical barriers (roads, railroads, buildings, rivers, and so forth)
- Remote data entry
- Mobile objects (car, airplanes, ships, and so forth)
- Connectivity to hard-to-wire places
- Worldwide connectivity for voice, video, and data communications
- Satellite communications
- Inexpensive setup

Wireless communication works on the same set of fundamental principles, whether it is computer nodes on a local area network (LAN) or the common cordless telephone. In this chapter, those common fundamentals are presented first. We will then discuss cordless phones, paging, cellular networks, personal communications systems (PCSs), and wireless data networks such as cellular digital packet data (CDPD), wireless LAN, and wireless asynchronous transfer mode (ATM).

PROPAGATION CHARACTERISTICS

The major factors that affect the design and performance of wireless networks are the characteristics of radio or electromagnetic wave propagation over the geographical area. The concept of propagation refers to the various ways by which an electromagnetic (EM) wave travels from the transmitting antenna to the receiving antenna. Propagation of EM wave may be regarded as a means of transferring energy or information from one point (a transmitter) to another (a receiver). Here we describe the free space propagation model and the empirical path loss formula.

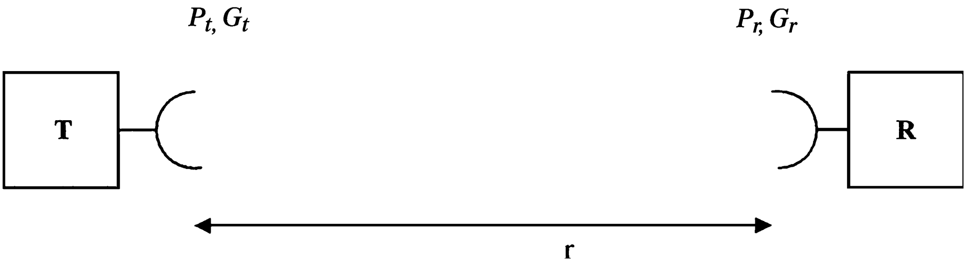

FIGURE 17.5.1 Basic wireless systems.

Free Space Propagation Model

Wireless links typically experience free space propagation. The free space propagation model is used in predicting received signal strength when the transmitter and receiver have a clear line-of-sight path between them. If receiving antenna is separated from the transmitting antenna in free space by distance r, as shown in Fig. 17.5.1, the power received P_r by the receiving antenna is given by Friis equation

$$P_r = G_r G_t \left(\frac{\lambda}{4\pi r}\right)^2 P_t \tag{1}$$

where P_t = transmitted power
G_r = receiving antenna gain
G_t = transmitting antenna gain
λ = wavelength ($=c/f$) of the transmitted signal

Friis equation relates the power received by one antenna to the power transmitted by the other, provided that the two antenna are separated by $r > 2d^2/\lambda$, where d is the largest dimension of either antenna. Thus, Friis equation applies only when the two antennas are in the far-field of each other. It also shows that the received power falls off as the square or the separation distance r. The power decay as $1/r^2$ in wireless systems as exhibited in Eq. (1) is better than the exponential decay in power in a wired link. In actual practice, the value of the received power given in Eq. (1) should be taken as the maximum possible because some factors can serve to reduce the received power in a real wireless system.

From Eq. (1), we notice that the received power depends on the product $P_t G_t$. The product is defined as the *effective isotropic radiated power* (EIRP), i.e.

$$\text{EIRP} = P_t G_t \tag{2}$$

The EIRP represents the maximum radiated power available from a transmitter in the direction of maximum antenna gain relative to an isotropic antenna.

Empirical Path Loss Formula

In addition to the theoretical model presented in the preceding section, there are empirical models for finding path loss. Of the several models in the literature, Okumura et al.'s model is the most popular choice for analyzing mobile-radio propagation because of its simplicity and accuracy. The model is based on extensive measurements in and around Tokyo between 200 MHz and 2 GHz, compiled into charts, which can be applied to VHF and UHF mobile-radio propagation. The medium path loss is given by

$$L_p = \begin{cases} A + B\log_{10}(r), & \text{for urban area} \\ A + B\log_{10}(r) - C, & \text{for suburban area} \\ A + B\log_{10}(r) - D, & \text{for open area} \end{cases} \tag{3}$$

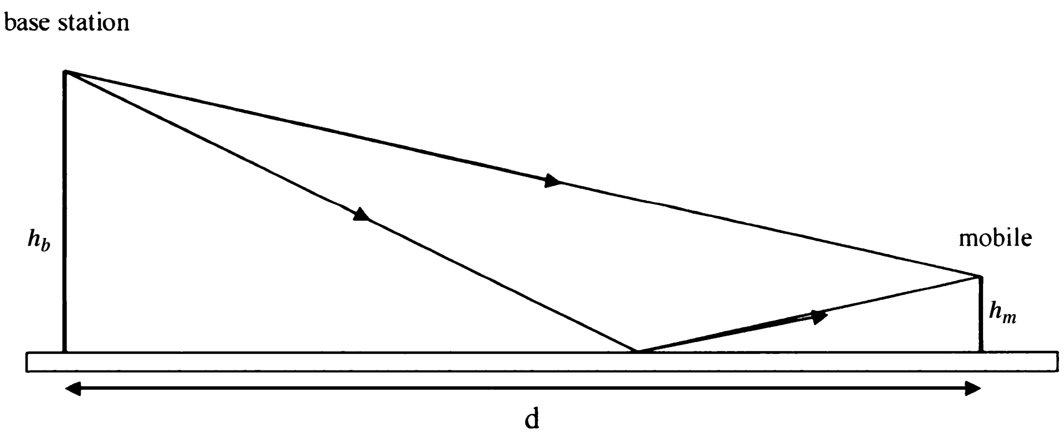

FIGURE 17.5.2 Radio propagation over a flat surface.

where r (in kilometers) is the distance between the base and mobile stations, as illustrated in Fig. 17.5.2. The values of A, B, C, and D are given in terms of the carrier frequency f, the base station antenna height h_b (in meters), and the mobile station antenna height h_m (in meters) as

$$A = 69.55 + 26.16 \log_{10}(f) - 13.82 \log_{10}(h_b) - a(h_m) \tag{4a}$$

$$B = 44.9 - 6.55 \log_{10}(h_b) \tag{4b}$$

$$C = 5.4 + 2\left[\log_{10}\left(\frac{f}{28}\right)\right]^2 \tag{4c}$$

$$D = 40.94 - 19.33 \log_{10}(f) + 4.78[\log_{10}(f)]^2 \tag{4d}$$

where

$$a(h_m) = \begin{cases} 0.8 - 1.56\log_{10}(f) + [1.1\log_{10}(f) - 0.7]h_m, & \text{for medium/small city} \\ 8.28[\log_{10}(1.54h_m)]^2 - 1.1, & \text{for } f \geq 200 \text{ MHz} \\ 3.2[\log_{10}(11.75h_m)]^2 - 4.97, & \text{for } f < 400 \text{ MHz} \\ & \text{for large city} \end{cases} \tag{5}$$

The following conditions must be satisfied before Eq. (3) is used: $150 < f < 1500$ MHz; $1 < r < 80$ km, $30 < h_b < 400$ m; $1 < h_m < 10$ m. Okumura's model has been found to be fairly good in urban and suburban areas, but not as good in rural areas.

CORDLESS TELEPHONY

Cordless telephones first became widespread in the mid-1980s as products became available at an affordable price. The earliest cordless telephone used narrow band technology and used separate channels for frequency channel for transmission to/from the base station. They had limited range, poor sound quality, and poor security—people could easily intercept signals from another cordless phone because of the limited number of channels. The Federal Communications Commission (FCC) granted the frequency range of 47 to 49 MHz for cordless phones in 1986 and the frequency range of 900 MHz in 1990. This improved their interference problem, reduced the power needed to run them, and allowed cordless phones to be clearer, broadcast a longer distance, and choose from more channels. However, cordless phones were still quite expensive.

The use of digital technology transformed the cordless phone. Digital technology represents the voice as a series of 0s and 1s, just as a CD stores music. Digital cordless phones in the 900-MHz frequency range were introduced in 1994. Digital signals allowed the phones to be more secure and decreased eavesdropping. With the introduction of digital spread spectrum (DSS) in 1995, eavesdropping on the cordless conversations was practically made impossible. The opening up of the 2.4-GHz range by the FCC in 1988 increased the distance over which a cordless phone can operate and further increased security. With the cordless phone components getting smaller, more and more features and functions can be placed in phones without making them any bigger. Such functions may include voice mail, call screening, and placing outside calls. With many appealing features, there continues to be a strong market interest in cordless telephones for residential and private office use.

As shown in Fig. 17.5.3, the cordless telephone has gone through an evolution. This started with the 46/49 MHz telephones. Although earlier cordless telephones existed, the 46/49 MHz cordless telephones were the first to be produced in substantial quantities. The second generation used 900-MHz frequency range resulting in longer range. The third generation introduced the spread spectrum telephones in the 900 MHz band. The fourth generation changed from 900-MHz to 2.4-GHz band, which is accepted worldwide. The fifth generation of cordless telephones is emerging now and employs time division multiple access (TDMA).

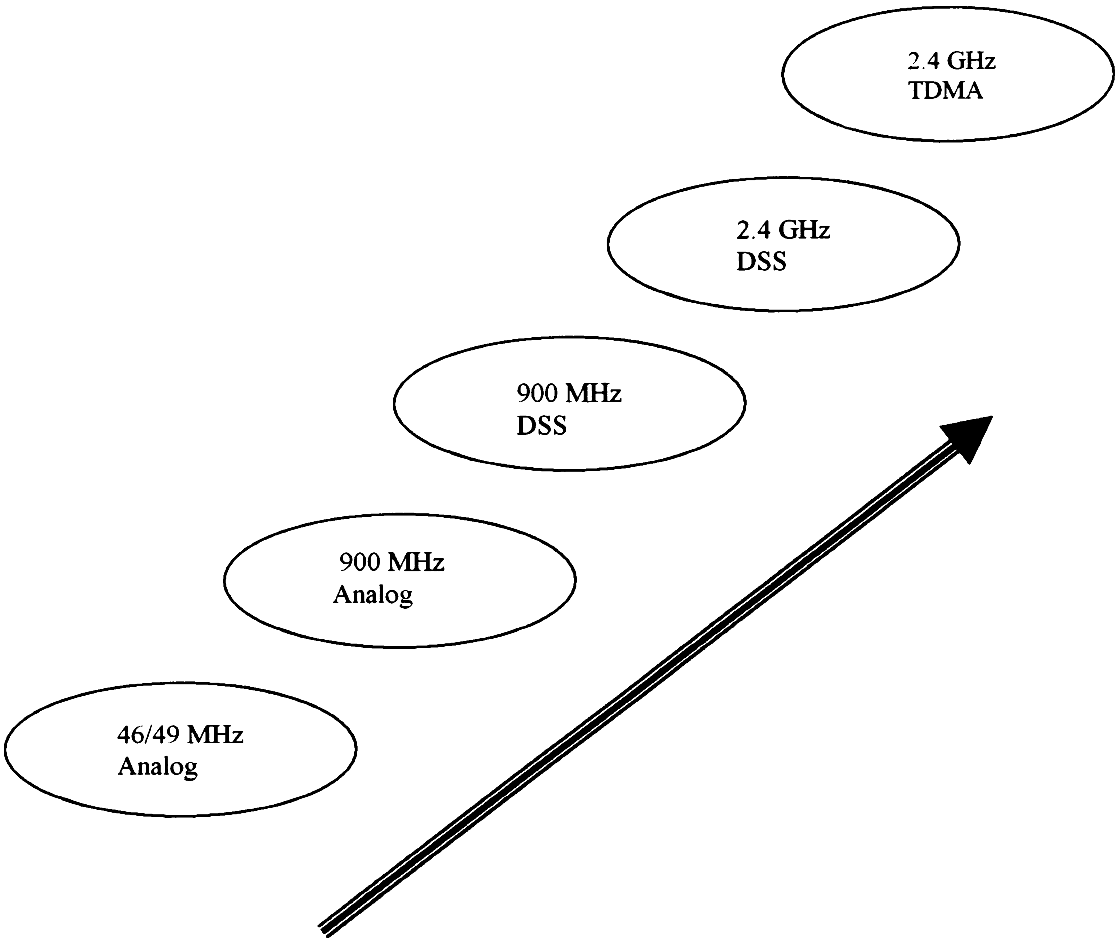

FIGURE 17.5.3 Evolution of cordless phone.

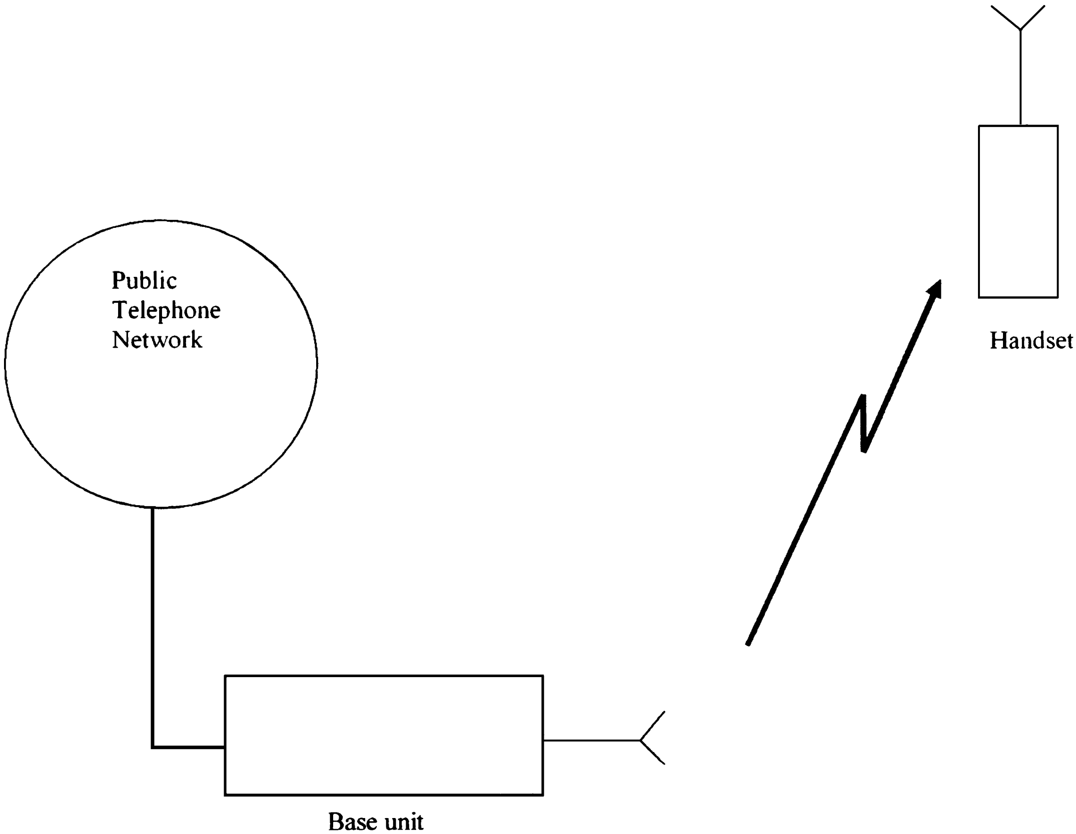

FIGURE 17.5.4 Cordless telephone system configuration.

Basic Features

A cordless phone basically combines the features of telephone and radio transmitter/receiver. As shown in Fig. 17.5.4, it consists of two major units: base and handset. The base unit interfaces with the public telephone network through the phone jack. It receives the incoming call through the phone line, converts it to an FM radio signal, and then broadcasts that signal. The handset receives the radio signal from the base, converts it to an electrical signal, and sends that signal to the speaker, where it is converted into the sound wave. When someone talks, the handset broadcasts the voice through a second FM radio signal back to the base. The base receives the voice signal, converts it to an electrical signal, and sends that signal through the phone line to the other party. The base and handset operate on a frequency pair (duplex frequency) that allows one to talk and listen simultaneously.

Types of Cordless Telephone

Over the years, several types of cordless have been developed. These include:

- *CT1*: This first generation cordless telephone was introduced in 1983. It provides a maximum range of about 200 m between handset and base station. It is an analog phone that is primarily designed for domestic use. It employs analog radio and uses eight RF channel and frequency division multiple access (FDMA) scheme.

TABLE 17.5.1 CT1 Cordless Telephone Duplex Frequencies

Channel number	Base unit transmission frequency (kHz)	Handset transmission frequency (MHz)
1	1642.00	47.45625
2	1662.00	47.46875
3	1682.00	47.48125
4	1702.00	47.49375
5	1722.00	47.50625
6	1742.00	47.51875
7	1762.00	47.53125 or 47.44375
8	1782.00	47.54375

Operation has to be on not more than one of the pair of frequencies shown in Table 17.5.1 at any one time. As the number of users grew, so did the co-channel interference levels, while the quality of the service (customer satisfaction) deteriorated.

- *CT2*: This second generation cordless telephone uses digitized speech and digital transmission, thereby offering a clearer voice signal than analog CT1. Another advantage is that CT2 does not suffer from the inherent interference problems associated with CT1.
- *DECT*: DECT stands for digital enhanced cordless telecommunications. The DECT specification was developed by European Telecommunications Standards Institute (ETSI) and operates throughout Europe in the frequency band 1880 to 1900 MHz. DECT provides cordless telephones with the greater range, up to several hundred meters, allows encryption, provides for greater number of handsets, and even allows data communication. It uses high-frequency signals (1.88 to 1.9 GHz) and also employs time division multiple access (TDMA), which allows several conversations to share the same frequency. Although CT1, CT2, and DECT are European standards, the US PCS standards have followed these models too. DECT is being adopted increasingly worldwide.
- *PHS*: The personal hand-phone system (PHS) was introduced in Japan in 1995 for private use as well as for PCS. Unlike conventional cellular telephone systems, the PHS system employs ISDN technology. With PHS, a subscriber can have two separate telephone numbers: one for the home and the other for outside the home. The PHS system uses TDMA format because of the flexibility for call control and economy—characteristics common to the cellular system. To allow for two-way communication, forward and reverse channels are located on the same frequency by employing time-division duplex (TDD). It employs carrier spaced 300 kHz apart over a 23-MHz band from 1895 to 1918 MHz. Each carrier supports four channels—one control channel broadcast on a carrier, while three speech channels broadcast on other carrier waves. PHS is attracting attention around the world, particularly in Asian nations.
- *ISM*: The 900-MHz digital spread spectrum (DSS) cordless telephone operates in the 902 to 928 MHz industrial-scientific-medical (ISM) band. The spread spectrum systems have the additional advantage of enhanced security. The channel spacing is 1.2 MHz and there are 21 nonoverlapping channels in the band. The system is operated using TDD at a frame rate of 250 Hz. It provides clear sound, superb range, and security. It has a greater output power than other cordless phones. This increased power dramatically boosts range. The 2.4-GHz DSS cordless telephone is an upgrade of this.

Cordless telephones are categorized by the radio frequency used and whether transmission between the handset and base unit is in the form of analog or digital signals. Generally speaking, the clarity of a cordless telephone improves with the use of higher frequencies and digital technology. Regulatory authorities in each country also specify and allocate the frequencies that may be used by cordless telephones in their respective countries and all telephones intended for use in their countries must receive their approvals. All cordless telephones are approved in the respective markets in which they are sold. Table 17.5.2 shows the common cordless telephone standards and their respective frequency range. In common with all areas of communications, the trend is away from analog systems to digital systems.

TABLE 17.5.2 Comparison of Cordless Telephone Standards

	Analog cordless telephone			Digital cordless telephone		
Standard	CT1	JCT	900 MHz	DECT	PHS	ISM
Region	Europe	Japan	worldwide	Europe	Japan	USA
Frequency (MHz)	914/960	254/380	900	1880–1990	1895–1918	2400–2485
Range (km)	Up to 7	0.3	0.25	0.4	0.2	0.5

JCT—Japanese cordless telephone; PHS—Personal Hand-phone System.

PAGING

Paging started as early as 1921 when the concept of one-way information broadcasting was introduced. The 1930s saw the widespread use of radio paging by government agencies, police departments, and the armed forces in the United States. Paging systems have undergone dramatic development. Radio transmission technology has advanced and so are the computer hardware and firmware (computer program) used in radio-paging systems.

One-Way Pagers

A paging system is a one-way wireless messaging system that allows continuous accessibility to someone away from the wired communications network. In its most basic form, the person on-the-move carries a palm-sized device (the pager) that has an identification number. The calling party inputs this number, usually through the public telephone network, to the paging system which then signals the pager to alert the called party. Early paging systems were nonselective and operator assisted. Not only did it waste airtime, the system was inconvenient, labor-intensive, and offered no privacy. With automatic paging, a telephone number is assigned to each pager and the paging terminal can automatically signal for voice input from the calling party.

The basic paging system consists of the following components:

- *Input Source*: A caller enters a page from a phone or through an operator. Once it is entered, the page is sent through the public switched telephone network (PSTN) to the paging terminal for encoding and transmission through the paging system.
- *Encoder*: The encoder typically accepts the incoming page, checks the validity of the pager number, looks up the database for the subscriber's pager address, and converts it into the appropriate paging signaling protocol. The encoded paging signal is then sent to the transmitters (base stations).
- *Base Station*: This transmits page codes on an assigned radio frequency. Most base stations are designed specifically for paging but some of those designed for two-way voice can also be used.
- *Page Receivers*: These are the pagers, which are basically FM receivers turned to the same RF frequency as the paging base station in the system. A decoder in each pager recognizes the unique code assigned to the pager and rejects all other codes for selective alerting. The most basic function of the pager is alerting. On receiving its own paging code, the receiver sets off an alert that can be audible (tone), visual (flashing indicator), or silent (vibrating). Messaging functions can also include voice and/or display (numeric/alphanumeric) messaging.

Today's paging systems offer much more than the basic system described above. A paging system subscriber can be alerted anytime and at almost any place as coverage can be easily extended, even across national borders. Paging systems are increasingly migrating from tone and numeric paging, to alphanumeric paging. Alphanumeric pagers display alphabetic or numeric messages entered by the calling party. The introduction of alphanumeric pagers also enables important information/data (e.g., business, financial news) to be constantly updated and monitored. Pagers that can display different ideographic languages, e.g., Chinese and Japanese, are now available in the market. The specific language supported is determined by the computer program installed in the pager.

Two-Way Pagers

The conventional paging systems are designed for one-way communication—from network toward pagers. Such systems provide the users one or more of the following services: beep, voice messaging, numeric messaging, and alphanumeric messages. With the recent development in paging systems, it is possible to supply a reverse link and thus allow two-way paging services. Two-way paging offers some significant capabilities with distinct advantages.

Two-way paging is essentially alphanumeric paging that lets the pager send messages, either to respond to received messages or to originate its own messages. The pagers come in various shapes and sizes. Some look almost like today's alphanumeric pagers, while some add small keyboards and larger displays. Two-way paging networks employ the 900-MHz band, a small fraction of the spectrum originally meant for PCS.

Networks are built around protocols. Two-way messaging network is based on Reflex, which is basically an extension of Motorola's Flex protocol for one-way paging. Reflex is a new generation of paging protocols. But reflex is a proprietary protocol. In view of the fact that two-way paging is the dominant application for wide area wireless networks and that a set of open, nonproprietary protocols is required to enable the convergence of the two-way paging and the Internet, efficient mail submission and delivery (EMSD) has been designed. EMSD is an open, efficient, Internet messaging protocol that is highly optimized for short messages. Devices that provide two-way paging capabilities should use this protocol (e.g., dedicated pagers, cell phones, palm PCs, handheld PCs, laptops, and desktops).

The majority of pagers are used for the purpose of contacting someone on the move. The most popular type of pager used for this application is the alphanumeric pager that displays the telephone number to call back after alerting the paging subscriber. Although they are not common or cheap, the trend toward alphanumeric paging is inevitable with improved speed and better pagers. There will be more varied applications of paging such as the sending of e-mail, voice mail, faxes, or other useful information to a pager, which will also take on more attractive and innovative forms. Future pagers may compete more aggressively with other two-way technologies, such as cellular and PCS. Although paging does not provide real-time interactive communications between the caller and the called party, it has some advantages over other forms of PCS, such as cellular telephone. These include less bandwidth requirement, larger coverage area, lower cost, and lighter weight. Owing to these advantages, paging service is bound to be in a strong competitive PCS services in years to come.

With more than 51 million paging subscribers worldwide, major paging markets in the world, especially in Asia, continue to expand rapidly. With the use of pagers getting more and more integrated into our daily lives, we will be seeing a host of new and exciting applications. There will emerge satellite pagers, which will send and receive messages through satellite systems such as Iridium, ICO, and Globalstar. With the help of such pagers, it is possible to supply paging services in global scale.

CELLULAR NETWORKS

The conventional approach to mobile radio involved setting up a high-power transmitter on top of the highest point in the coverage area. The mobile telephone must have a line-of-sight to the base station for proper coverage. Line-of-sight transmission is limited to as much as 40 to 50 miles on the horizon. Also, if a mobile travels too far from its base station, the quality of the communications link becomes unacceptable. These and other limitations of conventional mobile telephone systems are overcome by cellular technology.

Areas of coverage are divided into small hexagonal radio coverage units known as *cells*. A cell is the basic geographic unit of a cellular system. A cellular communications system employs a large number of low-power wireless transmitters to create the cells. These cells overlap at the outer boundaries, as shown in Fig. 17.5.5. Cells are base stations transmitting over small geographic areas that are represented as hexagons. Each cell size varies depending on the landscape and tele-density. Those stick towers one sees on hilltops with triangular structures at the top are cellular telephone sites. Each site typically covers an area of 15 miles across, depending on the local terrain. The cell sites are spaced over the area to provide a slightly overlapping blanket of coverage. Like the early mobile systems, the base station communicates with mobiles via a channel. The channel is made of two frequencies—one frequency (the forward link) for transmitting information to the base station and the other frequency (the reverse link) to receive from the base station.

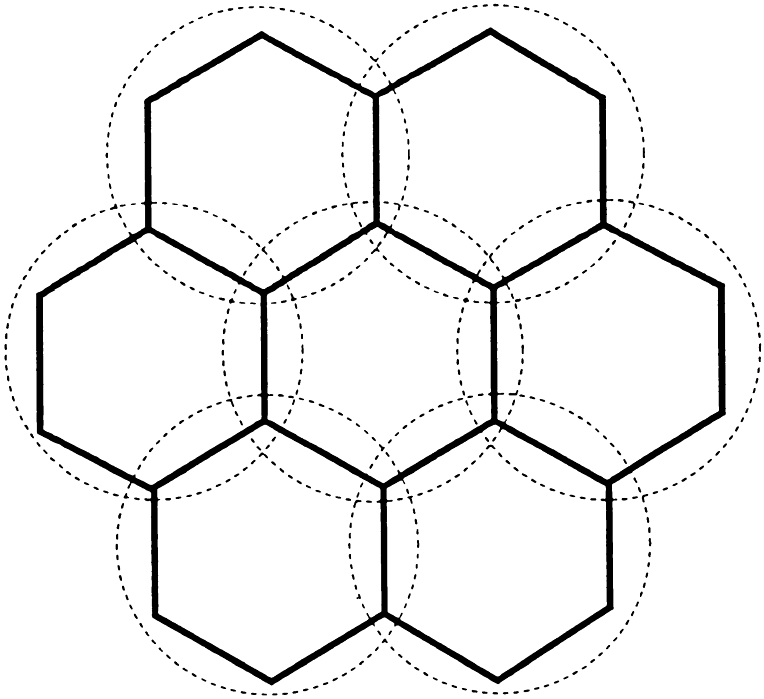

FIGURE 17.5.5 A typical wireless seven-cell pattern; cells overlap to provide greater coverage.

Fundamental Features

Besides the idea of cells, the essential principles of cellular systems include cell splitting, frequency reuse, handover, capacity, spectral efficiency, mobility, and roaming.

- *Cell Splitting*: As a service area becomes full of users, the single area is split into smaller ones. This way, urban regions with heavy traffic can be split into as many areas as necessary to provide acceptable service, while large cell can be used to cover remote rural regions. Cell splitting increases the capacity of the system.
- *Frequency Reuse*: This is the core concept that defines the cellular system. The cellular-telephone industry is faced with a dilemma: services are growing rapidly and users are demanding more sophisticated call-handling features, but the amount of the EM spectrum allocation for cellular service is fixed. This dilemma is overcome by the ability to reuse the same frequency (channel) many times. Several frequency-reuse patterns are in use in the cellular industry, each with its advantages and disadvantages. A typical example is shown in Fig. 17.5.6, where all the available channels are divided into 21 frequency groups numbered 1 to 21. Each cell is assigned three frequency groups. For example, the same frequencies are reused in cell designated 1 and adjacent locations do not reuse the same frequencies. A cluster is a group of cells; frequency reuse does not apply to clusters.
- *Handoff*: This is another fundamental feature of the cellular technology. When a call is in progress and the switch from one cell to another becomes necessary, a handoff takes place. Handoff is important because as a mobile user travels from one cell to another during a call, as adjacent cells do not use the same radio channels, a call must be either dropped or transferred from one channel to another. Dropping the call is not acceptable. Handoff was created to solve the problem. A number of algorithms are used to generate and process a handoff request and eventual handoff order. Handing off from cell to cell is the process of transferring the mobile unit that has a call on a voice channel to another voice channel, all done without interfering with the call. The need for handoff is determined by the quality of the signal, whether it is weak or strong. A handoff threshold is predefined. When the received signal level is weak and reaches the threshold, the system provides

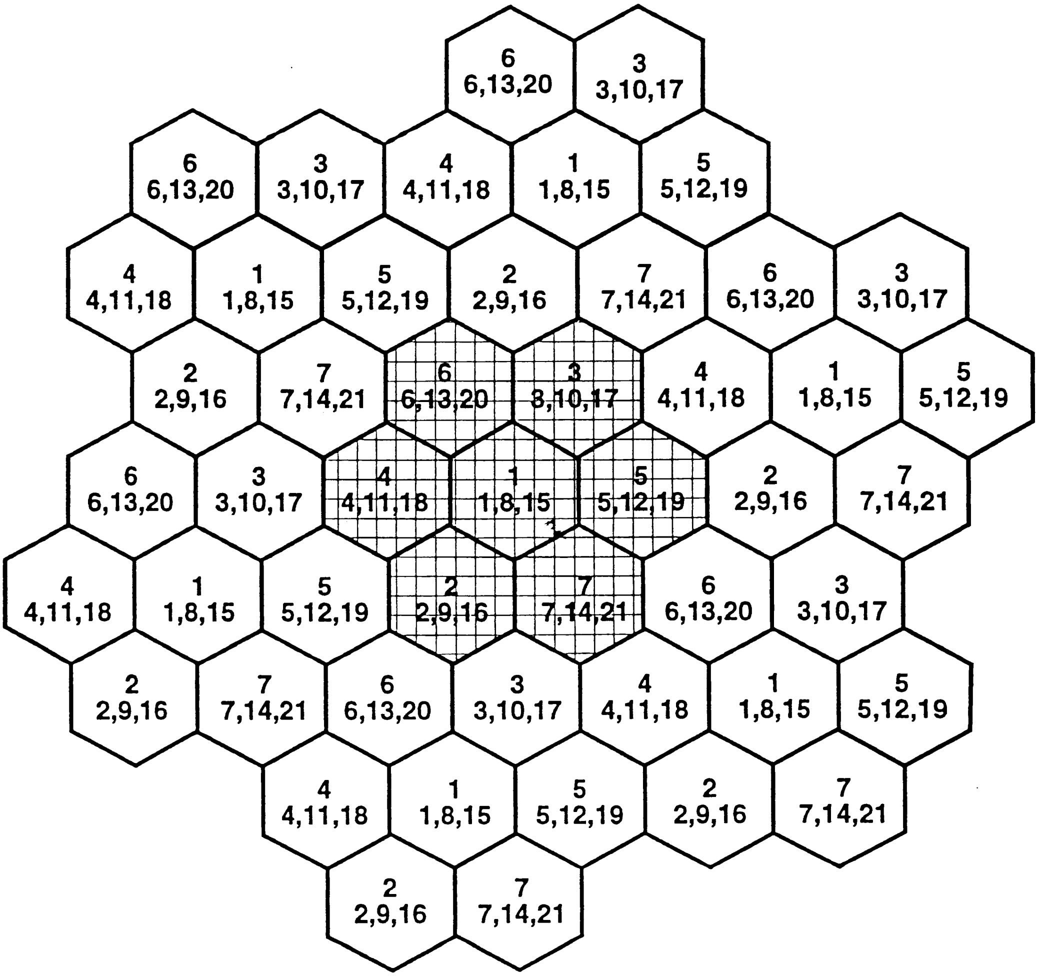

FIGURE 17.5.6 Frequency reuse in a seven-cell pattern cellular system.

a stronger channel from an adjacent cell. This handoff process continues as the mobile moves from one cell to another as long as the mobile is in the coverage area.

- *Mobility and Roaming*: Mobility implies that a mobile user while in motion will be able to maintain the same call without service interruption. This is made possible by the built-in-handoff mechanism that assigns a new frequency when the mobile moves to another cell. Because of several cellular operators within the same region using different equipment and a subscriber is only registered with one operator, some form of agreement is necessary to provide services to subscribers. Roaming is the process whereby a mobile moves out of its own territory and establishes a call from another territory. If we consider a cell (an area) with a perimeter L where ρ mobile units per unit area are located, the average number of users M crossing the cell boundaries per unit time is

$$M = \frac{\rho V L}{\pi} \tag{6}$$

where V is the average velocity of the mobile units.

- *Capacity*: This is the number of subscribers that can use the cellular system. For an FDMA system, the capacity is determined by the loading (no. of calls and the average time per call) and system layout (size of cells and amount of frequency reuse utilized). Capacity expansion is required because cellular systems must serve more subscribers. It takes place through frequency reuse, cell splitting, planning, and redesigning of the system.
- *Spectral Efficiency*: This a performance measure of the efficient use of the frequency spectrum. It is the most desirable feature of a mobile communication system. It produces a measure of how efficiently space, frequency, and time are used. Expressed in channels/MHz/km^2, channel efficiency is given by

$$\eta = \frac{\text{total no. of channels available in the system}}{\text{bandwidth} \times \text{total coverage area}}$$

$$\eta = \frac{\frac{B_w}{B_c} \times \frac{N_c}{N}}{B_w \times N_c \times A_c} = \frac{1}{B_c \times N \times A_c} \tag{7}$$

where B_w = bandwidth of the system in MHz
B_c = channel spacing in MHz
N_c = number of cells in a cluster
N = frequency reuse factor of the system
A_c = area covered by a cell in km^2

Cellular System

A typical cellular network is shown in Fig. 17.5.7. It consists of the following three major hardware components [3]:

- *Cell Site (Base Stations)*: The cell site acts as the user-to-MTSO interface, as shown in Fig. 17.5.7. It consists of a transmitter and two receivers per channel, an antenna, a controller, and data links to the cellular office. Up to 12 channels can operate within a cell depending on the coverage area.
- *Mobile Telephone Switching Office* (*MTSO*): This is the physical provider of connections between the base stations and the local exchange carrier. MTSO is also known as mobile switching center (MSC) or digital multiplex switch-mobile telephone exchange (DMS-MTX) depending on the manufacturer. It manages and controls cell site equipment and connections. It supports multiple-access technologies such as AMPS, TDMA, CDMA, and CDPD. As a mobile moves from one cell to another, it must continually send messages to the MTSO to verify its location.
- *Cellular (Mobile) Handset*: This provides the interface between the user and the cellular system. It is essentially a transceiver with an antenna and is capable of tuning to all channels (666 frequencies) within a service area. It also has a handset and a number assignment module (NAM), which is a unique address given to each cellular phone.

Cellular Standards

Because of the rapid development of cellular technology, different standards have resulted. These include:

- *Advanced Mobile Phone System (AMPS)*: This is the standard introduced in 1979. Although it was developed and used in North America, it has also been used in over 72 countries. It operates in the 800-MHz frequency band. It is based on FDMA. The mobile transmit channels are in the 825- to 845-MHz range, while the mobile receive channels are in the 870- to 890-MHz range. There is also the digital AMPS, which is also known as TDMA (or IS-54). FDMA systems allow for a single mobile telephone to call on a radio channel;

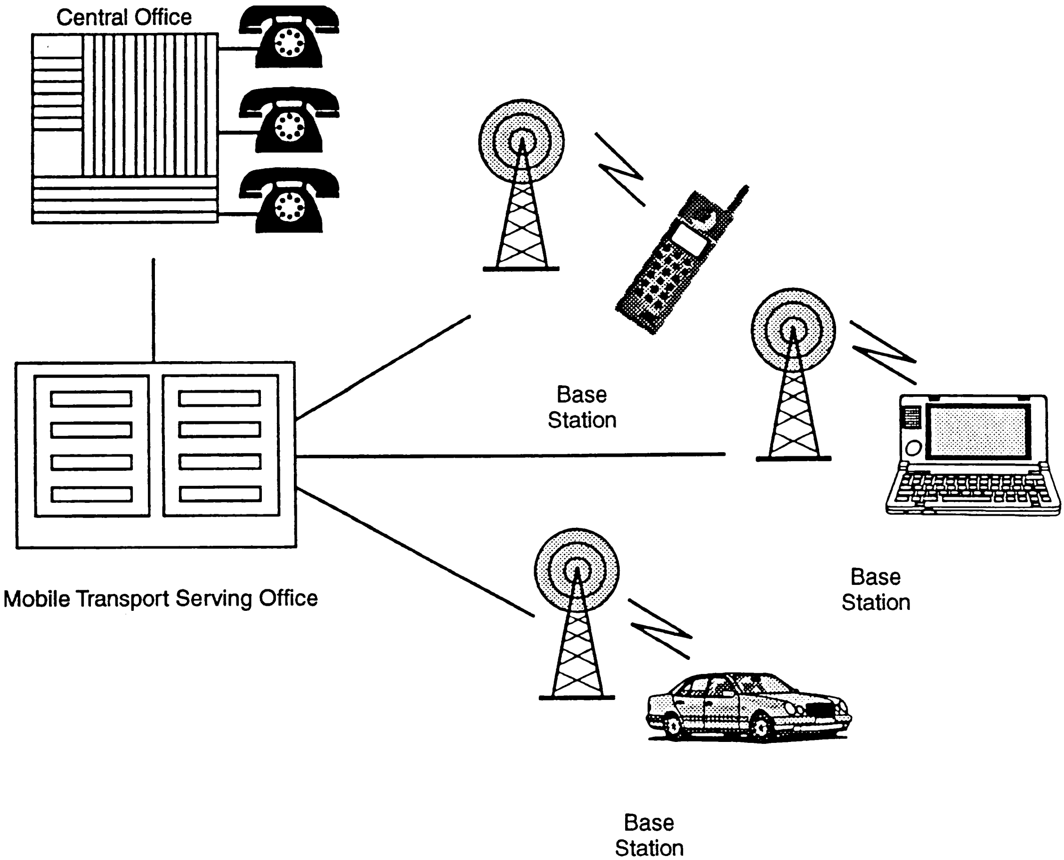

FIGURE 17.5.7 A typical cellular network.

each voice channel can communicate with only one mobile telephone at a time. TDMA systems allow several mobile telephones to communicate all the same time on a single radio carrier frequency. This is achieved by dividing their signal into time slots.

- *IS-54 and IS-95*: The IS-54 is a North American standard developed by the Electronic Industries Association (EIA) and the Telecommunications Industry Association (TIA) to meet the growing demand for cellular capacity in high-density areas. It is based on TDMA and it retains the 30-kHz channel spacing of AMPS to facilitate evolution from analog to digital systems. The IS-95 standard was also adopted by EIA/TIA. It is based on CDMA, a spread-spectrum technique that allows many users to access the same band by assigning a unique orthogonal code to each user.
- *Global System for Mobile Communications* (*GSM*): This is a digital cellular standard developed in Europe and designed to operate in the 900-MHz band. It is a globally accepted standard for digital cellular communication. It uses a 200-kHz channel divided into eight time slots with frequency division multiplexing (FDM). The technology allows international roaming and provides integrated cellular systems across different national borders. GSM is the most successful digital cellular system in the world. It is estimated that many countries outside Europe will join the GSM partnership.
- *Personal Digital Cellular* (*PDC*): This is a digital cellular standard developed in Japan. It was designed to operate in 800-MHz and 1.5-GHz bands.

- *Future Public Land Mobile Telecommunication Systems (FPLMTS)*: This is a new standard being developed in ITU to form the basis for third-generation wireless systems. It will consolidate today's increasingly diverse and incompatible mobile environments into a seamless infrastructure that will offer a diverse portfolio of telecommunication services to an exponentially growing number of mobile users on a global scale. It is a digital system based on 1.8- to 2.2-GHz band. It is being tested to gain valuable user and operator experience. In many European countries, the use of GSM has allowed cross-country roaming. However, global roaming has not been realized because there are too many of these incompatible standards.

PERSONAL COMMUNICATION SYSTEMS

The GSM digital network has pervaded Europe and Asia. A comparable technology known as PCS is beginning to make inroads in the United States. According to FCC, "PCS is the system by which every user can exchange information with anyone, at anytime, in any place, through any type of device, using a single personal telecommunication number (PTN)." PCS is an advanced phone service that combines the freedom and convenience of wireless communications with the reliability of the legacy telephone service. Both GSM and PCS promise clear transmissions, digital capabilities, and sophisticated encryption algorithms to prevent eavesdropping.

PCS is a new concept that will expand the horizon of wireless communications beyond the limitations of current cellular systems to provide users with the means to communicate with anyone, anywhere, anytime. It is called PCS by the FCC or personal communications networks (PCN) by the rest of the world. Its goal is to provide integrated communications (such as voice, data, and video) between nomadic subscribers irrespective of time, location, and mobility patterns. It promises near-universal access to mobile telephony, messaging, paging, and data transfer.

PCS/PCN networks and the existing cellular networks should be regarded as complimentary rather than competitive. One may view PCS as an extension of the cellular to the 1900-MHz band, using identical standards. Major factors that separate cellular networks from PCS networks are speech quality, complexity, flexibility of radio-link architecture, economics of serving high-user-density or low-user-density areas, and power consumption of the handsets. Table 17.5.3 summarizes the differences between the two technologies and services.

PCS offers a number of advantages over traditional cellular communications:

- A truly personal service, combining lightweight phones with advanced features such as paging and voice mail that can be tailored to each individual customer.
- Less background noise and fewer dropped calls
- An affordable fully integrated voice and text messaging that works just about anywhere, anytime
- A more secure all-digital network that minimizes chances of eavesdropping or number cloning
- An advanced radio network that uses smaller cell sites
- A state-of-the-art billing and operational support system

TABLE 17.5.3 Comparison of Cellular and PCS Technologies

Cellular	PCS
Fewer sites required to provide coverage	More sites required to provide coverage (e.g., a 20:1 ratio)
More expensive equipment	Less expensive cells
Higher costs for airtime	Airtime costs dropping rapidly
High antenna and more space needed for site	Smaller space for the microcell
Higher power output	Lower power output

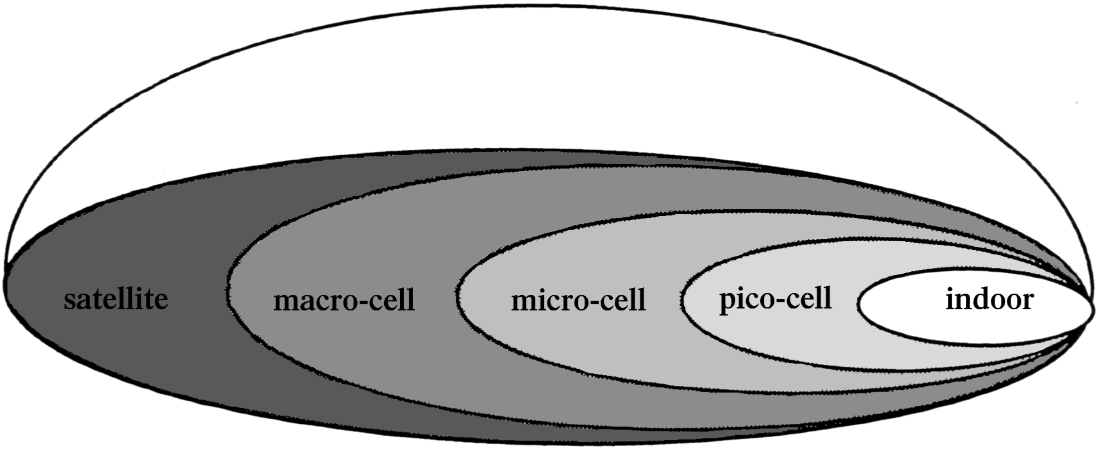

FIGURE 17.5.8 Various cell sizes.

Basic Features

PCS refers to digital wireless communications and services operating at broadband (1900 MHz) or narrowband (900 MHz) frequencies. Thus there are three categories of PCS: broadband, narrowband, and unlicensed. Broadband PCS addresses both cellular and cordless handset services, while narrowband PCS focuses on enhanced paging functions. Unlicensed service is allocated from 1890 to 1930 MHz and is designed to allow unlicensed short-distance operation.

The salient features that enable PCS to provide communications with anyone, anywhere, anytime include:

- *Roaming Capability*: The roaming service should be greatly expanded to provide universal accessibility. PCS will have the capability to support global roaming.
- *Diverse Environment*: Users must be able to use the PCS in all types of environments, e.g., urban, rural, commercial, residential, mountains, and recreational area.
- *Various Cell Size*: With PCS, there will be a mix of broad types of cell sizes: the picocell for low power indoor applications, the microcell for lower power outdoor pedestrian application, macrocell for high power vehicular applications, and supermacrocell with satellites, as shown in Fig. 17.5.8. For example, a picocell of a PCS will be in the 10 to 30 m range; a microcell may have a radius of 50 to 150 m; and a macrocell may have a radius of 1 km.
- *Portable Handset*: PCS provides a low-power radio, switched access connection to the PSTN. The user should be able to carry a single, small, universal handset outside without having to recharge its batter.
- *Single PTN*: The user can be reached through a single PTN regardless of the location and the type of service used.

The FCC frequency allocation for PCS usage is significant. FCC allocated 120 MHz for licensed operation and another 20 MHz for unlicensed operation, amounting to a total of 140 MHz for PCS, which is three times the spectrum currently allocated for cellular network. The FCC's frequency allocation for PCS is shown in Tables 17.5.4 and 17.5.5 for licensed and unlicensed operators. To use the PCS licensed frequency band, a company must obtain a license from FCC. To use the unlicensed (or unregulated) PCS spectrum, a company must use equipment that will conform with the FCC unlicensed requirements that include low power transmission to prevent interference with other users in the same frequency band.

PCS Architecture

A PCS network is a wireless network that provides communication services to PCS subscribers. The service area of the PCS network is populated with base stations, which are connected to a fixed wireline network

TABLE 17.5.4 The PCS Frequency Bands for Licensed Operation

Block	Spectrum low side (MHz)	Spectrum high side (MHz)	Bandwidth (MHz)
A	1850–1865	1930–1945	30
D	1865–1870	1945–1950	10
B	1870–1885	1950–1965	30
E	1885–1890	1965–1970	10
F	1890–1895	1970–1975	10
C	1895–1910	1975–1990	30
Total			120

through mobile switch centers (MSCs). Like a cellular network, the radio coverage of a base station is called a cell. The base station locates a subscriber or mobile unit and delivers calls to and from the mobile unit by means of paging within the cell it serves.

PCS architecture resembles that of a cellular network with some differences. The structure of the local portion of a PCS network is shown in Fig. 17.5.9. It basically consists of five major components:

- Terminals installed in the mobile unit or carried by pedestrians
- Cellular base stations to relay signals
- Wireless switching offices that handle switching and routing calls
- Connections to PSTN central office
- Database of customers and other network-related information

Since the goal of PCS is to provide anytime-anywhere communication, the end device must be portable and both real-time interactive communication (e.g., voice) and data services must be available. PCS should be able to integrator or accommodate the current PSTN, ISDN, the paging system, the cordless system, the wireless PBX, the terrestrial mobile system, and the satellite system. The range of applications associated with PCS is depicted in Fig. 17.5.10.

PCS Standards

The Joint Technical Committee (JTC) has been responsible for developing standards for PCS in the United States. The JTC committee worked cooperatively with the TIA committee working on the TR-46 reference model and ATIS committee working on the T1P1 reference model. Unlike GSM, PCS is unfortunately not a single standard but a mosaic consisting of several incompatible versions coexisting rather uneasily with one another. One major obstacle to PCS adoption in the United States has been the industry's failure to sufficiently convince customers on the advantages of PCS over AMPS, which already offers a single standard. This places the onus on manufacturers to inundate phones with features that attract market attention without compromising the benefits inherent in cellular phones. However, digital cellular technology enjoys distinct advantages. Perhaps the most significant advantage involves security because one cannot adequately encrypt AMPS signals.

TABLE 17.5.5 The PCS Frequency Bands for Unlicensed Operation

Block	Spectrum (MHz)	Bandwidth (MHz)
Isochronous	1910–1920	10
Asynchronous	1920–1930	10
Total		20

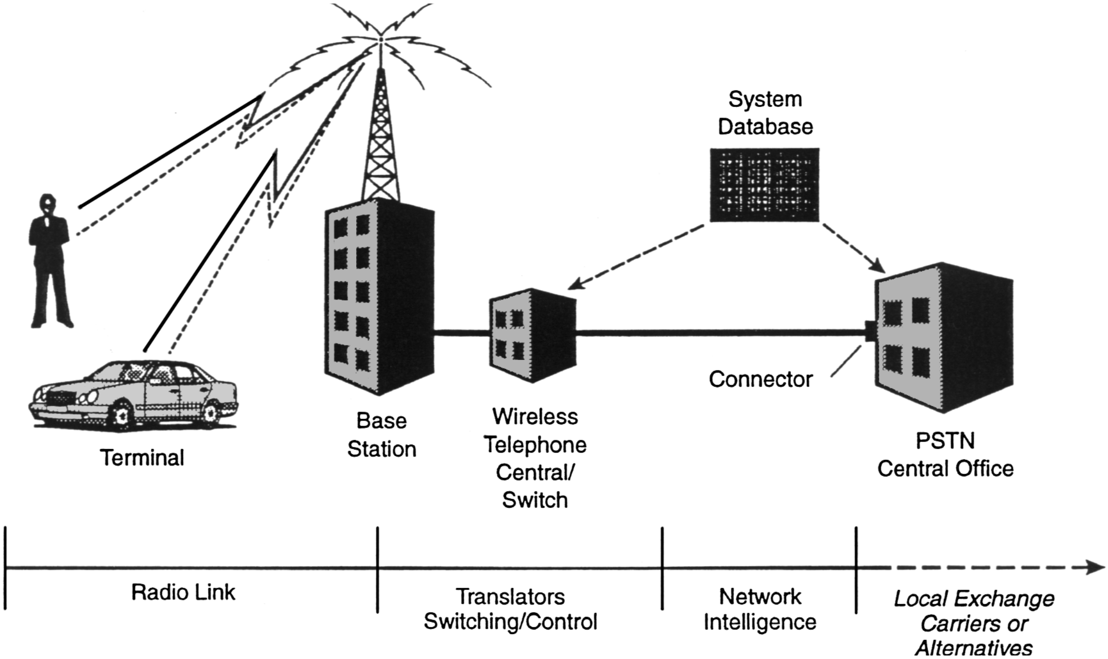

FIGURE 17.5.9 Structure of PCS network.

Satellites are instrumental in achieving global coverage and providing PCS services. Mobile satellite communications for commercial users is evolving rapidly toward PCS systems to provide basic telephone, fax, and data services virtually anywhere on the globe. Satellite orbits are being moved closed to the earth, improving communication speed and enabling PCS services. Global satellite systems are being built for personal communications. In the United States, the FCC licensed five such systems: Iridium, Globalstar,

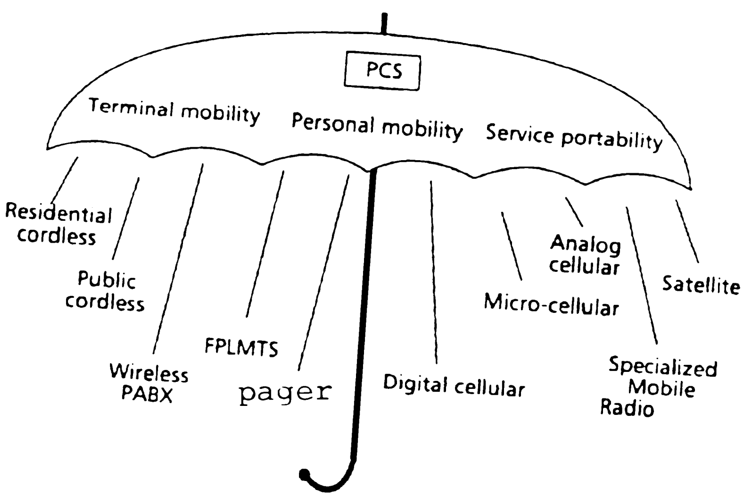

FIGURE 17.5.10 Range of applications associated with PCS.

Odyssey, Ellipso, and Aries. In Europe, ICO-Global is building ICO. Japan, Australia, Mexico, and India are making similar effort.

Future growth and success of PCS services cannot be taken for granted. Like any new technology, the success of PCS system will depend on a number of factors. These include initial system overall cost, quality, and convenience of the service provided, and cost to subscribers.

WIRELESS DATA NETWORKS

Wireless data networks are designed for low speed data communications. The proliferation of portable computers coupled with the increasing usage of the Internet and the mobile user's need for communication is the major driving force behind these networks. Examples of such networks include CDPD, wireless LAN, and wireless ATM.

Cellular Digital Packet Data

Cellular digital packet data is the latest in wireless data communication. CDPD systems offer one of the most advanced means of wireless data transmission technology. CDPD is a cellular standard aimed at providing Internet protocol (IP) data service over the existing cellular voice networks and circuit switched telephone networks. The technology solves the problem of business individuals on the move who must communicate data between their work base and remote locations.

The idea of CDPD was formed in 1992 by a development consortium with key industry leaders including IBM, six of the seven regional Bell operating companies, and McCaw Cellular. The goal was to create a uniform standard for sending data over existing cellular telephone channel. The Wireless Data Forum (www.wirelessdata.org), formerly known as CDPD Forum, has emerged as a trade association for wireless data service providers and currently has over 90 members. CDPD has been defined by the CDPD Forum CDPD Specification R1.1 and operates over AMPS.

By building CDPD as an overlay to the existing cellular infrastructure and using the same frequencies as cellular voice, carriers are able to minimize the capital expenditures. It costs approximately $1 million to implement a new cellular cell site and only about $50,000 to build the CDPD overlay to an existing site.

CDPD is designed to exploit the capabilities of the advanced cellular mobile services (AMPS) infrastructure throughout North America. One weakness of cellular telephone channels is that there are moments when the channels are idle (roughly 30 percent of the air time is unused). CDPD exploits this by detecting and using the otherwise wasted moments by sending packets during the idle time. As a result, data are transmitted without affecting voice system capability. CDPD transmits digital packet data at 19.2 kbps using idle times between cellular voice calls on the cellular telephone network.

CDPD has the following features:

- It is an advanced form of radio communication operating in the 800- and 900-MHz bands.
- It shares the use of the AMPS radio equipment on the cell site.
- It supports multiple, connectionless sessions.
- It uses the Internet protocol (IP) and the open systems interconnection (OSI) connectionless network protocol (CLNP).
- It is fairly painless for users to adopt. To gain access to CDPD infrastructure, one only requires a special CDPD modem.
- It supports both the TCP/IP protocols as well as the international set of equivalent standards.
- It was designed with security in mind unlike other wireless services. It provides for encryption of the user's data as well as conceals the user's identity over the air link.

CDPD provides the following services:

- Data rate of 19.2 kbps.

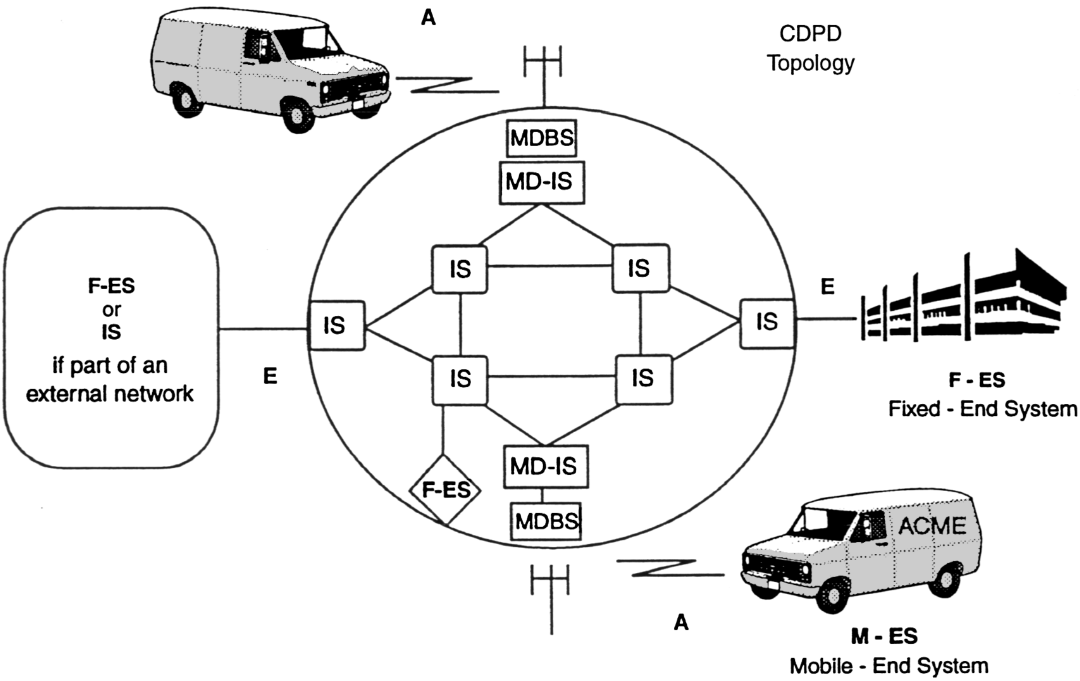

FIGURE 17.5.11 Major components of a CDPD network.

- Connectionless as the basic service; a user may build a connection-oriented service on top of that if desired.
- All three modes of point-to-point, multicast, and broadcast are available.
- Security that involves authentication of users and data encryption.

CDPD is a packet switched data transfer technology that employs radio frequency (RF) and spectrum in existing analog mobile phone system such as AMPS. The CDPD overlay network is made of some major components that operate together to provision the overall service. The key components that define CDPD infrastructure are illustrated in Fig. 17.5.11. They are as follows:

- *Mobile End System (MES)*: This is the subscriber's device for gaining access to the wireless communication services offered by a CDPD service. It is any mobile computing device, which is an equipment with a CDPD modem. Examples of an MES are laptop computers, palmtop computers, and personal digital assistants (PDAs), or any portable computing devices.
- *Fixed End System (FES)*: This is a stationary computing device (e.g., a host computer, a UNIX workstation, and so forth) connected to landline networks. The FES is the final destination of the message sent from an MES.
- *Intermediate System (IS)*: This is made up of routers that are CDPD compatible. It is responsible for routing data packets into and out of the CDPD service provider network. It may also perform gateway and protocol conversion functions to aid network interconnection.
- *Mobile Data Base Station (MDBS)*: CDPD uses a packet switched system that splits data into small packets and sends them across the voice channel. This involves detecting idle time on the voice channel and sending the packets on the appropriate unoccupied voice frequencies. This detection of unoccupied frequencies and sending of packets is done by the MDBS. Thus, the MDBS is responsible for relaying data between the mobile units and the telephone network. In other words, it relays data packets from the MES to the mobile data intermediate system (MDIS) and vice versa.

- *Mobile Data Intermediate System*: MDBSs that service a particular cell can be grouped together and connected to the backbone router, also known as the MDIS. The MDIS units form the backbone of the CDPD network. All mobility management functions are taken care of by MDIS. In other words, the MDIS is responsible for keeping track of the MES's location and routing data packets to and from the CDPD network and the MES appropriately.

Very little new equipment is needed for CDPD service since existing cellular networks are used. Only the MDBSs are to be added to each cell. One can purchase CDPD cellular communication systems for Windows or MS-DOS computers. The hardware can be a handheld AMPS telephone or a small modem which can be attached to a notebook computer. One would need to put up the antenna on the modem.

In order to effectively integrate voice and data traffic on the same cellular network without degrading the service provided for the voice customer, the CDPD network employs a technique known as *channel hopping*. When a mobile unit wants to transmit, it checks for an available cellular channel. Once a channel is found, the data link is established and the mobile unit can use the assigned channel to transmit as long as the channel is not needed for voice communication. Because voice is king, data packets are sent after giving priority to voice traffic. Therefore, if a cellular voice customer needs the channel, it will take priority over the data transmission. In that case, the mobile unit is advised by the MDBS to "hop" to another available channel. If there are no other available channels, then extra frequencies purposely set aside for CDPD can be used. This is a rare situation because each cell typically has 57 channels and each channel has an average idle time of 25 to 30 percent. The process of establishing and releasing channel links is called channel hopping and it is completely transparent to the mobile data unit. It ensures that the data transmission does not interfere with the voice transmission. It usually occurs within the call setup phase of the voice call. The major disadvantage of channel hopping is the potential interference to the cellular system.

CDPD has been referred to as an "open" technology because it is based on the OSI reference model, as shown in Fig. 17.5.12. The CDPD network comprises many layers: layer 1 is the physical layer; layer 2 is the data link layer; and layer 3 is the network layer; and so forth. For example, the physical layer corresponds to a functional entity that accepts a sequence of bits from the medium access control (MAC) layer and transforms them into a modulated waveform for transmission onto a physical 30 kHz RF channel. The network can use either the ISO

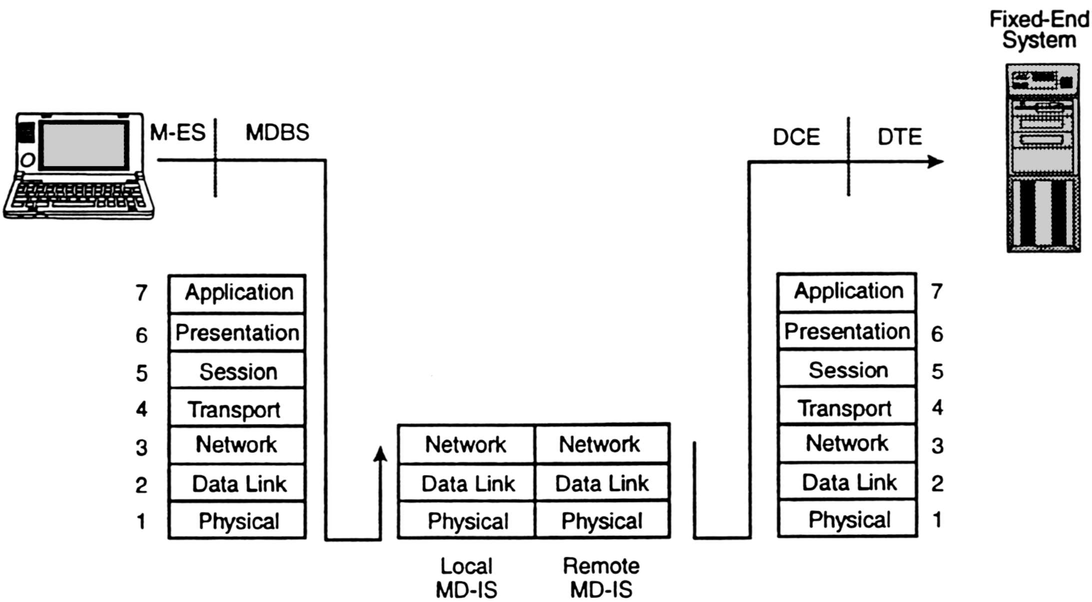

FIGURE 17.5.12 OSI reference model.

connectionless network protocol (CLNP) or the transmission control protocol/Internet protocol (TCP/IP). For now, CDPD can coexist with PCS and CDMA-based infrastructure.

Wireless LAN

Wireless local area network (WLAN) is a new form of communication system. It is basically a local area network, confined to a geographically small area such as a single building, office, store, or campus, that provides high data connectivity to mobile stations. Using electromagnetic airwaves (radio frequency or infrared), WLANs transmit and receive data over the air. A WLAN suggests less expensive, fast, and simple network installation and reconfiguration.

WLAN does not compete with wired LAN. Rather, WLANs are used to extend wired LANs for convenience and mobility. Wireless links essentially fill in for wired links using electromagnetic radiation at radio or light frequencies between transceivers. A typical WLAN consists of an access point and the WLAN adapter installed on the portable notebook. The access point is a transmitter/receiver (transceiver) device; it is essentially the wireless equivalent of a regular LAN hub. An access point is typically connected with the wired backbone network at a fixed location through a standard Ethernet cable and communicates with wireless devices by means of an antenna. WLANs operate within the prescribed 900-MHz, 2.4-GHz, and 5.8-GHz frequency bands. Most LANs use 2.4-GHz frequency bands because it is most widely accepted.

A wireless link can provide services in several ways. One way is to act as a stand-alone WLAN for a group of wireless nodes. This can be achieved using topologies similar to wired LAN, namely, a star topology can be formed with central hub controlling the wireless nodes, a ring topology with each wireless node receiving or passing information sent to it or a bus topology with each wireless capable of hearing everything said by all the other nodes. A typical WLAN configuration is shown in Fig. 17.5.13.

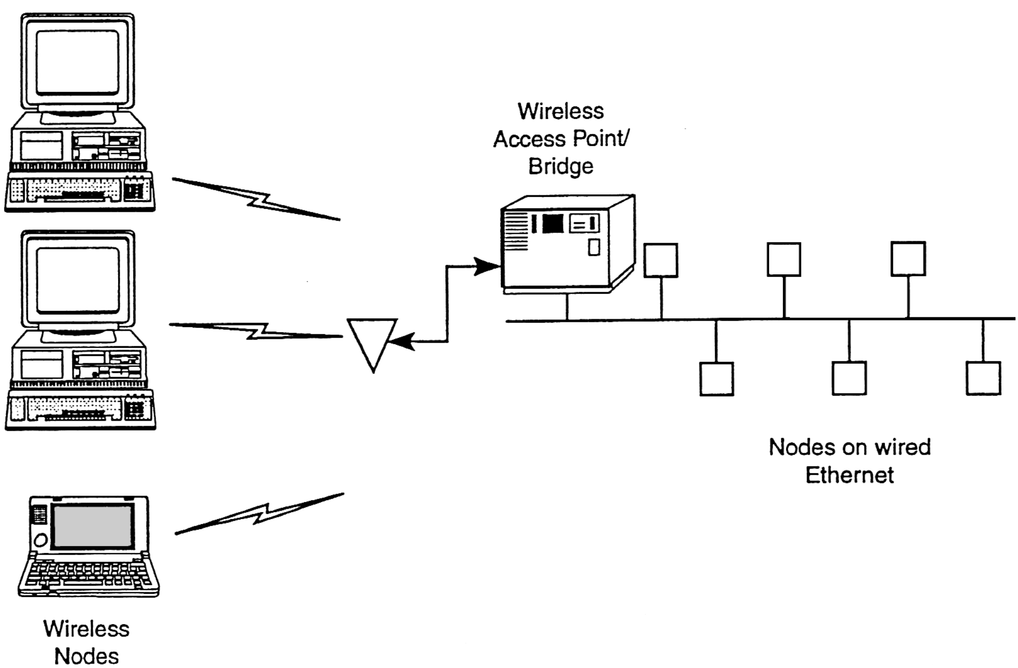

FIGURE 17.5.13 Connection of a wired LAN to wireless nodes.

When designing WLANs, manufacturers have to choose from two main technologies that are used for wireless communications today: radio frequency (RF) and infra red (IR). Each technology has its own merits and demerits. RF is used for applications where communications are over long distances and are not line-of-sight. In order to operate in the license free portion of the frequency spectrum known as the ISM band (industrial, scientific, and medical), the RF system must use a modulation technique called *spread spectrum* (SS). The second technology used in WLAN is infra red, where the communication is carried by light in the invisible part of the spectrum. It is primarily used for very short distance communications (less than 1 m), where there is a line-of-sight connection. Since IR light does not penetrate solid materials (it is even attenuated greatly by window glass), it is not really useful in comparison to RF in WLAN system. However, IR is used in applications where the power is extremely limited such as a pager.

Wireless ATM

Asynchronous transfer mode technology is the result of efforts to devise a transmission and networking technology to provide high-speed broadband integrated services: a single infrastructure for data, voice, and video. Until recently, the integration of wireless access and mobility with ATM has received little attention.

The concept of wireless ATM (WATM) was first proposed in 1992. It is now regarded as the potential framework for next generation wireless broadband communications that will support integrated quality-of-service (QoS) multimedia services. WATM technology is currently migrating from research stage to standardization and early commercialization.

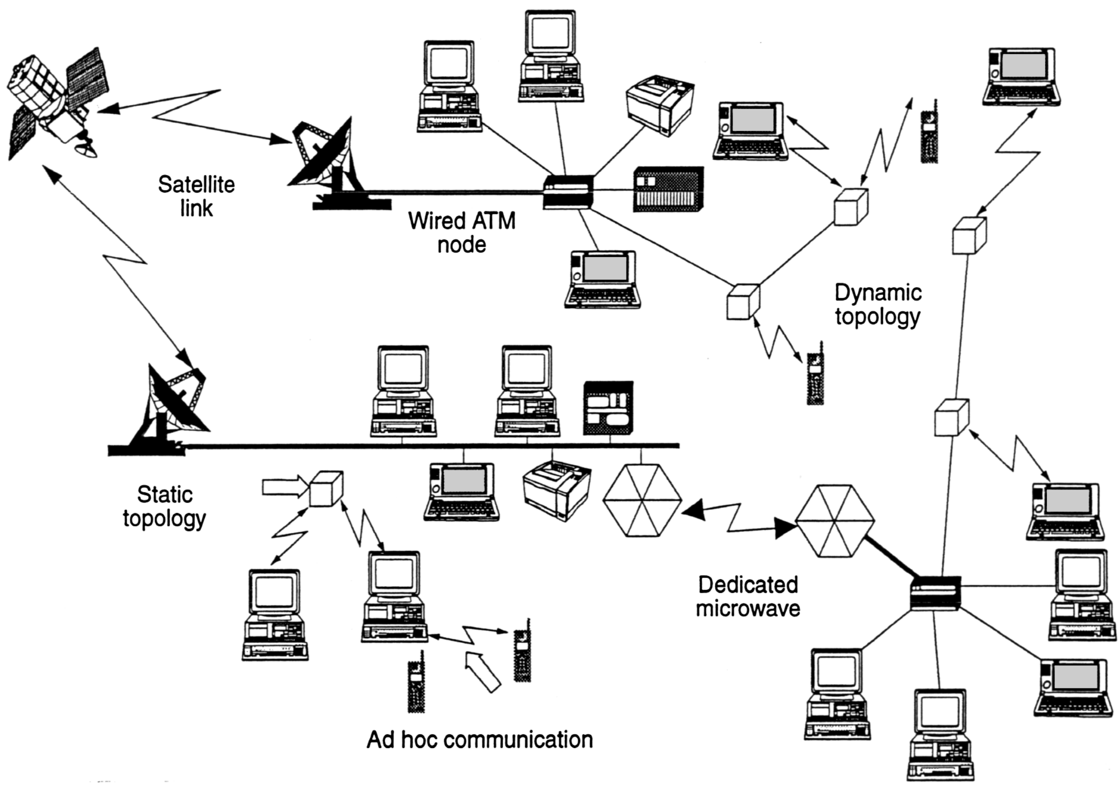

FIGURE 17.5.14 A typical wireless ATM network.

Wireless ATM network is basically the wireless extension of fixed ATM network. The 53-byte ATM cell is too big for wireless ATM network. Therefore, WATM networks may use 16 or 24 bytes payload. Thus, in a wireless ATM network, information is transmitted in the form of a large number of small transmission cells called *picocells*. Each picocell is served by a base station, while all the base stations in the network are connected via the wired ATM network. The ATM header is compressed or expanded to standard ATM cell at the base station. Base stations are simple cell relays that translate the header formats from the wireless ATM network to the wired ATM network. ATM cells are transmitted via radio frames between a central station (B-CS) and user radio modules (B-RM) as shown in Fig. 17.5.14. All base stations operate on the same frequency so that there is no hard boundary between picocells.

Reducing the size of the picocells helps in mitigating some of the major problems related to wireless LANs. The main difficulties encountered are the delay spread because of multipath effects and the lack of a line-of-sight path that results in high attenuation. Also, small cells have some drawbacks compared to large cells.

From Fig. 17.5.14, we notice that a wireless ATM typically consists of three major components: (1) ATM switches with standard UNI/NNI capabilities, (2) ATM base stations, and (3) wireless ATM terminal with a radio network interface card (NIC). There are two new hardware components: ATM base station and WATM NIC. The new software components are the mobile ATM protocol extension and WATM UNI driver.

In conventional mobile networks, transmission cells are "colored" using frequency-division multiplexing or code-division multiplexing to present interference between cells. Coloring is considered a waste of bandwidth because in order for it to be successful there must be areas between reuse of the color in which it is idle. These inactive areas are wasted rather than be used for transmission.

Wireless ATM architecture is based on integration of radio access and mobility features. The idea is to fully integrate new wireless physical layer (PHY), medium access control (MAC), and data link control (DLC), wireless control and mobility signaling functions into the ATM protocol stack.

Wireless ATM is not as matured as wireless LAN. No standards have been defined by either ITU-T or ATM Forum. However, the ATM Forum's WATM Working Group (started in June 1996) is developing specifications that will facilitate deployment of WATM.