Wireless Wide Area Networks (WWANs)

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WWANs have been in place since the early 1980s for voice communication, and since the early 1990s for data communication. Access to these networks requires users to sign an agreement with the company that operates the network they are interested in. This agreement will allow them to use the wireless network for a fee, which is often calculated by the number of minutes the user is connected to the network, or more recently, by the amount of data transferred over the network. This fee helps the service provider cover the cost of building and maintaining the wide area network, as well as the cost required to purchase the spectrum used for communication. Unlike WPANs and WLANs, wireless wide area networks do not operate over unlicensed frequencies, meaning they have to pay to purchase (or license) the spectrum being used. In some cases the amount of money paid for this spectrum is incredibly large. For example, the sale of spectrum for next-generation wireless networks cost more than $35 billion (U.S.). In order to recover some of those expenses, a usage fee has to be charged.

Do not let the prospect of a fee turn you away from using WWANs, however, as they provide an important component of many wireless solutions. When coverage beyond the range of a WLAN solution is required, WWANs are the place to look. They can provide national, and often international, wireless coverage for both voice and data communication. The communication quality and speed depends on the technology being used. Other properties that are network-dependent include area of wireless coverage, operating frequencies, handset availability, and, of course, cost.

In the remainder of this section we will take a look at the generations of wireless networks and the protocols currently being used. We will start with an overview of the terminology and concepts for wide area wireless networks.

Communication Fundamentals

Many technical concepts are involved with wireless voice and data transmissions. We are going to cover the most pertinent ones in this section before we discuss the evolution of wide area wireless networks. You will find these terms to be very relevant to WWANs.

Analog versus Digital Signals

The first wireless networks used analog signals to transmit sound. Analog signals constantly change as the voice is transmitted, similar to fluctuations in voice itself. Due to the fluctuating nature of analog waves, they are often represented by a sine wave. The first generation of wireless networks used analog transmission for voice communication.

As wireless networks evolved and started to be used for more data as well as voice traffic, a need for digital communication arose. Digital transmissions are a stream of 1s and 0s. Since the data stored on computers is inherently digital, digital networks proved to be more efficient in terms of both spectrum and power consumption. All second-generation wireless networks with data capabilities use digital technology.

The following are some of the many benefits attained by moving to digital networks:

- **Efficiency.** Digital networks can transfer more data over the same amount of spectrum; they also allow for compression for even higher efficiency. Additionally, digital signals consume less power than analog.
- **Security.** Analog signals can be easily listened to by eavesdroppers with a radio tuner; even encrypted analog signals can be cracked quite easily. Eavesdroppers have a much more difficult time with digital signals as they can be encrypted to various strengths, depending on the level of privacy required. In addition, the distribution techniques of digital signals make them more difficult to decipher.
- **Quality.** Digital signals result in better-quality sound with less interference. Advanced filters can be used to remove any noise.
- **Features.** Digital technology allows for voice features such as call answer and caller ID, as well as provide the basis for all data traffic as required for any wireless m-business application.

Circuit-Switching versus Packet-Switching

Two switching mechanisms are used for data transfer: circuit-switched and packet-switched. Circuit-switched networks establish a physical connection between the two communicating parties. This connection is maintained for the duration of the connection and cannot be used by any other parties. Landline telephone networks are circuit-switched. When you make a telephone call, you are granted a connection to the person you are talking to. The line becomes available again only after the conversation is finished and one party hangs up. Thus, for every conversation, a dedicated line is required.

Circuit-switching works well for voice communication where there is a constant stream of data being transferred, but is very inefficient for many forms of data communication where information is requested in bursts, such as when browsing Web pages, because even when no data is being transferred, the connection has to be maintained. This adds additional cost to consumers, as they pay according to the time connected to the network, not by the amount of data downloaded. From the wireless operators' perspective it is also wasteful, as they cannot use that connection for any other purpose. Additionally, if the connection is lost, the user has to establish a new connection, a process that takes anywhere from 5 to 40 seconds.

Packet-switched networks solve these problems. They do not require dedicated connections, but rather allow several users to share a single connection to maximize spectrum. Internet traffic uses packet-based networks for data transmission. This works by dividing data into small units called packets. These packets are then assigned a destination address that they carry around as they are being routed through the network. Multiple users can share the same data path since the data packets do not have to follow any specific path to get to their destination. This allows them to take the optimal path for bandwidth efficiency. At the receiving end, the data packets are then reassembled into their original format.

In terms of the user experience, packet-switched networks are far superior to circuit-switched when it comes to transferring data. Since a dedicated connection does not have to be established, and since no bandwidth is being wasted if data is not being transferred, devices are able to maintain a constant connection to the network without incurring additional costs or network burden. This alleviates users from having to establish a network connection each time they need to transfer data.

Additionally, users are charged only for the data they transmit rather than connection times. This can result in significant savings. Network operators also prefer packet networks since they can utilize all of their network bandwidth. Packet switching is the basis of always-on connectivity provided by third-generation wireless networks.

Cells, Handoffs, and Roaming

A cell is the geographical area that obtains wireless coverage from a single cell site (base station). The coverage area for a cell depends on the network protocol, signal power, and obstructions that may impede its progress. As you move further away from the base station, the signal strength is weaker. Typical cell sizes range from 1 to 40 kilometers in radius. For wireless wide area networks, multiple cells are coordinated into a cell system. These systems provide coverage over a larger geographic area. Figure 3.4a illustrates the coverage area of nine cells; Figure 3.4b illustrates the same cells as hexagons as they are often depicted in theoretical drawings.

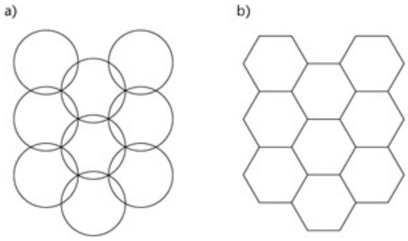

Figure 3.4: Cell coverage.

In highly populated areas, it is frequently necessary to create microcells, where base stations are positioned closer to one another to handle higher numbers of users. Microcells are often deployed in individual buildings, such as conference centers or airports, to handle the large volume of users. The coverage area of microcells is much less than a regular cell, typically around 100 meters in diameter.

When users move from one cell to another while a call is in progress, their connection has to be passed from cell to cell. This process is called a handoff (or in some cases, handover). The handoff is one of the most important aspects of mobile computing since it allows for the uninterrupted movement of mobile users. An unsuccessful hand-off results in a "dropped" call, which can be very frustrating for users. This is especially true on circuit-switched networks where users have to reestablish their connection before continuing.

When users move to a cell owned by a different wireless operator, they are roaming. Historically, wireless operators have charged high premiums for using services from other carriers, especially when roaming between countries. This situation is starting to change as carrier consolidation and strategic partnerships increasingly come into being. In fact, many wireless plans allow for unlimited roaming within the country or sometimes even the continent.

Multiplexing Techniques

Multiplexing is a term used to describe how a signal can be divided among multiple users. This spectrum sharing allows wireless operators to maximize the use of their spectrum to accommodate a large number of users over fewer channels. For digital systems, three main multiplexing techniques are being used for wide area networks: frequency division, time division, and code division. A fourth method, called orthogonal frequency division, is the most complex of all of these methods. It is commonly used in high-speed local area networks, as discussed earlier in this chapter, but is starting to grow in popularity for wide area networks as well.

- **Frequency-division multiplexing (FDM).** Numerous signals are combined on a single channel. Each signal on the channel is assigned unique frequency for communication. The caller and the receiver tune to the same frequency to communicate. This is similar to how radio stations work. Each has its own frequency band over which it broadcasts. To listen to a particular channel, you tune the receiver to that particular frequency. For person-to-person communication, this is a very inefficient use of spectrum, hence is only used by analog wireless networks.
- **Time-division multiplexing (TDM).** As with FDM, numerous signals are combined on a single channel, but with TDM they are divided into separate time slots. The time segments are assigned to an individual user and are rotated at regular intervals. The receiver interprets the appropriate time slot (channel) to receive the information. This technique allows for variation in the number of signals sent along the line, and constantly adjusts the time intervals to maximize bandwidth. Many of the current second-generation wireless systems are based on time-division multiplexing as it provides efficient use of spectrum with minimal interference.
- **Code-division multiplexing (CDM).** Rather than dividing the signal using frequency or time, CDM attaches a code to each signal, and sends them all over the same broad spectrum. This results in very high spectrum efficiency and low levels of interference by other signals. Even though all of the signals are being broadcast at once, a receiver will only accept the signals with the right code. This technique is used in several second-generation wireless networks and is the basis for nearly all third-generation networks.

First-Generation Networks (1G)

First-generation (1G) wireless networks were first constructed in the late 1970s in the United States and in the early 1980s in Europe. These analog networks were used only for voice communication and they suffered from high levels of interference, which led to unpredictable call quality. Early on, first-generation networks also suffered from poor handoffs, often resulting in dropped connections, low capacity, and almost no security. The devices also had to be quite large to incorporate the radio receivers necessary to capture the analog signal.

Despite these difficulties, first-generation networks were deployed commercially in many countries. In the early 1980s, the United States, along with Japan, Mexico, and Saudi Arabia, deployed networks using the Advanced Mobile Phone Service (AMPS). In Europe, several analog standards were introduced, including the Total Access Communications System (TACS) and Nordic Mobile Telephony (NMT).

Note Interestingly, the AMPS acronym later came to refer also to Analog obile Phone System, and then to American Mobile Phone System. All three terms are still in use.

Due to the limitations of the first-generation networks, European countries were quick to move to a new standard based on completely different technology. The case is different in the United States where the AMPS network was widely deployed across all geographies. In many regions, the AMPS network is still used, often as a backup when digital coverage is unavailable.

First-generation networks do not play much of a role in the current m-business environment. They are of interest only when looking at backward compatibility of second-generation networks or for broader coverage in rural areas for voice coverage.

Second-Generation Networks (2G)

Second-generation networks introduced digital capabilities to wireless in the early 1990s. This resulted in higher-quality voice as well as basic data services. In addition, other features such as voicemail, call waiting, caller ID, and three-way calling were introduced to the wireless voice market. Another incredibly important benefit of moving to digital technology was increased capacity. Digital technology allows for more users to communicate on the same amount of spectrum, thereby increasing efficiency. Additionally, digital networks also provide a means for strong security, which was missing in the first-generation analog networks.

All of the second-generation networks provide support for data communications, with the exception of TDMA, which uses Cellular Digital Packet Data (CDPD) for its data services. The rates of data transfer range between 9.6 and 19.2 Kbps. This is fast enough for simple Internet applications based on the Wireless Application Protocol (WAP) or text messaging with Short Message Service (SMS), but it is not adequate for more data-intensive applications.

Four major second-generation systems are currently in use:

- Digital AMPS (DAMPS, now known as TDMA), which can take advantage of first-generation AMPS service.
- Code Division Multiple Access (CDMA IS-95), introduced by QUALCOMM in 1995.
- Global System for Mobile Communications (GSM), which is the most popular of the 2G networks.
- Personal Digital Cellular (PDC), largely used in Japan.

These four networks are all based on different standards, making them incompatible with one another. Moreover, even the same network protocol may not be compatible due to frequency regulations. For example, in Europe, GSM networks operate on the 900-MHz and 1800-MHz frequency bands, while in North America GSM networks use the 1900-MHz frequency band.

To accommodate these differences, dual-band and tri-band handsets are available. These handsets can switch between the different GSM frequencies so a user can roam between countries, or even continents, and still use the same mobile phone. In North America there are also dual-mode phones, which allow for roaming between the digital DAMPS network and the analog AMPS network. Other features in second-generation handsets include WAP browsers, text messaging, contact lists, calendars, games, and changeable ringtones. Kits are also available that allow for PDAs to gain wireless access using a mobile phone as the modem. The handheld devices are either attached to the phone using a cable or via short-range wireless connectivity such as infrared or Bluetooth.

When it comes to deploying data-driven applications, second-generation networks are often inadequate. They are circuit-switched, which is inefficient and expensive, and provide very limited data transfer rates. The need for higher capacity, higher data transfer rates, and global roaming were the driving forces behind the introduction of third-generation wireless networks.

Second-and-a-Half-Generation Networks (2.5G)

Just as the name suggests, 2.5G networks are a step toward third-generation networks, but they are not quite there. The good news is that they provide the main feature that users require to be successful on the mobile Internet: packet data. The move from circuit-switched systems to packet-switched systems is the major difference between 2G and 2.5G networks. This move brings along many other positive features, the leading one being high-speed data transfer at rates up to 144 Kbps, nearly 10 times that of 2G networks. For wireless operators, upgrading to 2.5G networks often requires only a software upgrade, not hardware modifications. This is a very attractive option for carriers who want to test the market for enhanced data services without incurring large capital expenditures.

Note Although 115 to 144 Kbps is commonly used as the theoretical throughput of 2.5G systems, in practice, a more realistic data transfer rate is approximately 40 to 56 Kbps. This is still fast enough for a broad range of new applications.

Two leading 2.5G network protocols are in use: General Packet Radio Services (GPRS) Code Division Multiple Access 2000 1x (CDMA2000 1x). Both offer many compelling enhancements over existing 2G networks. The following are five important characteristics of 2.5G networks:

- **Efficiency.** More efficient use of spectrum by sharing connections among several users for both data and voice communication. This allows wireless operators to accommodate more users on the same network.
- **Speed.** By implementing more efficient modulation algorithms and by being able to use multiple channels simultaneously for data transfer, 2.5G networks can provide transfer rates up to 115 Kbps. This is a vast improvement over 2G systems.
- **Always-on capability.** Users can remain connected to the 2.5G network without having to pay by-the-minute charges, as they would on a circuit-switched network. This allows users to access data services at their convenience without incurring fees for resources they are not using. It also allows for a new range of applications that can push data to the user, rather than have them request it.
- **Upgrade to 2G systems.** Both 2.5G technologies, GPRS and CDMA 1x, are upgrades to existing cellular networks. Users still have the same voice capabilities as before, but now have high-speed data access with the same network coverage. In most cases, moving to 2.5G from 2G involves a software upgrade for the wireless carrier, as opposed to building new infrastructure from the ground up.
- **Foundation of 3G infrastructure.** The implementation of 2.5G technology lays the groundwork for future upgrades to 3G systems. This is true from both a business and technical standpoint. It is expected that as users experience the benefits of high-speed packet data, they will require even more speed and capacity, forcing carriers to upgrade to 3G. At the technical level, 2.5G provides the base packet network on which 3G networks can be built.

GPRS Handsets

Three classes of handsets have been defined to take advantage of the new GPRS services. Terminal is the term used to describe the GPRS unit, since it may not actually be a mobile handset, but instead a wireless network card or other module. The following are the three classes:

- **Class A.** These terminals handle both voice and packet data at the same time. This requires two transceivers, making Class A devices the most expensive of the three.
- **Class B.** These terminals can handle both voice and packet data, but not at the same time. This requires one transceiver that can be used for either voice or data. This keeps the cost of the handset down.
- **Class C.** These terminals can handle either voice or data. This class of terminal may be a low-end handset or, more likely, a wireless modem.

Often it is the device that is the limiting factor for the total data rates that 2.5G networks provide. In order to achieve the theoretical 115 Kbps, the device has to utilize all available time slots for both uploading and downloading data. Most devices do not provide this capability, as it increases the overall cost of the device for speed improvements that are not required by the average user.

2.5G Applications

Along with enhanced networks and new handsets come a full range of new wireless data applications. In some cases, the 2.5G applications are simply extensions to the applications used on 2G networks; in other cases, they are applications that previously were not practical or even possible on 2G networks. A good example of this is wireless Internet applications. On 2G networks, WAP applications are typically text-based with limited graphics. With 2.5G networks, wireless Internet applications can contain full graphics with some multimedia capabilities. The applications will also run more efficiently since the networks are packet-switched.

Other applications that lend themselves to 2.5G networks include:

- Corporate email, calendar, contact lists
- Instant messaging
- Still and moving images
- Job dispatch
- Vehicle positioning using location-based services
- Remote LAN access
- File-sharing applications

All of these applications take advantage of at least one of the characteristics mentioned earlier in this section. The increased data transfer rates apply to nearly all applications, while others, such as instant messaging and job dispatch, make particular use of the always-on functionality. In addition, since GPRS networks behave similarly to a typical LAN, they allow developers to build applications the same way they would for a typical IP network (of course, keeping the device and network limitations in mind).

Third-Generation Networks (3G)

Third-generation (3G) networks started with the vision to develop a single global standard for high-speed data and high-quality voice services. The goal was to have all users worldwide use a single standard that would allow for true global roaming. Unfortunately, as companies and standards bodies from Europe, North America, and Japan met, they could not agree on a single protocol for 3G systems. To help things progress, the leading standards bodies from these countries created a new group called the Third-Generation Partnership Project (3GPP). This group became the driving force behind the development of 3G standards.

After much negotiation, it was realized that backward compatibility with 2G networks and frequency differences among countries were too much to overcome, so agreement on a single 3G implementation could not be reached. Instead, three branches of 3G systems were created: Wideband CDMA (WCDMA), CDMA2000, and Enhanced Data Rates for Global Evolution (EDGE). In 1999, The International Telecommunication Union (ITU) approved an industry standard for third-generation wireless systems. This standard is called International Mobile Telecommunication-2000 (IMT-2000). Each of the 3G network protocols is explained in more depth in the section entitled "Network Protocols" later in this chapter.

Note Actually, there are more than three branches of 3G, since WCDMA varies in implementation between European and Japanese operators. Also note that, in Europe, 3G systems are often referred to as UMTS (Universal Mobile Telecommunications System) rather than WCDMA.

Interestingly, 3G systems are based on CDMA technology, whereas the majority of 2G implementations use TDMA. This fact was also an item of contention among the standards bodies. Several proposals were made to the 3GPP, but the eventual winner was the CDMA-based solutions mentioned previously. The first 3G systems were implemented on a trial basis in Japan and Europe in late 2001. Worldwide commercial rollouts of these networks began in late 2002, and will continue into 2005. By 2005 to 2006, 3G networks are expected to reach a critical mass in both the consumer and corporate markets. This is the point at which the high-speed wireless networks become a necessity, not a luxury. Over time, the goal of the IMT-2000 is to converge the three 3G standards into a single universally accepted standard. Only time will tell if this will occur.

Once there was agreement on the standards, details were provided on which features these networks would offer. Two main enhancements characterize third-generation networks:

- **Higher data rates.** 3G systems provide data transfer rates ranging from 144 Kbps to 2 Mbps, depending on the level of mobility. The IMT-2000 has defined three levels of mobility. All 3G networks must support the following minimum requirements:
  - *High mobility:* 144 Kbps for outdoor rural users who are traveling at speeds greater than 120 kilometers per hour (75 miles per hour).
  - *Full mobility:* 384 Kbps for users traveling less than 120 kilometers per hour in urban areas.
  - *Limited mobility:* 2 Mbps for users who are moving at less than 10 kilometers per hour (around 6 miles per hour).
- **Enhanced quality of service.** QoS is supported from end to end in 3G systems, unlike their 2.5G predecessors. This allows users to establish agreements with network operators for certain network properties such as data transfer rate and network latency.

Looking at the preceding information, note that most vendors talk about 2 Mbps bit rates for 3G networks, when in reality that is only for users in stationary indoor environments. A more typical rate for the average mobile user is around 384 Kbps, which is still close to 50 times the rates achieved in most 2G systems. This is also notable, because when users move away from 3G network coverage, they will typically drop into 2.5G or 2G networks that have wider coverage areas. This may result in an unacceptable decrease in speed, as users could potentially move from 384 Kbps to 56 Kbps, or possibly even 9.6 Kbps transfer rates.

Another important point is that the data transfer rates in 3G systems are dependent on the user's distance from the base station. The further a user moves from the base station, the more difficult it becomes to achieve high speeds. The QoS features of 3G networks often mitigate this, but distance still affects network performance.

Note We do not go into depth about the physical structure of 3G networks, as it is not pertinent to the development of m-business applications. Since 3G networks are IP-based, the applications created for one network should work equally well on others. This is a significant advantage introduced with 2.5G and 3G networks.

3G Devices

Device manufacturers typically trail network operators when releasing new devices. This means that we have yet to see many of the devices for third-generation networks. That said, many manufacturers have already started releasing devices for 3G networks. These devices usually have a few things in common, namely:

- Support for multimedia content such as video streaming
- Large, high-resolution screens
- Form factors similar to PDAs
- Integrated voice and data as seen in high-end smart phones
- Mobile operating systems that allow for sophisticated client-side applications

Looking at the device characteristics, it becomes clear that 3G networks are targeted at wireless data as much as they are at voice communication.

3G Applications

Many of the applications aimed at 3G networks are similar to those being developed for 2.5G systems. Both generations of networks support IP applications, providing an easy migration path for application developers. That said, there are several new applications that are enabled specifically by the increased bit rates 3G networks offer, namely:

- Streaming video applications
- Downloadable audio such as MP3s
- Over-the-air download of software programs
- Workplace collaboration
- Voice-over-IP (VoIP)
- Location-based services
- Multimedia messaging services
- Support for corporate email and a full range of attachments

This is just a sampling of the new applications that 3G networks will enable. As developers start to gain access to these networks, and the programming interfaces they provide, new and innovative applications will start to enter the market. This is a very exciting time for application developers, as they are just beginning to see the capabilities that wireless has to offer.

Network Protocols

Many network protocols were mentioned in the discussion of the different generations of wireless systems. This section offers more information on these protocols, such as the frequencies over which they operate, their data transfer rates, and the locations where they are deployed. We start with paging networks and data-only networks, and progress to third-generation networks.

Paging Networks

Paging networks provide an alternative to the networks discussed earlier in this chapter. While many people consider pagers to be behind the times, these devices continue to provide some advantages over the current wireless networks. Paging networks operate at a very low frequency, which allows them to have good in-building coverage and wider coverage areas per base station. This has enabled nationwide coverage for paging networks, even in very remote areas. Paging networks are packet-based, allowing for information to be pushed to the user. This is clearly an important characteristic as push data is fundamental to receiving a page.

Three leading paging networks are currently in use:

- **Flex/reflex.** A popular paging network in North America, invented by Motorola.
- **ERMES.** The European Radio Message System, developed for use in Europe, has been adopted by the ITU as the recommended paging system.
- **POCSAG.** This older paging system, named after the Post Office Code Standardization Group, has been replaced by more advanced systems, and is not widely used.

Even though paging networks are often overlooked when evaluating wireless network options, they still provide a service that is essential to many consumers and corporate workers: They are a low-cost alternative for users who do not require the additional features found in mobile phones or wireless PDAs.

Data-Only Networks

Several data-only networks are worth discussing. These networks are either used in conjunction with a voice network or on their own for data-driven applications.

CDPD

Cellular Digital Packet Data (CDPD) was introduced as a packet-switched option for AMPS and DAMPS. This allowed carriers to offer both voice and data services with their existing network infrastructure. It is the only way to send data over the analog AMPS network. Additionally, it is used as the data layer for TDMA networks.

CDPD has a maximum download speed of 19.2 Kbps and upload speed of 9.2 Kbps. In practice, these rates are lower, because they are shared among multiple users in a cell. Even with slow data rates however, CDPD became a popular option for wireless data using laptops and PDAs. In this scenario, wireless cards with embedded CDPD terminals are used for connectivity. For application developers, CDPD is a familiar protocol since it can run IP applications without modification. Every user connected to a CDPD network has a unique IP address. CDPD network coverage is found in most major cities in North America.

Mobitex

Mobitex is a narrowband, packet-switched protocol that provides data transfer rates up to 8 Kbps. It was first developed by Ericsson in the 1980s and has since been deployed in 23 countries worldwide. Mobitex networks provide low data rates at a low cost. The most substantial Mobitex network in North America is offered by Cingular Wireless; consequently, it is used by both Palm.net and BlackBerry.net networks in the United States.

Mobitex operates on three different spectrum bands: 400 MHz, 800 MHz, and 900 MHz. Any application developed for the Mobitex specification can operate equally well on any of these frequencies.

DataTAC

DataTAC stands for Data Total Access Communications. Like Mobitex, DataTAC offers packet-switched narrowband wireless data access, in this case with data transfer rates up to 19.2 Kbps. Three types of DataTAC networks have been deployed:

- DataTAC 4000, which operates in North America.
- DataTAC 5000, which operates in Asia and the Pacific.
- DataTAC 6000, which operates in Europe.

The DataTAC network is often referred to as ARDIS, which is the name brand it operates under in North America. According to ARDIS, its network covers more than 90 percent of the North American business population. Notably, the RIM BlackBerry 850 and 857 devices use the DataTAC network for wireless connectivity.

TDMA (2G)

In the Americas, the term Time-Division Multiple Access (TDMA) is used to describe the DAMPS network, which is used to provide digital capabilities to the AMPS network. TDMA by itself does not provide any data capabilities; these are provided by CDPD, which is commonly integrated into TDMA networks.

TDMA networks are the leading 2G technology in the Americas; in the United States, it has nearly 100 percent coverage, and it is the only national network in many South American countries. In this region, TDMA subscriber growth is outpacing all other technologies, although this is likely to change as third-generation networks become mainstream. AMPS operators are able to add a TDMA layer on their existing infrastructure. By moving to a TDMA network, AMPS operators can achieve a threefold increase in capacity.

In other locations, TDMA is viewed from more of an engineering level. It is a multiplexing technology that uses time slices to divide a signal among multiple users (as described earlier in this chapter). In this sense, TDMA, also referred to as ANSI-136, is the leading 2G technology, as it provides the base for other network protocols such as GSM.

GSM (2G)

The Global System for Mobile Communications (GSM) is the most extensively used 2G technology in the world. GSM is a circuit-switched technology based on TDMA (ANSI-136). TDMA operators in North America are increasingly seeing the benefits of GSM technology: high voice quality, international roaming capability, large number of handset manufacturers, and broad developer base. Additionally, GSM offers a clear path of migration to 3G networks, which is attractive for many TDMA carriers.

GSM operates on three distinct frequencies: 900 MHz, 1800 MHz, and 1900 MHz. The 900 MHz and 1800 MHz are used in Europe, while 1900 MHz is used in North America. In order to provide international roaming, handsets are available that support all three GSM frequencies. These devices are called world phones because they provide worldwide access to wireless networks.

The data transfer rate of GSM networks is 9.6 Kbps. This is enough for the popular text-messaging applications and WAP browsing, but inadequate for other types of applications. To address this concern, a transitional technology called High-Speed, Circuit-Switched Data (HSCSD) was introduced. HSCSD allowed for multiple time slots to be used in a single connection for data transfer up to 57.6 Kbps. This was the expected evolution of GSM networks until more attractive packet-based networks such as GPRS came along. Now HSCSD is rarely discussed as the future for GSM networks. Instead, GSM networks have an upgrade path to 3G using GPRS as the 2.5G technology.

cdmaOne (2G)

Similar to TDMA, Code-Division Multiple Access (CDMA) is both a multiplexing technique and a 2G wireless network protocol. In order to differentiate the two, the network protocol is commonly referred to as cdmaOne, while the standard itself is CDMA, or IS-95.

cdmaOne is a circuit-switched technology that uses a spread-spectrum signal propagation technique. A signal is divided using distinct codes, then spread over the entire spectrum available to it. The advantages of this approach are increased user capacity and high voice quality. CDMA is very efficient when it comes to using spectrum; cdmaOne has been shown to increase the user capacity of an AMPS network by 8 to 10 times.

cdmaOne operates over two main frequencies: 800 MHz and 1900 MHz. The 800 MHz implementation competes with TDMA (DAMPS) in the United States, while the 1900 MHz implementation competes with GSM. Each channel of a cdmaOne system is 1.25 MHz wide and offers data transfer rates of 14.4 Kbps. Like GSM, this is sufficient for text messaging and simple wireless Internet applications, but insufficient for richer applications using images and multimedia content. This has been addressed in the newer CDMA standards called CDMA2000 and WCDMA. Each of these is described later in this section.

QUALCOMM, the pioneer of CDMA, commercially introduced CDMA in 1995. The evolution and promotion of CDMA is now handled by the CDMA Development Group (CDG), which is composed of the leading CDMA service providers and manufacturers. CDMA has experienced broad commercial success in the United States and Asia Pacific where GSM is not as prevalent. It has also been selected by the ITU as the basis for third-generation networks.

PDC (2G)

Personal Digital Cellular (PDC), a system used in Japan, is based on TDMA and offers backward compatibility to the country's existing analog networks. PDC offers a 9.6 Kbps data transfer rate over circuit-switched networks.

In the 1990s, Japan's largest telecom company, NTT DoCoMo, added a packet-switched addition to PDC called Packet PDC (P-PDC) that provides packet data capabilities. It also launched a service called i-mode that provides wireless multimedia over this network. Due to the phenomenal success of i-mode, PDC is now one of the world's most popular wireless standards, even though it is used only in one country.

The evolution of PDC goes directly to third-generation networks using WCDMA. There is no intermediate transition to 2.5G networks.

GPRS (2.5G)

General Packet Radio System (GPRS) introduced packet-switched capabilities to wireless networks. It is a simple, cost-effective upgrade to GSM and TDMA networks that provides increased bit rates and an improved user experience. As discussed in the earlier section on 2.5G networks, packet data systems provide always-on capabilities that allow users to remain connected to the wireless network for extended periods of time without incurring large usage fees.

GPRS operates on the same frequencies as the 2G networks it upgrades, specifically 900 MHz, 1800 MHz, and 1900 MHz. It can provide high-speed data transfer at theoretical rates approaching 115 Kbps, although in practice the throughput has proven to be closer to 40 Kbps. Since GPRS is an upgrade to existing infrastructure, users are able to roam between the GPRS network and GSM/TDMA networks. This ability allows operators to upgrade the major urban centers first, and gradually extend the GPRS network into rural areas.

GPRS is considered a safe point between 2G and 3G networks. It allows operators to experiment with new data services without incurring high capital expenditures. As users become more familiar with the benefits that GPRS networks provide, it is expected they will want even faster data rates, therefore increasing demand for 3G networks. GPRS is the base for EDGE and WCDMA systems.

CDMA2000 1x (2.5G)

CDMA2000 1x is difficult to categorize. Officially, it is classified as a third-generation technology, as defined by the ITU. Practically, it is a 2.5G technology, as it does not meet the minimum speed requirements for 3G networks, and is very similar to GPRS, which is clearly defined at 2.5G. For this reason, we are including CDMA2000 1x as a 2.5G standard.

CDMA2000 1x supports both voice and data services over the standard 1.25 MHz CDMA channel. The 1x in the name signifies that it uses one 1.25 MHz channel. Due to improved modulation, power control, and overall design, it can achieve theoretical data transfer rates of 144 Kbps. In practice, the data throughput for CDMA2000 1x is closer to those of GPRS at 40 to 56 Kbps. Additionally, CDMA2000 1x provides nearly double the capacity of previous CDMA systems and even more substantial increases for TDMA and GSM systems. It also adds packet-data capabilities to provide always-on capabilities.

CDMA2000 1x is backward-compatible with cdmaOne, operating on the same 800-MHz and 1900-MHz frequency bands. It is a cost-effective upgrade to existing cdmaOne networks, paving the way for third-generation CDMA2000 1XEV and CDMA2000 3x networks (3x networks use three 1.25-MHz channels simultaneously, thereby providing increased data throughput).

EDGE (3G)

Enhanced Data Rates for Global Evolution (EDGE) is a technology that allows current GSM networks to offer 3G services within existing frequencies. TDMA or GSM/GPRS infrastructure can be upgraded to EDGE with minimum impact. Since EDGE is a narrowband (200-kHz channels) technology, wireless operators are able to deploy 3G EDGE services without obtaining a 3G license. These two factors make EDGE a lowcost, fast solution for providing 3G services on a nationwide level.

EDGE is able to increase the over-the-air data rates using the same spectrum as 2G/2.5G systems. The peak data rates with EDGE are typically around 384 Kbps, with actual download rates ranging between 75 and 150 Kbps, depending on the user's distance from the base station, among other factors.

EDGE provides a seamless upgrade from 2G GSM networks to 3G UMTS (WCDMA) networks. The frequency bands that EDGE operates in complement the UMTS/WCDMA technology, allowing for the deployment of networks that use GSM, EDGE, and WCDMA in a fashion that is transparent the to user.

CDMA2000 1x EV (3G)

There are two members of CDMA2000 1x EV family: CDMA2000 1x Evolution Data Optimized (CDMA 1x EV-DO) and CDMA2000 1x Evolution Data and Voice (CDMA 1x EV-DV).

CDMA2000 1x EV-DO is a data-optimized version of CDMA2000 that can provide peak data rates of up to 2.4 Mbps using a single CDMA 1.25-MHz channel. With the introduction of improved technology for modulation and dynamically assigned data rates, 1x EV-DO is able to achieve download rates near the theoretical levels. CDMA2000 1x EV-DO supports the complete range of available frequencies, including 450 MHz, 700 MHz, 800 MHz, 1800 MHz, 1900 MHz, and 2 GHz. CDMA 1x EV-DO can work on all IP networks, giving wireless operators an opportunity to gain experience with IP-based technologies before moving their voice networks to IP. It is the natural path of evolution for CDMA 2000 1x networks.

CDMA2000 1x EV-DV networks are expected to be available in 2003. They will provide similar wireless data capabilities as CDMA2000 1x EV-DO, but with the addition of integrated voice capabilities. CDMA2000 1x EV-DV will provide peak data rates topping 3 Mbps, with typical throughput around 1 Mbps. This technology will enable real-time packet services for two-way conversational communication.

WCDMA (3G)

Two types of Wideband CDMA (WCDMA) are in use: Frequency-Division Duplex (FDD) and Time-Division Duplex (TDD). TDD is a hybrid of CDMA and TDMA technologies and is not commonly used commercially for WWAN implementations. It is better suited for indoor usage. The FDD version is the focus here, as it is being deployed commercially in several countries. The "wideband" part of its name refers to the requirement for channel bandwidth of 5 MHz. This is four times larger than CDMA2000 1x (1.25-MHz channel width) and 25 times larger than the GSM (200-kHz channel width). The wider bandwidth allows for higher data transfer rates. WCDMA supports all three modes of mobility as defined in the IMT-2000. As a refresher, these modes are high mobility (144 Kbps), full mobility (384 Kbps), and limited mobility (2 Mbps).

The version of WCDMA being deployed in Europe is commonly referred to as Universal Mobile Telecommunication System (UMTS). It uses direct-sequence (DS) CDMA and therefore it is also called DS-WCDMA. For our purposes, we will continue to refer to it simply as WCDMA. WCDMA has been designed as an upgrade to existing GPRS and EDGE networks, operating on the 2-GHz frequency band, and providing peak data transfer rates of 2 Mbps in stationary environments. Unlike the upgrade to GPRS and EDGE, WCDMA requires coverage to be built from scratch. Since this requires significant capital expenditures by carriers, WCDMA coverage will initially be available only in urban centers. Fortunately, WCDMA is compatible with GSM, GPRS, and EDGE networks, so users do have the ability to roam between the various network implementations. This means that as users move out of WCDMA coverage, they will automatically be handed off to a GSM, GPRS, or EDGE network and continue communicating at a slower data rate.

In Japan, NTT DoCoMo has deployed a WCDMA-based 3G network called Freedom of Multimedia Access (FOMA). It uses a slightly different version of WCDMA than that used in Europe. It was designed as an upgrade from PDC, and therefore does not require backward compatibility with GSM-based networks. In North America, the 2-GHz frequency band is already in use, so WCDMA either has to be introduced into the existing frequencies or new spectrum has to be allotted. This is one of the reasons why a single 3G network protocol cannot be adopted worldwide.

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