Chapter 2  Modern Wireless Communication Systems


2.1  Second Generation (2G) Cellular Networks
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2.3  Wireless Local Loop (WLL) and LMDS
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2.x1  Ultra-Wideband (UWB)
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Since the mid 1990s, the cellular communications industry has witnessed explosive growth.

The widespread success of cellular has led to the development of newer wireless systems and standards for many other types of telecommunication traffic besides mobile voice telephone calls.
New standards and technologies are being implemented to allow wireless networks to replace fiber optic or copper lines between fixed points several kilometers apart (fixed wireless access).

Similarly, wireless networks have been increasingly used as a replacement for wires within homes, buildings, and offices settings through the deployment of wireless local area networks (WLANs).

Wireless personal area networks (WPANs) with distance of a few to tens of meters became possible with technologies such as IrDA, Bluetooth, UWB, and ZigBee.

The Bluetooth can replace appliance communication cords with indivisible wireless connections within a person’s personal workspace.

The Zigbee is simpler and cheaper than Bluetooth, providing lower data rate and longer battery life for secure networking.

The Ultra-wideband (UWB) has a very low power level for short range communications by using very large frequency spectrum.
2.1 Second Generation (2G) Cellular Networks

Unlike 1\textsuperscript{st} generation cellular systems that relied exclusively on FDMA/FDD and analog FM, 2\textsuperscript{nd} generation cellular (2G) standards use digital modulation and TDMA/FDD and CDMA/FDD multiple access techniques.

The most popular 2G standards include three TDMA standards and one CDMA standard:

(a) \textbf{Global System Mobile (GSM)}, which supports eight time slotted users for each 200 kHz radio channel and has been deployed widely in the cellular and PCS bands by service providers in Europe, Asia, Australia, South America, and some parts of the U.S. (in the PCS spectrum band only);

(b) \textbf{Interim Standard 136 (IS-136)}, also known as North American Digital Cellular (NADC) or US Digital Cellular (USDC), which supports three time slotted users for each 30 kHz radio channel and is a popular choice for carriers in North America, South America, and Australia (in both the cellular and PCS bands);

(c) \textbf{Pacific Digital Cellular (PDC)}, a Japanese TDMA standard that is similar to IS-136; and
(d) the popular 2G CDMA standard **Interim Standard 95 Code Division Multiple Access (IS-95)**, also known as **cdmaOne**, which supports up to 64 users that are orthogonally coded and simultaneously transmitted on each 1.25 MHz channel.

CDMA is widely deployed by carriers in North America (in both cellular and PCS bands), as well as in Korea, China, Japan, South America, and Australia.

Some wireless service providers use both first generation and second generation equipment in major markets and often provide customers with subscriber units that can support multiple frequency bands and multiple air interface standards.

Table 2.1 shows the key technical specifications of 2\textsuperscript{nd} generation standards: the dominant GSM, CDMA, IS-54/IS-136, and PDC.
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Uplink Frequencies</strong></td>
<td>824-849 MHz (US Cellular) 1850-1910 MHz (US PCS)</td>
<td>890-915 MHz (Europe) 1850-1910 MHz (US PCS)</td>
<td>800 MHz, 1500 MHz (Japan) 1850-1910 MHz (US PCS)</td>
</tr>
<tr>
<td><strong>Downlink Frequencies</strong></td>
<td>869-894 MHz (US Cellular) 1930-1990 MHz (US PCS)</td>
<td>935-960 MHz (Europe) 1930-1990 MHz (US PCS)</td>
<td>869-894 MHz (US Cellular) 1930-1990 MHz (US PCS) 800 MHz, 1500 MHz (Japan)</td>
</tr>
<tr>
<td><strong>Duplexing</strong></td>
<td>FDD</td>
<td>FDD</td>
<td>FDD</td>
</tr>
<tr>
<td><strong>Multiple Access Technology</strong></td>
<td>CDMA</td>
<td>TDMA</td>
<td>TDMA</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td>BPSK with Quadrature Spreading</td>
<td>GMSK with $BT = 0.3$</td>
<td>$\pi/4$ DQPSK</td>
</tr>
<tr>
<td><strong>Carrier Separation</strong></td>
<td>1.25 MHz</td>
<td>200 kHz</td>
<td>30 kHz (IS-136) (25 kHz for PDC)</td>
</tr>
<tr>
<td><strong>Channel Data Rate</strong></td>
<td>1.2288 Mchip/sec</td>
<td>270.833 kbps</td>
<td>48.6 kbps (IS-136) (42 kbps for PDC)</td>
</tr>
<tr>
<td><strong>Voice channels per carrier</strong></td>
<td>64</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td><strong>Speech Coding</strong></td>
<td>Code Excited Linear Prediction (CELP) @ 13 kbps, Enhanced Variable Rate Codec (EVRC) @ 8 kbps</td>
<td>Residual Pulse Excited Long Term Prediction (RPE-LTP) @ 13 kbps</td>
<td>Vector Sum Excited Linear Predictive Coder (VSELP) @ 7.95 kbps</td>
</tr>
</tbody>
</table>
2.1.1 Evolution to 2.5G Mobile Radio Networks

In Table 2.1 it is shown that all 2G networks only support single user data rate on the order of 10 kbps, which is too slow for rapid email and Internet browsing applications.

Even with relatively small user data rates, 2G standards are able to support limited Internet browsing and sophisticated short messaging capabilities using a circuit switched approach.

**Short messaging service (SMS)** is a popular feature of GSM.

With increased throughout data rates that are required to support modern Internet applications, new data-centric standards have been developed that can be overlaid upon existing 2G technologies.

These new standards represent 2.5G technology and allow existing 2G equipment to be modified and supplemented with new base station add-ons and subscriber unit software upgrades to support higher data rate transmissions for web browsing, e-mail traffic, mobile commerce (**m-commerce**), and location-based mobile services.
The 2.5G technologies also support a popular new web browsing format language such as Wireless Applications Protocol (WAP), that allows standard web pages to be viewed in a compressed format specifically designed for small, portable hand held wireless devices.

NTT DoCoMo introduced its own proprietary wireless data service and Internet micro-browser technology, called I-mode, on its PDC network in 1998.

I-mode supports games, color graphics, and interactive web page browsing using the modest 2G PDC data transmission rate of 9.6 kbps.

A wide range of 2.5G standards have been developed to allow each of the major 2G technologies (GSM, CDMA, and IS-136) to be upgraded incrementally for faster Internet data rates.

Figure 2.3 shows the various 2.5G and 3G upgrade paths for the major 2G technologies.

Table 2.2 shows the required changes to the network infrastructure (e.g., the base station and the switch) and the subscriber terminals (e.g., the handset) for the various upgrade options for 2.5G and 3G.
Figure 2.3 Various upgrade paths for 2G technologies.
<table>
<thead>
<tr>
<th>Wireless Data Technologies</th>
<th>Channel BW</th>
<th>Duplex</th>
<th>Infrastructure change</th>
<th>Requires New Spectrum</th>
<th>Requires New Handsets</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSCSD</td>
<td>200 KHz</td>
<td>FDD</td>
<td>Requires software upgrade at base station.</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New HSCSD handsets provide 57.6 Kbps on HSCSD networks, and 9.6 Kbps on GSM networks with dual mode phones. GSM-only phones will not work in HSCSD networks.</td>
</tr>
<tr>
<td>GPRS</td>
<td>200 KHz</td>
<td>FDD</td>
<td>Requires new packet overlay including routers and gateways.</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New GPRS handsets work on GPRS networks at 171.2 Kbps, 9.6 Kbps on GSM networks with dual mode phones. GSM-only phones will not work in GPRS networks.</td>
</tr>
<tr>
<td>EDGE</td>
<td>200 KHz</td>
<td>FDD</td>
<td>Requires new transceiver at base station. Also, software upgrades to the base station controller and base station.</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New handsets work on EDGE networks at 384 Kbps, GPRS networks at 144 Kbps, and GSM networks at 9.6 Kbps with tri-mode phones. GSM and GPRS-only phones will not work in EDGE networks.</td>
</tr>
<tr>
<td>W-CDMA</td>
<td>5 MHz</td>
<td>FDD</td>
<td>Requires completely new base stations.</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New W-CDMA handsets will work on W-CDMA at 2 Mbps, EDGE networks at 384 Kbps, GPRS networks at 144 Kbps, GSM networks at 9.6 Kbps. Older handsets will not work in W-CDMA.</td>
</tr>
<tr>
<td>IS-95B</td>
<td>1.25 MHz</td>
<td>FDD</td>
<td>Requires new software in base station controller.</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New handsets will work on IS-95B at 64 Kbps and IS-95A at 14.4 Kbps. CdmaOne phones can work in IS-95B at 14.4 Kbps.</td>
</tr>
<tr>
<td>cdma2000 1xRTT</td>
<td>1.25 MHz</td>
<td>FDD</td>
<td>Requires new software in backbone and new channel cards at base station. Also need to build a new packet service node.</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New handsets will work on 1xRTT at 144 Kbps, IS-95B at 64 Kbps, IS-95A at 14.4 Kbps. Older handsets can work in 1xRTT but at lower speeds.</td>
</tr>
<tr>
<td>cdma2000 1xEV (DO and DV)</td>
<td>1.25 MHz</td>
<td>FDD</td>
<td>Requires software and digital card upgrade on 1xRTT networks.</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New handsets will work on 1xEV at 2.4 Mbps, 1xRTT at 144 Kbps, IS-95B at 64 Kbps, IS-95A at 14.4 Kbps. Older handsets can work in 1xEV but at lower speeds.</td>
</tr>
<tr>
<td>cdma2000 3xRTT</td>
<td>3.75 MHz</td>
<td>FDD</td>
<td>Requires backbone modifications and new channel cards at base station.</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New handsets will work on 95A at 14.4 Kbps, 95B at 64 Kbps, 1xRTT at 144 Kbps, 3xRTT at 2 Mbps. Older handsets can work in 3X but at lower speeds.</td>
</tr>
</tbody>
</table>
2.1.2 Evolution for 2.5G TDMA Standards

Three different upgrade paths have been developed for GSM carriers, and two of these solutions also support IS-136.

The three TDMA upgrade options include: (a) High Speed Circuit Switched Data (HSCSD); (b) General Packet Radio Service (GPRS); and (c) Enhanced Data Rates for GSM Evolution (EDGE).

2.1.2.1 HSCSD for 2.5G GSM

High Speed Circuit Switched Data is a circuit switched technique that allows a single mobile subscriber to use consecutive user time slots in the GSM standard.

HSCSD relaxes the error control coding algorithms originally specified in the GSM standard for data transmissions and increases the available application data rate to 14.4 kbps, as compared to the original 9.6 kbps in the GSM specification.
By using up to 4 consecutive time slots, HSCSD is able to provide a raw transmission rate of up to 57.6 kbps to individual users.

HSCSD is ideal for dedicated streaming Internet access or real-time interactive web sessions and simply requires the service provider to implement a software change at existing GSM BSs.

2.1.2.2 GPRS for 2.5G GSM and IS-136

Unlike HSCSD, which dedicates circuit switched channels to specific users, General Packet Radio Service (GPRS) can support many more users than HSCSD, but in a bursty manner.

The GPRS standard provides a packet network on dedicated GSM or IS-136 radio channels.

GPRS retains the original modulation formats specified in the original 2G TDMA standards, but uses a completely redefined air interface in order to better handle packet data access.
When all 8 time slots of a GSM radio channel are dedicated to GPRS, an individual user is able to achieve as much as 171.2 kbps (8 time slots × 21.4 kbps of raw uncoded data throughput).

Note that GPRS was originally designed to provide a packet data overlay solely for GSM networks, but at the request of North American IS-136 operators, GPRS was extended to include both TDMA standards.

### 2.1.2.3 EDGE for 2.5G GSM and IS-136

EDGE, which stands for Enhanced Data rates for GSM (or Global) Evolution, is a more advanced upgrade to the GSM standard and requires the addition of new hardware and software at existing base stations.

EDGE introduces a new digital modulation format, 8-PSK, which is used in addition to GSM’s standard GMSK modulation.

EDGE allows for 8 different (autonomously and rapidly selectable) air interface formats, known as multiple modulation and coding schemes (MCS), with varying degrees of error control protection. Each MCS state may use either GMSK (low data rate) or 8-PSK (high data rate) modulation for network access,
depending on the instantaneous demands of the network and the operating conditions.

Because of the higher data rates and relaxed error control covering in many of the selectable air interface formats, the coverage range is smaller in EDGE than in HSDRC or GPRS. EDGE is sometimes referred to as Enhanced GPRS, or EGPRS.

EDGE uses the higher order 8-PSK modulation and a family of MCSs for each GSM radio channel time slot, so that each user connection may adaptively determine the best MCS setting for the particular radio propagation conditions and data access requirements of the user.

This adaptive capability to select the “best” air interface is called **incremental redundancy**, whereby packets are transmitted first with maximum error protection and maximum data rate throughput, and then subsequent packets are transmitted with less error protection (usually using punctured convolutional codes) and less throughput, until the link has an unacceptable outage or delay.

Rapid feedback between the base station and subscriber unit then restores the previous acceptable air interface state, which is presumably at an acceptable level but with minimum required coding and minimum bandwidth and power drain.
Incremental redundancy ensures that the radio link for each user will quickly reach a condition that uses the minimum amount of overhead, thereby providing acceptable link quality for each user while maximizing user capacity on the network.

When EDGE uses 8-PSK modulation without any error protection, and all 8 times slots of a GSM radio channel are dedicated to a single user, a raw peak throughput data rate of $547.2$ kbps can be provided.

By combining the capacity of different radio channels (e.g., using **multicarrier transmissions**), EDGE can provide up to several megabits per second of data throughput to individual data users.

### 2.1.3 IS-95B for 2.5G CDMA

Unlike the several GSM and IS-136 evolutionary paths to high speed data access.

CDMA (often called **cdmaOne**) has a single upgrade path for eventual 3G operation.
The interim data solution for CDMA is called IS-95B.

Like GPRS, IS-95B provides high speed packet and circuit switched data access on a common CDMA radio channel by dedicating multiple orthogonal user channels (Walsh functions) for specific users and specific purposes.

The original IS-95 throughput rate specification of 9600 bps was not implemented in practice, but was improved to the current rate of 14,400 bps as specified in IS-95A.

The 2.5G CDMA solution, IS-95B, supports medium data rate (MDR) service by allowing a dedicated user to command up to 8 different user Walsh codes simultaneously and in parallel for an instantaneous throughput of 115.2 kbps per user (8 × 14.4 kbps).

However, only about 64 kbps of practical throughput is available to a single user in IS-95B due to the slotting techniques of the air interface.

IS-95B also specifies hard handoff procedures that allow subscriber units to search different radio channels in the network without instruction from the switch so that subscriber units can rapidly tune to different base
stations to maintain link quality.

Prior to IS-95B, the link quality experienced by each subscriber had to be reported back to the switch through the serving base station several hundreds of times per second, and at the appropriate moment, the switch would initiate a soft-handoff between the subscriber and candidate base stations.

2.2 3rd Generation (3G) Wireless Networks

Multi-megabit Internet access, communications using Voice over Internet Protocol (VoIP), voice-activated calls, unparalleled network capacity, and ubiquitous “always-on” access are just some of the advantages being touted by 3G developers.

The International Telecommunications Union (ITU) formulated a plan to implement a global frequency band in the 2000 MHz range that would support a single, ubiquitous wireless communication standard for all countries throughout the world, which is called International Mobile Telephone 2000 (IMT-2000).
IMT-2000
The ITU vision of global wireless access in the 21st century
The eventual 3G evolution for 2G CDMA systems leads to cdma2000.

Several variants of cdma2000 are currently being developed, but they all are based on the fundamentals of IS-95 and IS-95B technologies.

The eventual 3G evolution for GSM, IS-136, and PDC systems leads to Wideband CDMA (W-CDMA), also called Universal Mobile Telecommunications Service (UMTS).

W-CDMA is based on the network fundamentals of GSM, as well as the merged versions of GSM and IS-136 through EDGE.

Table 2.3 shows the primary worldwide proposals that were submitted for IMT-2000 in 1998.

The ITU IMT-2000 standards organizations are currently separated into two major organizations reflecting the two 3G camps: 3GPP (3G Partnership Project for Wideband CDMA standards based on backward compatibility with GSM and IS-136/PDC) and 3GPP2 (3G Partnership Project for cdma2000 standards based on backward compatibility with IS-95).
Table 2.3 Leading IMT-2000 Candidate Standards as of 1998 (adapted from [Lib99])

<table>
<thead>
<tr>
<th>Air Interface</th>
<th>Mode of Operation</th>
<th>Duplexing Method</th>
<th>Key Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>cdma2000 US TIA TR45.5</td>
<td>Multi-Carrier and Direct Spreading DS-CDMA at $N = 1.2288$ Mcps with $N = 1, 3, 6, 9, 12$</td>
<td>FDD and TDD Modes</td>
<td>• Backward compatibility with IS-95A and IS-95B. Downlink can be implemented using either Multi-Carrier or Direct Spreading. Uplink can support a simultaneous combination of Multi-Carrier or Direct Spreading. • Auxiliary carriers to help with downlink channel estimation in forward link beamforming.</td>
</tr>
<tr>
<td>UTRA (UMTS Terrestrial Radio Access) ETSI SMG2</td>
<td>DS-CDMA at Rates of $N \times 0.960$ Mcps with $N = 4, 8, 16$</td>
<td>FDD and TDD Modes</td>
<td>• Wideband DS-CDMA System. • Backward compatibility with GSM/DCS-1900. • Up to 2.048 Mbps on Downlink in FDD Mode. • Minimum forward channel bandwidth of 5 MHz. • The collection of proposed standards represented here each exhibit unique features, but support a common set of chip rates, 10 ms frame structure, with 16 slots per frame. • Centralized dedicated pilot bits assist in downlink beamforming.</td>
</tr>
<tr>
<td>W-CDMA/NA (Wideband CDMA) USA T1P-ATIS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W-CDMA/Japan (Wideband CDMA) Japan ARIB</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CDMA II South Korea TTA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WIMS/W-CDMA USA TIA TR46.1</td>
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<td></td>
</tr>
<tr>
<td>CDMA I South Korea TTA</td>
<td>DS-CDMA at $N \times 0.9216$ Mcps with $N = 1, 4, 16$</td>
<td>FDD and TDD Modes</td>
<td>• Up to 512 kbps per spreading code, code aggregation up to 2.048 Mbps.</td>
</tr>
<tr>
<td>UWC-136 (Universal Wireless Communications Consortium) USA TIA TR 45.3</td>
<td>TDMA - Up to 722.2 kbps (Outdoor/Vehicular). Up to 2.5 Mbps (Indoor Office)</td>
<td>FDD (Outdoor/Vehicular). TDD (Indoor Office)</td>
<td>• Backward compatibility and upgrade path for both IS-136 and GSM. • Fits into existing IS-136 and GSM. • Explicit plans to support adaptive antenna technology.</td>
</tr>
<tr>
<td>TD-SCDMA China Academy of Telecommunication Technology (CATT)</td>
<td>DS-CDMA 1.1316 Mcps</td>
<td>TDD</td>
<td>• RF channel bit rate up to 2.227 Mbps. • Use of smart antenna technology is fundamental (but not strictly required) in TD-SCMA.</td>
</tr>
<tr>
<td>DECT ETSI Project (EP) DECT</td>
<td>1150-3456 kbps TDMA</td>
<td>TDD</td>
<td>• Enhanced version of 2G DECT technology.</td>
</tr>
</tbody>
</table>
ITU’s 2000 World Radio Conference established the 2500–2690 MHz, 1710–1885 MHz, and 806–960 MHz bands as candidates for 3G.

2.2.1 3G W-CDMA (UMTS)

The Universal Mobile Telecommunications System (UMTS) is a visionary air interface standard that has evolved since late 1996 under the auspices of the European Telecommunications Standards Institute (ETSI).

UMTS, or W-CDMA, assures backward compatibility with the second generation GSM, IS-136, and PDC TDMA technologies, as well as all 2.5G TDMA technologies.

The network structure and bit level packaging of GSM data is retained by W-CDMA, with additional capacity and bandwidth provided by a new CDMA air interface.

Figure 2.3 shows how the various 2G and 2.5G TDMA technologies will evolve into a unified W-CDMA standard.

The 3GPP standards body is developing W-CDMA for both wide area mobile cellular coverage (using FDD)
as well as indoor cordless type applications (using TDD).

The 3G W-CDMA air interface standard had been designed for “always-on” packet-based wireless service, so that computers, entertainment devices, and telephones may all share the same wireless network and be connected to the Internet, anytime, anywhere.

W-CDMA will support packet data rates up to 2.048 Mbps per user (if the user is stationary), thereby allowing high quality data, multimedia, streaming audio, streaming video, and broadcast-type services to consumers.

Future versions of W-CDMA will support stationary user data rates in excess of 8 Mbps.

W-CDMA provides public and private network features, as well as videoconferencing and virtual home entertainment (VHE).

W-CDMA designers contemplate that broadcasting, mobile commerce (m-commerce), games, interactive video, and virtual private networking will be possible throughout the world.
W-CDMA requires a minimum spectrum allocation of 5 MHz, which is an important distinction from the other 3G standards.

Although W-CDMA is designed to provide backward compatibility and interoperability for all GSM, IS-136/PDC, GPRS, and EDGE switching equipment and applications, it is clear that the wider air interface bandwidth of W-CDMA requires a complete change out of the RF equipment at each base station.

With W-CDMA, data rates from as low as 8 kbps to as high as 2 Mbps will be carried simultaneously on a single W-CDMA 5 MHz radio channel, and each channel will be able to support between 100 and 350 simultaneous voice calls at once, depending on antenna sectoring, propagation conditions, user velocity, and antenna polarizations.

As shown in Table 2.3, W-CDMA employs variable/selectable direct sequence spread spectrum chip rates that can exceed 16 Mcps per user.

A common rule of thumb is that W-CDMA will provide at least a 6 times increase in spectral efficiency over GSM when compared on a system wide basis.
Because W-CDMA will require expensive new base station equipment, the installation of W-CDMA will likely be slow and gradual throughout the world.

Thus, the evolutionary path to 3G will require dual mode or tri-mode cell phones that can automatically switch between the incumbent 2G TDMA technology, EDGE, or W-CDMA service where it is available.

### 2.2.2 3G cdma2000

The cdma2000 standard is being developed under the auspices of Working Group 45 of the Telecommunication Industry Association (TIA) of the US, and involves the participation of the international technical community through the 3GPP2 working group.

The first 3G CDMA air interface, cdma2000 1xRTT, implies that a single 1.25 MHz radio channel is used (e.g. 1x simply implies one times the original cdmaOne channel bandwidth, or, put another way, a multicarrier mode with only one carrier).

Within the ITU IMT-2000 body, cdma2000 1xRTT is also known as G3G-MC-CDMA-1x.
The initials MC stand for multicarrier, and the initials RTT stand for Radio Transmission Technology, language suggested by the IMT-2000 body.

For convenience, it is common to omit the MC and RTT designations, and simply refer to the standard as cdma2000 1x.

cdma2000 1x supports an instantaneous rate of up to 307 kbps for a user in packet mode, and yields typical throughput rates of up to 144 kbps per user, depending on the number of user, the velocity of a user, and the propagation conditions.

cdma2000 1x can also support up to twice as many voice users as the 2G CDMA standard, and provides the subscriber unit with up to 2 times the standby time for longer lasting battery life.

As seen in Table 2.3, cdma2000 is being developed for both FDD (mobile radio) and TDD (in-building cordless) applications.

As can be seen in Table 2.2, to upgrade from 2G CDMA to cdma2000 1x, a wireless carrier merely needs to
purchase new backbone software and new channel cards at the base station, without having to change out RF system components at the base station.

Cdma2000 1xEV is an evolutionary advancement for CDMA originally developed by Qualcomm as a proprietary high data rate (HDR) packet standard to be overlaid upon existing IS-95, IS-95B, and cdma2000 networks.

Qualcomm later modified its HDR standard to be compatible with W-CDMA as well, and in August 2001, ITU recognized cdma2000 1xEV as part of IMT-2000.

cdma2000 1xEV provides CDMA carriers with the option of installing radio channels with data only (cdma2000 1xEV-DO) or with data and voice (cdma2000 1xEV-DV).

Using cdma2000 1xEV technology, individual 1.25 MHz channels may be installed in CDMA base stations to provide specific high speed packet data access within selected cells.

The cdma2000 1xEV-DO option dedicates the radio channel strictly to data users, and supports greater than 2.4 Mbps of instantaneous high-speed packet throughput per user on a particular CDMA channel, although
actual user data rates are typically much lower and are highly dependent upon the number of users, the propagation conditions, and vehicle speed.

Typical users may experience throughputs on the order of several hundred kilobits per second, which is sufficient to support web browsing, email access, and m-commerce applications. cdma2000 1xEV-DV supports both voice and data users, and can offer usable data rates up to 144 kbps with about twice as many voice channels as IS-95B.

The cdma2000 3xRTT standard uses three adjacent 1.25 MHz radio channels that are used together to provide instantaneous packet data throughput speeds in excess of 2 Mbps per user, although actual throughput depends upon cell loading, vehicle speed, and propagation conditions.

Three non-adjacent radio channels may be operated simultaneously and in parallel as individual 1.25 MHz channels (in which case no new RF hardware is required at the base station), or adjacent channels may be combined into a single 3.75 MHz super channel (in which case new RF hardware is required at the base station).

With peak user data rates in excess of 2 Mbps, it is clear that cdma2000 3x has a very similar user data
rate throughput goal when compared to W-CDMA (UMTS).

Advocates of cdma2000 claim their standard gives a wireless service provider a much more seamless and less expensive upgrade path when compared to W-CDMA, since cdma2000 allows the same spectrum, bandwidth, RF equipment, and air interface framework to be used at each base station as the 3G upgrades are introduced over time.

2.2.3 3G TD-SCDMA

The China Academy of Telecommunications Technology (CATT) and Siemens Corporation jointly submitted an IMT-2000 3G standard proposal in 1998, based on Time Division-Synchronous Code Division Multiple Access (TD-SCDMA).

This proposal was adopted by ITU as one of the 3G options in late 1999.

TD-SCDMA relies on the existing core GSM infrastructure and allows a 3G network to evolve through the addition of high data rate equipment at each GSM base station.
TD-SCDMA combines TDMA and TDD techniques to provide a data-only overlay in an existing GSM network. Up to 384 kbps of packet data is provided to data users in TD-SCDMA.

The radio channels in TD-SCDMA are 1.6 MHz in bandwidth and rely on smart antennas, spatial filtering, and joint detection techniques to yield several times more spectrum efficiency than GSM.

A 5 millisecond frame is used in TD-SCDMA, and this frame is subdivided into seven time slots which are flexibly assigned to either a single high data rate user or several slower users.

By using TDD, different time slots within a single frame on a single carrier frequency are used to provide both forward channel and reverse channel transmissions.

For the case of asynchronous traffic demand, such as when a user downloads a file, the forward link will require more bandwidth than the reverse link, and thus more time slots will be dedicated to providing forward link traffic than for providing reverse link traffic.
2.2.x1  Evolution to 3.5G Mobile Radio Networks


2.2.x1.1  cdma2000 1xEV-DO and 1xEV-DV

2.2.x1.1.1  1xEV-DO (Evolution-Data Only)

1xEV-DO stands for enhanced version of single carrier (1x) for data only.

There are two versions: single mode and dual mode. Single mode version can only access the high-speed data rate (HDR) services on the EV-DO radio channel at a rate of 2.4576 Mbps.

The dual mode version can access either the EV-DO HDR channel or the IS-95 voice with medium-rate data traffic channels.

1xEV-DO takes advantage of the characteristics of data services:
a. The data rate requirements on the forward link are usually higher than those on the reverse link.

b. Data services can tolerate the latency

c. Take the last part of the burst period of data transmission to manage the control functions

Also, it has an access terminal (AT) for data connectivity to the MS.

The access network (AN) provides data connectivity between a packet-switched data network and AT.

In 1xEV-DO, the radio interfaces of forward link and reverse link are different.

### 2.2.x1.1.2 1xEV-DV (Evolution-Data and Voice)

The high-speed packet enhancement of cdma2000 Revision C and D is called 1xEV-DV system.

The objective of this enhancement was to improve the bandwidth efficiency of the cdma2000 system by creating a new set of high-speed packet data channels: the Forward Packet Data Channel (F-PDCH) and the Reverse Packet Data Channel (R-PDCH).
This new set of high-speed packet data channels uses technologies such as fast packet scheduling, hybrid automatic repeat request, and adaptive modulation and coding.

- Fast Packet Scheduling:
  The purpose of performing fast packet scheduling for the F-PDCH and R-PDCH is to reduce the inherent delay in L3 message-based scheduling and channeling all the scheduling-associated control information to the physical or medium access control layer.

- Hybrid Automatic Repeat Request:
  One of the major enhancements in cdma2000 Revisions C and D is the inclusion of HARQ for the F-PDCH and R-PDCH.
  HARQ enhances the performance of a wireless system by making retransmissions in the physical layer that can be combined by either chase combining or incremental redundancy with previously received transmission.

- Adaptive Modulation and Coding (AMC):
  For the F-PDCH, AMC is used to countermeasure against fading.
The encoder packet size modulation and coding rate of each transmission are adapted as often as every 1.25 ms.

For the R-PDCH, power control is used counteract the effect of time-variant multipath fading.

EV-DV uses the flexible TDM-CDM multiplexing to send voice and data services on the same carrier.

Because the nature of VoIP is a packet stream, the data and voice can share the same carrier.

The bandwidth is first prioritized to voice traffic, and then the remaining bandwidth is shared between the data users.

Because data traffic is typically running in bursts and does not necessarily have to be in a real-time delivery, there is plenty of bandwidth to go around.

All of these fit into a single carrier of 1.25 MHz spectrum.

The EV-DV technology provides a 3.1 Mbps down channel and a 300 kbps up channel. EV-DV is backward compatible to IS-95A/B and CDMA1x.
It can be used for a two-way video conference call at 15 frames per second and with full live images.

2.2.x1.2 W-CDMA HSDPA and HSUPA

2.2.x1.2.1 HSDPA (High Speed Downlink Packet Access)

HSDPA is a packet-based data access protocol in downlink with data transmission rate up to 8–14 Mbps (and 20 Mbps for MIMO system) over a 5 MHz bandwidth.

HSDPA implementations include adaptive modulation and coding (AMC), multiple-input multiple-out (MIMO), hybrid automatic repeat request (HARQ), packet scheduler, fast cell site selection (FCSS) search, and advanced receiver design.

The techniques are employed to achieve the high data rates yet maintaining compatibility with currently
available equipment. HSDPA is a new transport channel, the downlink shared channel (HS-DSCH) that is optimized for shared data.

It also provides higher order modulation, shorter transmission time interval (TTI), fast link adaptation, fast scheduling, and fast HARQ.

### 2.2.x1.2.2 HSUPA (High Speed Uplink Packet Access)

HSUPA, introduced in Release 6 of the 3GPP standards, is a packet-based data access protocol in uplink with data transmission rate up to 5.76Mbps. The aims of HSUPA are to increase data rates in uplink, reduce overall delay in the system, and allow the overall cell capacity to be increased.

HSUPA uses an uplink enhanced dedicated channel (E-DCH) on which it employs link adaptation methods similar to those employed by HSDPA including a shorter transmission time interval (TTI), hybrid automatic repeat request (HARQ), and packet scheduler.

HSUPA has the advantages of radio-based local networks and WLAN in providing inexpensive broadband
internet. HSUPA is also relatively inexpensive, because it is based on software. No new infrastructure needs to be developed or installed by the mobile network providers. Their network equipment need only be updated with new software.

2.2.x1.2.3 3GPP LTE (Long Term Evolution)

3GPP LTE is the result of ongoing work by the 3GPP (3rd Generation Partnership Project), a collaborative group of international standards organizations and mobile-technology companies.

3GPP LTE will offer operators networks with a target of two to four times the spectral efficiency of 3G/HSPA networks. The targets for 3GPP LTE indicate data transmission rate increases as high as 100 Mbps on the downlink, and up to 50 Mbps on the uplink. 3GPP LTE is optimized for data traffic on IP-based traffic and offers operators a simple upgrade path from 3G networks.

3GPP LTE defines new radio connections for mobile networks, and utilizes OFDM (Orthogonal Frequency Division Multiplexing) a widely used modulation technique that is the basis for Wi-Fi, WiMAX, and the DMB digital broadcasting technologies.
An important feature of 3GPP LTE is the amount of flexibility it allows operators in determining the spectrum in which it will be deployed. Not only will 3GPP LTE have the ability to operate in a number of different frequency bands, but also features scalable bandwidth. Whereas WCDMA/HSPA uses fixed 5 MHz channels, the amount of bandwidth in a 3GPP LTE system can be scaled from 1.25 to 20 MHz.

According to its requirement, 3GPP LTE has the following characteristics.

- Radio access network latency is significantly reduced.
- Mobility is enhanced (up to 350 km/h).
- It co-exists and interworks with 3GPP.
- It supports service provided from the packet service domain.
- Peak data rate is 100 Mbps at 20 MHz for DL and 50 Mbps at 20 MHz for UL.
- Cell edge throughput is improved.
- Spectrum efficiency is enhanced.
2.3 Wireless Local Loop (WLL) and LMDS

Particularly in developing nations where there is inadequate telecommunications backbone infrastructure, there is a tremendous need for inexpensive, reliable, rapidly deployable broadband connectivity that can bring individuals and enterprises into the information age.

Fixed wireless equipment is extremely well suited for rapidly deploying a broadband connection in many instances, and this approach is steadily becoming more popular for providing “last mile” broadband local loop access, as well as for emergency or redundant point-to-point or point-to-multipoint private networks.

Unlike mobile cellular telephone systems, fixed wireless communication systems are able to take advantage of the very well-defined, time-invariant nature of the propagation channel between the fixed transmitter and fixed receiver.

Furthermore, modern fixed wireless systems are usually assigned microwave or millimeter radio frequencies in the 28 GHz band and higher, which is greater than ten times the carrier frequency of 3G terrestrial cellular telephone networks.
At these higher frequencies, the wavelengths are extremely small, which in turn allows very high gain directional antennas to be fabricated in small physical form factors.

At higher frequencies, too, more bandwidth can be easily used.

Fixed wireless networks at very high microwave frequencies are only viable where there are no obstructions, such as in a relatively flat suburban or rural setting.

A vast array of new services and applications have been proposed and are in the early stages of commercialization.

These services include the concept of Local Multipoint Distribution Service (LMDS), which provides broadband telecommunications access in the local exchange.

In 1998, 1300 MHz of unused spectrum in the 27 – 31 GHz band was auctioned by the US government to support LMDS.

Similar auctions have been held in other countries around the world.
Figure 2.5 shows various spectrum allocations made by countries throughout the world.

Note that most LMDS allocations share frequencies with the Teledesic band which was approved by the ITU World Radio Conference for broadband satellite systems.

The Teledesic band was originally established for the Motorola Iridium System, whose spectrum was later merged into the Teledesic system.

Ironically, as of late 2001, broadband low earth orbit (LEO) satellite services were not yet commercially viable.
Figure 2.5  Allocation of broadband wireless spectrum throughout the work.
(Courtesy of Ray W. Nettleton and reproduced by permission of Formus Communications.)
Figure 2.6 shows the tremendous amount of spectrum in the 59–64 GHz range that is earmarked for unlicensed WLAN use.
60 GHz Unlicensed, 5000 MHz, 1998

LMDS, 1300 MHz, 1998
UNII, 300 MHz, 1997

Cellular, 50 MHz, 1983

PCS, 150 MHz, 1995

- A voice channel occupies ≈ 10 kHz of spectrum.
- A TV channel occupies ≈ 5 MHz of spectrum.

**Figure 2.6** Comparison of spectrum allocations for various US wireless communications services. The areas of the rectangles are proportional to the amount of bandwidth allocated for each service.
The US LMDS band is $27.5 - 28.35$ GHz, $29.1 - 29.25$ GHz, and $31.075 - 31.225$ GHz.

The IEEE 802.16 Standards Committee is developing interoperability standards for fixed broadband wireless access.

In Europe, a similar standard, HIPERACCESS, is being developed by a standardization committee for Broadband Radio Access Networks (BRAN) for operation in the $40.5 - 43.5$ GHz band; it will use TDMA.

Also, HIPERLINK is a very high speed short range interconnection for HIPERLANs and HIPERACCESS, up to $155$ Mbps within $150$ meters, and is planned to operate in the $17$ GHz band in Europe.

One of the most promising applications for LMDS is in a local exchange carrier (LEC) network.

Figure 2.7 shows a typical network configuration.

Where the LEC owns a very wide bandwidth asynchronous transfer mode (ATM) or Synchronous Optical Network (SONET) backbone switch, capable of connecting hundreds of megabits per second of traffic with the Internet, the PSTN, or to its own private network.
As long as a LOS path exists, LMDS will allow LECs to install wireless equipment on the premises of customers for rapid broadband connectivity without having to lease or install its own cables to the customers.
Figure 2.7  A wireless Competitive Local Exchange Carrier (CLEC) using Asynchronous Transfer Mode (ATM) distribution.
Unfortunately, finding a line-of-sight path is not the only requirement for maintaining a suitable fixed wireless connection for millimeter wave fixed wireless links.

Rain, snow, and hail can create large changes in the channel gain between transmitter and receiver.

Figure 2.8 shows actual measured received power levels, as a function of precipitation, for a fixed 605 meter wireless hop operating at 38 GHz over several different days.
Received Power at 38 GHz During Rain (40 mm/hour) and Hail in 1998 with T–R Separation of 605m

Attenuation due to hail: 25.7 dB.
Hail size: 0.5-1.5 cm in diameter.

Figure 2.8 Measured received power levels over a 605 m 38 GHz fixed wireless link in clear sky, rain, and hail [from [Xu00], ©IEEE].
Figure 2.9 shows how the instantaneous received power is directly a function of the instantaneous rain rate.

Figure 2.9  Measured received power during rain storm at 38 GHz [from [Xu00], ©IEEE].
2.4 Wireless Local Area Networks (WLANs)

As shown in Figure 2.6, in 1997 the FCC allocated 300 MHz of unlicensed spectrum in the Industrial Scientific and Medical (ISM) bands of 5.150–5.350 GHz and 5.725–5.825 GHz for the express purpose of supporting low-power license-free spread spectrum data communication.

This allocation is called the Unlicensed National Information Infrastructure (UNII) band.

By providing a license-free spectrum allocation, the FCC hoped to encourage competitive development of spread spectrum knowledge, spread spectrum equipment, and ownership of individual WLANs and other low-power short range devices that could facilitate private computer communications in the workplace.

The IEEE 802.11 Wireless LAN working group was founded in 1987 to begin standardization of spread spectrum WLANs for use in the ISM bands.

Despite the unrestricted spectrum allocation and intense industry interest, the WLAN movement did not gain momentum until the late 1990s, when the phenomenal popularity of the Internet combined with widespread acceptance of portable, laptop computers finally caused WLAN to become an important and rapidly growing
segment of the modern wireless communications marketplace.

IEEE 802.11 was finally standardized in 1997 and provided interoperability standards for WLAN manufactures using 11 Mcps DS-SS spreading and 2 Mbps user data rates (with fallback to 1 Mbps in noisy conditions).

With an international standard now approved, numerous manufacturers began to comply for interoperability, and the market began to accelerate rapidly. In 1999, the 802.11 High Rate standard (called IEE 802.11b) was approved, thereby providing new user data rate capabilities of 11 Mbps, 5.5 Mbps in addition to the original 2 Mbps and 1 Mbps user rates of IEEE 802.11, which were retained.

Figure 2.10 shows the evolution of IEEE 802.11 Wireless LAN standards, which also include infrared communications.
Figure 2.10  Overview of the IEEE 802.11 Wireless LAN standard (Updated).
Figure 2.10 shows how both frequency hopping and direct sequence approaches were used in the original IEEE 802.11 standard (2 Mbps user throughput), but as of late 2001 only direct sequence spread spectrum (DS-SS) modems had thus far been standardized for high rate (11 Mbps) user data rates within IEEE 802.11.

The IEEE 802.11a standard provides up to 54 Mbps throughput in the 5 GHz band.

The DS-SS IEEE 802.11b standard has been named Wi-Fi by the Wireless Ethernet Compatibility Alliance (WECA), a group that promotes adoption of 802.11b DS-SS WLAN equipment and interoperability between vendors.

IEEE 802.11g is developing Complimentary Code Keying Orthogonal Frequency Division Multiplexing (CCK-OFDM) standards in both the 2.4 GHz (802.11b) and 5 GHz (802.11a) bands, and will support roaming capabilities and dual-band use for public WLAN networks, while supporting backward compatibility with 802.11b technology.

The frequency-hopping spread spectrum (FH-SS) proponents of IEEE 802.11 have formed the HomeRF standard that supports frequency hopping equipment.
In 2001, HomeRF developed a 10 Mbps FH-SS standard called HomeRF 2.0.

It is worth noting that both DS and FH types of WLANs must operate in the same unlicensed bands that contain cordless phones, baby monitors, Bluetooth devices, and other WLAN users.

Both DS and FH vendors claim to have advantages over the other for operation in such radio environments.

Figure 2.12 shows the unique WLAN channels that are specified in the IEEE 802.11b standard for the 2400–2483.5 MHz band.
Figure 2.12 Channelization scheme for IEEE 802.11b throughout the world.
All WLANs are manufactured to operate on any one of the specified channels and are assigned to a particular channel by the network operator when the WLAN system is first installed.

The channelization scheme used by the network installer becomes very important for a high density WLAN installation, since neighboring access points must be separated from one another in frequency to avoid interference and significantly degraded performance.

As we show in Chapter 3, all wireless systems must be designed with knowledge of the interference and propagation environment-prudent WLAN deployment dictates that the placement of transmitters and their frequency assignments be done systematically to minimize impact.

Even though WLAN networks are designed to work in an interference-rich environment, and manufacturers may downplay the importance of planning, the fact is that the ability to measure or predict the coverage and interference effects caused by specific placements of access points can provide orders of magnitude of improvement in cost and end user data throughputs in a heavily loaded system.

Research conducted in [Henty 2001] showed that the user throughput performance changes radically when access points or clients are located near an interfering transmitter or when frequency planning is not carefully
conducted.

In Europe in the mid 1990s, the High Performance Radio Local Area Network (HIPER-LAN) standard was developed to provide a similar capability to IEEE 802.11.

HIPERLAN was intended to provide individual wireless LANs for computer communications and used the 5.2 GHz and the 17.1 GHz frequency bands.

HIPERLAN provides asynchronous user data rates of between 1 to 20 Mbps, as well as time bounded messaging at rates of 64 kbps to 2.048 Mbps. HIPERLAN was designed to operate up to vehicle speeds of 35 km/hr, and typically provided 20 Mbps throughput at 50 m range.

In 1997, Europe’s ETSI established a standardization committee for Broadband Radio Access Networks (BRANs).

The goal of BRAN is to develop a family of broadband WLAN-type protocols that allow user interoperability, covering both short range (e.g., WLAN) and long range (e.g., fixed wireless) networking.
HIPERLAN/2 has emerged as the next generation European WLAN standard and will provide up to 54 Mbps of user data to a variety of networks, including the ATM backbone, IP based networks, and the UMTS core.

HIPERLAN/2 is anticipated to operate in the 5 GHz band.

Meanwhile, IEEE 802.11a is emerging as North America’s next generation WLAN.

Like HIPERLAN/2, IEEE 802.11a supports up to 54 Mbps user data rate for integration into backbone ATM, UMTS, and IP networks and will operate in the 5.15 – 5.35 GHz ISM band.

Meanwhile, Japan’s Multimedia Mobile Access Communication System (MMAC) has been developing high data rate (25Mbps) WLAN standards for use in the 5.15 – 5.35 GHz band.
2.5 Bluetooth and Personal Area networks (PANs)

Bluetooh is an open standard that has been embraced by over 1,000 manufacturers of electronic appliances.

It provides an ad-hoc approach for enabling various devices to communicate with one another within a nominal 10 meter range.

Named after King Harald Bluetooth, the 10th century Viking who united Denmark and Norway, the Bluetooth standard aims to unify the connectivity chores of appliances within the personal workspace of an individual.

Bluetooth operates in the 2.4 GHz ISM Band (2400 – 2483.5 MHz) and uses a frequency hopping TDD scheme for each radio channel.

Each Bluetooth radio channel has a 1 MHz bandwidth and hops at a rate of approximately 1600 hops per second.
Transmissions are performed in 625 microsecond slots with a single packet transmitted over a single slot.

For long data transmissions, particular users may occupy multiple slots using the same transmission frequency, thus slowing the instantaneous hopping rate to below 1600 hops/second.

The frequency hopping scheme of each Bluetooth user is determined from a cyclic code of length $2^{27} - 1$, and each user has a channel symbol rate of 1 Mbps using GFSK modulation.

The standard has been designed to support operation in very high interference levels and relies on a number of forward error control (FEC) coding and automatic repeat request (ARQ) schemes to support a raw channel bit error rate (BER) of about $10^{-3}$.

Different countries have allocated various channels for Bluetooth operation.

In the US and most of Europe, the FHSS 2.4 GHz ISM band is available for Bluetooth use as shown in Table 2.4.
A detailed list of states are defined in the Bluetooth standard to support a wide range of applications, appliances, and potential uses of the Personal Area Network.

Audio, text, data, and even video is contemplated in the Bluetooth standard.

Figure 2.17 provides a depiction of the Bluetooth concept where a gateway to the Internet via IEEE 802.11b is shown as a conceptual possibility.
### Table 2.4  IEEE 802.11b Channels for Both DS-SS and FH-SS WLAN Standards

<table>
<thead>
<tr>
<th>Country</th>
<th>Frequency Range Available</th>
<th>DSSS Channels Available</th>
<th>FHSS Channels Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>2.4 to 2.4835 GHz</td>
<td>1 through 11</td>
<td>2 through 80</td>
</tr>
<tr>
<td>Canada</td>
<td>2.4 to 2.4835 GHz</td>
<td>1 through 11</td>
<td>2 through 80</td>
</tr>
<tr>
<td>Japan</td>
<td>2.4 to 2.497 GHz</td>
<td>1 through 14</td>
<td>2 through 95</td>
</tr>
<tr>
<td>France</td>
<td>2.4465 to 2.4835 GHz</td>
<td>10 through 13</td>
<td>48 through 82</td>
</tr>
<tr>
<td>Spain</td>
<td>2.445 to 2.4835 GHz</td>
<td>10 through 11</td>
<td>47 through 73</td>
</tr>
<tr>
<td>Remainder of Europe</td>
<td>2.4 to 2.4835</td>
<td>1 through 13</td>
<td>2 through 80</td>
</tr>
</tbody>
</table>
Figure 2.17  Example of a Personal Area Network (PAN) as provided by the Bluetooth standard.
The IEEE 802.15 standards committee has been formed to provide an international forum for developing Bluetooth and other PANs that interconnect pocket PCs, personal digital assistants (PDAs), cellphones, light projectors, and other appliances [Braley 2000].

With the rapid proliferation of **wearable computers**, such as PDAs, cellphones, smart cards, and position location devices, PANs may provide the connection to an entire new era of remote retrieval and monitoring of the world around us.

### 2.x1 Ultra-Wideband (UWB)


#### 2.x1.1 UWB Basics

Impulse radio communication systems and impulse radars both utilize very short pulses in transmission that results in an ultra-wideband spectrum.

For radio applications, this communication method is also classified as a pulse modulation technique because the data modulation is introduced by pulse position modulation (PPM).

The UWB signal is noisely which makes interception and detection quite difficult. Due to the low-power spectral density, UWB signals cause very little interference with existing narrow-band radio systems.

Depending on the attitude of national and international regulatory bodies, this should allow license-free operation of radio systems.

Time-modulated™ impulse radio signal is seen as a carrier-less baseband transmission.

The absence of carrier frequency is the very fundamental character that differentiates impulse radio and impulse radar transmissions from narrow-band applications and from direct sequence (DS) spread spectrum (SS) multi-carrier (MC) transmissions, which can also be characterized as an (ultra) wideband technique.
Fast slewing chirps and exponentially damped sine waves are also possible methods of generating UWB signals.

2.x1.1.1 Advantages of UWB

UWB has a number of advantages that make it attractive for consumer communications applications.

In particular, UWB systems

- have potentially low complexity and low cost,
- have noise-like signal,
- have very good time domain resolution allowing for location and tracking applications.

The low complexity and low cost of UWB systems arises from the essentially baseband nature of the signal transmission.

Unlike conventional radio systems, the UWB transmitter produces a very short time domain pulse, which is
able to propagate without the need for an additional RF (radio frequency) mixing stage.

Due to the low energy density and the pseudo-random (PR) characteristics of the transmitted signal, the UWB signal is noiselike, which makes unintended detection quite difficult.

While there is some debate in the literature, it appears that the low power, noise-like, UWB transmissions do not cause significant interference to existing radio systems.

The interference phenomenon between impulse radio and existing radio systems is one of the most important topics in current UWB research.

Time-modulation systems offer possibility for high data rates for communication. Hundreds of Mbps have been reported for communication links.

It is estimated [Time Domain Corporation, 1998; Kolenchery et al., 1997] that the number of users in an impulse radio communication system is much larger than in conventional systems.

Because of the large bandwidth of the transmitted signal, very high multipath resolution is achieved.
The large bandwidth offers (and also requires) huge frequency diversity which, together with the discontinuous transmission, makes the TM-UWB signal resistant to severe multipath propagation and jamming/interference.

TM-UWB systems offer good LPI and LPD (low probability of interception/detection) properties which make it suitable for secure and military applications.

The very narrow time domain pulses mean that UWB radios are potentially able to offer timing precision much better than GPS (global positioning system) [Time Domain Corporation, 1998] and other radio systems.

Together with good material penetration properties, TM-UWB signals offer opportunities for short range radar applications such as rescue and anti-crime operations, as well as in surveying and in the mining industry.

One should however understand that UWB does not provide precise targeting and extreme penetration at the same time, but UWB waveforms present a better choice than conventional radio systems.
2.x1.2 Technology overview


There are three UWB technologies being used.

① Pulse-based single carrier method

Given this option for a multiband system, information can either be transmitted by the traditional pulse-based single-carrier method or by more advanced multicarrier techniques.

Pulse-based single-carrier systems transmit signal by modulating the phase of a very narrow pulse. Although this is a proven technology that only requires a very simple transmitter design, several inherent disadvantages exist:

a. It is difficult to collect enough signal energy in a typical usage environment (with many reflecting surface) using a single RF chain.

b. Switching time requirements can be very stringent at both the transmitter and receiver.

c. The receiver signal processing is very sensitive to group delay variations introduced by analog front-end components.

d. Spectral resources are potentially wasted to avoid narrowband interference.
② MB-OFDM (MultiBand Orthogonal Frequency Division Multiplexing)

This is one of the IEEE 802.13.3a’s technology proposed by MBOA (Multiband OFDM Alliance) led by T1/Intel.

③ DS-USB (Direct Sequence UWB)

This is the other IEEE 802.15.3a’s technology proposed by UWB Motorola/Freescale.

2.x1.3 UWB Regulation

Before 2002, UWB was used for radar, sensing, military communications and niche applications.

In February 2002, the FCC in the U.S. issued the FCC UWB ruling that provided the first radiation limitations for UWB and also permitted the technology commercialization.

The final report of the FCC First Report and Order, which was released in April 2002, introduced 4
different categories for allowed UWB applications such as data communications, radar, and safety applications, and set the radiation masks for them.

Generally it is expected that ETSI/CEPT will follow the FCC’s recommendations but will not directly adopt the FCC’s regulations.

Figure 1.1x shows the current proposal for the European spectral mask limits as well as the FCC masks.

The upper plot represents the masks for data communication applications for indoor and outdoor use.

The lower plot gives the FCC radiation mask for radar and sensing applications.

In all cases the maximum average power spectral density.
Figure 1.x1 UWB radiation mask defined by FCC and the existing CEPT proposal.
Whilst UWB is still the subject of significant debate, there is no doubt that the technology is capable of achieving very high data rates and is a viable alternative to existing technology for WPAN; short-range, high-data-rate communications; multimedia applications, and cable replacement.

2.x2 802.16 and Associated standards


IEEE has established a hierarchy of complementary wireless standards.

These include IEEE 802.15 for the personal area network (PAN), IEEE 802.11 for the local area network (LAN), 802.16 for the metropolitan area network (MAN), and the proposed IEEE 802.20 for wide area network (WAN).

The operating frequencies of these IEEE wireless standards are shown in figure 2.x1.
Figure 2.x1  IEEE wireless standards operating frequencies.
Each standard represents the optimized technology for a distinct market and usage model and is designed to complement the others.

A good example is the proliferation of home and business wireless LANs and commercial hot spots based on the IEEE 802.11 standard.

This proliferation of WLANs is driving the demand for broadband connectivity back to internet, which 802.16 can fulfill by providing the outdoor, long-range connection back to the service provider.

For the operators and service providers, systems built upon the 802.16 standard represents an easily deployable “third pipe” capable of delivering flexible and affordable last-mile broadband access for millions of subscribers in homes and business throughout the world.

The 802.16 standard, the “Air Interface for Fixed Broadband Wireless Access Systems,” is also known as the IEEE Wireless MAN air interface.

This technology is designed from the ground up to provide wireless last-mile broadband access in the metropolitan area network (MAN), delivering performance comparable to traditional cable, DSL, or T1.
2.x2.1 802.16a (a BWA System)

802.16a specifies a protocol that supports low latency applications such as voice subscriber terminal (ST) and base transceiver station (BTS).

A single BTS will serve hundreds of ST.

The standard is for broadband wireless access (BWA) and is played by the world-wide microwave interoperability for microwave Access (WiMAX) forum.

BWA is for both the physical layer environment (outdoor RF transmissions) and QoS needs, delivering high-speed internet access to business, homes, and Wi-Fi hot spots.

2.x2.2 802.16-2004

802.16-specified Fixed Broadband Wireless Access (FBWA) operates in the 10 to 66 GHz frequency range.
The goal is to provide a wireless alternative to wireline broadband access, such as cable, DSL, and T1 and T3. 802.16a extended the frequency range to 2 to 11 GHz.

802.16c added profiles for 10 to 66 GHz equipment and defined a set of features and functions used for vendor conformance testing.

802.16-REVd-defined air interface for fixed broadband access added 2-11 GHz profiles.

802.16-2004 (Local and Metropolitan Area Networks) is composed of 802.16 fixed broadband wireless access (10-66 GHz), 802.16a Fixed Broadband Wireless Access (2-11 GHz), and 802.16c Amendments (10-66 GHz).

802.16-2004 is sometimes known as 802.16d.

802.16-2004 FBWA has point to multipoint (PMP), where traffic goes through base station (BS), and Mesh network, where communication can go directly between subscriber station (SS) options.

It supports four different PHY on two distinct bands as shown in Figure 2.x2.
Figure 2.x2  802.16-2004 reference model.
2.x2.3  802.16e

802.16e is extension to IEEE 802.16-2004 MAC and PHY for providing mobility and is known as mobile MAN or mobile WiMAX.

A mobile PHY is designed to provide robust and efficient operation in harsh mobile environment, and at the same time coexistence with the fixed 802.16-2004.

The PHY layer is based on OFDM/OFDMA and operation frequency range is 2-6 GHz licensed bands. To add mobility, functionalities such as handover and power saving are supported.

2.x2.4  WiBro (Wireless Broadband Internet)

WiBro is Korean version of IEEE 802.16e.

In 2004, TTA (Telecommunication Technology Association) project group 302 (TG 302) adopted IEEE
802.16e as the baseline document for WiBro standard.

The WiBro supports all mandatory features of IEEE 802.16e and operates 2.3 GHz licensed band providing mobility 60 km/h with up to 1 Mbps (2 Mbps in second generation).

2.03 802.20


The goal of 802.20 is to define a standard to provide full mobility, broadband data at high speed, supporting mobility up to 150 Mph with data rate up to 6 Mbps.

802.20 operates in frequency bands below 3.5 GHz and supports 1.25 MHz and 5 MHz channel bandwidth (same as 3G cellular standards).

Proposed data rate is 6 Mbps downlink and 3 Mbps uplink in a 5 MHz channel.
Appendix.

**Acronym of Systems for Wireless Communications**

4G: 4th Generation  
AMPS: Advanced Mobile Phone System  
B3G: Beyond 3rd Generation  
cdma2000: Code Division Multiple Access 2000  
CDPD: Cellular Digital Packet Data  
CT-2: Cordless Telephone-2  
DCS-1800: Digital Communication System-1800  
DECT: Digital European Cordless System  
ETACS: Extended European Total Access Cellular System  
GSM: Global System for Mobile  
IMT-2000 International Mobile Telecommunication 2000  
Originally FPLMTS (Future Public Land Mobile Telephone System)  
IS-95: EIA Interim Standard-95
PDC: Pacific Digital Cellular,
    Originally JDC (Japanese Digital Cellular)
PCS: Personal Communication Service
    Once used with PCN: Personal Communication Network
PHS: Personal Handyphone system
POCSAG: Post Office Code Standard Advisory Group
PSTN: Public Switched Telephone Network
TACS: Total Access Communication System
TD-SCDMA: Time Division-Synchronous Code Division Multiple Access
USDC: U.S. Digital Cellular. TIA IS-54
UWB: Ultra-Wideband
W-CDMA: Wideband-Code Division Multiple Access
Acronym of Organizations for Wireless Communications

3GPP: Third Generation Partnership Project
3GPP 2: Third Generation Partnership Project 2
ARIB: Association of Radio Industries and Businesses (Japan)
CEPT: European Conference of Postal and Telecommunications (Europe)
ETSI: European Telecommunications Standard Institute (Europe)
FCC: Federal Communications Commission (U.S.A.)
ITU: International Telecommunications Union
ITU-R: ITU’s Radiocommunications Sector
TIA: Telecommunications Industry Association (U.S.A.)
TTA: Telecommunications Technology Association (Korea)
TTC: Telecommunications Technology Committee (Japan)
WARC: World Administrative Radio Conference