CHAPTER 9

CDMA and 3G

9.1 INTRODUCTION

The popularity and growth of cellular phones is keeping technology and business people on their toes. Technologists are busy developing even newer technologies to offer better user experience. Operators and service providers, on the other hand, are coming up with innovative applications and services to get a share of this market. Users today expect better quality of voice and data services while on the move. Not too long ago, hardly any one would have imagined mobile phone being used not only for voice communication, but also for watching a video clip or as a network interface for a laptop. CDMA and 3G expressly support such versatile usage.

Many of these opportunities and challenges made the scientific and business community look at the Spread-Spectrum technology as an option for wireless communication. Mobile phone technology had a reincarnation from first generation analogue (using FDMA) to second generation digital (using TDMA). The next incarnation is from second generation digital TDMA to third generation packet (using CDMA). CDMA is a specific modulation technique of Spread-Spectrum technology. Third generation or 3G is more of a generic term to mean mobile networks with high bandwidth. Looking at the success of second generation GSM (using TDMA and roaming) and also the potential of second generation cdmaOne (IS-95 using CDMA), it was quite apparent that the next generation networks would have to be a combination of the best of these two technologies with amalgamation of some of the recent technology innovations.

9.1.1 How it Started

Let us tell you an interesting story about the origin of the Spread-Spectrum technology. Have you heard the name of the famous Hollywood actress Hedy Lamarr? She was born in Vienna in 1914 as Hedwig Eva Maria Kiesler (note the full name). In 1933, Hedy Kiesler married the Austrian industrialist Fritz Mandl, CEO of the Hirtenberger Patronenfabrik, then one of the world's leading arms producers. Fritz was interested in control systems and conducted research in that field. Hedy was so beautiful that he was obsessed with keeping Hedy at his side all the time. He would take her even to business meetings and parties. Hedy received an education in munitions manufacturing from her husband and other Nazi officials through these meetings. Hedy escaped to London in 1937 and later traveled to the US to become one of the better known actresses in Hollywood. What many people may not know is that Hedy Lamarr helped the Allies win World War II, and she was the original patent holder of Spread-Spectrum technology, which is at the foundation of today's CDMA (Code Division Multiple Access), Wireless LAN, IMT-2000 (International Mobile Telecommunication–2000), 3G (Third Generation), and GPS (Global Positioning System) technology.

With the help of an electrical engineering professor from MIT, Hedy Lamarr and George Antheil, a film music composer patented "Secret Communication System" in 1942. Like many other great technologies, the idea of "Secret Communication System" was ahead of its time. Electronic technologies were beginning to develop and in the 1950s, engineers from Sylvania Electronic Systems Division began to experiment with the ideas in the Secret Communication System patent, using digital components. They developed an electronic spread-spectrum system that handled secure communications for the US during the Cuban Missile Crisis in 1962. It was in the early 1960s that the term "spread-spectrum" began to be used. Today it refers to digital communications that use a wide frequency spreading factor (much wider than typical voice telephone communications), and are not dependent on a particular type of tonality (such as a human voice) in the transmitting waveform.

In the mid-1980s, the US military declassified Spread-Spectrum technology. Immediately, the commercial sector began to develop it for consumer electronics. Qualcomm was the first to use this technology for commercial deployment of CDMA. 3G has been in gestation since 1992, when the International Telecommunications Union (ITU) began work on a standard called IMT-2000. IMT stands for International Mobile Telecommunications; the number 2000 initially had three meanings: the year that services should become available (year 2000), the frequency range in MHz that would be used (2000 MHz or 2 GHz), and the data rate in Kbits/sec (2000 Kbps or 2 Mbps).

9.2 Spread-Spectrum Technology

In a conventional transmission system, the information is modulated with a carrier signal and then transmitted through a medium. When transmitted, all the power of the signal is transmitted centered around a particular frequency. This frequency represents a specific channel and generally has a very narrow band. In spread-spectrum we spread the transmission power over the complete band as shown in Figure 9.1.

In spread-spectrum the transmission signal bandwidth is much higher than the information bandwidth. There are numerous ways to cause a carrier to spread; however, all spread-spectrum systems can be viewed as two steps modulation processes. First, the data to be transmitted is modulated. Second, the carrier is modulated by the spreading code, causing it to spread out over a large bandwidth. Different spreading techniques are:

- **Direct Sequence (DS):** DS spread spectrum is typically used to transmit digital information. A common practice in DS systems is to mix the digital information stream with a pseudo random code.

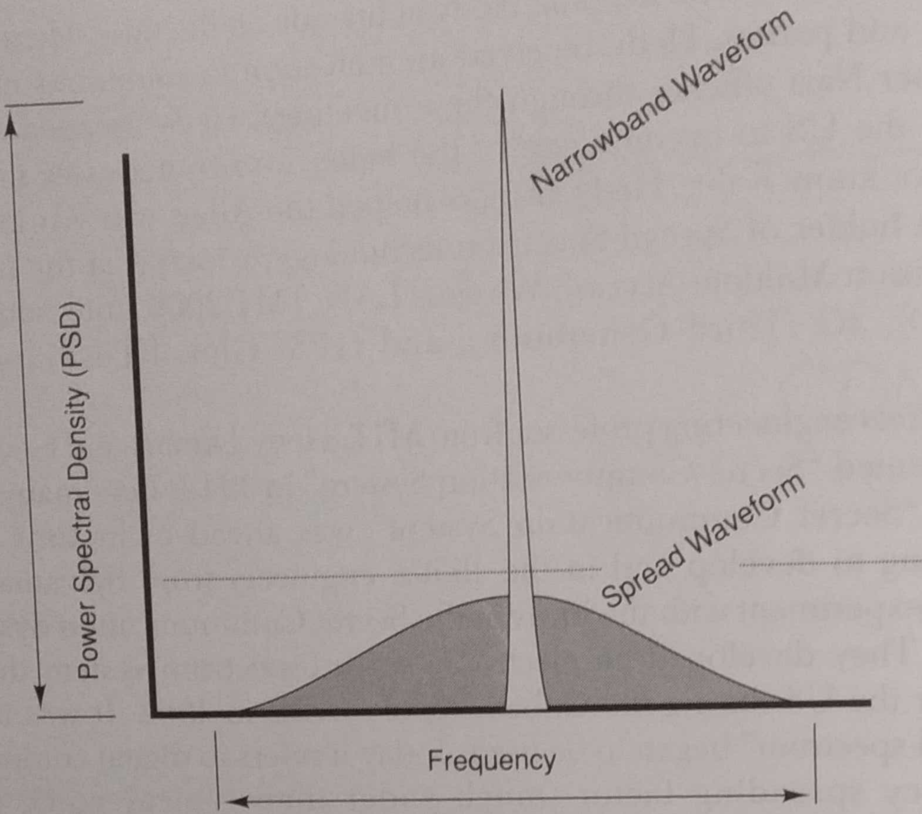

Figure 9.1 Narrow Band and Spread Spectrum

- **Frequency Hopping (FH):** Frequency hopping is a form of spreading in which the center frequency of a conventional carrier is altered many times within a fixed time period (like one second) in accordance with a pseudo-random list of channels.
- **Chirp:** The third spreading method employs a carrier that is swept over a range of frequencies. This method is called chirp spread spectrum and finds its primary application in ranging and radar systems.
- **Time Hopping:** The last spreading method is called time hopping. In a timehopped signal, the carrier is on-off keyed by the pseudo-noise (PN) sequence resulting in a very low duty cycle. The speed of keying determines the amount of signal spreading.
- **Hybrid System:** A hybrid system combines the best points of two or more spread-spectrum systems. The performance of a hybrid system is usually better than can be obtained with a single spread-spectrum technique for the same cost. The most common hybrids combine both frequency-hopping and direct-sequence techniques.

Amateurs and business community are currently authorized to use only two spreading techniques. These are frequency hopping and direct sequence techniques. Rest of the Spread-Spectrum technologies are classified and used by military and space sciences.

9.2.1 Direct Sequence Spread Spectrum (DSSS)

Direct Sequence Spread Spectrum (DSSS) is often compared to a party, where many pairs are conversing, each in a different language. Each pair understands only one language and therefore, concentrates on his or her own conversation, ignoring the rest. A Hindi-speaking couple just homes on to Hindi, rejecting everything else as noise. Its analogous to DSSS is when pairs spread over the room conversing simultaneously, each pair in a different language. The key to DSSS is to be able to extract the desired signal while rejecting everything else as random noise. The analogy may not be exact, because a roomful of people all talking at once soon becomes very loud. In general, Spread-Spectrum communications is distinguished by three key elements:

1. The signal occupies a bandwidth much larger than what is necessary to send the information.
2. The bandwidth is spread by means of a code, which is independent of the data.
3. The receiver synchronizes to the code to recover the data. The use of an independent code and synchronous reception allows multiple users to access the same frequency band at the same time.

In order to protect the signal, the code used is pseudo-random, which makes it appear random while being actually deterministic, which enables the receivers to reconstruct the code for synchronous detection. This pseudo-random code is also called pseudo-noise (PN). DSSS allows each station to transmit over the entire frequency all the time. DSSS also relaxes the assumption that colliding frames are totally garbled. Instead, it assumes that multiple signals add linearly.

DSSS is commonly called Code Division Multiple Access or CDMA in short. Each station is assigned a unique *m*-bit code. This code is called the CDMA chip sequence. To transmit a 1 bit, the transmitting station sends its chip sequence, whereas to send 0, it sends the complement chip sequence. Thus if station *A* is assigned the chip sequence 00011011, it sends bit 1 by sending 00011011 and bit 0 by sending 11100100. Using bipolar notations, we define bit 0 as +1 and bit 1 as −1. The bit 0 for station *A* will now become (−1 −1 −1 +1 +1 −1 +1 +1) and 1 becomes (+1, +1, +1, −1, −1, +1, −1, −1). Figure 9.2 depicts this with 6 chips/bit (011010). For manipulation of bits, we XOR (addition with modulo 2) the input bits, in bipolar notations we multiply to get the desired result:

```
0 XOR 0 = 0 ⇒ +1 × +1 = +1
1 XOR 1 = 0 ⇒ -1 × -1 = +1
1 XOR 0 = 1 ⇒ -1 × +1 = -1
0 XOR 1 = 1 ⇒ +1 × -1 = -1
```

Each station has its unique chip sequence. Let us use the symbol *S* to indicate the m-chip vector for station *S*, and $\overline{S}$ is for its negation. All chip sequences are pair-wise orthogonal, by which we mean that the normalized inner product of any two distinct chip sequences, *S* and *T* (written as $S{\cdot}T$) is 0. In mathematical terms,

$$S \cdot T = \frac{1}{m}\sum_{i=1}^{m} S_i \cdot T_i = 0$$

$$S \cdot S = \frac{1}{m}\sum_{i=1}^{m} S_i \cdot S_i = 1$$

This orthogonality property is very crucial for mobile communication. Note that if $S{\cdot}T = 0$ then $S{\cdot}\overline{T}$ is also 0. The normalized inner product of any chip sequence with itself is 1. This follows because each of the *m* terms in the inner product is 1, so the sum is *m*. Also note that $S{\cdot}\overline{S} = -1$. When two or more stations transmit simultaneously, their bipolar signals add linearly. For example, if in one chip period three stations output +1 and one station outputs −1, the result is +2.

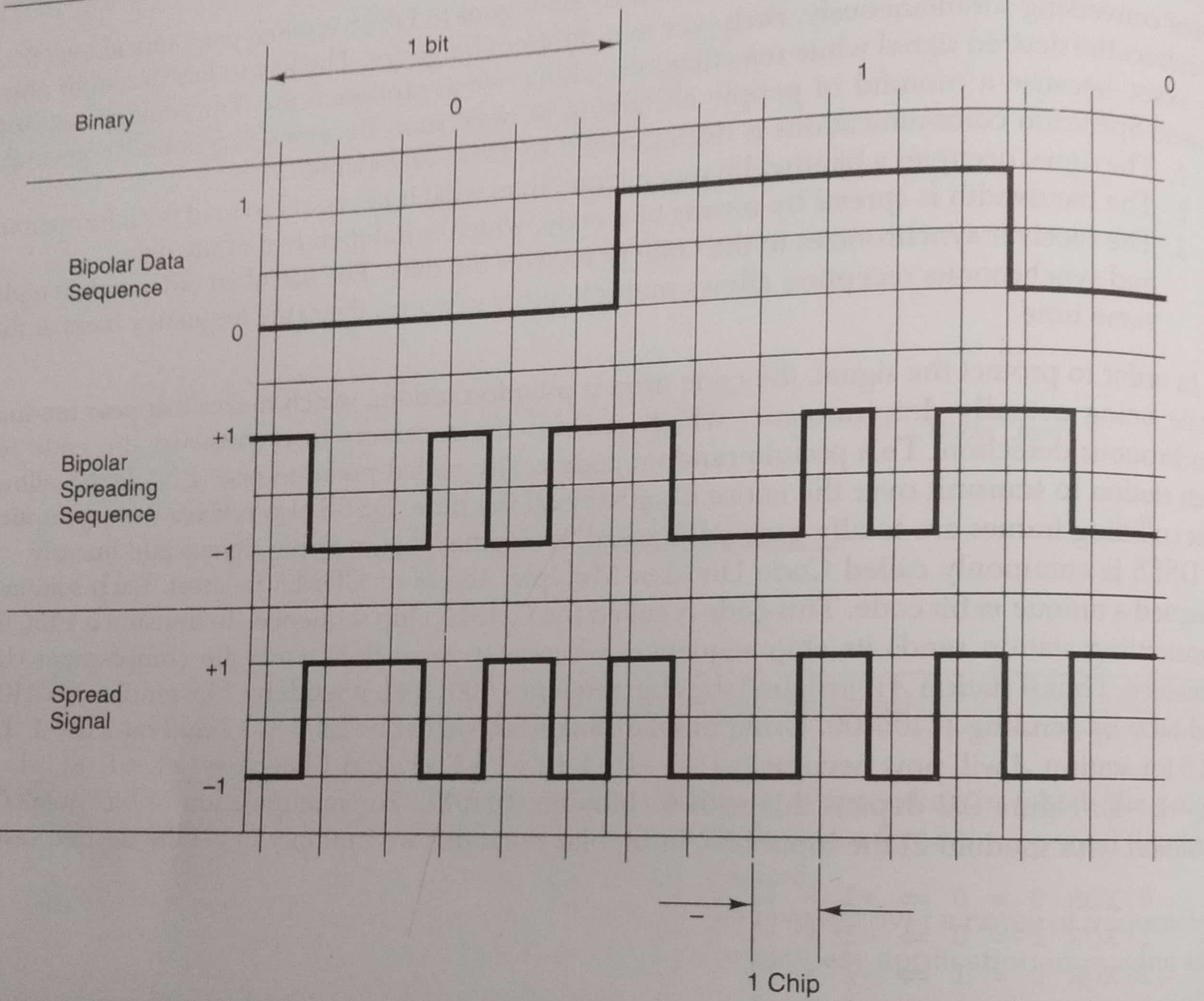

Figure 9.2 The CDMA Chip Sequence

One can think of this as adding voltages: three stations outputting +1 volt and one station outputting −1 volts gives 2 volts.

In Figure 9.3, we see there are four stations A, B, C, and D with their chip sequences. In this example, we have taken eight chips. Figure 9.3(a) is the bit sequence of the chips whereas Figure 9.3(b) is the bipolar notations of the same. In Figure 9.3(c) we assume that there are six cases of four stations transmitting at the same time. In the first example, Figure 9.3(c), we assume that only C is transmitting bit 1. In the second example, B transmits a bit 1, and C transmits a bit 1. Therefore, we get:

$(-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1) = S_1$

$(-1\ -1\ +1\ -1\ +1\ +1\ +1\ -1) + (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1) = (-2\ 0\ 0\ 0\ +2\ +2\ 0\ -2) = S_2$

In the third example, station A transmits a 1 and station B transmits a 0, others are silent. In the fourth example, A and C transmit a 1 while B sends a 0. In the fifth example, all four stations transmit a 1. Finally, in the last example, A, B, and D transmit a 1, while C sends a 0. The result of these transmissions are different sequences S_1 through S_6 as given in Figure 9.3(d). All these examples represent only one bit time.

To recover the bit stream of any station, the receiver must know that station's chip sequences in advance. This is similar to the example of the party where different couples are conversing in different languages. We know someone is speaking in Hindi and may be someone else is speaking in French. The listener who knows Hindi can only understand the message from the partner speaking in Hindi. Someone knowing French can extract the French message.

```
A: 00011011
B: 00101110
C: 01011100
D: 01000010
```

9.3(a)

```
A: (-1,-1,-1,+1,+1,-1,+1,+1)
B: (-1,-1,+1,-1,+1,+1,+1,-1)
C: (-1,+1,-1,+1,+1,+1,-1,-1)
D: (-1,+1,-1,-1,-1,-1,+1,-1)
```

9.3(b)

--1-	C
-11-	B + C
10--	A + $\overline{B}$
101-	A + $\overline{B}$ + C
1111	A + B + C + D
1101	A + B + $\overline{C}$ + D

9.3(c)

```
S1 = (-1,+1,-1,+1,+1,+1,-1,-1)
S2 = (-2, 0, 0, 0,+2,+2, 0,-2)
S3 = ( 0, 0,-2,+2, 0,-2, 0,+2)
S4 = (-1,+1,-3,+3,-1,-1,-1,+1)
S5 = (-4, 0,-2, 0,+2, 0,+2,-2)
S6 = (-2,-2, 0,-2, 0,-2,+4, 0)
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9.3(d)

```
S1.C = (+1+1+1+1+1+1+1+1)/8 = 1
S2.C = (+2+0+0+0+2+2+0+2)/8 = 1
S3.C = (+0+0+2+2+0-2+0-2)/8 = 0
S4.C = (+1+1+3+3+1-1+1-1)/8 = 1
S5.C = (+4+0+2+0+2+0-2+2)/8 = 1
S6.C = (+2-2+0-2+0-2-4+0)/8 =-1
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9.3(e)

Figure 9.3 CDMA Code Arithmetic

DSSS does the recovery by computing the normalized inner product of the received chip sequence (the linear sum of all the stations that transmitted) and the chip sequence of the station whose bit stream it is trying to recover. Let us assume that we are interested in recovering the bit sequence of station C. If the received chip sequence is S (S_1, S_2, … S_6) we compute the normalized inner product, S C. From each of the six sums S_1 through S_6, we calculate the bit by summing the pairwise products of the received S and the C vector of Figure 9.3(d) and then take 1/8 of the result. As shown in Figure 9.3(e), the product extracts the correct bit. Note that $S_3{\cdot}C = 0$; this means that in the third example of 9.3(c) station C did not transmit. Also, note that $S_6{\cdot}C = -1$; this means that in the sixth example station C transmitted a 0.

9.3.7 IS-95 Channel Capacity

In first generation mobile networks the frequency channels were fixed and hence the capacity too. This is true with GSM as well. In GSM we multiply 125 frequencies with eight time slots to get 1000 channels. Therefore TDMA and FDMA capacities are bandwidth limited and hard-limited. The capacity of CDMA has a soft limit in the sense that we can add one additional user and tolerate a slight degradation of the signal quality. This is similar to a room full of people. Let us assume that people are talking to each other using a loudspeaker. In such a case not many people will get a chance to talk or to listen. However, more people can talk to each other if they converse in low voices. Another conclusion that can be drawn from this fact is that, any reduction in the multiple access interference converts directly and linearly into an increase in the capacity. The capacity of a CDMA system depends on the following criteria:

- *Voice Activity Detection (VAD)*: The human voice activity cycle is 35 percent. This means that during a conversation people talk about 35% of the time. When users assigned to a cell are not talking, VAD will allow all other users to benefit due to reduced mutual interference. Thus interference is reduced by a factor of 65 percent. CDMA is the only technology that takes advantage of this phenomenon. It can be shown that the capacity of CDMA is increased by about three times due to VAD.
- *Sectorization for Capacity*: In FDMA and TDMA systems, sectoring is done to reduce the co-channel interference. In GSM there are in total 1000 channels distributed between multiple operators, sectors and cells. The trunking efficiency of these systems decreases due to sectoring. This in turn reduces the capacity. On the other hand, sectorization increases the capacity of CDMA systems. Sectoring is done by simply introducing three (similar) radio equipments in three sectors. The reduction in mutual interference due to this arrangement translates into a three-fold increase in capacity (in theory). In general, any spatial isolation through the use of multibeam or multisector antennas provides an increase in the CDMA capacity.
- *Frequency Reuse Considerations*: The previous comparisons of CDMA capacity with those of conventional systems primarily apply to mobile satellite (single cell) systems. In the case of terrestrial cellular systems, the biggest advantage of CDMA over conventional systems is that it can reuse the entire spectrum over all the cells since there is no concept of frequency allocation in CDMA. This increases the capacity of the CDMA system by a large percentage (related to the increase in the frequency reuse factor).

As a rule of thumb the CDMA capacity is about four times that of TDMA and eight times that of FDMA.

9.4 CDMA VERSUS GSM

GSM is a relatively mature technology, now several years in existence with a huge installation base. GSM has many experienced operators and equipment manufacturers. Interoperability within GSM is well proven. GSM is complete, open and has proven standards. GSM includes all the specifications from the handset other over the air, switch, interconnect it with switching, and every-aspect of mobile telecommunication. On the other hand, IS-95 is mainly a single vendor (Qualcomm cdmaOne) specification. IS-95 only covers the air interface making it incomplete. Though there are many claims and counter claims, it is generally believed that CDMA has high potential to address some of the difficult challenges of the past quite effectively. These are described in Table 9.1.

Table 9.1 GSM versus 3G

Functions	*GSM*	*IS-95*
Frequency	900 MHz; 1800 MHz (DCS180); 1900 MHz (PCS 1900)	800 MHz; 1900 MHz
Channel bandwidth	Total 25 MHz bandwidth with 200 KHz per channels, 8 timeslots per channel with frequency hopping	Total 12 MHz with 1.25 MHz for the spread spectrum
Voice codec	13 Kbits/second	8 Kbits/sec or 13 Kbps
Data bit rate	9.6 Kbits/second and expandable	9.6 Kbits
Short message service	160 characters of text Supports	120 characters
SIM card	Yes	No
Multipath	Causes interference and destruction to service	Used as an advantage
Radio interface	TDMA	CDMA
Handoff	Hard Handover (handoff)	Soft Handoff (handover)
System Capacity	Fixed and limited	Flexible and higher than GSM
Economics	Expensive	Due to many technological advantages, dimension of investment per subscriber is expected to be lower than GSM

9.5 Wireless Data

Data transmission over wireless networks like CDMA or GSM is always a challenge. Typically raw channel data error rates for cellular transmission are 10^{-2}. This means that one in every 100 bits has an error. This is an error rate, which can be tolerated for voice transmission. This is because; our perception of hearing cannot detect it. Even if our ear is sometime able to detect it, our mind is able to correct it from the context. This error rate of 10^{-2} is too high for data transmission. An acceptable BER (Bit Error Rate) for data transmission is 10^{-6}. This means that one bit in a million can be tolerated as an error. In order to achieve this high level of reliability, it requires a design of effective error correction code and Automatic Repeat Request (ARQ). The CDMA protocol stack (Fig. 9.8) for data and facsimile has the following layers.

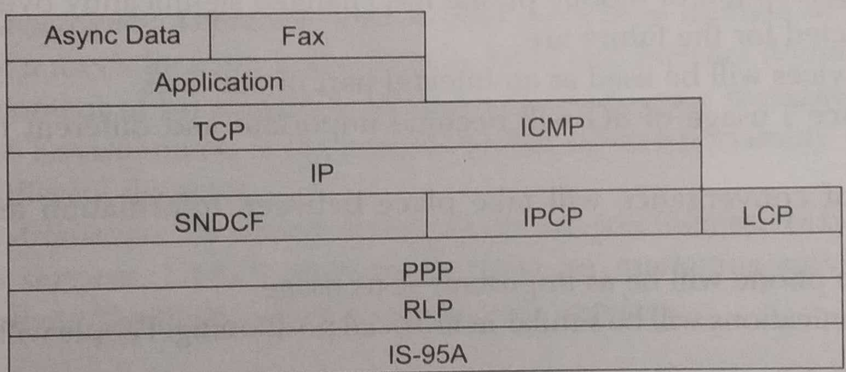
Application Interface Layer: This layer includes an application interface between the data source in the mobile station and the transport layer. The application interface provides functions like modem control, AT (Attention) command processing, data compression, etc.

Transport Layer: The transport layer for CDMA asynchronous data and fax is based on TCP. TCP has been modified for IS-95.

Network Layer: The network layer for CDMA asynchronous data and fax services is based on IP. The standard IP protocol has been enhanced for IS-95.

Sub-network Dependent Convergence Function: The SNDCF performs header compression on the header of the transport and network layers. Mobile station supports Van Jacobson TCP/IP header compression algorithm. Negotiation of the parameters for header compression is carried out using IPCP (Internet Protocol Control Protocol). The SNDCF sublayer accepts the network layer datagram packets from the network layer, performs header compression and passes that datagram to the PPP (Point to Point Protocol) layer. In the reverse operation, it receives network layer datagrams with compressed header from the PPP layer and passes it to the network layer.

Data Link Layer: This layer uses PPP. The PPP Link Control Protocol (LCP) is used for initial link establishment and for the negotiation of optional link capabilities.



ICMP : Internet Control Message Protocol
IP : Internet Protocol
IPCP : Internet Protocol Control Protocol
LCP : Link Control Protocol
PPP : Point-to-Point Protocol
RLP : Radio Link Protocol
SNDCF : Subnetwork Dependent Convergence Function
TCP : Transmission Control Protocol

Figure 9.8 CDMA Data Protocol Stack

Internet Protocol Control Protocol Sublayer: This sublayer supports negotiation of the IP address and IP compression protocol parameters. In general, a mobile station does not have a permanent IP address. Therefore, the IP address needs to be negotiated and obtained from the network. IPCP does this job of leasing an IP address when the transport connection is established. The IP address is discarded when the connection is closed. This is similar to obtaining the IP address from a DHCP (Dynamic Host Configuration Protocol) server in a LAN environment.

Radio Link Protocol Layer: This layer provides octet stream service over the air. This service is responsible for reducing the error rate over the forward and reverse channels. There is no direct relationship between PPP packet and the traffic channel frame. A large packet may span multiple traffic channel frames. A single traffic channel frame may contain multiple PPP packets. RLP frames may be transported as traffic or signaling via data burst message.

9.5.1 Short Message Service

SMS in IS-95 is similar to SMS in GSM. Unlike GSM, the maximum size of a SMS in IS-95 is 120 octets. The SMS in IS-95 work the same way as in GSM. It supports SMPP protocol and other features as in GSM. Like in GSM, the SMS in IS-95 uses the signaling channel for data transfer. SMS administration features include storage, profiling, verification of receipt and status enquiry capabilities.

9.6 Third Generation Networks

The telecommunications world is changing due to trends in media convergence and industry consolidation. The perception of mobile phone has changed significantly over the last few years. More changes predicted for the future are:

- The mobile devices will be used as an integral part of our lives.
- Data ("non-voice") usage of 3G will become important and different from the traditional voice business.
- A great deal of convergence will take place between information and communication technology.
- The look of the phone will be as important as its usage.
- Mobile communications will be similar in its social positioning. People will have only a mobile device.

To address these challenges and opportunities, the mobile telecommunication technology needs to adapt new techniques, facilities and services. The 3G system will offer a plethora of telecommunication services including voice, multimedia, video and high speed data. With 3G mobile Internet technology significant changes will be brought about in the day-to-day life of the people.

CDMA is the preferred approach for the third generation networks and systems. In North America cdma2000 is the version of 3G. cdma2000 standards are being driven by Telecommunication Industries Association (TIA). It uses the CDMA air interface, which is based on IS-95 and cdmaOne. In Japan 3G standard uses (Wideband Code Division Multiple Access) WCDMA (DoCoMo) version. This standard is being driven by ARIB. In Europe, Asia, Australia and many parts of the world 3G has been accepted as UMTS and WCDMA. UMTS/WCDMA is being driven by ETSI, and is the normal evolution from GSM/GPRS.

The main goal of UMTS (Universal Mobile Telecommunications System) is to offer a much more attractive and richer set of services to the users.

- *Universal Roaming*: Any user will be able to move across the world and access the network.
- *Higher Bit Rate*: More speed would open the path toward multimedia applications.

In the beginning of 1998 six partners—ARIB (Association of Radio Industries and Businesses), T1, TTA (Telecommunications Technology Association, Korea), ETSI in Europe, CWTS (China Wireless Telecommunication Standard group), TTC (Telecommunication Technology Committee, Japan) started discussions to cooperate for creating a standards for a third generation mobile system with a core network based on evolution for GSM and an access network based on all the radio access technologies supported by the different partners. This project was called the Third Generation Partnership Project (3GPP). About a year later ANSI decided to establish 3GPP2, a 3G partnership project for evolved ANSI/Telecommunications Industry Association (TIA)/ Electronics Industry Association (EIA)-41 networks. There is also a strategic group called International Mobile Telecommunication Union-2000 (IMT-2000) within the International Telecommunication Union (ITU), which focuses its work on defining interface between 3G networks evolved from GSM on one hand and ANSI-41 on the other, in order to enable seamless roaming between 3GPP and 3GPP2 networks. 3GPP started referring to 3G mobile system as Universal Mobile Telecommunication System (UMTS).

- *Mobile-Fixed Convergence*: There is a need to offer users cross-domain services. An example is the tracking of a user's location in the mobile, fixed and Internet domain and automatically adapting the content of his incoming messages to SMS, voice message, fax or email. VHE (Virtual Home Environment) is the enabler to this service portability across networks and terminals in different domains.
- *Flexible Service Architecture*: By standardizing not the services themselves but the building blocks that make up services, UMTS shortens the time for marketing services from GSM and enhances creativity/flexibility when inventing new services.

9.6.1 International Mobile Telecommunications–2000

2G mobile networks were mainly built for digital voice; data was available only over circuits. The first major step towards packet data in the evolution to 3G occurred with the introduction of GPRS, which came to be known as 2.5G. GPRS offered a moderate data bandwidth that was sufficient for services like Wireless Application Protocol (WAP) access, Multimedia Messaging Service (MMS) and low bandwidth Internet. GPRS networks evolved into Enhanced Data rates for GSM Evolution (EDGE) networks that offered high bandwidth packet data capable of multimedia video; however, it fell slightly short of 3G and is often referred to as 2.75G. Then, finally IMT 2000/3G evolved.

International Mobile Telecommunications-2000 (IMT-2000) is the global standard for third generation (3G) wireless communications, defined by a set of interdependent ITU Recommendations. IMT-2000 will provide a framework for worldwide access of services by linking the diverse systems of terrestrial and/or satellite based networks through the synergy between digital mobile telecommunications technologies and systems for fixed and mobile wireless access systems. IMT-2000 was, originally, envisioned to be launched in the year 2000 with a bandwidth of 2000Kbits/second (2Mbps). It is also popularly known as 3G or 3rd Generation that includes EDGE, CDMA 2000, UMTS, DECT and WiMAX (which was added in 2007) standards. These standards are both evolutionary and revolutionary. They are evolutionary standards in the sense that they are backward compatible to interoperate with pre-existing 2G networks while they are revolutionary as they require all-new networks and frequency allocations. Various independently developed standards like DECT and WiMAX were included because they fit the IMT-2000 definition. The services provisioned by IMT-2000 set of standards include wide area wireless voice telephone, video calls and wireless data for a mobile user. Therefore, 3G networks enable network operators to offer users a wide range of more sophisticated services while achieving greater network capacity through improved spectral efficiency (which is possible through simultaneous use of speech and data services and better data rates). Table 9.2 shows an overview of IMT-2000 standards.

Table 9.2 Overview of 3G/IMT 2000 standards

ITU IMT-2000	*Common name(s)*	*High-speed data*	*Pre-4G*	*Duplex*	*Channel*	*Description*	*Geographical areas*
CDMA Single-Carrier (IMT-SC)	EDGE (UWT-136)	EDGE Evolution	None		TDMA	Evolutionary upgrade to GSM/GPRS	Worldwide except Japan and Korea
CDMA Multi-Carrier (IMT-MC)	CDMA 2000	EV-DO	UMB	FDD	CDMA	Evolutionary upgrade to cdmaOne (IS-95)	America, Asia and some others
CDMA Direct Spread (IMT-DS) CDMA TDD (IMT-TC)	W-CDMA UMTS TD-CDMA TD-SCDMA	HSPA	LTE			Family of revolutionary standards.	Worldwide esp. Europe and China
FDMA/TDMA (IMT-FT)	DECT	None		TDD	FDMA/TDMA	Short-range; standard for cordless phone	Europe, USA
IP-OFDMA	WiMAX (IEEE 802.16)				OFDMA	Late addition	Worldwide

Evolution beyond IMT-2000 and towards 4G

3GPP and 3GPP2 are researching on further extensions to current 3G standards, namely Long Term Evolution (LTE) and Ultra Mobile Broadband, respectively. As these technologies would be fully based on an all-IP network infrastructure, they have started displaying characteristic features for IMT-Advanced (4G) standards. Practically, these standards fall short of the speed requirements for 4G (which is set to be 1 Gbit/s for stationary and 100 Mbit/s for mobile operations). Therefore, these standards are classified as 3.9G or Pre-4G. Progress is all the more accelerated by valuable contributions from mobile IT Forum (mITF) Japan and other professional bodies in Europe.

9.6.2 CDMA-2000

cdma2000 is the third generation version of cdmaOne or IS-95. The cdma2000 Radio Transmission Technology (RTT) is a spread spectrum, wideband radio interface. It uses CDMA technology as its underlying modulation technology. cdma2000 meets the specification for ITU (International Telecommunication Union) and IMT-2000. It addresses the specification for indoor, indoor-to-outdoor, pedestrian and vehicular environment. cdma2000 can operate in wide range of environments, viz.,

- Indoor/Outdoor picocell (< 50 meter radius; e.g., one office floor)
- Indoor/Outdoor microcell (up to 1 km radius; e.g., a shopping mall)
- Outdoor macrocell (1–35 km radius)
- Outdoor megacell (> 35 km radius)
- Wireless in Local Loop (WiLL).

cdma2000 supports chip rates of N × 1.2288 Mcps (where N = 1, 3, 6, 9, 12). For N = 1, the spreading is similar to IS-95. However, for forward link QPSK modulation is used before the spread. There are two option for chips rate for N > 1. These are multicarrier and direct spread (Fig. 9.9). In the multicarrier procedures for N > 1, the modulation symbols are demultiplexed on to N separate 1.25 MHz carriers where N = 3, 6, 9, 12. Each of these carriers is then spread with 1.2288 M chips. For direct spread procedures for N > 1, the modulation symbols are spread on a single carrier with a chip rate of N × 1.2288 M chips where N = 3, 6, 9, 12.

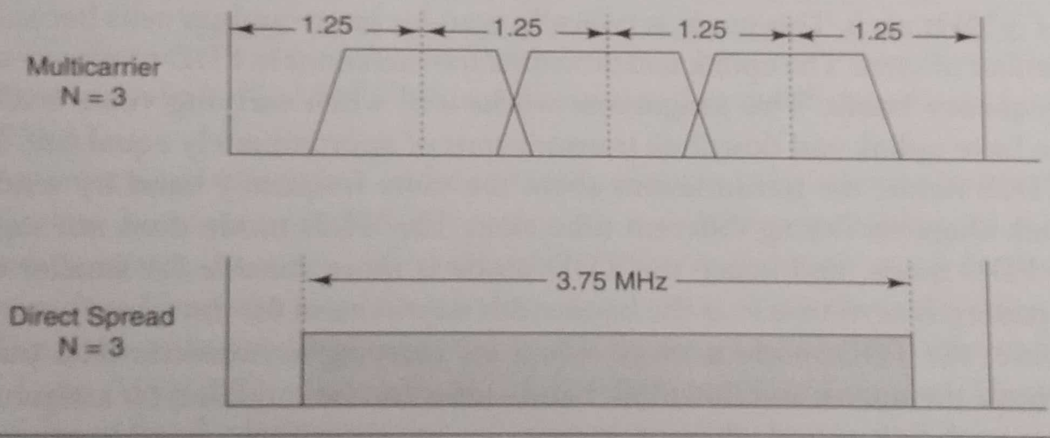


Figure 9.9 Multicarrier and Direct Spread in cdma2000

Two types of data services are currently under consideration for cdma2000. These are packet data and high speed circuit switched data. Packet data will be used for asymetric bursty traffic like Internet browsing or mails. The circuit switched data can be used for delay sensitive real-time traffic. Video applications are potential candidates for circuit switch data as they need a dedicated channel for the duration of the call.

The cdma2000 will have phased development. Phase 1 of the cdma2000 effort, branded as CDMA 1x, employs 1.25 MHz of frequency bandwidth and delivers a peak data rate of 144 Kbps for stationary or mobile applications. In India some of the WiLL operators (Tata Telecom and Reliance Infocomm) are using this technology for WiLL and mobile services. Reliance Infocomm in India is also offering data services with multimedia applications. Phase 2 of cdma2000

Wireless LAN

10.1 INTRODUCTION

Wireless Local Area Network (LAN) is a local area data network without wires. Wireless LAN is also known as WLAN in short. Mobile users can access information and network resources through wireless LAN as they attend meetings, collaborate with other users, or move to other locations in the premises. Wireless LAN is not a replacement for the wired infrastructure. It is implemented as an extension to a wired LAN within a building or campus.

10.2 WIRELESS LAN ADVANTAGES

Schools, campuses, manufacturing plants, hospitals and enterprises install wireless LAN systems for many reasons. Some of these are:

- **Mobility:** Productivity increases when people have access to data and information from any location. The decision-making capability based on real-time information can significantly improve work efficiency. Wireless LAN offers wire-free access to information within the operating range of the WLAN.
- **Low Implementation Costs:** WLANs are easy to set up, relocate, change and manage. Networks that frequently change, both physically and logically, can benefit from WLAN's ease of implementation. WLANs can operate in locations where installation of wiring may be impractical.
- **Installation Speed and Simplicity:** Installing a wireless LAN system can be fast and easy and can eliminate the need to install cable through walls and ceilings.
- **Network Expansion:** Wireless technology allows the network to reach where wires cannot.
- **Reduced Cost-of-Ownership:** While presently the initial investment required for Wireless LAN hardware is higher than the cost of wired LAN hardware, overall installation expenses

and life-cycle costs are expected to be significantly lower. Long-term cost benefits are the greatest in dynamic environments requiring frequent moves, adds and changes.

- **Higher User to Install Base Ratio:** Wireless environment offers a higher user to capacity ratio. For example in a wired network like telephone, physical wire needs to be laid for each and every subscriber. Whereas, for a cellular network the ratio between subscribers and available channel is from 10 to 25 or even more. This means that if there is capacity for 100 channels, the network operator can safely have 2500 subscribers. Likewise in a wireless LAN, the network can offer a very high level of return on investment.
- **Reliability:** One of the common causes of failure in wired network is downtime due to cable fault. WLAN is resistant to different types of cable failures.
- **Scalability:** Wireless LANs can be configured in a variety of topologies to meet the needs of specific applications and installations. Configurations are easily changeable and range from peer-to-peer networks suitable for a small number of users to full infrastructure networks of thousands of users that allow roaming over a broad area.
- **Usage of ISM band:** Wireless LAN operates in the unregulated **ISM** (Industrial Scientific and Medical) band (2.40 GHz to 2.484 GHz, 5.725 GHz to 5.850 GHz) available for use by anyone. A user need not go to the government to get a license to use the wireless LAN. In India 2.4 GHz band is made free for use in WLANs. The 5.7 GHz band is not yet unregulated as it may conflict with the C-band of satellite.

Wireless LAN is also commercially known as WiFi or Wi-Fi. Wi-Fi is an acronym for Wireless Fidelity. The Wi-Fi™ logo is a registered trademark of the Wireless Ethernet Compatibility Alliance (http://wi-fi.org), a group founded by many companies that develop 802.11 based products.

10.2.1 Wireless LAN Evolution

Wireless LAN development started in an unstructured way. Some vendors started offering wireless communication between the corporate LAN and mobile devices (like laptop computers). This is like using a wireless keyboard or a wireless mouse. Protocols and interfaces were proprietary. However, within a short period of time many vendors started offering products in this space. These products were incompatible and soon interoperability became an issue. As IEEE is responsible for maintaining Ethernet LAN standards, IEEE assumed the responsibility of defining the wireless Ethernet LAN standards. The initial standard was published in June 1997. All these early 802.11 systems are first generation systems.

It was not until the introduction of the 11-Mbps 802.11b standard in September 1999 that the horizontal WLAN market achieved some semblance of legitimacy. Also, standards like 802.11a and 802.11g offered much higher bandwidth. All these are second generation WLANs. Second generation WLANs extended the security through 802.1x specifications and offered horizontal roaming. In horizontal roaming, a user can move from one AP to another AP seamlessly.

In third generation WLANs, vertical roaming will be possible. Vertical roaming will provide seamless roaming between different networks. Third generation WLANs will integrate with third generation (3G) telecom networks. These WLANs will eliminate the boundaries between enterprise LAN (both wireline and wireless) systems and the public wireless systems for seamless roaming. It will extend the application of IP mobility standards. The security system is also being extended. These will be achieved through standards like 802.11f and 802.11i.

10.2.2 Wireless LAN Applications

There are many areas and applications of wireless LAN. Wireless LAN is best suited for dynamic environments. Following are some of the examples.

Office/Campus Environment

WLAN is very useful in office environments and buildings with a big campus. In big buildings or in campuses people move between floors, rooms, indoors and outdoors. In an office environment, a person can move with his laptop to the meeting room and continue working. In a university campus, a student can move from the library to the cafeteria and continue working. In a hotel, a guest can move to the pool and work. In a hospital, a doctor can carry the patient information with him while on a regular round.

Factory Shop Floor

This includes environments like factory shop floor, warehouse, exhibition sites, retail shops, labs, etc. These are very dynamic environments, where floor layouts change very frequently; objects within the building are constantly moving. Laying cables and setting up a wired LAN in these kinds of facilities are almost impossible. Wireless LAN can be very useful in such situations.

Homes

In homes WLAN can be used for convergence applications. These will include networking of different home devices like phones, computers and appliances.

Workgroup Environment

WLAN can be very useful for any set-up where small workgroups or teams need to work together, be it within a building or in the neighborhood. This may include a survey team on top of a hill or rescue members after a natural disaster or an accident site. WLAN can be very useful in civil construction sites as well.

Heritage Buildings

There are many buildings of national heritage, where a data network needs to be set up. In a very old church for example, if we need to setup a virtual reality show, it is difficult to install a wired LAN. Wireless LAN can solve the problem.

Public Places

This includes airports, railway stations or places where many people assemble and need to access information.

War/Defense Sites

When there is a war or war game, access to networks help. There is some major research going on in the US on mobile ad hoc networks for defense establishments.

10.3 IEEE 802.11 STANDARDS

The IEEE 802 committee was set up in February 1980 (that is the origin of the name) to set the standard for local area networks. From time to time, IEEE came up with different standards in the LAN domain. This includes all the layers from physical, media access, and data link layer. When IEEE deliberated the standards for WLAN, it was clear that wireless LAN will be different only at the physical and media access layer.

There were many WLAN technologies developed by researchers and industry driven by different motivations; some of them were even standardized (Table 10.1). However, WiFi or IEEE 802.11 became the most popular WLAN protocol world over. When we refer to 802.11 or IEEE 802.11, we generally mean the gener , IEEE 802.11 WLAN family of standards. The 802.11 standardization originally published in 1997 with the goal to support 1 Mbit/s and 2 Mbit/s, 2.4 GHz RF and infrared transmission. All others standards released following that were amendments to this original standard with almost all the letters from the English alphabet starting from 'a' to 'z' like IEEE 802.11a, IEEE 802.11b or IEEE 802.11z. Different standards covered different aspects of WLAN like bandwidths, modulation techniques, physical media, security, roaming etc. Table 10.2 is a list of these standards.

Table 10.1 The IEEE Wireless LAN Standards

Standard	*Description*	*Publication*
IEEE 802.11	Standard for Wireless LAN operations at data rates up to 2 Mbps in the 2.4-GHz Industrial, Scientific and Medical (ISM) band.	1997
IEEE 802.15.1	Wireless Personal Area Network standard based on the Bluetooth specification, operating at the 2.4-GHz ISM band.	2002
IEEE802.1x	Port-based network access control defines infrastructures in order to provide a means of authenticating and authorizing devices attached to a LAN port that has point-to-point connection characteristics.	2001

To avoid confusion, on June 12, 2007 IEEE published the consolidated IEEE Std 802.11-2007 standard entitled "IEEE Standard for Information Technology–Telecommunications and information exchange between systems–Local and metropolitan area networks–Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications". This standard gives users, in one document, the entire IEEE 802.11 set of specifications for wireless local area networks with many amendments that have been published till 2007. This standard includes all amendments of a, b, d, e, g, h, i and j. Theoretically, today standards like IEEE 802.11a or IEEE 802.11g do not exist. The next consolidated standard is expected to be released in 2011 when standards like IEEE 802.11k, IEEE 802.11y and many other may be merged into IEEE Std 802.11-2011.

Table 10.2 The IEEE 802.11 Wireless LAN standards

Standard	*Description*	*Publication*
IEEE 802.11a	54 Mbit/s, 5 GHz standard	1999
IEEE 802.11b	Enhancements to 802.11 to support 5.5 and 11 Mbit/s	1999
IEEE 802.11c	Bridge operation procedures; included in the IEEE 802.1D standard	2001
IEEE 802.11d	International (country-to-country) roaming extensions	2001
IEEE 802.11e	Enhancements QoS including packet bursting	2005
IEEE 802.11f	Inter-Access Point Protocol	2003
IEEE 802.11g	54 Mbit/s, 2.4 GHz standard (backwards compatible with b)	2003
IEEE 802.11h	Spectrum Managed 802.11a (5 GHz) for European compatibility	2004
IEEE 802.11i	Enhanced security	2004
IEEE 802.11j	Extensions for Japan	2004
IEEE 802.11k	Radio resource measurement enhancements	2008
IEEE 802.11n	Higher throughput improvements using Multiple Input, Multiple Output (MIMO) antennas	2009 (target)
IEEE 802.11p	WAVE–Wireless Access for the Vehicular Environment	2010 (target)
IEEE 802.11r	Fast roaming	2008
IEEE 802.11s	Mesh Networking, Extended Service Set (ESS)	2010 (target)
IEEE 802.11t	Wireless Performance Prediction (WPP)–test methods and metrics recommendation	
IEEE 802.11u	Interworking with non-802 networks (for example, cellular)	2010 (target)
IEEE 802.11v	Wireless network management	2010 (target)
IEEE 802.11w	Protected Management Frames	2009 (target)
IEEE 802.11y	3650–3700 MHz Operation in the U.S.	2008
IEEE 802.11z	Extensions to Direct Link Setup (DLS)	2011 (target)
IEEE 802.11aa	Robust streaming of Audio Video Transport Streams	2011 (target)
IEEE 802.11mb	Maintenance of the standard	2011 (target)
IEEE 802.11ac	Very High Throughput $<$ 6 GHz; potential improvements over 802.11n:	2012 (target)
IEEE 802.11ad	Very High Throughput 60 GHz	2012 (target)

10.4 WIRELESS LAN ARCHITECTURE

10.4.1 Types of Wireless LAN

There are different types and flavors of wireless local area networks. Some of the most popular ones are:

- **802.11:** In June 1997, the IEEE finalized the initial specification for wireless LANs: IEEE 802.11. This standard specifies a 2.4 GHz frequency band with data rate of 1 Mbps and 2 Mbps. This standard evolved into many variations of the specification like 802.11b, 802.11a, 802.11g, etc., using different encoding technologies. Today these standards offer a local area network of bandwidths going up to a maximum of 54Mbps.
- **HyperLAN:** HyperLan began in Europe as a specification (EN 300 652) ratified in 1996 by the ETSI Broadband Radio Access Network group. HyperLAN/1, the current version works at the 5 GHz band and offers up to 24 Mbps bandwidth. Next version HyperLAN/2 (http://www.hyperlan2.com) will support a bandwidth of 54 Mbps with QoS support. This will be able to carry Ethernet frames, ATM cells, IP packets and support data, video, voice and image.
- **HomeRF:** In 1998, the HomeRF Working Group (http://www.homerf.org) offered to provide an industry specification to offer Shared Wireless Access Protocol (SWAP). This standard will offer interoperability between PC and consumer electronic devices within the home. SWAP uses frequency hopping spread spectrum modulation and offers 1 Mbps and 2 Mbps at 2.4 GHz frequency band.
- **Bluetooth:** Bluetooth was promoted by big industry leaders like IBM, Ericsson, Intel, Lucent, 3Com, Microsoft, Nokia, Motorola, and Toshiba. It was named after Danish king Harold Bluetooth during 952 to 995 A.D., who had a vision of a world with cooperation and interoperability. Bluetooth is more of a wireless Personal Area Network (PAN) operating at 2.4 GHz band and offers a peak 1Mbps data rate. Bluetooth uses frequency hopping spread-spectrum modulation with relatively low power and smaller range.
- **MANET:** Manet (http://www.ietf.org/html.charters/manet-charter.html) is a working group within the IETF to investigate and develop the standard for Mobile ad hoc NETworks.

10.4.2 Ad hoc versus Infrastructure Mode

Wireless Networks are of two types, infrastructure mode and ad hoc mode. In an infrastructure mode, the mobile stations (MS) are connected to a base station or Access Point (AP). This is similar to a star network where all the mobile stations are attached to the base station. Through a protocol the base station manages the dialogues between the AP and the MS. Figure 10.1 depicts a wireless LAN in infrastructure mode.

In an ad hoc mode, there is no access point or infrastructure. A number of mobile stations form a cluster to communicate with each other. Figure 10.2 depicts wireless LAN in adhoc mode.

In an Infrastructure mode, 802.11 LAN is based on a cellular architecture where the system is subdivided into small clusters or cells (see Fig. 10.1). Each cell is called Basic Service Set, or BSS. Depending on the topology one BSS is connected to other BSS or other infrastructure. In an ad hoc network, the BSS is completely independent. Therefore, technically an ad hoc network is

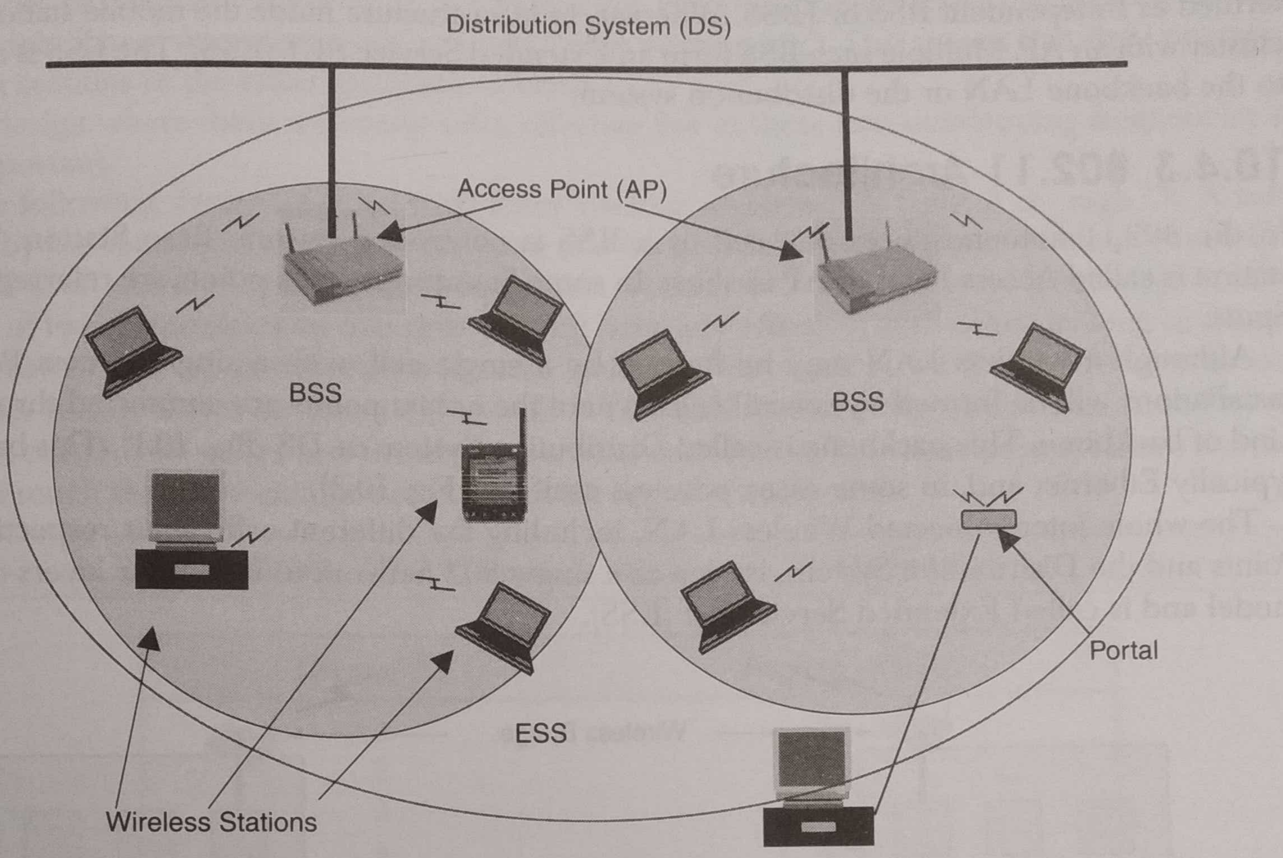


Figure 10.1 Wireless LAN in Infrastructure Mode

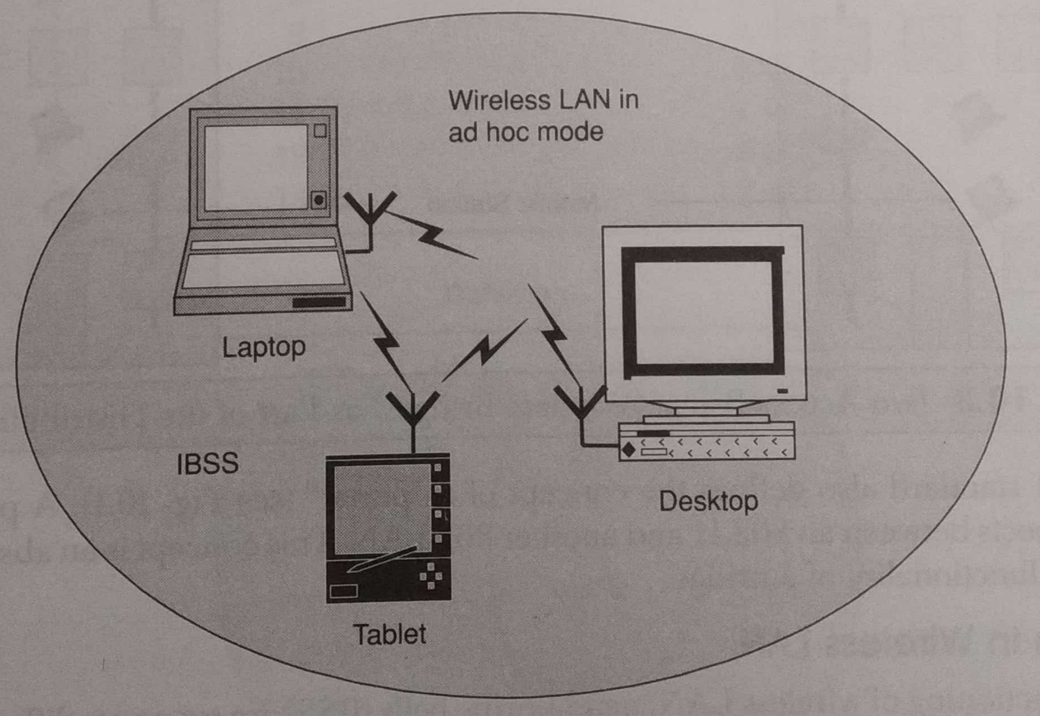


Figure 10.2 Wireless LAN in Ad hoc Mode

termed as Independent BSS or IBSS. Whereas, in infrastructure mode the mobile stations form a cluster with an AP. Multiple such BSS form an Extended Service SET (ESS). The ESS is connected to the backbone LAN or the distribution system.

10.4.3 802.11 Architecture

In the 802.11 nomenclatures one cell or a BSS is controlled by one Base Station. This base station is called Access Point or AP in short. In some literature, access points are referred to as Hot Spots.

Although a wireless LAN may be formed by a single cell, with a single Access Point, most installations will be formed by several cells, where the access points are connected through some kind of backbone. This backbone is called Distribution System or DS (Fig. 10.1). This backbone is typically Ethernet and, in some cases, wireless itself (see Fig. 10.3).

The whole interconnected Wireless LAN, including the different cells, their respective Access Points and the Distribution System, is seen as a single 802 network to the upper layers of the OSI model and is called Extended Service Set (ESS).

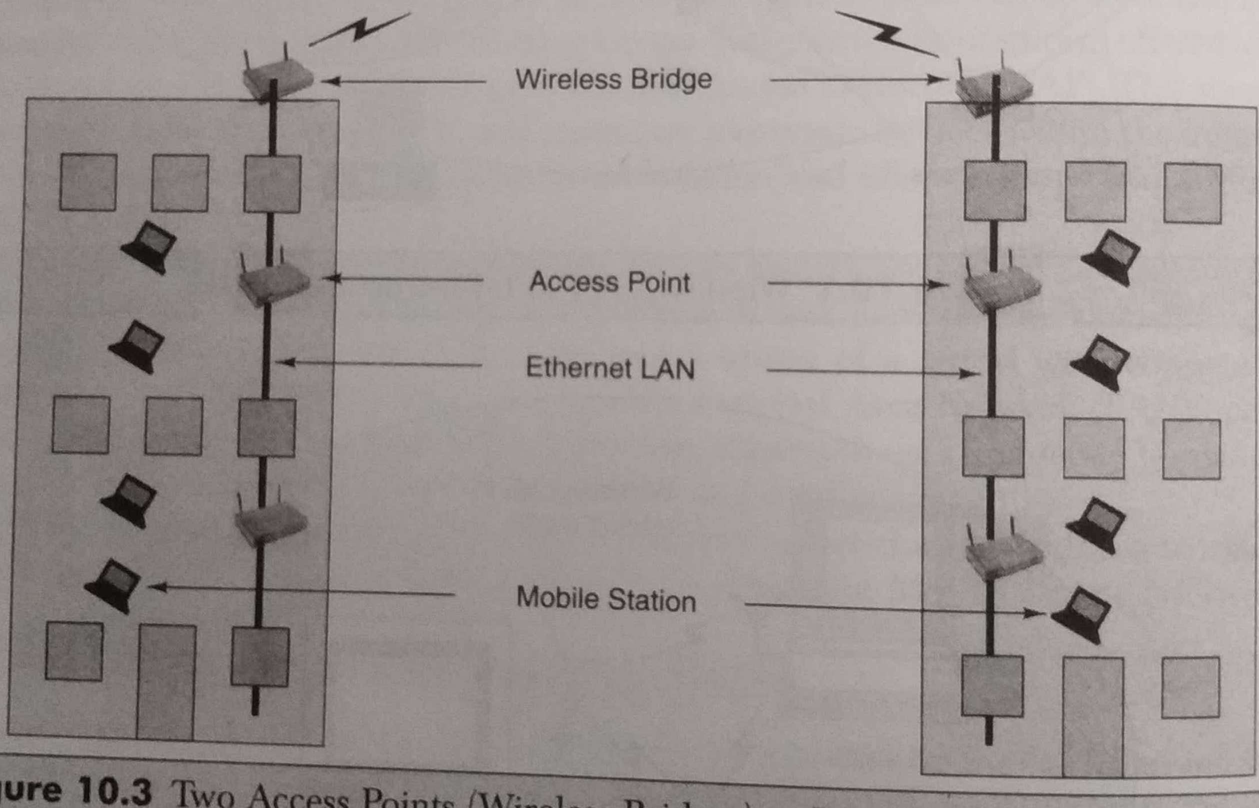


Figure 10.3 Two Access Points (Wireless Bridges) as Part of the Distribution System

The 802.11 standard also defines the concept of a "portal" (see Fig. 10.1). A portal is a device that interconnects between an 802.11 and another 802 LAN. This concept is an abstract description of part of the functionality of a bridge.

Cell Design in Wireless LAN

For proper functioning of wireless LAN, neighboring cells (BSS) are set up on different frequencies, so that wireless LAN cards in each cell do not interfere with one another when they transmit signals. In order for these cells to work without interference, the DSSS standards define 13 different frequencies or channels (Table 10.3). For Frequency Hopping Spread Spectrum (FHSS) there are 79 channels. These frequencies are typically "non-overlapping". This means that they operate in different sections of the radio spectrum or band.

In a design where there are many cells, effective use of these non-overlapping frequencies are very important.

In the following design (see Fig. 10.4) there are four wireless cells (cells A through D). A cell is defined by the space and area the radio wave of a wireless LAN access point is able to cover. Cells A, B and C all use non-overlapping frequencies, while cell D uses the same frequency as cell A. The use of two frequencies by two cells will not have any effect on each other, as long as distance "x" is great enough to ensure effective radio isolation from each other. Radio isolation or radio separation means that a device in cell A will not be able to detect the signal transmitted by any device in cell D. This is because the air distance between two cells attenuates or weakens the radio signal so much that they cannot detect the radio signal of each other.

Table 10.3 Channels within the 2.4GHz band

Channel No	*Frequency (GHz)*
1	2.412
2	2.417
3	2.422
4	2.427
5	2.432
6	2.437
7	2.442
8	2.447
9	2.452
10	2.457
11	2.462
12	2.467
13	2.472

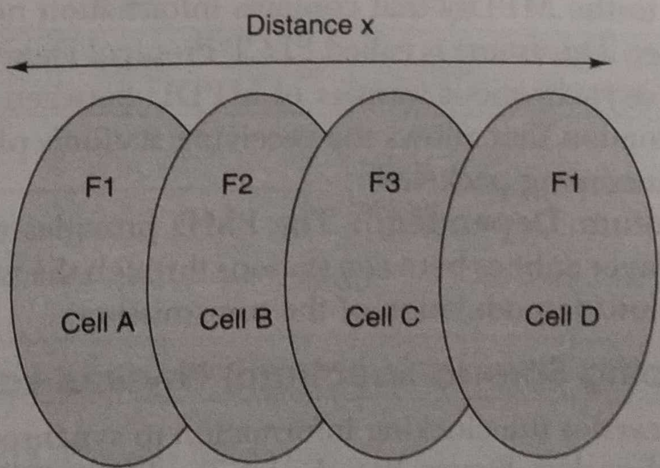


Figure 10.4 Cell Design in a WLAN

CHAPTER 21

Next Generation Networks

Popularity of Internet helped growth of new research and new business opportunities starting from search engines, wikis, email, social networks, publishing and e-commerce services. Through Internet, enterprises have been able to make their presence global and keep their stores open 24 hours a day and 365 days a year. The demand in Internet forced POTS (Plain Old Telephone Service) to enhance its services into broadband. Various DSL (Digital Subscriber Line) technologies came into existence. The other revolutionary technology of recent times is cellular telephony. Nonetheless, it has changed the landscape of public telephony. The services provided by the cellular operators are no longer limited to speech telephony, they include SMS (Short Message Service) and now MMS (Multimedia Message Service). Nowadays, cellular users are also able to surf the Internet, read electronic mails and avail location-based services on their cellular handsets. While telecommunication networks offered data services, the cable TV industry also realized the need of similar services and offer data services over cable.

All this calls for a judicious blend of Internet, broadband, cellular telephony and TV into a technological mosaic that best combines the advantages of communications, covering their limitations. Next Generation Network or NGN is the converged solution for all these communications services. In next generation networks, all traffic will be packet based and that too, through IP (Internet Protocol) and subsequently, with next generation IP—IPv6. It will offer high bandwidth, be it over the wire or wireless. Also, the NGN will offer seamless roaming not only from one geography to another, but also from one type of network to another type of network within a geography or across geographies. According to ITU (International Telecommunication Union), NGN is defined as "A packet-based network able to provide services including Telecommunication Services and able to make use of multiple broadband, QoS-enabled transport technologies and in which service-related functions are independent from underlying transport related technologies".

NGN is about convergence—all technologies of the past and the future will converge in the even playfield of NGN. It will seamlessly blend the public switching telephone network (PSTN) and the public switched data network (PSDN). Rather than having a large centralized switch, NGN pushes the central office (CO) functions to the edge of the network with distributed network infrastructure. It can be thought of as object oriented networks where objects are various services. These services are primarily running in various servers and developed using IT (Information Technology). The advantage of IT is that services can be created quickly and commissioned at a low cost. The access methodology will use all kinds of communications and networking technologies.

21.1 ALL IN ONE—THE CONVERGED SCENARIO

NGN, in essence, is the convergence of IT and CT (Communications Technology). IT and CT are derived from different roots with diverse business objectives; this makes NGN very complex. As NGN will be over IP only, it is also called "All IP Networks" or AIPN. NGN is also referred to in some literature as B3G (Beyond 3G).

21.1.1 Convergence of Voice and Data

Voice is easily comprehensible—it is the sound that we create in the mouth by vibrating our vocal chord or it is the sound produced while human beings speak or shout. Voice is generally perceived through the ear. However, the definition of data is, sometimes, a misnomer. In the context of mathematics, it is used as a basis for reasoning, discussion or calculation. However, in the context of computers or IT, it can be defined as unstructured stream of bytes. When we add a context or put a structure on data, it is converted into information. Majority of information is generally perceived through eyes and visual means. In NGN, voice and data will converge with voice using the VoIP technology and transmitted as data over the IP network.

21.1.2 Convergence of Wireline and Wireless

Wireline technology started with telegraph in 1832; and then, it was telephone in 1871. All these were analog till electronic switches were invented. Also, the analog voice became digital with the invention of PCM. However, all these technologies worked over physical electronic wire, which mainly was copper. Then came fiber optic where digital data is converted into light and transmitted. Fiber allows a higher level of concentration and multiplexing. However, all these—be it analog voice or digitized data, over copper or fiber are transmitted over a physical media—which are termed as fixedline or wireline.

With the discovery of radio in 1901, voice went wireless. Unlike wireline, wireless is bandlimited—there is a fixed band in the electro-magnetic spectrum that is used for radio transmission. In wireline, a transmission can be pointed to a particular destination and can be changed by moving the wire; however, in wireless it functions in broadcast mode transmitting a signal over radio in all directions. Radio started with simplex mode of transmission where there was a radio station with multiple receivers; then it graduated to duplex mode of transmission with walky-talkies. The frequency reuse concept led to the development of cellular telephony. The cellular telephony matured from 1st generation analogue AMPS to 2nd generation GSM. Then it moved to 2.5 generation GPRS to 3rd Generation technologies like UMTS and IMT-2000.

Wireless was also being tried in a variety of applications and services. These were using the free band that is generally known as ISM band. ISM band is unlicensed and free. This motivated researchers and enterprises to come up with wireless LAN (Local Area Network), that is commonly known as WiFi. The pressure on bandwidth kept on increasing leading to the introduction of broadband wireless commonly known as Worldwide interoperability for Microwave Access (WiMAX).

In NGN wireline and wireless will converge. Both data and voice will be carried over wireline and wireless. However, the backbone transmission will continue to remain wireline. There will not be any functional differentiation between an Internet service provider, mobile service provider, or long-distance carriers.

21.1.3 Convergence of Circuit Switching and Packet Switching

In circuit, we establish an end-to-end channel for communication. This channel is reserved for a period of time irrespective of whether the channel is carrying any traffic. Also, in a circuit, the user has to pay for the period the channel is reserved. Circuits ensure a predictable quality of service (QoS). However, in case of packets a communication channel is shared by many packets that may have different source and destination. Packet switching technology is subject to delay, latency, jitter and loss. Any service that demands for QoS preferably should to be over circuit; on contrast any service that can withstand delay can be over packets. Data transmission is well suited for packet switching. In NGN, circuit switching and packet switching will converge—circuit switched data and packet switched data will all be carried over packet switched networks.

21.1.4 Convergence of IT and CT

The first step towards the convergence between telecommunication and IT happened in 1965 when AT&T used computers to do the switching in Electronic Switching System (ESS). On the other hand, the packet switch network was bringing communication closer to computers. The World Wide Web (WWW), which was started by Tim Berners Lee in 1989 as a text processing software, brought these two faculties of technology together and established Internet as a powerful media. The Internet meets four primary needs of the society: communication, knowledge sharing, commerce and entertainment. This convergence is called Information and Communication Technologies (ICT). Through ICT, we are now moving towards an information based society. ICT will address the need to access data, information and knowledge from anywhere at any time.

The convergence of IT and CT has changed the end user devices as well. Sometime ago, both telephone and computer devices were without any intelligence. These devices were connected to the powerful central switch and central mainframe computer, respectively. Convergence of IT and CT is leading the way to multi-access, multi-use and multi-network devices. We mentioned that NGN can be thought of as an object-oriented network where objects are created using IT. The access methodology by these objects will use all kinds of communications networks. In NGN devices will be a fusion of technologies that will adopt the best features and functions from IT and CT platforms. These devices will not discriminate between different networks, but rather, allow users to move seamlessly between cellular and digital Wi-Fi infrastructures.

The role of device diversity on the NGN will not be limited to handling calls from cell towers to WiMAX networks and back again. A user of the next generation network will expect an ability to connect wherever and however, it is most convenient and (probably) cheapest without being concerned about which network is being connected to. Today's phone subscribers may be more interested in voice than data services; however, tomorrow priorities may change, with functions like groupware, collaboration, and videoconferencing making an important difference, particularly to road warriors and telecommuters. The incorporation of RFID technology into phones are helping a phone to transform into an electronic wallet that will help payments at fast food drive-ins, retail stores and other venues.

21.1.5 Convergence of OSS and BSS

Traditionally networks are managed through some NMS (Network Management Systems). When these networks are too large like telecommunications networks, where network elements are in hundreds of thousands, it is not sufficient to have simple NMSs. These complex networks need manager of managers that are called OSS (Operations Support Systems) that manage networks through NOC (Networks Operations Centers). OSS systems do the management of the services that a network offers. OSS systems manages operations functions like FCAPS (Fault, Configuration, Accounting, Performance, Security) combined with inventory, and Trouble Ticketing.

While OSS manages the operation, BSS (Business Support System) manages the financial side of the business i.e., the billing, accounting, and revenue of the network operator. Fraud management and churn management also fall within the domain of BSS. BSS also offers the Customer Care interface with products, contracts, and sales.

Traditionally these two systems were asynchronous and used to be run as two independent systems in a network. However, the need of NGN will change all these; OSS and BSS systems will converge where they not only interact real-time, they need to make instant decisions on services related to content.

21.2 Narrowband to Broadband

Multimedia is changing the communications scenario. Users want various contents over unified bearers and devices. This demands higher bandwidth compared to simple data. This is now possible through cable modem, DSL, fixed wireless, satellite or other means. While DSL and Cable Modem do not offer mobility, other wireless technologies offer mobility at slow speed to vehicular state. A single broadband connection can accommodate multiple users simultaneously. More often, it can be left in a stand-by mode as a "Always on" network. Unlike traditional wireline telephony, broadband communications do not require distinct call lengths that can be metered for billing and signaling purposes.

21.2.1 DSL (Digital Subscriber Line) Broadband Networks

DSL is a family of technologies that provide data services over the wires of a local telephone network. DSL can be asynchronous and synchronous. In asynchronous DSL (ADSL) the bandwidth for download is higher that upload. These are quite suitable for Internet access or TV over IP network where the traffic pattern is asymmetric with small number of bytes for upload and a large number of bytes for download. However, for interractive services or VoIP, the traffic load in both upload and download are of similar order. For these types of services synchronous DSL (SDSL) are more suitable. In a fixedline telephone voice requires 3.4 kHz bandwidth. However, the copper wire that is used for local loop is capable of carrying frequencies well beyond the 3.4 kHz upper limit of POTS. Depending on the length and quality of the loop, the upper limit can be tens of megahertzs. DSL takes advantage of this unused bandwidth of the local loop. As DSL uses frequencies beyond our audible limits, voice and data connection can operate simultaneously without interference. This means that while data exchange is in progress, one can use the telephone to converse with others without interference. Typically, the download speed of consumer DSL services ranges from 256 kilobits per second (kbit/s) to 24,000 kbit/s, depending on DSL technology, line conditions and service level implemented. Other DSL technologies like HDSL (High bit-rate Digital Subscriber line) offer much higher bandwidth.

21.2.2 WiMAX Broadband Wireless Networks

We introduced 802.16 and WiMAX (Worldwide Interoperability for Microwave Access) in Chapter 4 where we categorized it as emerging technology. WiMAX is showing lot of promises and being rolled out by many network providers as wireless broadband. WiMAX can be either fixed or mobile. Fixed WiMAX deployments do not cater for handoff between Base Stations, therefore the service provider cannot offer mobility. Mobile WiMAX on contrast offers a handoff that can be used to deliver both fixed and mobile services. With a line-of-sight environment with a portable Mobile WiMAX device, bandwidth can be expected around 10 Mbit/s over a 10 km radius. However, in urban environments they may not have line-of-sight; therefore, users of WiMAX may only receive 10 Mbit/s over 2 km.

21.2.3 High Speed Broadband Cellular Networks

High Speed Packet Access (HSPA) is a suite of mobile telephony protocols that aim to extend and improve the performance of existing UMTS family of protocols. Better performance is achieved using improved modulation schemes and by fine-tuning the protocols by which cellular handsets and base stations communicate. This helps in efficient utilization of the available bandwidth. Under HSPA, High Speed Uplink Packet Access (HSUPA) and High Speed Downlink Uplink Packet Access (HSDPA) are already existing protocols.

- **High Speed Uplink Packet Access (HSUPA):** Defined by UMTS release 6, the 3GPP definition of HSUPA is "technical purpose of the Enhanced Uplink feature is to improve the performance of uplink dedicated transport channels, i.e., to increase capacity and throughput and reduce delay". HSUPA provides uplink speeds up to 5.76 Mbit/s. HSUPA uses enhanced dedicated channels on which it employs link adaptation methods which help in faster link adaptation and effective retransmissions. There are seven HSUPA categories provisioning speeds from 0.73 Mbits/s to 5.76 Mbits/s.
- **High Speed Downlink Uplink Packet Access (HSDPA):** Defined by UMTS release 5, HSDPA provisions downlink speeds of 1.8, 3.6, 7.2 and 14.4 Mbit/s. Normally, deployments provide up to 7.2 Mbit/s in downlink while supporting uplink speeds to a maximum of 384 kbit/s. HSUPA improves downlink performance using faster scheduling of packets and quick retransmissions (at the base stations) and Adaptive Modulation and Coding (AMC). HSDPA has more than 10 different categories supporting various data rates.

21.2.4 WiBro

WiBro or Wireless Broadband is the South Korean name for IEEE 802.16e (mobile WiMAX) standard. The base stations in WiBro would offer an aggregate data throughput from 30 to 50 Mbit/s while covering a radius of 1–5 km for the use of Internet. It can, actually, provide mobility for moving devices up to 120 km/h (74.5 miles/h) compared to Wireless LAN (WLAN) which provides mobility up to walking speed. WiBro does so by adapting Time Division Duplexing (TDD) and OFDMA while using 8.75 MHz as channel bandwidth.

21.3 ALL IP AND B3G NETWORK

We have mentioned that according to ITU NGN is defined as a packet-based network able to provide various telecommunications and data services. NGN is also called Beyond 3G (B3G) network. The B3G network architectures will evolve to include a much wider range of users, applications and economic deployment. 4G (again, also known as Beyond 3G) is an acronym for Fourth Generation Communications system to identify the next step in wireless communications. There is no industry consensus on what a "Beyond 3G network", will look like; but, as far as the next generation networks are concerned, concepts and ideas include the following:

- Transition towards an "All-IP based network infrastructure".
- Support of heterogeneous technologies (i.e., PSTN, UTRAN, Ad-hoc, WLANs, WiMAX, UMTS, WiFi, etc.).
- Seamless handover across both homogeneous and heterogeneous wireless access technologies.
- Multilayer Mobility Management suitable to support fast mobile users that may access a wide range number of services with diverse characteristics.
- QoS support on the IP layer.
- Use of policy-based mechanisms in order to determine QoS, accounting, and billing mechanisms for multimedia services.
- Network access control of mobile users (i.e., deployment of AAA protocols that allow inter-domain network access control) regardless of heterogeneous wireless access network used.
- Distributed AAA architecture for the dynamic establishment of trust relations in hybrid IPv4/IPv6 networks.
- Secure access to multimedia services across different networking environments.
- Access to multimedia services in hybrid IPv4/IPv6 based networks.
- It will offer RASP that includes reliability, availability, security, and performance.
- More users per cellular cell.
- A highly efficient spectral system.
- Backward compatibility with existing wireless standards.

21.4 OFDM (ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING)

As we move towards convergence and AIPN, the bandwidth requirements for IP increase. To allow higher spectrum utilization OFDM (Orthogonal Frequency Division Multiplexing) is increasingly being used. Some services that use OFDM today are: DSL, WiMAX, DAB (Digital Audio Broadcast), DVB (Digital Audio Broadcast), 3GPP LTE (3GPP Long Term Evolution), etc.

OFDM transmission scheme is an optimal version of the multi-carrier data transmission scheme. OFDM is based on the principle of spreading the data to be transmitted over a large number of carriers when each of them is being modulated at a low rate. The carriers are made orthogonal to each other by appropriately choosing the frequency spacing between them. Orthogonality helps in elimination of cross-talk between the sub-channels and the use of inter-carrier guard bands. Although the sidebands from each carrier channel overlaps, they can still be received without interference as they are orthogonal in position among each other. This is achieved by putting the carrier spacing equal to the reciprocal of the symbol period. Figure 21.1 depicts an OFDM spectrum.

The data to be transmitted on an OFDM signal is spread across the carriers of the signal wherein each carrier takes part of the payload. This immensely reduces the data rate taken by each carrier. This is effected by adding a guard band time or guard interval into the system. This makes sure that data is sampled only when the signal is stable and no new delayed signals arrive that would alter the timing and phase of the signal.

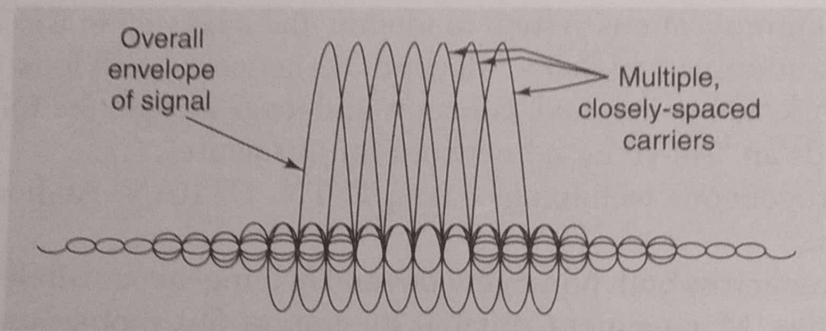


Figure 21.1 OFDM Spectrum

The data distribution across a large number of carriers in the OFDM signal has some significant advantages. Nulls caused by multi-path effects or interference on a given frequency only affect a small number of the carriers, the remaining ones being received correctly. Further, error coding techniques enable many or all of the corrupted data to be reconstructed within the receiver. The receiver at OFDM acts as a bank of demodulators converting each carrier to direct current. The resulting signal is integrated over the symbol period to regenerate the data from that carrier. The same demodulator also demodulates other carriers. As the carrier spacing equal to the reciprocal of the symbol period means that they will have a whole number of cycles in the symbol period and their contribution will sum to zero resulting in no interference. One requirement of the OFDM transceiver systems is that they must be linear as any non-linearity would cause interference between the carriers as a result of inter-modulation distortion. This results in impairing the orthogonality of the transmission.

Although OFDM requires costly circuitry and is sensitive to frequency synchronization issues, it has the following major advantages:

- High spectral efficiency.
- Facilitation of transmitter macro-diversity.
- Robustness against Inter Symbol Interference (ISI) and severe channel circumstances.

21.5 FAMA/DAMA

In order to resolve medium access control issues, the Fixed Assignment Multiple Access (FAMA) protocol was proposed. The applications of FAMA protocol are characterized by the assignment of capacity in a fixed manner amongst multiple stations. Irrespective of the fluctuating demands (of stations), the stations are assigned a fixed channel capacity. However, this results in significant underuse of the overall available capacity.

FAMA protocols can be in of different flavors such as Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA) or Space Division Multiple Access (SDMA). However, all such FAMA flavored protocols assign a static portion which can be in terms of time, frequency, code or space, of the overall link capacity to different stations. That is the assignment of resources are fixed and do not change according to station traffic patterns. The major benefit of FAMA based protocols is they can provide bounds for delay performance which become of paramount importance in real-time applications. However, following are some potential drawbacks:

- It is difficult to configure FAMA protocols when a new station comes in or moves out of a network system.
- The schemes of tuning FAMA flavored protocols (like TDMA, FDMA and Multi-Frequency TDMA) are labor intensive and unscalable.
- It is difficult to implement FAMA based protocols in a distributed mode.

Improvement over FAMA protocols, Demand Assignment Multiple Access (DAMA) protocols have capacity assignment in a manner that optimally respond to demands from/amongst multiple stations. DAMA protocols assign channels to stations based on the traffic information in the network. The assignment of channels is achieved through reservation or polling techniques so that each station can express their interest in using the channel for transmission based on its own traffic information. Such a process differs for different flavors of DAMA protocols. The reservation process can take place either in the primary communication channel or in a separate signaling channel depending upon the actual protocol. DAMA protocols can be collision free, in which each station will be assigned a fixed reservation slot, or it can be collision based, in which each station needs to compete with other stations when transmitting requests. Polling techniques can be used to decide which station should get the right of transmission over a certain channel during a certain time period as polling is naturally suited to networks with a centralized base station.

21.6 Multi Protocol Label Switching (MPLS)

As a packet in a connectionless network layer protocol like IP travels from one router to the next, each router makes an independent forwarding decision for that packet. A smarter routing is essential for traffic engineering and efficient routing of packets in a converged network where there are payloads from both circuit switched networks and packet switched networks. Multiprotocol Label Switching (MPLS) as described in RFC 3031 (Multiprotocol Label Switching Architecture), does exactly this. MPLS operates at an OSI Model layer that is generally considered to lie between traditional definitions of Layer 2 (data link layer) and Layer 3 (network layer) to perform smarter routing, and thus is often referred to as a "Layer 2.5" protocol.

MPLS is a packet forwarding technology which makes the use of labels for data forwarding decisions. It provides a unified data carriage service for different traffic categories like IP packets, frames of ATM and SONET, etc. Such a model facilitates MPLS to be a generic model for both, circuit switched and packet switched data. The MPLS working group aims to standardize a base technology which can combine the use of label swapping in the forwarding component with network layer routing in the control component and thus, provisioning:

- MPLS to run over any link layer technology while supporting both unicast and multicast traffic flows.
- MPLS to be scalable enough to support Internet growth while being compatible with the IETF Integrated Services Model and its related protocols.
- MPLS to support current IP network operations.

Coming from the family of IETF, MPLS initiates assignment and distribution of label bindings for the establishment of Label Switched Paths (LSPs). LSPs can be created by concatenating one or more label switched hops which, in turn, provision a packet to be forwarded from one Label Switching Router (LSR) to another LSR across the whole MPLS domain. MPLS defines standard based IP signaling and label distribution protocols along with extensions to existing protocols. This helps multi-vendor interoperability. With MPLS, the network layer header analysis is done when the packet enters its domain and this label inspection drives subsequent packet forwarding across the whole of domain. Figure 21.2 depicts an overview of MPLS functioning.

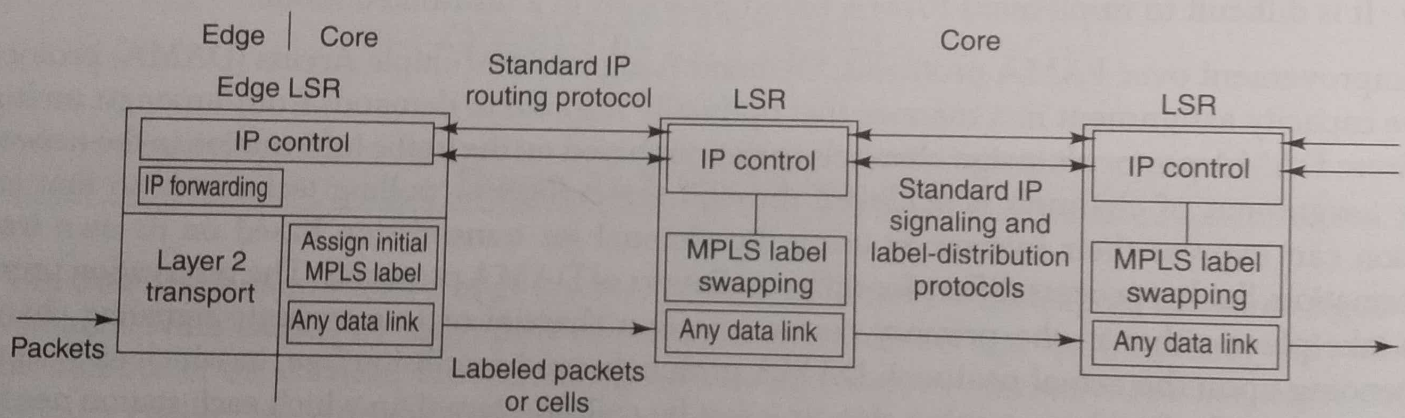


Figure 21.2 Functioning of MPLS

Currently, MPLS has the following major applications:

- *Traffic Engineering*: MPLS helps Traffic Engineering in view of the unprecedented growth in demand for network resources and real-time nature of IP applications. MPLS facilitates Traffic Engineering to allow ISPs to move traffic flows away from the shortest path on to potentially less congested physical paths across the network.
- *Class of Service (CoS)*: MPLS offers great flexibility to the ISPs in terms of different types of services that they can provide to their customers. The precedence bits are used only to classify packets into one of various classes of service. Then onwards, ISPs can determine the specific type of service that is supported by each service classification bits.
- *Virtual Private Networks (VPNs)*: MPLS lets ISPs offer VPN services by providing a flexible and powerful tunneling mechanism.

MPLS offers enhanced routing mechanisms by supporting more than just destination-based forwarding which makes it permit ISPs to deliver new services that can not be easily provided by conventional IP routing techniques.

21.7 WIRELESS ASYNCHRONOUS TRANSFER MODE

Wireless Asynchronous Transfer Mode (WATM) adds up the mobility advantages to the ones provided by ATM networks. The mobility aspect forces a decoupling of the normal mapping of node and switch port. In Wireless ATM, a wireless access point connects the set of wireless nodes while servicing on a single port of ATM switch. As it is known, ATM technology offers speed, scalability, multimedia integration and uniform API features with good cost performance. To develop WATM, the following are needed:

- Protocol extensions to support mobility within an ATM infrastructure.
- Radio access technology necessary for seamless delivery of ATM services to mobile terminals.

According to the WATM working group charter WATM "specification will include both mobile ATM extensions for mobility support within an ATM network as well as radio access layer for ATM-based wireless access. The WATM specifications are intended for use in networks involving terminal mobility and/or radio access, and will be designed for compatibility with ATM equipment adhering to the (then) current ATM Forum specification".

Wireless/Mobility protocols are incorporated into standard ATM stack keeping the following as mandatory:

- ATM cell as basic unit in both wireless and backbone.
- Standard ATM services at transport interface.
- Custom medium access and data link control for wireless segment.
- Mobility extensions to ATM signaling: handoff and location management.

Figure 21.3 depicts the WATM system. It brings out the individual contribution of ATM switches, mobility protocols and WATM radio access. Normally, Wireless ATM systems can be constructed via hardware/software plug-ins to the existing ATM switches.

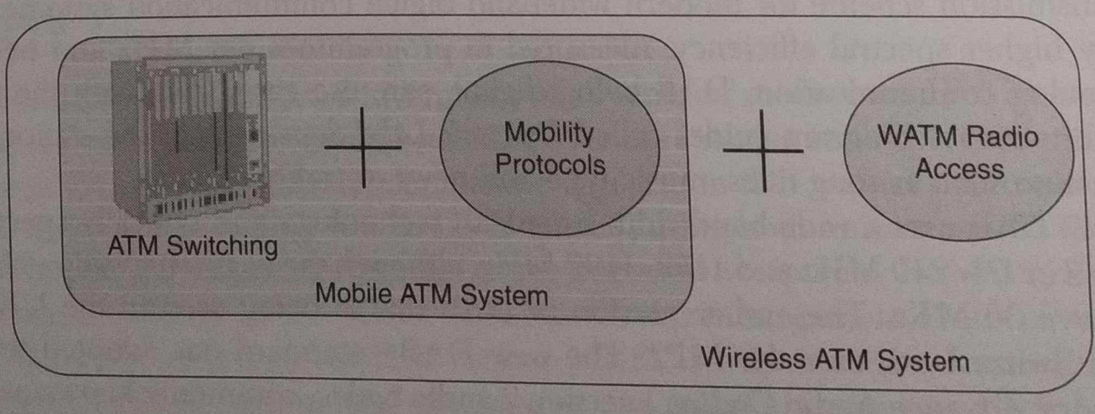


Figure 21.3 Overview of WATM System

and a single bill. They are looking for simplicity in managing and using their various services and devices while willing to pay a bit of a premium for it.

21.10 Future Trends

In this section, we discuss some other emerging technologies that look promising in the NGN space. These are 3GPP LTE, and iBurst.

21.10.1 3GPP Long Term Evolution

The 3GPP Long Term Evolution (3GPP LTE) project would result in the release 8 (of 3GPP) having extensions and modifications of the current UMTS system. Sometimes called a fourth generation mobile communications technology, 3GPP LTE will be a wireless broadband Internet system with other services (like voice and data) built over it. Objectively, it has the following goals:

- Backward compatibility with legacy standards.
- Optimal cell size of 5 km, 30 km cell size with reasonable performance and sometimes, more than 30 km (up to a maximum of 100 km) cell size with acceptable performance.
- Download rates of 100 Mbit/s and upload rates of 50 Mbit/s for every 20 MHz of available spectrum with support for 200 active phone calls for every 5 MHz cell.
- Small latencies for small IP packets.
- Increased spectrum flexibility with slices as small as 1.25 MHz supported.

The project is ongoing and general in scope and yet to experience exhaustive trials and demonstrations before touching base.

21.10.2 iBurst

iBurst or High Capacity Spatial Division Multiple Access (HC-SDMA) is a wireless broadband technology which optimally uses the available bandwidth by using smart antennas. HC-SDMA interface provides wide area broadband wireless connectivity for fixed, portable and mobile computing devices. It can be implemented with smart antenna array techniques to substantially improve the radio frequency coverage and performance of the system.