Chapter 9

Wireless Networks

In the very near future, the number of wireless devices will outnumber wired devices. A few decades ago, wireless voice (walkie-talkie and other vocal variants), wireless audio (radio), wireless video (television), and wireless data (satellite, microwave, and so on) were each developed to address a particular communication purpose. Of these, wireless voice has found great acceptance through a fundamental one-on-one communication style. Flexibly switched to any other number in the world, wireless voice adds the enchantment of portability and mobility to individual communications. To a large extent, personal wireless voice has become the axis of communication convergence.

Wireless mobility is a must-have. Like an explorer's compass, your mobile phone has become your navigator to personal communication. You use it to blaze new conversations ahead while you maintain association with current and past acquaintances.

Wireless computing is a need-to-have on its way to a must-have reality and is leading personal computing into the superpersonal realm. As your personal access card into the world's storehouse of knowledge, it becomes your private window into a vast library of learning, of which data, audio, and video are an indispensable part of the total comprehension of knowledge.

A remarkable convergence of wireless communications and wireless low-power computing is colliding into handheld form factors for pocket or purse.

Wireless networks enable the capability and equality of personal communications, superpersonal computing, and timesaving information to everyone who chooses to explore the communication landscape. Without them, you might never leave home or the office. With wireless networks, wherever you and your wireless communication devices are becomes your digital home and office.

This chapter introduces many of the technologies behind the success of wireless cellular mobility networks, wireless local area networks (WLANs), wireless personal area networks (WPANs), and both fixed and satellite wireless networks.

Cellular Mobility Basics

Cellular phones are sophisticated radios that, at a basic level, use frequency modulation in full-duplex fashion. That means that both parties can speak and listen at the same time, which would be really useful if you could develop the multiplexing skills required to comprehend and absorb such a bidirectional exchange. These mobile phones are generally referred to as cellular because of the cell-by-cell approach the wireless provider uses to divide up and provide citywide service. More conversationally, they're referred to as cell phones.

This section introduces mobility basics under the context of analog and digital cellular systems and reviews the underlying seed technologies that make them work.

Analog Cellular Access Technology

Cellular access technologies, particularly frequency division multiple access (FDMA), are generally used with analog systems such as Advanced Mobile Phone Service (AMPS). The FDMA technique, used in the United States since 1983, separates the usable frequency channels into uniform blocks of bandwidth—each phone call using a different frequency. As a nondigital technology, FDMA systems handle voice circuit switching and aren't designed to carry data. Traditionally, AMPS has been called an analog cellular standard.

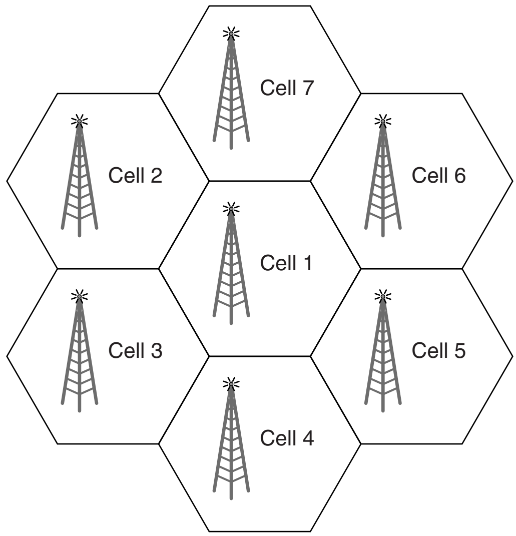
The concept of a cell is the basic geographic service area on which providers build signal coverage. The cell-based design approach for mobile radio services has its roots in an R&D project at Bell Labs in the 1970s. An original cellular infrastructure, conceptually designed much like an invisible honeycomb, uses variable low-power transmitters to cover approximately 10 square miles per cell, with each cell containing one or more broadcasting antennae or base stations that are connected back to the provider's mobile telephone switching office (MTSO).

In practice, cell sites are different sizes to best serve the natural landscape, often ranging from .62 mile (1 km) to about 6.2 miles (10 km). The natural terrain and other structures can alter the coverage and shape of an individual cell. Figure 9-1 shows a conceptual layout of a cluster of cells.

A cellular phone is often designed to communicate on 1664 frequency-modulated channels, of which 832 channels are for one digital band or frequency range, while the other 832 channels are intended to support an additional digital band or frequency range. These 1664 channels are fundamental to a dual-*band* phone, to make the phone applicable to these wireless mobility frequency ranges. In addition, many phones are also dual-*mode*, which means that they support both digital cellular/PCS and analog services. The dual-*mode* capability supplements gaps in digital coverage with legacy AMPS service, for example, whenever you're roaming beyond your digital wireless provider's coverage area.

A wireless provider is assigned 832 radio frequencies to use within a city, which are then engineered into a spectrum plan that the provider divides across the cells of the coverage area. Within a cell, a provider generally uses one-seventh of these possible frequencies, while different frequencies are used in up to six adjacent cells to form a seven-cell cluster. Beyond an adjacent cell, providers can reuse the same frequencies once again as long as they don't interfere with other cells.

Figure 9-1 *Cellular Cluster*

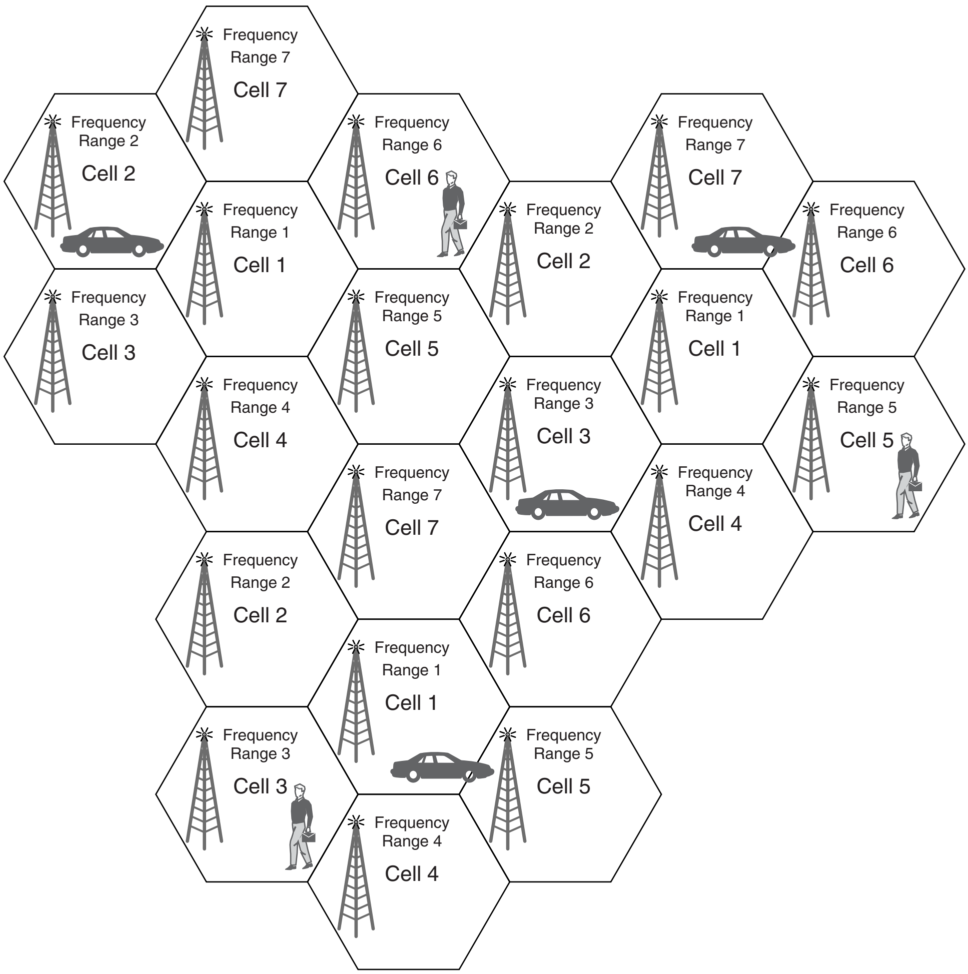


To complete the cell-by-cell design, the provider also uses variable low-power transmitters for the base station antennae. By combining this low-power design with particular frequency coverage for a specific cell, frequencies weaken and fade about a mile into adjacent cells. By this time, your cellular phone has frequency hopped as it moves into a new cell, automatically releasing the weakening frequencies of the cell behind and switching to the strengthening, but different range of frequencies in the cell ahead.

By using the cellular concept with variable low-power transmitter levels, cells can be sized according to the subscriber density and demand of a given area. As the population grows, cells can be added to accommodate that growth. Frequencies used in one cell cluster can be reused in other cells. Conversations can be handed off from cell to cell to maintain constant phone service as the user moves between them. The cellular radio equipment (base station) can communicate with mobile phones as long as they are within range. Figure 9-2 depicts a multiple-cell cluster.

With AMPS systems (EIA/TIA-553) using FDMA access technology and the 824 to 893 MHz frequency band, there are 395 voice channels (30 kHz frequency channels) for usage by an AMPS provider. Designers then usually divide that capacity by a seven-cell cluster to properly distribute the frequency range such that adjacent cells don't reuse the same frequencies. Adjusting for interchannel separation, a typical AMPS cell concurrently carries about 40 to 50 mobile conversations. For a seven-cell cluster, there are about 280 to 350 concurrent conversations.

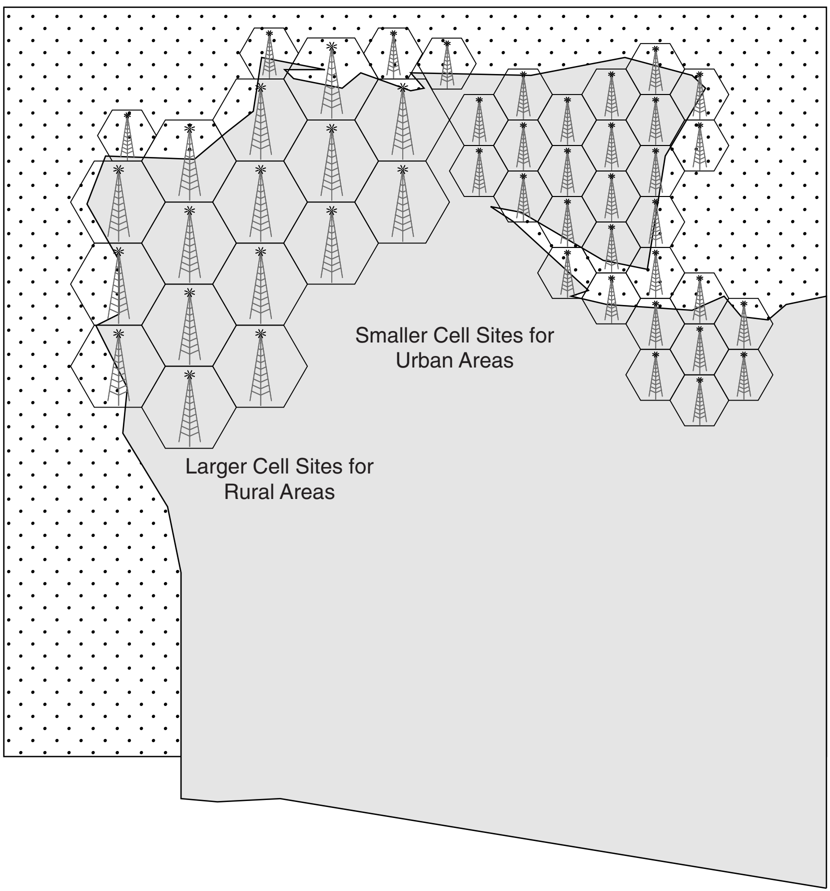
Figure 9-2 *Multiple Cell Clusters*



Radio energy dissipates over distance, so the cellular phones must be within the operating range of the base station. Like the early mobile radio system, the base station communicates with mobiles via a channel. The channel is made up of two frequencies, one for transmitting to the base station and one to receive information from the base station. This is why an 832-channel AMPS system supports less than half this number of concurrent voice calls, allowing for special control channels and so on.

A cell cluster's mileage radius depends on numerous factors, such as subscriber density, but theoretically could be up to about a 30-mile diameter. Designers continue to build out their citywide coverage areas with multiple clusters that reuse the same frequencies over and over again to scale their total concurrent user capacity. In dense, urban areas, smaller cells and cell clusters are typically designed to accommodate subscriber call capacity requirements and to maintain enough signal power despite a number of building and structural objects that attenuate and reflect cellular frequencies. Figure 9-3 illustrates the concept of using different-sized cell clusters to properly engineer for terrain and capacity.

Figure 9-3 *Conceptual Cell Cluster Design*



This cell-based approach to mobile telephony allows the provider to use and reuse its assigned frequency spectrum extensively across its assigned coverage area. Because providers are assigned different frequency ranges for their unequivocal use, there are numerous, invisible "honeycombs" of frequency coverage layered over the same geographic coverage areas, each communicating with provider-sourced cellular phones programmed to explicitly operate within their assigned frequency range, type of access technology, and system parameters.

Under power, your mobile handset's unique electronic serial number (ESN) is continuously broadcasting its reachability to the local cell. The ESN is a unique 32-bit number that is factory programmed when the phone is manufactured. In addition to the factory-programmed 32-bit ESN, the wireless provider uses other numbers to identify and track your cellular handset on its network:

- **System Identification Code for Home System (SIDH)**—This is a unique five-digit number assigned to each cellular provider by the Federal Communications Commission (FCC) and is used to identify your handset as belonging to the provider's system. This identifies your handset as belonging to, for example, the Sprint PCS system rather than the Verizon Wireless system. SIDH is often abbreviated to SID.
- **Mobile Identification Number (MID)**—Your provider uses this ten-digit number (your assigned mobile telephone number) to uniquely identify your handset within its network.

The combination of a factory-programmed ESN, along with a wireless, provider-programmed SID and MID, allows the provider to activate your handset, in effect, registering your phone to send and receive calls bearing your mobile telephone number.

At power-up, your phone listens for the SID on its control channel, a special frequency used between the phone and base station for call setup and channel switching. It compares the SID it receives with the one that it is specifically programmed for. A match indicates that it is communicating with its home system, and a nonmatch indicates it is out of range or roaming on a different provider system. Along with the SID, your phone will continuously transmit a registration request, which updates the MTSO database so that the MTSO knows which particular cell you are currently in. By keeping track of your current cell position in the database, the MTSO knows how to reach you for an incoming call.

To deliver a call, the MTSO first determines which cell you are in, then picks an unused frequency pair for that cell, signaling your phone over the control channel to switch to those frequencies to connect and receive the call. To initiate a call, your handset sends a request to the MTSO over the control channel, the database is scanned to validate your phone's ESN, SID, and MID as a registered device, and then the MTSO selects and sends your phone the frequency pair to use to continue call setup and connection. All of this is done in mere seconds.

An enhancement to the AMPS system was later developed and called Narrowband AMPS (NAMPS, EIA/TIA/IS-91), squeezing channel spacing from 30 kHz to 10 kHz channel widths, effectively tripling the capacity of NAMPS per cell and per cluster. AMPS is the first analog wireless network standard in the world and is principally used in the United States, Australia, South America, and China. In the U.S., the Federal Communications Commission has scheduled the sunset of the AMPS networks for November 2007.

Digital Cellular Access Technologies

In addition to analog access technology, a digital transmission technique called time division multiple access (TDMA) assigns each call a certain portion of time along with a particular frequency. Another method called code division multiple access (CDMA) assigns unique codes to each concurrent call and spreads a call over any of the available frequencies within the current cell. An enhanced frequency division multiplexing technology called orthogonal frequency division multiplexing (OFDM) makes more optimal use of frequency spectrum. These are discussed next.

These cellular access technologies, TDMA, CDMA, and OFDM, are used for various network standards and mobile operations throughout the world.

TDMA

Earlier digital cellular used TDMA in combination with AMPS technology (sometimes called Digital AMPS). It is important to note that TDMA-based systems still use FDMA technology and frequency division duplexing (FDD) as well, overlaying TDMA timing functions on the FDMA frequencies. The combination is an FDMA/TDMA/FDD technique but is usually referred to as a TDMA system.

TDMA systems break up the frequency range into sets that can be used on a cell cluster basis. A different set of frequencies is used in each adjacent cell as discussed previously. When a cell phone moves from one TDMA cell to an adjacent TDMA cell, the network system must rapidly terminate the call frequencies in that cell, switch the call to the adjacent cell tower, and reestablish communications over a different frequency channel set to the cell phone—doing so without dropping the call or dropping large parts of the conversation. This practice of terminating frequency channels and reestablishing new frequency channels is referred to as a *hard handoff*.

In TDMA systems, the time slot is 6.7 milliseconds long on a narrowband, 30 kHz–wide frequency range within the band, allowing from three to six simultaneous digital conversations on the same strip of frequency. This allows multiple users to have concurrent calls on the same frequency channel of the TDMA-based cellular system. The timeshare technique of TDMA keeps these calls from overlapping. This affords a TDMA system about three to six times the concurrent call capacity of a system based on FDMA only.

TDMA, often referred to as a narrowband digital cellular system, operates in either the 800 MHz (IS-54) frequency band or the 1900 MHz (IS-136) frequency band in the United States. In Europe, TDMA-based systems, such as Global System for Mobile Communications (GSM), operate in the 900 MHz and 1800 MHz frequency bands.

TDMA can also be designed in a Hierarchical Cell Structure (HCS), allowing for the use of macrocells, microcells, and picocells for better optimization and localization of coverage. Using these HCS designs with adaptive channel allocation techniques (enhanced TDMA) and more intelligent antennas have the potential to extend TDMA to scale to many times the capacity of an original AMPS.

NOTE Initial TDMA implementations increased calls per channel to about three times that of FDMA. Newer versions of TDMA technology have improved to six times that of analog systems, and through the use of an enhanced version of TDMA called E-TDMA, the concurrent capacity increases to 15 times FDMA. E-TDMA accomplishes this by compressing quiet time during conversations and through further time division of the frequency channels.

Variants of TDMA technology are used in different digital cellular systems within the overall market. The European GSM standard implements TDMA differently than the older U.S. specification IS-136 protocol standard. Motorola developed a proprietary technology called integrated dispatch-enhanced network (iDEN), used as the basis for the original Nextel network in the U.S. TDMA technology has also been ported to wireline use, with cable modem systems using advanced TDMA (A-TDMA) for upstream data channels between cable modems and the cable modem termination system (CMTS).

CDMA

CDMA is another digital access technique that assigns a unique code to each call and then spreads the call over any available frequencies in the wireless provider's complete frequency range. This access technique is a variant of digital spread-spectrum technology, an idea coinvented by a Hollywood, California actress/scientist named Hedy Lamarr back in 1940.

NOTE At the height of her acting career in 1942, Hedy Lamarr, along with coinventor George Antheil, patented an 88-key frequency-switching system for torpedo guidance. Though never used for military applications, Sylvania later developed the concept using 1962-vintage electronics for the purpose of naval communications. Subsequent patents in frequency hopping have referred to the Lamarr-Antheil patent as the basis of the field.

Originally used for secure military communications during World War II, today's digital spread-spectrum technology rapidly switches from one frequency to the next, or from code to code over several frequencies, all synchronized with GPS clocks and pseudorandom number generators.

CDMA-based systems also use FDMA technology and FDD, overlaying CDMA spread-spectrum functions on the FDMA frequencies. The combination is an FDMA/CDMA/FDD technique but is usually referred to as a CDMA system. CDMA is used for both voice calls and data transmission over CDMA systems.

Essentially, CDMA allows all of the system's users to transmit and receive in the same wideband block of the provider's entire spectrum assignment, accurately time stamping and spreading each mobile user's signal over the entire frequency bandwidth with a unique spreading code. This means that multiple transmitters are sending to the same receiver at the same time. A particular pseudorandom code is assigned to a CDMA-based cell phone when it is on the system, and transmission to this particular phone is spread across a wide range of available frequencies using the pseudorandom code. The phone is able to decipher its particular code from the different bit streams and multiplex the bits back together. Using this approach, each CDMA cell can use the same full frequency band per cell, eliminating the cell-cluster design requirement. This also allows the cell phone to use the same frequencies as it moves from cell to cell, because all frequencies are usable in all adjacent cells. The ability for a CDMA cell phone to transition between cells and use the same frequencies is known as a *soft handoff*.

CDMA system cell phone users are isolated by up to 4.4 trillion codes rather than frequencies. Frequency separation space that goes unused in TDMA systems is available for use with CDMA technology. With the CDMA handsets transmitting at about .6 watts, the low-power transmission across the wide band of frequencies gives CDMA the colloquial reference of "wide and weak." With 4.4 trillion codes modulated and distributed at high speed over a wide range of frequency signals at such low power, a CDMA call appears inconspicuous and transparent, much like background noise—extremely difficult to intercept and demodulate. Through use of supersecure CDMA technology, you can place from 10 to 20 concurrent calls in the same channel space as that of a traditional analog FDMA-only system.

CDMA depends on power control of the mobile cell phones to maintain good call capacity. The CDMA base station transceiver automatically throttles power of cell phones close to the cell tower and boosts weaker signals of cell phones furthest from the tower to allow all phone transmissions to access the tower at approximately the same power. CDMA systems can use forward error correction (FEC) coding to improve the bit error rate factor, achieving gains in channel capacity.

In the United States, CDMA also operates in the 1900 MHz frequency band but is generally transparent to TDMA systems using the same frequency space. This is because the wideband usage of CDMA transmits at a much lower spectral power density then the narrowband transmitters as used in TDMA. This lower transmit power density characteristic allows both spread-spectrum (CDMA) and narrowband signals (TDMA) to cooperate in the same frequency bands.

CDMA is the seed technology for a number of digital cellular standards, of which some are covered later. These include variations of CDMA beyond the original IS-95 standards such as CDMA2000 1x/1xRTT (a high data rate version of CDMA 1x EV-DO), CDMA2000 1xEV-DV, wideband CDMA (WCDMA), and time-division synchronous CDMA (TD-SCDMA).

- **cdmaOne**—cdmaOne is a brand marketing name. The original IS-95A and IS-95 B CDMA specifications are now referred to as cdmaOne. The technologies use 1.25 MHz–wide channels to deliver voice and data.
- **CDMA2000**—A direct evolution of cdmaOne, CDMA2000 provides a set of specifications for enhancing voice and data capacity of cellular and PCS systems. The CDMA2000 family includes:
  - **CDMA2000 1x**—Referred to as 1x, or sometimes 1xRTT (Radio Transmission Technology), 1x is 21 times more efficient than analog cellular and four times more efficient than TDMA networks according to Qualcomm. This designation of 1x is used by Qualcomm to denote the type of CDMA radio technology used over a pair of 1.25 MHz frequency width channels.
  - **CDMA2000 1xEV-DO**—1xEV-DO is short for first evolution (1xEV) data optimized (DO). It is considered part of the Qualcomm CDMA2000 1xEV family, which is 1x technology with high data rate (HDR) technology applied. 1xEV-DO provides peak data rates of over 2.4 Mbps and an average of 700 Kbps inside a 1.25 MHz channel.
  - **CDMA2000 1xEV-DV**—1xEV-DV stands for first evolution data and voice, and targets speeds of 3.1 Mbps downstream (forward link) and 1.8 Mbps upstream (reverse link). It is also part of the CDMA2000 1xEV family.
- **WCDMA**—An additional 3G data overlay is known as wideband code division multiple access (WCDMA). WCDMA is based on the UMTS and IMT-2000 specifications.
- **TD-SDCMA**—Called time division synchronous CDMA, TD-SCDMA is one of three internationally accepted CDMA standards. This technology is being pursued in mainland China to avoid royalties from other CDMA systems.

OFDM

OFDM is a relatively new option for wireless access technology. Researchers developed OFDM as an access technique in the 1980s. Only recently has it been finding its way into commercial communication systems, primarily because Moore's Law has driven down the cost of the signal processing needed to implement OFDM-based systems.

NOTE Gordon Moore, cofounder of Intel, observed in 1965 that the density of transistors per square inch of silicon-based integrated circuits had doubled every year, predicting the trend would continue in subsequent years. While this pace has slowed somewhat, data density on integrated circuits doubles approximately every 18 months, which is the current definition of Moore's law. This allows more processing per square inch for less cost per bit.

OFDM can be thought of as a combination of modulation and multiple-access schemes that segment a communication channel in such a way that many users can share it. Whereas TDMA segments are according to time and CDMA segments are according to spreading codes, OFDM segments are according to frequency.

The OFDM technique divides the spectrum into a number of equally spaced tones and carries a portion of a user's information on each tone. A tone can be thought of as a frequency, in much the same way that each key on a piano represents a unique sound and frequency. OFDM can be viewed as a form of frequency division multiplexing (FDM); however, OFDM has an important special property that each tone is orthogonal, or independent of every other tone. Typical FDM techniques require the provisioning of a frequency guard band between adjacent frequencies to mitigate interference with each other. OFDM allows the spectrum of each tone to overlap, and because they are orthogonal, they do not interfere with each other. By allowing the tones to overlap, the total required spectrum is reduced.

OFDM, therefore, provides the best of the benefits of TDMA in that users are orthogonal to one another, and CDMA, while avoiding the limitations of each; which are the need for TDMA frequency planning and equalization, and the engineering to avoid multiple access interference in the case of CDMA. Wideband OFDM is another variant of OFDM that is promising for cellular systems.

NOTE Traditional broadband wireless technologies have struggled to overcome problems caused by radio frequency (RF) waves bouncing off tall objects such as buildings or low objects such as lakes and pavements. The distance traveled by the primary signal is shorter than the deflected signal; the resulting time differential causes the two signals to be received, overlapped, and merged into a single distorted signal. The original signal plus duplicate or echoed signals from deflections is known as *multipath,* and results in intersymbol interference and distortion.

Cellular Standards

Cellular standards are defined by national and international organizations to promote wide acceptance, common equipment, interoperability, and quicker deployment.

The various types and generations of cellular standards and industry terminology have rapidly increased since the 1980s. Mobile telephony is extremely international in nature, with major standards at work in Europe, Japan, and the United States. Table 9-1 is offered to increase your understanding of these international wireless standards, generations, and terminology. Also included is a reference to the relative functionality of these systems as they apply to the mobile technology generation categories of 1G, 2G, 2.5G, and 3G. (These generations are described later).

Table 9-1 *International Wireless Systems and Standards*

Year	Cellular Systems	Global Theater	Frequency Band	Primary Air Link Access Type	Standard	Functional Generation
1983	Advanced Mobile Phone Service (AMPS)	United States	800 MHz	FDMA	EIA-553	1G
1985	Extended Total Access Communications (E-TACS)	Europe	900 MHz	FDMA	—	1G
1985	Japan Total Access Communications (J-TACS)	Japan	900 MHz	FDMA	—	1G
1986	Nordic Mobile Telephone	Europe	450 MHz, 900 MHz	FDMA	—	1G
1986	Personal Digital Cellular (PDC)	Japan	900 MHz, 1500 MHz	TDMA	—	2G
1990	GSM (2G)	Europe	900 MHz, 1800 MHz	TDMA	GSM	2G
1991	U.S. Digital Cellular (Digital AMPS)	United States	800 MHz, 1900 MHz	TDMA	IS-54, supplanted by IS-136	2G
1992	Narrowband AMPS (NAMPS)	United States	800 MHz	FDMA	—	1G
1995	Personal Communications Services (PCS)	Canada	1900 MHz	TDMA, GSM, CDMA	ANSI 95A and 95B	2/2.5G

Table 9-1 *International Wireless Systems and Standards (Continued)*

Year	Cellular Systems	Global Theater	Frequency Band	Primary Air Link Access Type	Standard	Functional Generation
1996	PCS	United States	1900 MHz	TDMA, GSM, CDMA	IS-136, GSM, ANSI 95A and 95B	2/2.5G
1996	PCS	United Kingdom, Hong Kong	GSM-1800	TDMA GSM	GSM	2/2.5G
1998	GSM	United States, Canada	800 MHz, 1900 MHz	TDMA, GSM	GSM, Release 97 and 99	2.5
1998	GSM	Europe	900 MHz, 1800 MHz	TDMA, GSM	GSM, Release 97 and 99	2.5
2000	CDMA (2G)	Japan, Asia	900 MHz	cdmaOne	ANSI 95A and 95B	2G
2001	CDMA2000	United States South America Asia	1900 MHz	CDMA 1xRTT	IS-2000, part of IMT-2000	3G
2001	Universal Mobile Telecommunications System (UMTS), wide-band CDMA (WCDMA)	Europe, Japan, Asia, United States	900 MHz, 1800 MHz, 2000 MHz	WCDMA, TDMA, CDMA	UMTS, (often called 3GSM), part of IMT-2000	3G
2002/3	CDMA 1xEV-DO	Japan/ Korea, United States, South America	1900 MHz	CDMA 1xEV-DO	IS-856	3G

Wireless network standards exist for analog systems, digital cellular systems, digital PCS, and so on. This section discusses the more prominent digital cellular network standards—GSM, CDMA2000, PCS, UMTS, and IMT-2000.

GSM

GSM is one of the major digital cellular network standards. GSM uses a variant implementation of TDMA as its access technology. Beginning with the formation of the GSM forum in Europe in 1982, GSM adopted the digital TDMA access technology in 1987 and opened commercial GSM operations in European countries in 1991. GSM's popularity in Europe has recently immigrated into the United States. The worldwide standard allows for interoperability, and a GSM subscriber can roam on most of the GSM systems in the world.

Used by Verizon Wireless, Cingular Wireless, and T-Mobile in the United States, GSM's primary functional benefit through the use of TDMA is improved digital voice quality and advanced features. Short messaging services, multiparty calling, voice mail, fax mail, caller ID, and cell broadcast are a few of the more notable capabilities. GSM uses companion technologies to support data rates up to 384 Kbps and beyond.

GSM uses the 900 and 1800 MHz frequency ranges in most of the world, excluding North America. In the United States, GSM operates in the 800 and 1900 MHz frequency band. Through use of digital TDMA access technology, a GSM cell usually supports about 6 to 15 times that of an AMPS cell or about 300 to 750 concurrent calls per cell depending on the particular TDMA version. This greatly increases the mobile subscriber scalability per cluster and is well suited to dense metropolitan areas referred to as metropolitan statistical areas (MSAs). A GSM cell phone includes a feature called a subscriber identification module (SIM). The SIM stores subscriber profile information (for secure authentication purposes), the subscriber's telephone book, and other appropriate information items. This allows the GSM subscriber to easily change phones or systems, as the SIM module can be transferred to the new cell phone without having to reinput all of the essential information.

GSM uses a structured cell design made up of the following:

- **Macro cells**—Antenna on mast or tall building
- **Micro cells**—Urban rooftop antennas
- **Pico cells**—Smart cells covering a few dozen meters
- **Umbrella cells**—Special purpose cells used to plug gaps in shadowed regions of other cells

Cell radius varies depending on the height of antennas, terrain, and so on, but the longest distance for a GSM cell is about 35 km (21.7 miles). GSM authenticates the user's cell phone handset to the GSM network and also uses cryptographic algorithms to ensure the privacy of the air link. GSM uses 200 kHz–wide radio frequency channels into which eight voice channels are time division multiplexed at 25 kHz per user. Based on TDMA, GSM must use separate frequencies, often called sets, in adjacent cells. A typical concurrent call number for GSM cells is four times that of AMPS systems, or about 224 theoretical calls per cell.

GSM networks are capable of both 2G and 2.5G network classification depending on the implementation of optional features and data rates. These generations are described later in this section.

CDMA2000

The original CDMA version, now called cdmaOne, increased simultaneous call capacity per cell from 8 to 15 times that of early FDMA systems, which had approximately 56 users per cell. That's a range of about 512 (8 carriers) to 960 (15 carriers) theoretical active conversations per cell.

The CDMA2000 family of CDMA cellular and PCS standards is extending wireless voice and data capabilities even further. The CDMA2000 1x has doubled voice capacity (approximately 128 calls per 1.25 MHz carrier x 8 carriers equal 1024) over the previous cdmaOne technology, while remaining compatible with cdmaOne systems. CDMA2000 uses a signaling standard known as IS-2000. The IS-2000 signaling protocol adds more traffic channels, link and media access control layers, and quality of service (QoS) control.

CDMA2000 1xRTT (sometimes called 1x or 3G1x) is the basic layer of CDMA2000. CDMA2000 meets the requirements of 3G networks. Sprint PCS and Verizon Wireless use Qualcomm-developed CDMA as the fundamental access technology for their wireless networks. Basic CDMA2000 1xRTT networks can use data rates up to about 150 Kbps. To extend data rates even further, Qualcomm developed the high data rate (HDR) technology that could be added to CDMA2000 1xRTT networks. This combination of CDMA2000 1xRTT plus HDR technology is known as the CDMA2000 1xEV (EV for Evolution) family.

The first technology of the family is CDMA2000 1xEV-DO (Evolution-Data Optimized). This adds higher data rates to over and above the CDMA2000 1xRTT voice and data capacity, up to 3.1 Mbps toward the cell phone (forward link), and up to 1.8 Mbps toward the cell tower (the reverse link). This is performed within a radio channel dedicated to carrying high-speed packet data. In the United States, both Verizon Wireless and Sprint PCS are deploying CDMA2000 networks with the 1xEV-DO high data rate technology. Japanese operator KDDI is also deploying the CDMA2000 1xEV-DO network.

China Unicom began a 2003 commercial trial and is now overlaying CDMA2000 data service on Unicom's GSM core network. This included the ability to perform real-world testing of dual-mode GSM/CDMA2000 handsets extending to its 60 million plus subscriber base the increased voice capacity, higher data rates, and spectral efficiency of CDMA2000. CDMA2000 is also one of five approved radio access technologies of the International

Mobile Telecommunications-2000 (IMT-2000) framework. IMT-2000 is intended to bring high-quality mobile multimedia telecommunications to a worldwide mass market based on a set of interfaces specified in the global, mobile, ITU standards.

CDMA2000 can be deployed in all cellular and PCS radio frequency regions, as well as in the United States, Europe, and the rest of the world.

SK Telecom of Korea deployed the first CDMA2000 1x network in October of 2000. Since then, CDMA2000 has expanded across all regions. According to the CDMA Development Group, as of 2005 there are 144 commercial networks in operation, and 40 more are being deployed within Asia, Australia, Africa, Europe, and the Americas.[1]

PCS

PCS is the designated name for the 1900 MHz radio frequency band for using digital mobile phone services in North America.

TDMA, GSM, and CDMA technologies are used to build digital cellular systems. All of them are adaptable to PCS. PCS networks began implementation in Canada in 1995, and then entered the United States in 1996.

PCS was a 1994 spectrum assignment decision made by the U.S. Federal Communications Commission (FCC) and Industry Canada to expand digital cell phone operations beyond the original North American 800 MHz cellular phone band. The new 1900 MHz band is called the PCS band. So, PCS is more of a reference for systems, be they TDMA, CDMA, or GSM based, that operate in the 1900 MHz band in North America or within the GSM-1800 MHz band in the United Kingdom and Hong Kong. At the time of the 1994 PCS digital cellular standard, PCS defined a new generation of wireless phone technology that introduced a range of features and services surpassing those available in analog and digital cellular phone systems. PCS networks usually provide the user with an all-in-one wireless phone, paging, messaging, data service, and video services having a greatly improved battery standby time. In the United States, Sprint adopted the terminology as part of its name for its wireless business unit known as Sprint PCS.

One of the unique features introduced with PCS phones is that of dual-band and dual-mode. PCS dual-band phones operating at 800 and 1900 MHz enable users to receive full PCS features and services for TDMA, CDMA, or GSM systems wherever they may roam. The PCS phone's dual-mode capability provides service continuity and interoperability between analog and digital networks. As a result, a PCS phone can transition well across outdoor wireless services and serve as a flat-rate digital cordless phone at home.

PCS phones also have a better standby time through more efficient monitoring of the digital control channel (DCCH). Whenever a PCS phone is idle, it camps on the DCCH, and after a few milliseconds shuts off much of its circuitry to conserve power. A PCS phone will then check in with the DCCH channel every few milliseconds to see if there are any incoming calls or pages.

UMTS

The UMTS network standard is recognized as a 3G (third-generation) function set. UMTS is generally referenced as 3GSM among European GSM technology operators, and is envisioned as the successor to GSM, signaling the move into the 3G of mobile networks. UMTS also addresses the growing demand for new mobile and Internet applications and for added capacity in the overcrowded mobile communication sky.

The new network standard, essentially referred to as UMTS/W-CDMA, uses W-CDMA as the air link along with GSM infrastructure and establishes a global roaming standard. The W-CDMA specification increases theoretical data transmission speed to peak rates of 1.92 Mbps per mobile user, with average rates beginning at 384 Kbps. W-CDMA, while based on CDMA multiplexing principles, is an independently developed, complete, and detailed mobile phone protocol that is not compatible with the Qualcomm CDMA family of technologies. Another data service specification called High-Speed Downlink Packet Access (HSDPA) is planning to advance peak data rates to beyond 10 Mbps. HSDPA is described in a following section on mobile data overlays.

UMTS uses a pair of 5 MHz–wide radio frequency channels, selecting the uplink from the 1900 MHz band and the downlink from the 2100 MHz band. Specifically, the UMTS standard defines 1885–2025 MHz for the uplink range, and 2110–2200 MHz for the downlink range. As of 2005, the 1900 MHz range is available for UMTS systems in the United States, but the 2100 MHZ range is largely reserved for U.S. satellite operations. In the United States, the FCC is attempting to free up space within the 2100 MHz range for full-scale UMTS.

UMTS was first deployed in 2001 by DoCoMo of Japan. T-Mobile has launched UMTS in Austria and Germany. Plus GSM of Poland launched in 2004. In the United States, AT&T Wireless (now part of Cingular Wireless) has deployed UMTS systems in over a half dozen cities, while Cingular Wireless plans to accelerate UMTS deployment. Dozens of UMTS networks are deployed.

UMTS is envisioned to allow many more applications to be introduced to a worldwide base of users and provides a vital link between today's multiple GSM systems and International Mobile Telecommunications–2000 (IMT–2000), the ultimate single worldwide standard for all mobile telecommunications.

IMT-2000

The vision of IMT-2000 is the *global* standardization for 3G and beyond *wireless* communications, defined by a set of interdependent International Telecommunication Union (ITU) recommendations. IMT-2000 provides a framework for worldwide wireless access by linking the diverse systems of terrestrial and satellite-based networks. This includes cellular, PCS, LANs, cordless, and satellite radio frequency environments.

As a global effort, the idea is to provide common radio spectrum across the world, initially in the 1900–2200 MHz range, extend this to include the 2500–2900 MHz range and the 700 MHz band, and—long term—include the heavily utilized 800–1800 MHz range. Targeting global seamless roaming and a wide range of multimedia services across all IMT-2000 family networks, IMT-2000 plans to integrate telecommunications networks worldwide.

The coordination of radio spectrum and network infrastructure specifications is an international effort, and the ITU works with global government and industry to coordinate and apply standards to radio spectrum, telecommunications networks, and network services. Over time, all network standards are expected to migrate toward the IMT-2000 specification. In 1999, the IMT-2000 specification adopted five types of terrestrial radio access technology standards for use. The IMT-2000 Terrestrial Radio Interface standards are

- **CDMA direct spread**—CDMA direct spread is a form of CDMA technology that directly "spreads" its pseudorandom sequence codes over the radio frequency channel in the frequency domain. This implies the underlying use of FDD. Direct spread is short for Direct Sequence Spread Spectrum (DSSS). The selected radio frequency bandwidth channel is a 5 MHz–wide channel and technique using wideband CDMA (WCDMA). WCDMA is the air link standard for the UMTS 3G wireless telecommunications standard.
- **CDMA multicarrier**—CDMA multicarrier spreads the data signal over multiple carriers. For the IMT-2000 CDMA multicarrier specification, the use of CDMA2000 1x and CDMA2000 1xEV technologies meet the requirements.
- **CDMA time-division duplexing**—Universal Terrestrial Radio Access (UTRA) is a standard that identifies the radio modes of access for UMTS networks. Both FDD and TDD are specified. The mode of UTRA TDD is specified for the CDMA TDD radio air interface. Another UMTS technology that implements TDD is TD-SCDMA.
- **TDMA single-carrier**—The TDMA single-carrier radio interface uses TDMA techniques as found in AMPS and EIA/TIA-136 cellular systems. The specific radio air interface is the use of UWC-136 for voice and EDGE for data. Universal Wireless Consortium-136 (UWC-136) is designed to provide an evolutionary path from AMPS and 2G EIA/TIA-136 networks to 3G participation with the IMT-2000 specification. The use of Enhanced Data rates for the GSM Evolution (EDGE) is the specification for data. These network technologies use TDMA in single-carrier mode.
- **FDMA/TDMA**—FDMA/TDMA is the use of both frequency and time-division multiplexing techniques. The specification calls for a local cordless telecommunications technology known as Digital Enhanced Cordless Telecommunications (DECT). DECT is a European Telecommunications Standards Institute (ETSI) standard that acts like a minicellular system in principle for cordless telephones. The cell distance is from 25 to 100 meters, typical of many cordless technologies today around homes and businesses. The DECT standard used FDMA, TDMA, and TDD modes to create

radio frequency communication channels in both frequency and time. DECT is specified to operate in the 1900 MHz range, but only for the short distances specified. Table 9-2 summarizes these IMT-2000 Terrestrial Radio Interfaces.

Table 9-2 *IMT-2000 Terrestrial Radio Interfaces*

IMT-2000 Radio Interface Technologies	Technology Application
CDMA direct spread	WCDMA (UMTS)
CDMA multicarrier	CDMA2000 1x and 1xEV
CDMA TDD	UTRA TDD and TD-SCDMA
TDMA single-carrier	UWC-136 and EDGE
FDMA/TDMA	DECT

For IMT-2000, data rates up to 2 Mbps for indoor wireless environments is specified for phase 1. The bandwidth size of 2 Mbps happens to be the size of an E1 telecommunications interface, for which most of the European wireline infrastructure is optimized using 4/3/1 digital access cross-connect systems. Additional phases will define data rates for wireless indoor and mobility specifications. Since IMT-2000 is based on the 3G classification, it is useful to examine these classifications next.

Generation Upon Generation

There are several competing standards for wireless communications. The technologies of GSM, TDMA, and especially CDMA are leading the wireless pack. Then there's the data add-ons of GPRS, PCS, EDGE, variations of CDMA such as CDMA2000 1x, wideband CDMA (W-CDMA), and high data rate technology CDMA 1x EV-DO. Each of these is designed to deliver particular mobile service functionality and features, and the industry classifies them into functional generations (xG) such as 1G, 2G, 2.5G, 3G, and beyond.

1G Systems

First-generation (1G) systems are generally referred to as analog cellular systems using the AMPS standards. These systems were typically designed and deployed in the 1970s and 1980s, offering primarily voice-only services. These included the Nordic mobile telephone system, the AMPS systems used for the United States, and the early TACS system in the United Kingdom.

2G Systems

Second-generation (2G) systems began deployment in the 1990s. The digital version of AMPS referred to as D-AMPS was considered a 2G technology, in that it basically provided voice communications and some improvements to handset technology only.

2G systems enhanced the use of the frequency spectrum, providing more security in through-the-air communications and allowing mobile telephony to begin linkage with computer information systems such as databases. Both the signaling and the speech channels are digital transmission technology. These digital systems also improved the battery performance of the digital mobile handsets.

2.5G Systems

In the late 1990s, new requirements for two-way messaging, digital voice mail, wireless data such as e-mail and Internet, and personal number services drove an evolutionary enhancement to 2G systems, known commonly as 2.5G. It is the increased sophistication of these digital voice enhancements and low-speed digital data transmission capabilities that generally identifies 2.5G systems. Short Message Service (SMS), wireless application protocol (WAP), and General Packet Radio Service (GPRS) are some of the defining data applications in 2.5G systems. The current European GSM network standard is usually classified as 2.5G network functionality. Data transmission in 2.5G systems is faster than that of 2G systems, benefiting from GPRS and helping designate European 2.5G systems with the nomenclature of GSM/GPRS.

You learn more about GPRS later in this chapter.

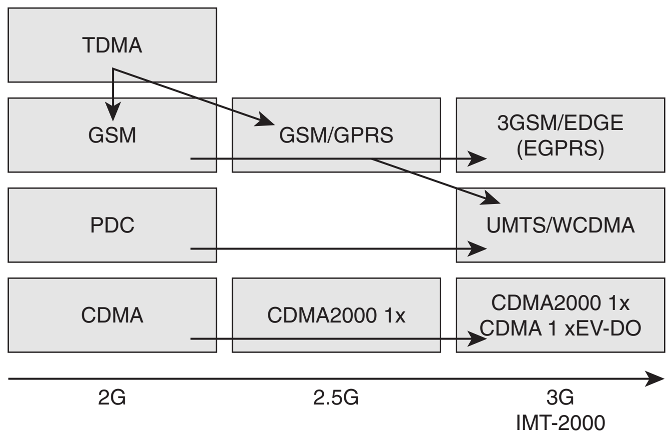
3G Systems

Often termed the holy grail of wireless capabilities, advanced mobile wireless, or third-generation (3G) services, 3G systems allow for high-speed, always-on data transmission. They are intended to provide access to a wide range of telecommunications services, specifically for mobile users. Worldwide roaming and services capability, Internet, and other multimedia applications are some of the key features that fit the 3G paradigm. The use of volume-based billing of content services by the kilobyte in addition to voice minutes is another goal of 3G systems. For 3G data applications, the specifications generally require the ability to support both circuits and packets with the following rates and caveats:

- 144 Kbps (minimum) or higher for vehicular traffic
- 384 Kbps (minimum) for pedestrian mobile users
- 2 Mbps or more for indoor, semi-stationary mobile users
- Asymmetric data rates for send and receive
- Multimedia mail store and forward
- Both fixed and variable rate data traffic

Figure 9-4 shows a typical evolution path from 2G operator networks, through 2.5G to 3G networks.

Figure 9-4 *Typical 3G Migration Path*



Beyond 3G to 4G Systems

There is so much emphasis on the deployment and utilization of 3G systems that there is little definition work or development effort, at least by the current 3G standards organizations in regard to 4G mobile systems. It appears that many new technologies (such as HSDPA) will become folded into 3G system enhancements or considered as either beyond 3G (B3G) or perhaps 3.5G systems. The aforementioned IMT-2000 is a long-term project, so much effort will be placed in that direction on an international basis.

Possible directions for 4G systems will likely proceed along a couple of paths and be driven by entrepreneur forums and countries that wish to get a jump on future mobile communications. First, the push for even higher data rates of 10 Mbps and more, may or may not be significant enough to classify a technology as 4G status. Secondly, the press for open and pervasive wireless ubiquity may lay claim to 4G status. This would take the form of efforts to create software-defined mobile phones that can seamlessly roam from GSM or UMTS to CDMA to Wi-Fi, to satellite and other air link technologies, and perhaps even wireline. Data rates of 100 Mbps or more could become available to mobile phones and pocket PCs within a few years. Scaling from product trials to millions of subscribers and pervasive geographic coverage is always a challenge. The goal of seamless, ubiquitous connectivity for open architecture wireless is somewhat embodied in the IMT-2000 effort, as previously discussed, and more specifically listed as the charter of the 4th Generation Mobile Forum (4GMF). As always, time will tell.

Mobile Data Overlay

Many of the early voice access technologies are not designed to carry high-speed data. Wireless operators have chosen to overlay their networks with data support technology in a modular fashion. The data overlay technologies have resulted from requirements, design, and usability efforts to standardize and deliver the technology for use by providers worldwide. As you learn in the next sections, a few of these data standards are

- High-Speed Circuit-Switched Data (HSCSD)
- Generalized Packet Radio Service (GPRS)
- Personal Communications Services (PCS), described earlier in the chapter
- Enhanced Data rates for GSM Evolution (EDGE)
- Variants of CDMA, such as CDMA2000 1x and 1xEV-DO
- Wideband CDMA (WCDMA)
- Time-division synchronous code division multiple access (TD-SCDMA)
- High-Speed Downlink Packet Access (HSDPA)

HSCSD

HSCSD is an enhancement of data services (Circuit-Switched Data, or CSD) of all current GSM networks. It allows for access of data applications services, sending and receiving data from portable computers at a speed of up to 28.8 Kbps. The HSCSD solution enables higher rates by using multiple channels, allowing subscribers to enjoy faster rates for their Internet, e-mail, calendar, and file transfer services. Many operators that use HSCSD technology are currently upgrading their networks to rates of up to 43.2 Kbps. The HSCSD technology is a data attribute of a 2G network.

GPRS

GPRS was made available in GSM Release 97. GPRS is a standardized packet-switched data service and an extension of the GSM architecture. Packet switching means that GPRS radio resources are used only when users are actually sending or receiving data. Rather than dedicating a radio channel to a mobile data user for a fixed period of time, the available radio resource can be concurrently shared between several users. GPRS, therefore, lets network operators maximize the use of their network resources more dynamically.

GPRS uses TDMA time slot techniques. GPRS phase 1 support of about 28 Kbps of user data was introduced in 2000. In later phases, GPRS supports up to a 114 Kbps and may extend to a 171 Kbps data rate, although doing so would require using all eight TDMA time slots. In reality, GPRS generally uses two to three time slots. GPRS is commonly the data overlay technology for GSM 2.5G networks, so you may see designations of a provider network as a GSM/GPRS network infrastructure.

EDGE

The first of the data overlay technologies applicable to the 3G specifications is EDGE. EDGE was made available in GSM Release 99. It is a technology that operates from about 384 Kbps and higher, which is essentially wireless broadband, providing three times the data capacity of GPRS with what is sometimes termed Enhanced GPRS (EGPRS) technology.

Essentially, this increased data capacity is accomplished through enhanced modulation and coding techniques that allow 3 bits per symbol rather than the 1 bit per symbol for GPRS. Using EDGE, operators can choose to handle three times more subscribers than GPRS, triple their data rate per subscriber, or add extra capacity to their voice communications.

EDGE uses the same TDMA frame structure, logic channel, and 200 kHz carrier bandwidth as current GSM networks, which allows the existing cellular plant to remain intact. Using EDGE technology, the typical data rate is targeted for 384 Kbps and the theoretical data rate improves to about 553 Kbps. In the United States, Cingular Wireless made the EDGE overlay technology commercially available on its network in 2003.

CDMA2000 Family for Mobile Data

CDMA2000 is a family of Qualcomm-developed technology supporting both voice and data services over a standard (1x) CDMA channel. Since this section defines mobile data, it is useful to discuss the data transmission attributes of the CDMA2000 family, which include CDMA2000 1x, CDMA2000 1xEV-DO, and CDMA2000 1xEV-DV.

CDMA2000 1x

CDMA2000 1x provides many performance advantages including up to twice the capacity of earlier cdmaOne systems, helping to accommodate the continuing growth of voice services as well as new wireless Internet data services. CDMA2000 1X also provides peak data rates of up to 153 Kbps (and up to 307 Kbps in the future), without sacrificing voice capacity for data capabilities. From a data throughput perspective, it often compares and competes with the EDGE technology approach.

CDMA2000 1xEV-DO

For those who want higher-speed or larger-capacity data services, a data-optimized version of CDMA2000 1x, called 1xEV-DO, provides peak rates of over 3.1 Mbps, with an average throughput of over 700 Kbps. 1x EV-DO is comparable to wireline DSL services and fast enough to support demanding applications such as streaming video and large file downloads. Achieving these improvements through variable-rate speech codecs, dual receivers in handsets, and four-branch diversity in the base stations, CDMA2000 1xEV-DO also delivers data for the lowest cost per megabyte, an increasingly important factor as wireless Internet use grows in popularity. 1xEV-DO devices provide “always-on” packet data connections, helping to make wireless access simpler, faster, and more useful than ever. After conducting field trials, several providers began commercial deployments of 1xEV-DO during 2002. By combining CDMA2000 and 1xEV-DO as needed, CDMA2000 provides a flexible, integrated solution that maximizes capacity and throughput for both voice and data.

CDMA2000 1xEV-DV

The Qualcomm 1xEV-DV (Evolution-Data and Voice) specification is similar to 1xEV-DO. The difference is that 1xEV-DV can support the 3.1 Mbps data rate, along with concurrent operation of CDMA2000 1x and 1xRTT data users within the same 1.25 MHz radio frequency channel.

WCDMA

An additional 3G data overlay is known as WCDMA. Providing mobile users with wide area data rates initially from 384 Kbps and local area data rates up to about 2 Mbps, WCDMA is an ultra high-speed, ultra high-capacity radio technology that generates and carries a superbroadband wireless bandwidth for demanding applications such as streaming video, animations, and digital audio.

WCDMA uses spectrum with a 5 MHz–wide radio signal and a chipping rate of 3.8 megachips per second (Mcps) over which to apply its DSSS techniques. WCDMA is one of the data technologies initially targeting up to 2 Mbps data rates for both indoor wireless and mobile technologies, and is one of the enabling technologies for the European data specification of UMTS. A common reference to a 3G European network would be characterized as UMTS/WCDMA.

TD-SCDMA

TD-SCDMA uses a time-based (TDD) multiplexing technique to employ only a single frequency channel for both downstream and upstream data communications from the mobile cell phone to the base station transceiver. The RF channel width is 1.6 Mbps and enables data rates of 1.2 Kbps to 2 Mbps. The use of a single RF channel is termed *TDD unpaired mode*, meaning that the single channel is used for both upstream and downstream data communications. This is contrasted with *FDD paired* channel techniques, which use one frequency channel for the downstream data path and another for the upstream data path. TD-SCDMA is one of the data technologies approved for the IMT-2000 CDMA TDD radio interface specification. TD-SCDMA was jointly developed by Siemens AG, Datang, and the China Academy of Telecommunications Technology.

High-Speed Downlink Packet Access (HSDPA)

HSDPA is a relatively new technology that has evolved from experience with UMTS's WCDMA Release 99, but implementing a fast and complex channel control mechanism with new adaptive modulation and coding techniques and a fast scheduler. HSDPA works within a WCDMA downlink 5 MHz channel and is targeted at 0.9 to 10 Mbps data rates with the current standard allowing up to 14.4 Mbps. HSDPA is a 3rd Generation Partnership Project (3GPP) standard that achieves up to 10 Mbps in release 5, and using an option called multiple input multiple output (MIMO) is targeting 20 Mbps in release 6 of the 3GPP standardization process. Early HSDPA deployments will likely target about 3.6 to 4 Mbps data rates.

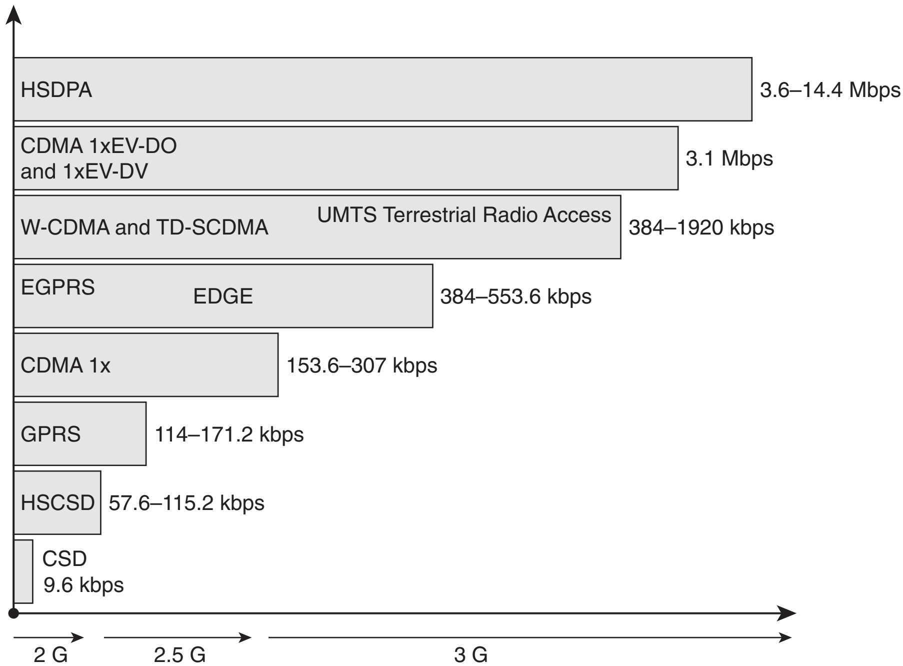
These speeds approach the range of wireline DSL and cable modem technology. This places HSDPA data capabilities into the 3.5G range (greater than 2 Mbps for mobile users). The first UMTS/HSDPA trial completed in Israel in 2005, and a UMTS/HSDPA network expansion is in the plans for Cingular Wireless in the United States.

Most operators of GSM networks view both EDGE and WCDMA as complementary technologies, allowing for a staged migration from GPRS data rates to EDGE, to those of WCDMA. WCDMA is likely to be used in dense metropolitan areas while EDGE serves the smaller metro areas, highways, and rural countryside. HSDPA is also a consideration for newer GSM networks or network upgrades. The moniker of 3GSM is the common marketing name for these advancing networks.

Comparing Mobile Data Rates

Figure 9-5 depicts target data rates for the various wireless technologies.

Figure 9-5 *Target Data Rates for Mobile Services*



To put these mobile wireless data rates in perspective, it is helpful to compare them with a typical user application, such as the download of an MP3 audio file from the Internet to a mobile phone. Table 9-3 depicts the approximate transmission times (theoretical) for a 23.04-megabit MP3 song file using the various data overlay technologies.

Table 9-3 *Approximate Download Times for Three-Minute MP3*

Network Technology	Maximum Data Rate	Download Time
GSM (CSD)	9.6 Kbps	41 minutes
IS95-A CDMA	14.4 Kbps	31 minutes
GSM (HSCSD)	43.2 Kbps	9.5 minutes
GPRS (TDMA)	45 Kbps	9 minutes
IS95-B CDMA	64 Kbps	6 minutes
CDMA2000 1x	153 Kbps	1.5 minutes
EDGE	553 to 1920 Kbps	12 to 41 seconds
WCDMA	384 to 1920 Kbps	12 to 60 seconds

Table 9-3 *Approximate Download Times for Three-Minute MP3 (Continued)*

Network Technology	Maximum Data Rate	Download Time
TD-SCDMA	2.0 Mbps	12 seconds
CDMA 1xEV-DO	3.1 Mbps	8 seconds
HSDPA	3.6 Mbps to 14.4 Mbps	2 to 7 seconds

Mobile Radio Frequency Spectrum

Since the topic of radio frequency spectrum is so vast, this section focuses on only those particular areas that pertain to wireless communications via cellular and PCS technologies.

In the United States, analog and digital cellular frequencies are assigned about 70 MHz from the 824–894 MHz range. This band is one of the usable modes in dual-mode phones. Whenever the digital cellular PCS or GSM up-spectrum band (1800 and 1900 MHz) is out of range, the analog mode (800 MHz band) of a dual-mode phone will become active to fill in gaps of coverage.

In the United States, the TDMA version of PCS operates in the 1850–1990 MHz band, specifically using about 60 MHz from 1850–1910 MHz for phone transmit, followed by a 20 MHz separation or guard band, and then another 60 MHz from 1930–1990 MHz for the base station transmit.

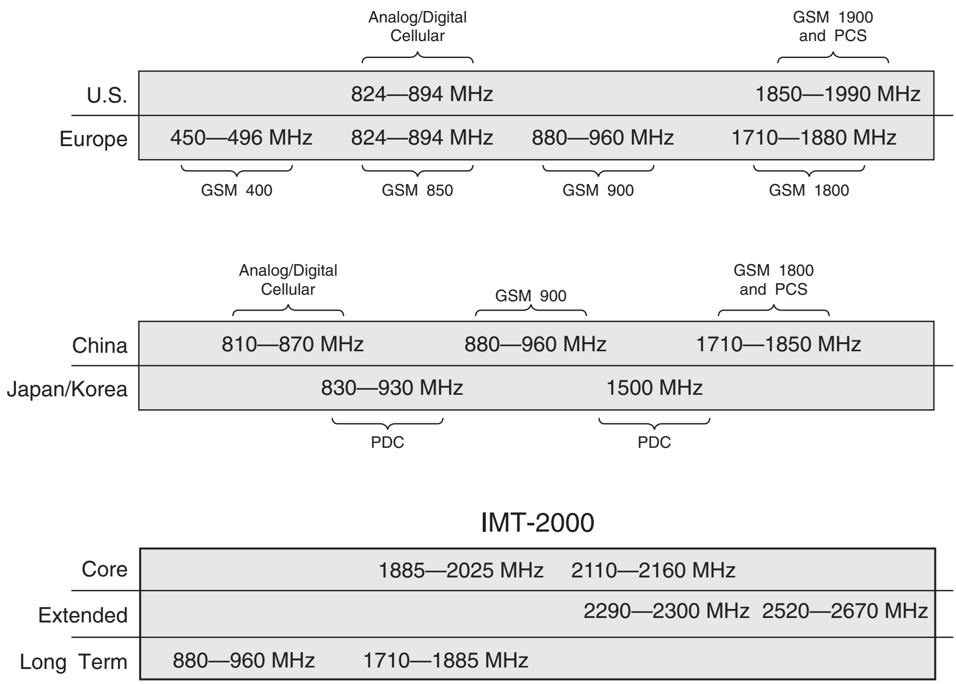
The CDMA version of PCS uses the same frequency range, but as previously mentioned, CDMA will use a digital spread-spectrum technique to encode and distribute mobile calls across the available range of assigned frequencies. This allows both the use of TDMA and CDMA in the same frequency ranges.

In the United States, GSM operates in the 1850–1990 MHz frequency band and is generally referred to as GSM1900. In Europe, where mobility began in the Nordic Scandinavian countries (home of Ericsson, Nokia), GSM networks have a very strong legacy in assigned frequency use. GSM base station transceivers and cell phones can use four frequency ranges, referred to as GSM400, GSM850, GSM900, and GSM1800. Additionally, the GSM1800 range is referred to as the PCS range for Europe as well as China. Also in Europe, the UMTS assigned frequency range is the 1885–2025 MHz range and the 2110–2190 MHz range. Figure 9-6 provides a conceptual view of the wireless mobile phone spectrum allocations.

IMT-2000 is intended to bring high-quality mobile multimedia telecommunications to a worldwide mass market based on a set of interfaces specified in the global, mobile, ITU standard. It's best to think of the IMT-2000 frequency assignments as a global overlay approach. Systems looking to provide worldwide interoperability and IMT-2000 status should work within the IMT-2000 designated bands. For example, the current European UMTS frequency bands fit within the IMT-2000 frequency bands.

The IMT-2000 usable bands, initially identified at the World Radiocommunications Conference (WRC) in 1992, are 1885–2025 MHz and 2110–2200 MHz. These are called the IMT-2000 *core* or *current* frequency bands. At the WRC-2000 meeting, additional usable spectrum was proposed, extending IMT-2000 future allocations in the 2290–2300 MHz and 2520–2670 MHz bands. The ITU is also suggesting allocation of existing 2G spectrum as long-term spectrum for IMT-2000, with "long term" defined as years 2005–2010. For a summary of these allocations, see Figure 9-6.

Figure 9-6 *Wireless Mobile Spectrum Allocations*



There is also momentum for establishing 90 MHz of spectrum for 3G services in the 1710–1755 MHz band and another 45 MHz of spectrum from within the 2110–2170 MHz band. To do so will require clearing of several existing aeronautical mobile and tactical radio relay systems that currently operate in the area.

Navigating the Mobile Spectrum

When you place a call from a North American digital cellular phone to another North American PCS phone (TDMA), you begin to surf the spectrum. Let's assume that you use the first available channel in the assigned spectrum, and after negotiation with the base station (MTSO) your digital cellular–initiated call starts transmitting on a narrowband frequency channel at 825 MHz. You will hear the call progress or ringing tones coming back to your phone's earpiece via the receive channel at about 870 MHz. In this example, the MTSO determines that the destination mobile ID number of the PCS phone is not on your subscribed system, so it will switch the call over landline facilities to get to the MTSO of the destination PCS network. Borrowing the previous assumptions about the availability of the first frequency channel, the MTSO will send the call request to the PCS phone via a TDMA narrowband channel at 1930 MHz and the PCS phone will answer and transmit back to the PCS's MTSO via the 1850 MHz channel. In summary, this two-way conversation used four wireless narrowband 30 kHz frequency channels—two on the digital cellular network at 825/870 MHz and two on the PCS network at 1850/1930 MHz—and also switched between the different MTSOs via landline services.

If the destination PCS phone is on a CDMA system, then the spread-spectrum design of CDMA will encode, encrypt, spread, and modulate the information onto a pair of 1.25 MHz bandwidth radio carriers between the CDMA network's MTSO and the PCS phone, making it more difficult for you to know what data are manipulated as CDMA carries the conversation.

Let's stretch the example to an international call to Europe, with the destination being a GSM subscriber. Let's assume that your digital cellular phone negotiates the 825 MHz transmit and 870 MHz receive to connect to the local MTSO, and that the call destination digits are determined to be international and will route via long-distance facilities of the wireless provider's choosing. If the call destination is a country with GSM1800 system coverage, then the call could be delivered to the GSM phone handset using the Euro-GSM frequency allocation of 1710 MHz for phone transmit and 1805 MHz for the phone's receive frequency.

For the first part of the complete round trip, your conversation gets digitized and modulated onto, for example, the U.S. 825 MHz channel, then hops from MTSO to local switching office(s), then to an international long-distance provider to skip across the Atlantic Ocean, and finally jumps to the destination European GSM1800 system which modulates the conversation onto the 1805 MHz frequency channel to the GSM phone.

For the return path, the GSM phone converses via the 1710 MHz channel to the GSM MTSO, which hops, skips, and jumps back across the Atlantic to your digital cellular MTSO to send the return conversation to your digital cellular handset over the 870 MHz channel. In summary, that's U.S. 825 MHz transmit to European 1805 MHz receive to 1710 MHz transmit to U.S. 870 MHz receive. If the international long-distance segment of this call were delivered via satellite, then the call would use additional spectrum in the uplink and downlink from the appropriate satellite(s).

Wireless LANs

Wireless LANs (WLANs) are creating attractive new growth opportunities. Simple to deploy and relatively inexpensive to acquire, WLAN technology uses unlicensed spectrum to achieve data transfer rates at 1 Mbps, 2 Mbps, 5.5 Mbps, 11 Mbps, 54 Mbps, and beyond. These data rates are significantly higher than the specifications of 3G and are potentially disruptive to 3G data service offerings—especially for pedestrian-based wireless services.

The early iterations of WLAN technology left much room for improvement with primary issues related to security and limited distance. Deployed in the Industrial, Scientific, and Medical (ISM) band of the radio spectrum at 2.4 GHz (2400 MHz), there are caps and limitations on power and range to reduce interference with the surplus of other devices in this unlicensed area.

The 802.11x standard represents the technical specifications of WLANs. The 802.11b, 802.11a, and 802.11g standards are currently the most rampant. Given the statutory and physics-related constraints on the improvement vector of WLANs, or more specifically, the 802.11x standard, 3G data technologies and 802.11x technologies could end up as complementary products that can be knitted together as a blanket of coverage. A parallel for this is one where 802.11x would represent wireless LANs while 3G data technologies would characterize wireless WANs.

WLANs are more commonly referred to using the marketing term Wi-Fi—which is short for wireless fidelity. Using a Wi-Fi card or Wi-Fi integrated technology in laptops or handhelds, mobile computing users can surf the Internet at 11 Mbps up to 54 Mbps speeds without physically plugging their computer into anything, in this case, as long as they are within about 300 feet of a Wi-Fi "hotspot's" central access point (AP). Essentially, Ethernet through the air, Wi-Fi is a technology that is easily co-opted and overlaid on existing wired LANs to provide laptop computers more ubiquitous access and always-connected capability. Wi-Fi is cellular in concept—the Wi-Fi AP is generally at the center of a wireless cell that radiates the radio frequencies for a few hundred feet in circumference. Deploying several APs and tying them together through a network backbone infrastructure enables wireless roaming from Wi-Fi cell to Wi-Fi cell.

Before moving into a discussion of the 802.11 standards, it is first helpful to work through the underlying seed technologies that make WLANs possible. A brief review of the 802.11 physical layers is necessary. Following will be an introduction of the 802.11a, b, and g standards and their comparative merits. Additional wireless technologies are then reviewed, such as WiMAX, Bluetooth, Ultra-Wideband (UWB), and wireless optics, closing the chapter with fixed wireless topics such as MMDS, LMDS, and satellite.

802.11 Physical Layer (PHY) Techniques

In June 1997, the IEEE released 802.11 as the first international standard for WLANs. Initially defined for 1 and 2 Mbps data rates, the original standard employed three physical techniques:

- Diffused infrared
- Frequency hopping spread spectrum (FH or FHSS)
- Direct sequence spread spectrum (DS or DSSS)

NOTE In September 1999, the 802.11 standard was updated to the 802.11b version, which dropped the use of the diffused infrared PHY layer while maintaining and enhancing the FHSS and DSSS PHY layers.

Diffused Infrared

The diffused infrared method is essentially photonic wireless and fiberless transmission, using the 850- to 950-nm band of infrared light with a peak power of about 2 watts. Restricted to close-proximity operation and constrained by low-power requirements to reduce any possible damage to the human retina, diffused infrared is limited to approximately 25 to 35 feet at a speed of 1 to 2 Mbps. The diffusion property of the infrared transmitter fills an area much like a light bulb, bouncing off of the walls and ceiling. Many early laptop PCs incorporated diffused infrared ports with which to communicate with other like PCs on an ad hoc networking basis. Part of the original 802.11 standard, the specification of diffused infrared as a PHY layer in the 802.11b standard revision, was dropped.

FHSS

The 802.11b standard uses the FHSS as one of two PHY specifications. FHSS is analogous to FM radio transmissions where a data signal is superimposed on a narrowband carrier, but in this case the data signal can change frequency or “hop”. The standard provides for 26 hop patterns or frequency sequences to choose from as it operates in the ISM band at around 2.4 GHz.

The 2.4 GHz band is unlicensed radio space, about 82 MHz of it used for a bundle of things that use wireless communications. With FHSS, each of 79 channels is 1 MHz wide and the selected channel must hop at a fixed but nearly random rate. (The United States specifies a minimum of 2.5 hops/sec.) This rapid modulation or frequency hopping helps protect the signal from radio interference that may be concentrated around one frequency. By frequently hopping at a pace of about .4 seconds in the 2.402–2.4835 GHz range, the signal transmission is successful and reasonably secure as long as the transmitter and receiver know the rate and the sequence of the frequency hops. However, the ISM band is full of other wireless devices, and a good percentage of the FHSS frequency "hopping" time may encounter it. Actual throughput per user using FHSS could be less than 1 Mbps, which is fine for applications like inventory scanners and warehouse telemetry systems, but comes up short of the higher bandwidths needed for multimedia data and database applications.

FHSS is generally limited to 2 Mbps data rates but the bandwidth can be increased to up to 24 Mbps by designing multiple APs into the network. The standard doesn't include coordination of hopping sequences for multiple APs, so more interference is likely unless the AP and wireless card vendor uses a proprietary mechanism to provide this on its equipment solution. The FHSS technique has a limited range compared to other modulation techniques. For that reason, FHSS is primarily an intrabuilding technology and is largely unused in Wi-Fi deployments looking for 11 Mbps and higher speeds.

DSSS

Another physical layer technique is called DSSS. First developed by the U.S. military as a secure wireless technology, it modulates or changes a radio signal on a pseudorandom interval, making it very hard to distinguish and decipher from background noise. To provide the most robust security, encryption techniques are often used with DSSS technologies.

DSSS works by taking a data stream of ones and zeros, and then modulating the stream with a second pattern known as the *chipping sequence*. The chipping or spreading code is used to generate a redundant bit pattern to be transmitted, and the resulting signal appears as wideband noise to the unintended receiver. This is important because 802.11 WLANs work in the ISM band, which is unlicensed and fraught with interference from other wireless devices. It's like yelling a secret to one other person in a crowded room—the two of you being the only persons who understand the language.

With the 802.11b specification, DSSS divides the 2.4 GHz radio frequency band into three nonoverlapping, 22 MHz–wide channels (channels 1, 6, and 11). Data is sent across one of the 22 MHz–wide channels without hopping to either of the other channels. It is the function of the 11-bit chipping sequence, known as the *Barker sequence*, combined with spreading the data signal across the 22 MHz channel, that provides the extra bits necessary for the error checking and correction needed to recover the data at the receiver. This is like taking one bit and making it into 11 bits, hoping that at least enough of the bits will be received despite any interference to determine the proper value of the bit that was originally sent. Without knowing the spreading code, the data appears as background noise and is effectively unintelligible. However, the proper receiver knows the code and despreads the signal for use. While this seems like a lot of overhead, the result is more data throughput per bit-time, fewer retransmissions, and lower latency. Low latency is especially important to wireless voice applications. The net result is that DSSS is more tolerant of noise and interference, and therefore can expand data capacity in these environments.

The DSSS modulation technique was selected to support not only the 1 and 2 Mbps speeds, but also two additional speeds of 5.5 and 11 Mbps, the speedy crux of the 802.11b standard. To enable the higher speeds of 5.5 and 11 Mbps in the 802.11b standard, in 1998 Lucent Technologies and Harris Semiconductor proposed a new redundant sequencing method called Complementary Code Keying (CCK). Through the CCK replacement of the original 11-bit chipping sequence, which effectively coded one data bit at a time, the 5.5 Mbps wireless data rate is achieved using CCK to encode 4 bits per carrier. By enhancing CCK to 8 bits per carrier, you can double the rate to the 11 Mbps threshold that is so highly desired with today's wireless infrastructures. DSSS-based 802.11b WLANs running at 11 Mbps establish a kinship with their wired 10 Mbps Ethernet cousins, leading to the popularity of the 11 Mbps WLANs as the minimum entry into WLANs.

Orthogonal Frequency Division Multiplexing (OFDM)

OFDM has previously been reviewed as a wireless access technology. OFDM has applicability not only to wireless mobility devices such as data-enabled cell phones, but also to wireless LANs. In fact, the IEEE 802.11 standards that support up to 54 Mbps WLAN transmission rates do so using the OFDM multiplexing technique to achieve data rates higher than 11 Mbps. OFDM research is leading to capabilities to push the top end to 108 Mbps. Variants of OFDM are often referred to as coded OFDM (COFDM) and vector OFDM (VOFDM), described later.

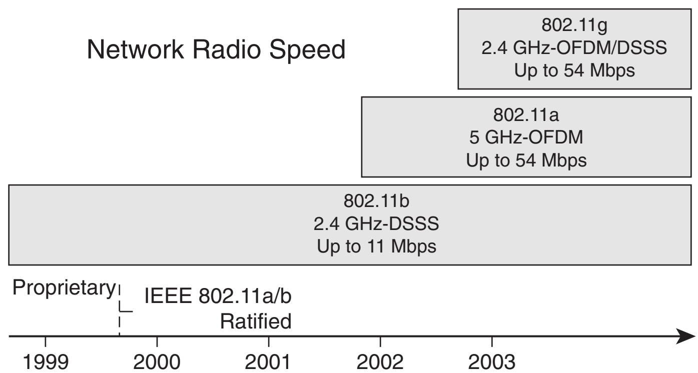
802.11—11 Mbps and Beyond

The wireless speed of 11 Mbps has initiated the charge toward a critical mass of WLAN deployments. 11 Mbps represents a 10x performance improvement over the original 1997 IEEE 802.11 standard, while providing a suitable substitute for wired 10-megabit Ethernet connections. In this section, you'll review some highlights of the 802.11b, 802.11a, and 802.11g specifications within the 802.11 standard. These are primarily differentiated by their achievable speeds, their assigned frequency range, or their effective channels and channel throughput. Figure 9-7 shows the IEEE standardization timeline for 802.11b, 802.11a, and 802.11g.

802.11b

The 802.11b revision of the standard specifies the use of both FHSS- and DSSS-based PHY layers for achieving data speeds up to 11 Mbps per radio frequency channel. 802.11b operates in the 2.4 GHz band, so the use of DSSS as an access technique is the most popular, achieving rates of 1, 2, 5.5, and 11 Mbps. The higher speeds were accomplished using a high-rate DSSS channelization scheme using either CCK or an optionally available packet binary convolutional coding (PBCC) scheme. Three nonoverlapping channels are used, each 22 MHz wide within the 82 MHz of 2.4 GHz assigned spectrum.

Figure 9-7 *Timeline for 802.11 WLAN Standards*



Because the U.S. FCC regulates output power for 2.4 GHz and ISM-band products to no more than 1 watt, all 802.11b AP radios will adapt to a less-complex and slower encoding technique, as an 802.11b wireless device moves farther away from the AP. For example, the 2.4 GHz DSSS radios transmit at a maximum of 100 mW. If your wireless-enabled device is within 130 feet, it will typically move data at 11 Mbps speeds. As you move further away from the AP, there is a power fade because your device no longer is receiving a full 100 milliwatts. The AP detects this movement and "downshifts" the transmission to the next slower technology, for example, 5.5 Mbps. As you move to the fringe of the AP's coverage area, your data transmission speed will drop to 2 Mbps and finally to 1 Mbps. While building layouts cause these numbers to vary, the approximate distance from the AP at which you will likely downshift to slower rates is as follows:

- 1–130 feet: 11 Mbps
- 131–180 feet: 5.5 Mbps
- 181–feet: 2 Mbps
- 251–350 feet: 1 Mbps

An 802.11b AP generally reaches a maximum aggregate capacity of 18 Mbps, delivering about 6 Mbps per user if all three channels are in concurrent use. To support more concurrent users, multiple AP designs factor in effective per-client throughput, the types of wireless data and voice applications in use, and their delay bounds.

802.11a

Enter 802.11a, an amendment designed to operate within more recently allocated 5 GHz spectrum known as the Unlicensed National Information Infrastructure (U-NII) bands. The U-NII bands cover about 300 MHz of spectrum for 802.11a, 200 MHz of which is at 5150–5250 MHz (U-NII indoor) and 5250–5350 MHz (U-NII low power) and the remaining 100 MHz of which is at 5725 to 5825 MHz (U-NII/ISM). In November 2003, the FCC allocated the 5470–5725 MHz spectrum to 802.11a operation as well, extending the U-NII/ISM range by another 255 MHz. The higher-frequency U-NII bands have more inherent performance from the shorter-length radio waves, and much less competing interference than today's 2.4 GHz ISM band. However, remember that higher frequency radio waves propagate for shorter distances and are less effective at passing through walls and other obstructions. The effective distance of 802.11a is less than that of 802.11g, for example.

802.11a uses 20 MHz–wide frequency channels, assigning four channels per 100 MHz (the original three U-NII bands) for a total of 12 concurrent wireless channels in the United States. Europe uses an amendment called 802.11h, which doubles the channels for use in Europe to 24 channels. 802.11h is the European version of 802.11a, but it includes radar detection capabilities in this European ETSI standard so the 802.11h AP radios can have up to 24 channels. With more channels, more aggregate throughput is the result.

The 802.11a standard utilizes this new frequency space, along with increases in power radiation (50 mw in U-NII bands 1 and 2 up to 1 watt in U-NII band 3) and a new coded orthogonal frequency division multiplexing (COFDM) encoding scheme to achieve the higher symbol rates of as much as 54 Mbps. Transmitting over multiple carrier frequencies in parallel, COFDM is the antidote for intersymbol interference. Actually, this 802.11a standard uses 6, 12, 24, and 54 Mbps as well-defined data rates. Cisco System's 802.11a-compliant radios additionally support speed options of 36 and 48 Mbps.

Again, the further you wander from the AP, the more your data rate proceeds along a downramp of speed bumps. As you reach the fringe of 802.11a AP coverage, you are still transmitting at about 6 Mbps, six times the entry performance of the 802.11b standard. The use of Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA), a common error avoidance technique in wired Ethernet networks, rounds out the ability of the 802.11a standard to achieve such high data rates. The maximum theoretical data rate of the COFDM technique is considered to be 108 Mbps, about double today's WLAN radio capabilities.

The maximum aggregate capacity of an 802.11a AP is about 300 Mbps, with all 12 channels in concurrent operation, delivering about 25 Mbps per channel. The average throughput rate per client is dependent on the number of simultaneous clients and the types and data sizes of the applications in use.

Despite the benefits of the less-crowded 5 GHz band, 802.11a is therefore in a completely separate frequency band than 802.11b or 802.11g, with no backward compatibility to support an ordered migration of 802.11b wireless clients. A flash cut to 802.11a would be required. If you're adding WLAN to a kitchen microwave assembly and testing plant, you may want to consider the 802.11a radio, as microwaves operate in the 2.4 GHz unlicensed range. The added irritant of operating in a regulated frequency band (5 GHz) adds to uneven coverage worldwide, as each region will have different regulatory approaches to allowing the use of the spectrum for 802.11a.

802.11g

In 2003, another amendment to the 802.11 standard was finalized: 802.11g. The 802.11g specifications allow 802.11g radios to transmit up to 54 Mbps, but does it in the 2.4 GHz ISM-band operating range. The 802.11g standard is a fifth generation of 2.4 GHz radios and provides data performance comparable to that of the 802.11a WLAN standard, which operates in the 5 GHz bands, while providing backward compatibility with the legacy 11 Mbps 802.11b standard, which operates at 2.4 GHz. To accommodate this compatibility, the 802.11g radio standard uses any of three modulation techniques of the DSSS, PBCC, and OFDM technologies, with a variety of supported data rates of 1, 2, 5.5, 6, 9, 11, 12, 18, 24, 36, 48, and 54 Mbps. Data rates at 12 Mbps and above typically use the OFDM method. This makes for an easy and speedier upgrade path from the 802.11b radios, which operate at 2.4 GHz and at a maximum data rate of 11 Mbps. While backward compatibility of 802.11g APs with 802.11b wireless client cards is great for migration, it should be understood that any 802.11b client that associates with an 802.11g AP will cause the AP to slow down to 11 Mbps transmission rates on all channels to achieve the header timing necessary to accommodate the lone 802.11b client.

At close proximity, a single-user 802.11g wireless client can approach 54 Mbps of throughput. An 802.11g AP will generally have a maximum aggregate throughput of 66 Mbps, allowing each of the three nonoverlapping channels to achieve about 22 Mbps of utilization each for concurrent operations. When an 802.11b client is present within the 802.11g domain, the aggregate throughput drops to about 24 Mbps, doling out about 8 Mbps per channel.

The added benefits of the 802.11g techniques are the lower cost of the 2.4 GHz radios as well as the lower power requirements of the 2.4 GHz transmitters in end devices. Low power is extremely important to many wireless handheld devices. Power-efficient Wi-Fi will be a key component in tomorrow's mobile handhelds and pocket PCs.

Comparing 802.11 Standards

Within the context of WLANs, network capacity is roughly calculated as the product of throughput multiplied by the number of available radio channels. The 802.11b and 802.11g devices at 2.4 GHz are limited by their respective standards to no more than three non-overlapping radio channels. The 802.11a specification at 5 GHz allows for up to 12 radio channels in the United States and up to 24 channels in Europe(802.11h). More radio channels provide more aggregate data capacity per access point, and practical use normally yields data throughput per channel less than the advertised maximums. Table 9-4 provides useful perspective for approximate network capacity, throughput, and channel comparisons of 802.11x wireless radio technology.

Table 9-4 *Approximations for 802.11b, 802.11g, and 802.11a Networks*

IEEE Standard	Maximum Data Rate (Mbps)	Throughput (Mbps)	Channels	Access Point Capacity (Mbps)
802.11b	11	6	3	18
802.11g (with 802.11b clients)	54	8	3	24
802.11g	54	22	3	66
802.11a	54	25	12	300
802.11a (with 802.11h)	54	25	24	600

Both the 2.4 and 5 GHz 802.11 wireless products are successful, providing distinct price/performance data points along the mobile computing curve. A variety of task groups are continuing work to enhance security (802.11i), quality of service (QoS) (802.11e), wireless bridge operations (802.11c), AP interroaming recommendations (802.11f), virtual wireless LANs, and other features that are desirable in maturing the Wi-Fi technology. Another high rate specification is in the works as 802.11n, seeking to create an 802.11 standard for 108 Mbps operation.

The IEEE 802.11 standards group has defined a very rich feature set with an abundance of options. The Wi-Fi Alliance, an industry group, is focused on streamlining the 802.11 feature set to enhance interoperability and, above all, acceptability of wireless LANs in the marketplace.

Cisco Systems takes the minimal feature sets defined by the Wi-Fi Alliance and adds some additional, differentiating features into its 802.11*x* radios. All vendors and groups are focused on stoking the take-up rate of wireless LANs into departmental networks; public access hotspots such as airports, hotels, and coffee shops; service provider commercial offerings; and, of course, into the home and mobile networking techno-set.

802.16

802.16a is a relatively new IEEE standard also known by its IEEE marketing term of IEEE Wireless MAN 802.16. Colloquially, the industry refers to the resulting products, networking, and functionality afforded by the standard as WiMAX. The 802.16a wireless networking standard offers broadband wireless access at greater range and bandwidth than the Wi-Fi set of 802.11 standards. 802.16a is targeting available radio spectrum from 10 to 66 GHz with amendments to use frequencies in the 2–11 GHz range as well, supporting both licensed and unlicensed bands. A variant of the standard, called 802.16e, is specified to enable a single base station to support both fixed and mobile users, and is gaining traction very fast with service providers. Further standardization revisions are occurring in 2005, and WiMAX-certified products are relatively new.

The technology supports adaptive modulation, effectively balancing different data rates and wireless link quality. The original standard expects to use both FDD and TDD. The legacy FDD method, widely deployed in cellular networks, requires two channel pairs for transmit and receive with frequency separation to limit interference. The use of TDD uses a single channel for both transmit and receive transmission, dynamically allocating upstream and downstream bandwidth depending on traffic requirements. Both 802.16a and 802.16e will likely use OFDM as a multiplexing technique for the standard.

The WiMAX standard is targeting about 70 Mbps of shared throughput up to a distance of 31 miles (50 km) from a single base station, with features such as QoS and data, voice, and video services. This greater range and increased bandwidth would be most appealing to service providers seeking price performance options in delivering last-mile access to broadband users rurally, nationally, and internationally. With this type of range, bandwidth, and coverage area, WiMAX would be classified as a wireless metropolitan area network (WMAN). As a WMAN, the last-mile(s) technology would hope to connect to Wi-Fi networks (the last few hundred feet), such as 802.11x access points in your business or residence, to bridge Wi-Fi access technology to core service provider networks. The inclusion of Layer 2 roaming features into the technology would be a forward-thinking capability.

Wireless Personal Area Networks

Additional wireless technologies target short-range applications for personal area networking, sometimes referred to as wireless personal area networks (WPANs). These technologies are Bluetooth and Ultra-Wideband (UWB), and they are are being addressed in the IEEE 802.15 standards working group.

Bluetooth

Conceptually similar to a very low speed Universal Serial Bus (USB) technology, Bluetooth wirelessly connects personal computer peripherals, consumer electronics, and telephone systems within a 10-meter range. It uses autonegotiation to connect to other Bluetooth-enabled devices such as a notebook computer to a mouse, to a printer, to a PDA, or to a mobile phone, creating cable-free connections between up to seven devices. Bluetooth is also targeting consumer electronics such as audio and video entertainment systems to reduce the cable clutter.

NOTE The Bluetooth RF standard took its name from the 10th century king of Denmark, Harald Blatand, which transliterated to English means Bluetooth. Harald Blatand, son of the first king of Denmark, "Gorm the Old," was credited with uniting Denmark and parts of Sweden and Norway into a single kingdom.

Bluetooth (IEEE 802.15.1) communicates in the ISM band of 2.4 GHz using FHSS and TDD at 1600 times per second. In practice, the frequency range is 2402–2480 MHz, with 79 1 MHz–wide channels in the United States. In Japan, the frequency range is 2472–2497 MHz, with 23 1 MHz RF channels. Data in a packet can be up to about 2745 bits in length. Transmitting at no more than the allowed 1 mW, Bluetooth asynchronous speeds reach 721 Kbps in one direction, with 57.6 Kbps in the return path. Synchronous rates are supported at a speed of 432.6 Kbps.

Automatic and inexpensive, Bluetooth wants to take over the short-range world. The current Bluetooth standard is found in over 1000 different devices. Bluetooth 2.0 extended data rate (EDR) is now achieving about 3.0 Mbps at distances of 10 meters.

Ultra-Wideband (UWB)

UWB is a more recent development in short-range radio frequency technology that is targeting the high bit rate WPAN consumer markets in the areas of personal computing, consumer electronics, and automotive industries. Other potential uses for UWB are imaging applications such as ground penetrating radar and medical imaging systems, due to UWB's radar-like properties and its resistance to multipath interference. UWB has the potential for very high data rates using very low power at limited range.

NOTE Multipath interference is the reception of two or more signals over different paths. The direct signal may combine with a reflection off a roof, wall, or other surface. It can be refraction off of trees or an atmospheric inversion layer. The received signal is the vector sum of the two signals creating both an amplitude and phase change. This type of distortion may move rapidly across the frequency band. UWB devices use a RAKE receiver to combine multipath signals and benefit from them.

UWB is unique in that it achieves wireless communications without using an RF carrier. Instead, UWB uses modulated pulses of energy less than a nanosecond in duration. Like tracer fire on an anti-aircraft gun, the UWB modulation technique encodes the data bits into a pulse train instead of a continuous wavelength, which has the benefit of power efficiency.

The technology uses multiple wideband channels with a minimum effective throughput of 50 to 100 Mbps per channel. To create the multiple channels, the familiar technologies of TDMA, CDMA, FDM, and time hopping (TH) are all usable for UWB designs. UWB has a potential for 500 Mbps or more at ranges less than 10 meters, transmitting between 3.1 and 10.6 GHz spectrum at power levels up to one milliwatt. This is a very wide RF channel at 7 GHz of width. The UWB technology is finding use in Wireless USB 2.0, which is using UWB technology to achieve data rates up to 480 Mbps at a distance of 10 meters.

Although used in the U.S. military for years under special license, the FCC has only recently (February 2002) granted manufacturers permission for developing and commercially marketing UWB products in the United States. UWB has the potential to take market share from short-range Wi-Fi home networking and perhaps compete with wired bus technologies such as IEEE 1394 (e.g., Apple's *FireWire*) and USB 2.0 in the personal computer market. Digital TVs, home theater systems, digital cameras, and camcorders are some of the consumer electronic devices being targeted for early UWB technology chip sets.

Wireless Optics

Wireless optics is the use of lasers to send voice, video, and data through the air from one building to another instead of through expensive, underground fiber-optic cables. This is very significant when you consider that such technology could go a long way toward solving the "last-mile problem"—the inability of businesses and consumers to access and afford superbroadband fiber-optic cables at their doorstep.

Often termed *free-space optics (FSO)*, this point-to-point wireless broadband technology sends an invisible, eye-safe beam of laser light through the air, from rooftops, through windows, or from cell towers to another receiving location. Current FSO systems provide excellent reliability through recently developed active pointing and tracking technology. Exceptionally high security is provided due to narrow beam divergence. Mesh network design for FSO systems also increases reliability in weather such as advection fog and snowstorm conditions, and in excessive building sway. Active laser-gain mechanisms allow the lasers to compensate for air clarity, tuning the laser output to deal with changing weather conditions. The primary appeal of these systems is that they do not require the purchase of spectrum licenses or expensive trenching for in-ground fiber.

Some of the manufacturers in this space are offering carrier-grade, network-ready FSO connectivity at Fast Ethernet (100 Mbps) and OC-3/STM-1 (155 Mbps) capacities. The solution works in either indoor or outdoor configurations, with two transceiver units placed within line of sight of one another. Network traffic is converted to infrared light at 1550 nm and transmitted through the air at about 15 mW of power. On the other end, specialized lenses and mirrors focus the signal onto a receiver, which converts it back to the original data and sends it over the building's network infrastructure to the appropriate destination. These types of FSO systems are full duplex, and they transmit data at the full rated speed.

There are also FSO products that support OC-12/STM-4 (622 Mbps) and GigE (1.25 Gbps) data rates. Some products create redundant links that can be used to deliver bit error rates (BERs) of 10^{12}, a performance previously only available via fiber.

Wireless optics solutions are uniquely designed to meet the short-distance, point-to-point and point-to-multipoint line-of-sight wireless broadband requirements of today's enterprise and provider networks. They can be deployed in any situation where fiber optic or leased lines are unavailable, too costly, or bandwidth constrained, as long as the buildings are within line of sight and under a 4 km distance. Carrier-class high-availability specifications generally require shorter line-of-sight distances, usually in the range of 500 meters.

Typical wireless optics applications include provider fiber network extension (or last-mile deployment), LAN-to-LAN or LAN-to-campus connections, spatially diverse/redundant connections, temporary links, mobile wireless network backhaul or extension, fiber backup, and disaster recovery.

Fixed Wireless

Fixed wireless systems are often used for both extensions of wireline telephony and for broadcast video, audio, and data applications. Fixed wireless can be used to extend wireline services at an appropriate cost factor. In a telephony example, fixed wireless can be a radio spectrum-based local exchange service in which telephone service is provided by common telephony providers. It is primarily a rural application, because it reduces the cost of conventional wireline. Fixed wireless extends telephone service to rural areas by replacing a wireline local loop with radio communications.

There are several other terminologies for fixed wireless, including

- Wireless local loop
- Fixed loop
- Fixed radio access
- Wireless telephony
- Radio loop
- Fixed wireless
- Radio access

Fixed wireless access systems generally employ TDMA or CDMA access technologies and, more recently, VOFDM.

VOFDM

VOFDM is a Cisco Systems innovation that is widely hailed for its ability to overcome multipath interference for wireless communications. VOFDM allows for provision of fixed wireless systems that reach near line-of-sight environments. Previously, fixed wireless technologies required deployment on very tall buildings or towers with an absolute line-of-sight requirement to the receiving antennas. This prerequisite limited deployment options and customer reachability. VOFDM has now made possible near line-of-sight configurations of both point-to-multipoint and point-to-point at a range of up to 30 miles. This technology can increase the effective market reach beyond the capabilities of traditional last-mile broadband wireless systems.

VOFDM employs a vector processing technique that combines frequency and spatial diversity to mitigate multipath fading and narrowband interference. VOFDM delivers higher spectral efficiency, even in obstructed paths or interference-limited cells. Spatial diversity increases a system's tolerance to noise and multipath interference in both upstream and downstream directions in a point-to-multipoint wireless system. VOFDM effectively increases the transmission strength by combining multiple signals at the receiving end, boosting overall wireless system performance, link quality, and availability.

There are also fixed wireless networks to support and augment data applications that aren't cost effective by using wireline technologies. Some of these examples are Multichannel Multipoint Distribution Service (MMDS) and Local Multipoint Distribution Service (LMDS).

MMDS

MMDS is a broadband wireless system presently used in North America to deliver video program content for television entertainment and, in cooperation with Instructional Television Fixed Services (ITFS) operators, to deliver video for distance-learning activities. Most systems traditionally use analog transmission under the National Television Systems Committee (NTSC) standard to deliver one video program per 6 MHz radio frequency (RF) channel on about 31 channels. These fixed wireless systems require line of sight to a metropolitan or residential area rather than cellular, as found in mobile PCS systems. This requires the transmission towers to seek maximum elevation to cover the largest area possible. MMDS broadcast signals are usually received via fixed rooftop antenna.

A broadband wireless system such as MMDS can deliver up to 30 Mbps data capacity in a 6 MHz channel; therefore, many providers have adapted their systems to provide data capabilities via unused or reallocated channel space. A strong point of fixed wireless is that it can quickly provide high-speed bursty data such as Internet access to a 10-mile, 20-mile, or 35-mile radius depending on the frequency band used. This allows the MMDS service provider to work with or compete with cable TV to serve small-sized and medium-sized businesses and high-end users with data offerings. As was mentioned in Chapter 8, "Wireline Networks," a cable provider's coaxial cable plant typically serves residential neighborhoods and underserves the premium business market. The available downstream spectrum for fixed wireless systems includes the following:

- Two Multipoint Distribution System (MDS) channels, 2150–2162 MHz, that generally are single-channel broadcast stations
- Sixteen Instructional Television Fixed Systems (ITFS) channels, A through D Group, 2500–2596 MHz, which are educational television and distance learning
- Eight MMDS channels, E and F Group, 2596–2644 MHz
- Four ITFS G Group, interleaved with three MMDS H1/2/3 channels, 2644–2686 MHz

In many other countries, a similar amount of downstream spectrum has been assigned for MMDS use within the range of 2 to 3 GHz.

A major change is occurring in the MMDS industry with the transition to digital video compression and transmission. Digital technology enables compression of at least five video streams of similar resolution to NTSC-standard analog video into one 6 MHz RF channel. In the digital environment, an operator that has access to most of the downstream channels listed above can offer a selection of program streams that can aggressively compete with either direct broadcast satellite (DBS) or CATV entertainment video delivery systems with several channels to spare. MMDS has also adopted the cable labs' Data over Cable Systems Interface Specifications (DOCSIS). (The moniker of DOCSIS+ denotes the wireless broadband version of DOCSIS.) MMDS will likely be in competition with 802.16 WiMAX.

LMDS

Local Multipoint Distribution Service (LMDS) is another fixed wireless system characterized by shorter-range, three-mile radius transmissions, but at wider channel spacing. LMDS channels are 20 MHz wide each, and are assigned in the 27.5–28.35 GHz, 31–31.3 GHz, and 38 GHz band. LMDS uses small line-of-sight antennas with which to communicate. This is a relatively new service definition compared with traditional broadcast fixed wireless systems, and applications for LMDS are developing. Examples of LMDS applications include a fixed wireless Internet data solution or wireless cable television targeting a residential neighborhood or concentrated business park center. These early systems promised cheaper building access than fiber, but technology challenges, labor-intensive assembly, and roof-right negotiations have not allowed LMDS to catch up to its marketing vision. Like MMDS, LMDS has also adopted the cable labs' DOCSIS specifications (DOCSIS+) to deal with theft-of-service issues. LMDS will likely compete with 802.16 WiMAX as well.

Satellite Wireless

From 22,223 feet above the Earth, in what is known as the Clarke belt, geo-stationary satellites, often termed GEOs, blanket the Earth with wireless audio, video, and data received from ground broadcast stations. From that altitude, you can cover the Earth with three satellites, which must orbit very rapidly to keep up their stationary, relative position as the world turns. At such a distance (more than 35,000 km), communication satellite technology inherits a one-way, 275–300 millisecond (ms) propagation delay (round trip of 550–600 ms), reducing its effectiveness for interactive two-way communication applications. Since signal power attenuates in proportion to the square of the traveled distance, Earth-based transmitters require large antenna dishes and megawatts of focused beam power to work with GEO satellites.

That's why several new providers in this space want to deploy low-to-medium Earth-orbiting satellite technology, often referred to as LEOs. The lower the orbit, the less the round-trip delay, yet the more satellites it takes to provide global coverage, in this case, about 30. How low? Many of these LEO projects are targeting a mere 500 to 1500 km above the Earth, making them 25 to as much as 60 times nearer than GEO satellites way out in the Clarke belt. Yet this also reduces the power requirements and metric form factors of the satellite receiver in user technology. Many of these LEO providers may start with about 12 satellites to cover key population areas with broadband Internet access, interactive multimedia, and high-quality voice. Using the Ka band of frequencies from about 17 to 36 GHz, small-aperture antennas—a little over two-feet wide—are capable of discriminating between satellites. For example, using the Ka-band frequencies such as 28.6–29.1 GHz for the uplink and 18.8–19.3 GHz for the downlink, these low-to-medium Earth-orbiting satellites can send about 20 Mbps to user terminals on the downlink and up to 2 Mbps on the uplink.

Both TDMA and CDMA are transmission technologies used in satellite services.

Applications for satellite services range from wireless cellular mobility, to Internet broadband services, to high-speed TCP/IP-based multimedia delivery. The market for these types of services is generally considered those areas that cannot be reached with fiber optics but that need performance approaching that of fiber optics. These nongeostationary orbit satellites (NGSOs), as they are sometimes called, must work with international organizations for spectrum allocations.

Technology Brief—Wireless Networks

This section provides a brief study on wireless networks. You can revisit this section frequently as a quick reference for key topics described in this chapter. This section includes the following subsections:

- **Technology Viewpoint**—Intended to enhance perspective and provide talking points regarding wireless networks.

- **Technology at a Glance**—Uses figures and tables to show wireless network fundamentals at a glance.
- **Business Drivers, Success Factors, Technology Application, and Service Value at a Glance**—Presents charts that suggest business drivers and lists those factors that are largely transparent to the customer and consumer but are fundamental to the success of the provider. Use the charts shown in the figures in this section to see how business drivers are driven through technology selection, product selection, and application deployment to provide solution delivery. Additionally, business drivers can be appended with critical success factors and then driven through the technology, product, and application layers, coupled as necessary with partnering, to produce customer solutions with high service value.

Technology Viewpoint

Wireless networks now cover the spectrum from cellular phones to wireless Ethernet to fixed wireless and satellite wireless services. Since 1985, the United States has amassed over 200 million cellular subscribers that are served by some 176,000 cellular sites. Of the 60 plus percent penetration of U.S. mobile phones to U.S. citizens, the conversion to digital cellular and PCS subscribers have reached greater than 90 percent of that install base, doing so rapidly since digital handsets first became available in the first quarter of 1996. Worldwide, subscribers are expected to top 2 billion users by 2010. It is this massive digitalization that enables the convergence of data, audio, and video to the palm-sized communicators with a surplus of portable possibilities.

Wireless mobility stands at a difficult junction. The industry is becoming increasingly involved in delivering data, audio, and video over its wireless networks. A struggle to standardize data services over cellular and PCS infrastructure looms very large indeed. Though mobile phones are pervasive, the industry is a worldwide tower of complex technologies and diversified markets. A global orbit would require a suitcase of different phones, varied technologies, unique data transports, and a plethora of radio spectrum to semi-continually stay in touch.

Multiple generations of wireless classifications add to the burgeoning acronym soup of mobile wireless technologies. There are access standards, data standards, network standards, and usability specifications—all are used to classify a network as 1G, 2G, 2.5G, and 3G. Each of these is generally "crammed" into the existing RF spectrum assignments. While the overall mixture creates complexity, options are increasing for wireless providers to craft personable, mobile services that customers will use. It is apparent that the wireless manufacturers and wireless providers are preparing for increased mobile data usage in the years to come, as mobility and computing, voice and data come together to provide a seamless, untethered, spectrum-efficient, and robust mobility experience.

Providers should focus on allowing seamless roaming among different networks without interruption of user service, working with manufacturers and standards organizations to create solutions that support multiple technologies of 802.11, 802.16e, CDMA 1xRTT and CDMA 1xEV-Dx, GSM/GPRS, EDGE, and UMTS/WCDMA networks. IMT-2000 is one approach.

As the industry integrates data communications and computing into the mobile phone form factor, industry leaders should consider following the way of the Internet. Standards are crucial if mobile devices are to seamlessly connect with the Internet and the vast data warehouses of the world's enterprises. IP networking, the fundamental carriage of the global Internet, provides an open, standards-based protocol suite for supporting data delivery, whether for personal computing or mobile phone networks. With mobile IP networking, wireless networks can become seamless extensions of the Internet, the enterprise, the home, and the individual.

Wireless LANs are all about portability of personal computing. Industries such as government, healthcare, education, and manufacturing have led the charge into untethered computing, realizing productivity gains as much as 40 percent. Internet networking standards have swiftly coupled the world's disparate computers, PDAs, and pocket PCs together for a best-yet data-sharing experience. WLAN standards have adopted the Internet Protocol suite and, through the deployment of WLAN infrastructures, are becoming last-link enablers to anytime, anywhere computing. The integration of voice services through Voice over IP protocols becomes yet another data application to carry on the computing backplanes of current and future handheld personal computers.

Enterprises will be looking for WLAN and Wi-Fi ease of deployment, centralized management, high performance, and scalability, as well as robust security in WLAN options. These are generally addressed with features such as dynamic power and channel assignment, automated RF site surveys and RF validation, rouge AP detection, and load balancing. Also high on the list are QoS, low-latency support for wireless voice and video, seamless roaming, high-throughput (Gbps) switching capacity, Wi-Fi–protected access, and advanced encryption standard security and integration support for advancing standards such as WiMAX. WPANs and WMANs are recent developing market spaces with promising opportunities.

The mobile and wireless industry has already matured beyond adolescence and cannot ignore the fundamentals of longevity. Mobile and wireless service providers that focus on the basics of service quality, customer service and segmentation, ease of use, and operational performance—while using technological, procedural, and cultural innovation to differentiate—will enjoy the best success.

Technology at a Glance

Figure 9-8 illustrates the application of wireless data technology.

Figure 9-8 *Wireless Data Technology Application*

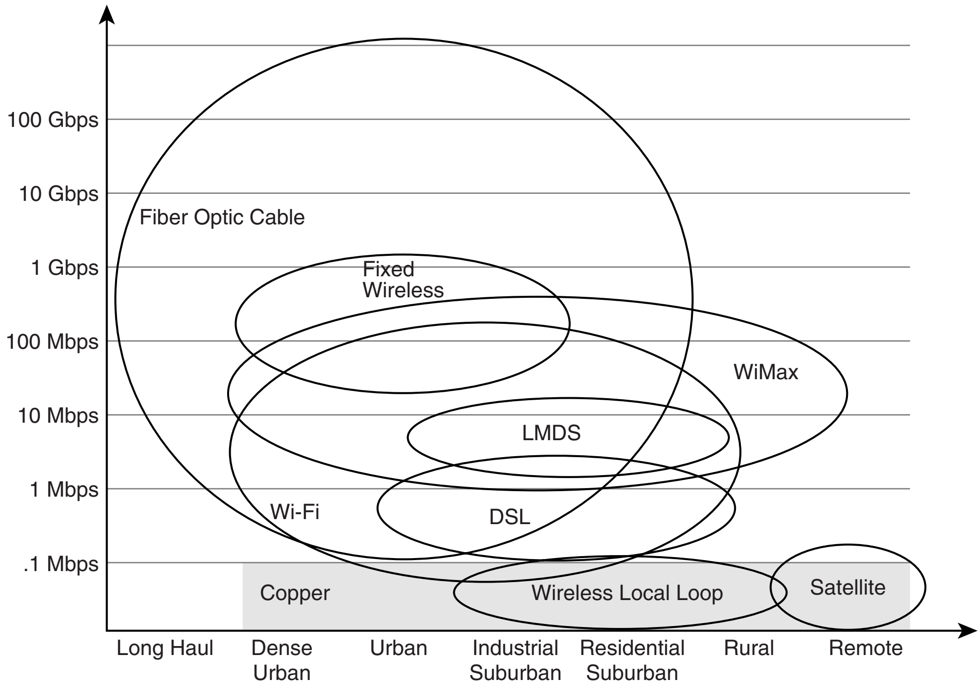


Table 9-5 compares wireless technologies.

Table 9-5 *Wireless Technologies*

	WPAN	**WLAN**	**WMAN**	**WWAN**
Standards or developing standards	Bluetooth (802.15.1) Ultra-wideband	802.11 Wi-Fi	MMDS and LMDS 802.11 Wi-Fi 802.16 WiMAX	GSM, GPRS, EDGE, WCDMA, cdmaOne, CDMA 1xRTT, CDMA 1xEV-DO, 2.5G–3G, satellite, and others
Seed technology	FHSS, TDMA	FHSS, DSSS, OFDM	FHSS, DSSS, OFDM, VOFDM	FDMA, TDMA, CDMA, OFDM

continues

Table 9-5 *Wireless Technologies (Continued)*

	WPAN	WLAN	WMAN	WWAN
Speed	1 to 3 Mbps Bluetooth 250-500 Mbps UWB	11 to 54 Mbps	11 to 100 Mbps	10 Kbps to 2.4 Mbps
Range	Short	Medium	Medium–long	Long
Applications	Peer-to-peer Device-to-device Home theatre and entertainment systems Vehicle proximity SmartCard transactions PC peripherals	Mobile enterprise computing Mobile Internet computing Home networking	Wireline replacement Last-mile broadband access	Mobile telephony Mobile messaging Media on demand Mobile Internet Mobile enterprise Mobile/global positioning system

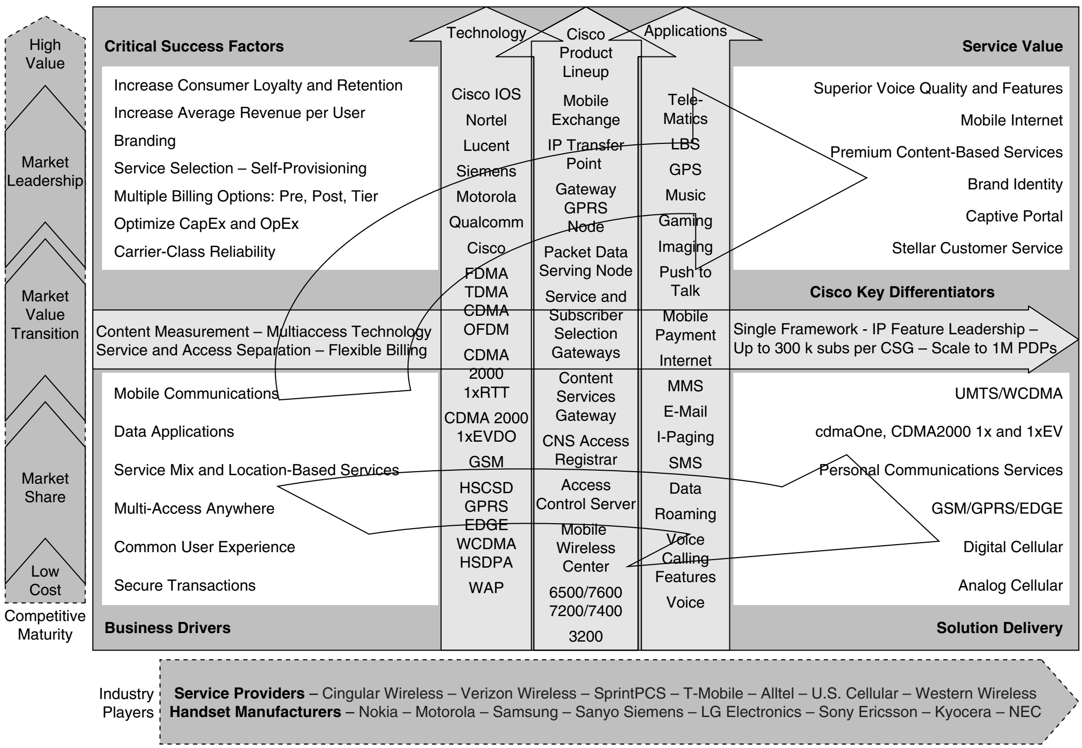
Business Drivers, Success Factors, Technology Application, and Service Value at a Glance

Solutions and services are the desired output of every technology company. Customers perceive value differently, along a scale of low cost to high value. Providers of solutions and services should understand business drivers, technology, products, and applications to craft offerings that deliver the appropriate value response to a particular customer's value distinction.

The charts shown in the following figures list typical customer business drivers for the subject classification of networks. Following the lower arrow, these business drivers become input to seed technology selection, product selection, and application direction to create solution delivery. Alternatively, from the business drivers, another approach (the upper arrow) considers the provider's critical success factors in conjunction with seed technology, products and their key differentiators, and applications to deliver solutions with high service value to customers and market leadership for providers.

Figure 9-9 charts the business drivers for wireless mobility.

Figure 9-9 *Wireless Mobility*



Wireless Mobility

Figure 9-10 charts the business drivers for WLANs.

Figure 9-10 *Wireless LANs*

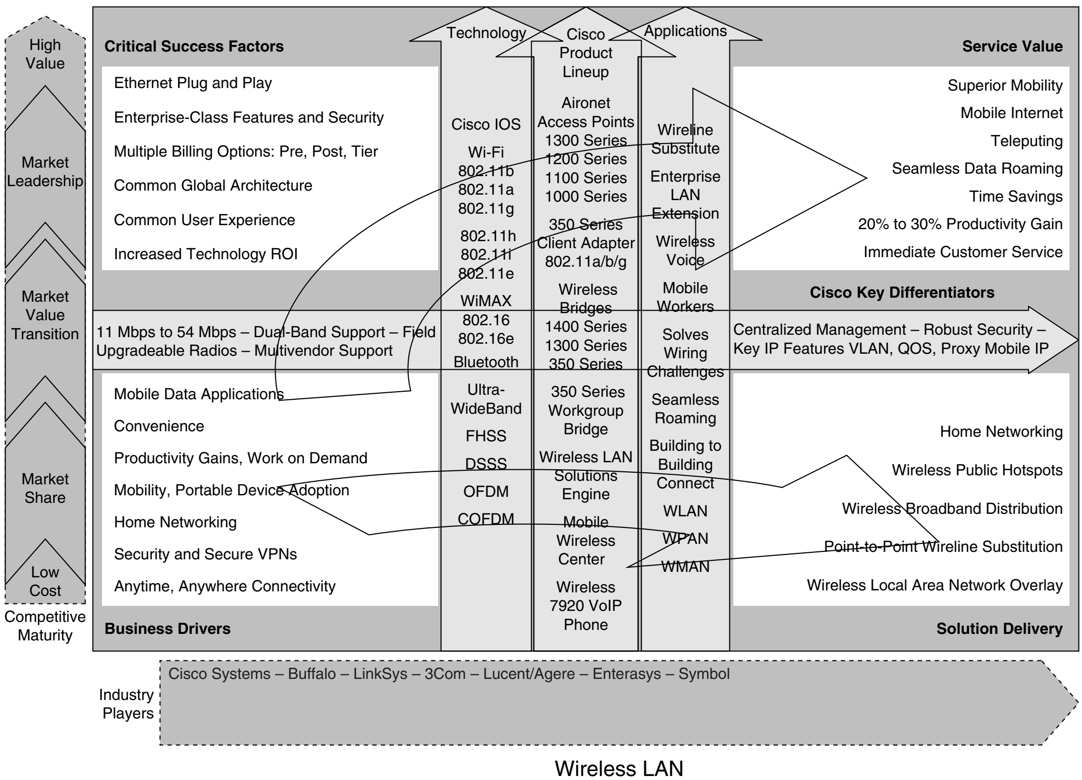
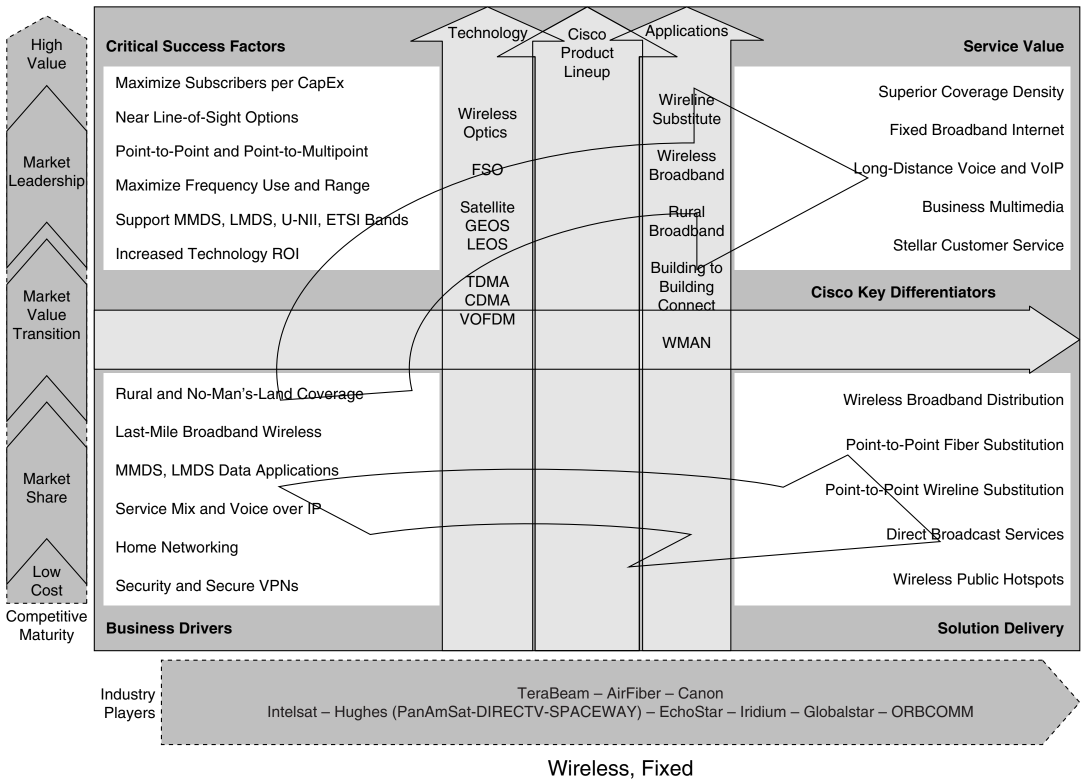


Figure 9-11 charts the business drivers for fixed wireless.

Figure 9-11 *Fixed Wireless*



End Notes

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