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ACCESS TECHNOLOGIES FOR WIRELESS COMMUNICATION

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ABSTRACT

This project are compares three prominent contenders for the history of 3G wireless communication. These are the TDMA, CDMA, and MC-CDMA .CDMA 2000 a hybrid of the first two. The Orthogonal Frequency Multiple access technique, has gained increasing acceptance as an alternative to single carrier modulation for wireless systems. Potential exists for very high bit rates and for reaching the channel capacity even over frequency-selective fading channels. CDMA, i.e., Code Division Multiple Access, is the technique being most seriously considered for 3G wireless systems. It uses PN sequences to spread the signal spectrum to a wideband thereby achieving robustness to the deep fades than a narrowband signal, and the capability for multiple-user access. The third technique, MC-CDMA, uses a combination of the above two, and has some advantages as will be pointed out in the project. Finally, the project will touch upon an TDMA and CDMA, with abrief history of wireless communications.

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INTRDUCTION

Wireless communications is a rapidly growing segment of the communications industry, with the potential to provide high-speed high-quality information exchange between portable devices located anywhere in the world. Potential applications enabled by this technology include multimedia Internet-enabled cell phones, smart homes and appliances, automated highway systems, video teleconferencing and distance learning, and autonomous sensor networks, to name just a few. However, supporting these applications using wireless communication techniques poses a significant technical challenge.This project will cover advanced topics in wireless communications for voice, data, and multimedia. We begin the first chapter with an overview of current wireless systems and some standards.then characterize the wireless channel, including path loss for different environments, random log-normal shadowing due to signal attenuation, and the flat and frequency-selective properties of multipath fading wireless communication channels and the characteristics of the capacity-achieving transmission strategies. These strategies are typically not practical. Thus, our next focus will be on practical digital modulation techniques and their performance under wireless channel impairments, including flat and frequency selective fading. The second chapter of the project is spent investigating the 3G multiple access technique TDMA(time division multiple access) , including full preview and Architecture of TDMA(time division multiple access) withen its transmitter and reciever to improve the speed and performance of wireless links. And the multiple access capabilities of spread spectrum with multiuser detection. Finally, chapter three which invetigating the CDMA(code division multiple access) Signaling Applications in the CDMA System and CDMA Architecture we also discussed the Multi-Carrier CDMAwith Principle of Multi carrier (MC-CDMA) and having alook to Wideband Code Division Multiple Access (W–CDMA) and we mentioned CDMA2000 Technical Information .The project concludes with a brief overview of wireless networks, including multiple and random access techniques, WLANs, cellular system design, and ad-hoc network design. Applications for these systems.

1. WIRELESS COMMUNICATIONS

1.1. Overview

What is Wireless Communication?

Wire-Less - having no wire or relating to radiotelephony.

Com-Mu-Ni-Ca-Tion -a process by which information is exchanged within a reasonable time period Essentially any form of information exchange without the use of wires.

The need to increase public safety was key to the genesis of today's rapidly growing wireless communications industry. In the 1920s, police departments in Detroit, Michigan and Bayonne, New Jersey and the Connecticut State Police were among the first who sought to use in their patrol cars the technology that had improved the safety of oceangoing vessels - radio telephone service. But the technology to enable mobile communications services for public safety agencies was not yet available. Early radiotelephone systems could be housed on ships with reasonable ease, but were too large and unwieldy for cars. Also, bumpy streets, tall buildings and uneven landscapes prevented successful transmission of the radiotelephone signals on land. The technological breakthrough came in 1935, when Edwin Howard Armstrong unveiled his invention, Frequency Modulation (FM), to improve radio broadcasting. This technology reduced the required bulk of radio equipment and improved transmission quality. The United States' involvement in World War II created an urgent need for FM technology to take the place of Amplitude Modulated (AM) technology for higher quality, two-way mobile radio communications on the battlefield. The strategic value of wireless communication on the battlefield spurred companies like AT&T, Motorola and General Electric to focus on refining mobile and portable communications. Motorola's FM Handie-Talkie and Walkie-Talkie figured prominently among the products developed during the war years and carried over into peacetime use.Although there was a form of mobile telephone service available in the late 1940s, its capacity was limited - with few radio channels available to carry calls, and cities like New York limited to 12 simultaneous callers. In 1947, in an effort to use the airwaves more efficiently, AT&T engineers decided to stretch the limited number of radio frequencies available for mobile service by scattering multiple low-power transmitters throughout a metropolitan area, and "handing off" calls from transmitter to transmitter as customers moved around in their vehicles. This new technique would allow more customers to access to the system simultaneously, by re-using the frequencies across the city. When more capacity was needed, the area served by each transmitter could be divided again. This was the birth of wireless technology. But the service was ahead of its time. It took 20 years to develop sophisticated call "handoff" technology - and for the FCC to give tentative approval for cellular service to proceed. By the early 1970s, the technological pieces of the wireless puzzle had fallen into place. In 1973, Motorola introduced its revolutionary new DynaTAC mobile phone, a conveniently sized radiotelephone set. In 1977, The FCC authorized two experimental licenses - to AT&T in Chicago, and to Motorola and American Radio Telephone Service, Inc. in the Baltimore/Washington, D.C. corridor. As these systems were put into place, the FCC began to consider how best to grant commercial licenses to provide wireless service. AT&T supported a single wireline company in each market, while non-wireline companies argued for a competitive marketplace. In May 1981, the FCC announced that there would be two licenses in each market - a non-wireline carrier (the so-called "A" side carrier) and a wireline (local phone) company (the "B" side carrier.) Two licensees would serve each of the 306 urban areas deemed Metropolitan Statistical Areas (MSAs) and each of the 428 Rural Service Areas (RSAs). MSAs cover 75 percent of the population and 20 percent of the landmass while RSAs cover 25 percent of the population and 80 percent of the landmass. By the time the first commercial license was granted - to AT&T in Chicago on October 6, 1983 - the FCC knew it had a problem as 567 applications were filed just for the 30 markets ranked 61st-to-90th in size. It was then taking 10 to 18 months of deliberation and more than $1 million in costs to award a single license. The FCC realized that "comparative hearings" were too slow and anew licensing process had to be found. On October 18, 1983, the FCC announced that lotteries would be used to award licenses in all markets below the top 30 systems. The FCC then spent the next six years fine-tuning the lottery process, as hundreds of thousands of applications were filed for the remaining licenses. By 1984, at least one city - Washington, D.C. - had two competing wireless providers. By 1990, construction permits had been issued for at least one system in every market in the United States. By the end of 1990, long before most systems had come on-line, the wireless subscriber count topped five million. Subscribership broke the 10 million mark on November 23, 1992. In August 1993, the FCC received authorization to auction PCS (personal communications service) licensees when President William Jefferson Clinton signed the Omnibus Budget Reconciliation Act of 1993. The FCC defined PCS as a "broad family" of mobile radio services which could be used to provide service to individuals and businesses, and would be integrated with a variety of competing networks. The FCC anticipated that PCS licenses would be used to provide such new services as advanced voice paging, two-way acknowledgment paging and data services. In October of 1993, the FCC concluded that a combination of large Major Trading Areas (MTAs) overlapping smaller Basic Trading Areas (BTAs) would "promote the rapid deployment and ubiquitous coverage of PCS and a variety of services and providers." The FCC awarded a total of 102 PCS licenses in 51 Major Trading Areas. Each MTA license covers 30 Megahertz of radio spectrum in the 1.8 GHz band, which the FCC opened for commercial communications services. Under the auction rules, wireless providers were eligible to bid for new radio spectrum in areas not covered by their existing licenses. Billions of dollars were raised by the initial PCS auctions for the MTA-based licenses. Three more auctions followed, as the FCC offered 1,972 additional BTA-based licenses. Since the licensing of PCS providers and the roll-out of Enhanced Specialized Mobile Radio Services (ESMR) by Nextel and other ESMR providers, the number of competitive options available to consumers have multiplied across the country. The wireless competition that began in 1983 with two licensees per market was further expanded in 1995 to provide for up to nine carriers per market. The wireless industry has become a model for what consumers can expect as other markets become competitive. As a result, the wireless industry is also at the forefront as government policy evolves from a substitute for competition to an enabler of competition. Congress adopted the wireless model of competition in lieu of government intervention for the entire telecommunications industry in 1996, recognizing that competition has been the driving force behind the innovation and growth that has characterized wireless telecommunications. Today, wireless competition has accelerated to the point that more than 241 million Americans can now choose between 3 and 8 wireless service providers. More than 178 million Americans can now choose from among 5 or more wireless providers, and over 81 million Americans can choose among 6 wireless providers. As of December 31, 1999, there were over 86.1 million wireless subscribers. Today, there are 100 million U.S.

wireless subscribers - that is more than 36 percent of the U.S. population. And subscribership is growing at a rate of 67,082 new wireless subscribers every day, about one subscriber every two seconds. From 1983 to 1992 the wireless industry grew by ten million customers. From 1993 to 2000, the wireless industry grew by 90 million customers. And it has been recently suggested that wireless subscribership will double within the next two years.

1.2. Wireless history

1.2.1. Prehistory

The history of the wireless technology goes far back in time. Already in 1843 Morse transferred the first message over a telegraph line in the USA. This event can be looked at as the first kind of e-mail message in history, and in 1858 the first telegraph cable connected Europe and America through the Atlantic Ocean. The next big happening was in 1876 when the american scientist Alexander Graham Bell invented the telephone. The year later Thomas Edison invented the carbon-microphone and he did the first recording of a human voice ("Mary had a little lamb"). The first wireless system became a reality in 1894 when an italian guy named Marconi invented a wireless telegraph. This is the first event that can be directly linked to wireless technology, and six years later, in 1900, the first human voice was broadcasted with radiotechnology in the US. The radiosignal was sent over the Atlantic Ocean from England to USA by Marconi in 1901. (encyclopedia n.d.)

1.2.2. Advantages

There are many different types of wireless communication that are available. This is a major advantage of wireless communication. Different types of wireless communication products exist to get different jobs done. No matter what type of business people are in, there is usually a wireless device that can make their job a lot easier. For instance, doctors on call require one-way communication, or pagers. Businessmen may require two-way communication to be in touch with customers all the time, thus a cellular phone may be useful to them. Also, email is becoming a popular way of communication amongst many people. Wireless Internet technology is becoming available that allows people to have access to email without having to find a computer console. The types of wireless communication that will be explained in this section are cellular phones, pagers and wireless Internet services.

Cellular phones are probably the most popular kind of wireless communication products that exist today. They have many advantages, such as safety and productivity just to name a few. Sooner or later, people often find themselves in an emergency situation. If the emergency occurs in a place where there is no phone available, a cellular phone can come in handy to call for help. Cellular phones can also increase productivity for a businessman who needs to keep in touch with clients on a constant basis. If ever a client or potential customer has a concern, the businessman or salesman can be reached through a cell phone.

Another popular wireless communication device is pagers. They allow quick, one-way communication to people. They are advantageous because the one with the pager can decide whether or not to respond to the page or not. This type of technology is especially beneficial to doctors who are on call. Whenever there help is needed, they can be notified by a pager.

1.2.3. Disadvantages

There are two main disadvantages related to the wireless communication technology. They are health and safety problems and privacy issues. The former disadvantage will be discussed first. The major health and safety issue regarding wireless communication is in the usage of cellular phones. Cellular phones emit an electromagnetic field, and some researchers say that brain tissue (or any bodily tissue, but mostly brain tissue due to the location of the cellular phone while in use) can absorb the electromagnetic field. Possible side effects, some researchers say, can be cancer or memory loss. However, the consensus of most researchers is that using cellular phones in a confined area (such as a car or elevator) is worse than using out in the open, where it is not dangerous. The reason for this is electromagnetic fields in an open area can be dispersed and spread out, while in a confined area the field can bounce back and forth. Hearing all this, one often wonders why despite this disadvantage the use of cellular phones and other types of wireless communication are rising. The reason is simple: it has not been proven. The other disadvantage that was mentioned earlier was privacy issues. It is possible to intercept cellular phone calls, and there have been cases in the past where this has happened. For example, the New York Law Journal had an article in their February 3, 1997 issue regarding this very subject. Newt Gingrich, a Georgian U.S. representative, was on a high priority call with several other republican leaders. This call was intercepted by a couple using a hand-held police scanner. Also, other types of wireless communication can be intercepted, for example portable home phones and text pagers. Despite the fact that disadvantages for this technology exist, the usage of wireless communication is constantly rising.

1.3. GSM

1.3.1. Objectives

During the early 1980's, analog cellular telephone system were growing rapidly in Europe. Each country developed its own system, which was incompatible with others equipment and operation. In Scandinavia the Nordic Mobile Telephony (NMT) was developed and used (Scourias 1995). Because of this situation where the mobile equipment was limited within national boundaries, the Conference of European Post and Telecommunications (CEPT) formed a group to study and develop a pan-Europen mobile cellular radio system (Sempere 1998). Unlike the existing cellular systems the GSM was developed using a digital technology and should meet certain criteria (Sempere 1998):

- spectrum eciency
- international roaming
- low terminal and sevice cost
- good subjective speech quality
- ability to support handheld terminals
- support for range of new services and facilities
- ISDN compatibility

1.3.2. Further history of GSM

In 1989 the responsibility for the GSM specifications passed from the CEPT to the European Telecommunications Standards Institute (ETSI). In1990, the phase 1 of the GSM specification were published and the commercial use did start in mid-1991. Initially GSM was an acronym for the group formed by CEPT; Groupe Special Mobile but became later the acronym for Global System for Mobile communications (Sempere 1998). The GSM Association which represents the interests of 500 organisations that provide wireless services to more than half the world's mobile phone customers, expects that during the first half of 2001 GSM will have half a billion customers. The GSM system is then the lesading wireless system in the world.

1.3.3. Technogical features of GSM, compiled from Sempere and Scourias

The GSM network can be divided into three broad parts. The Mobile Station/terminal, the Base Station Subsystem and the Network Subsytem.

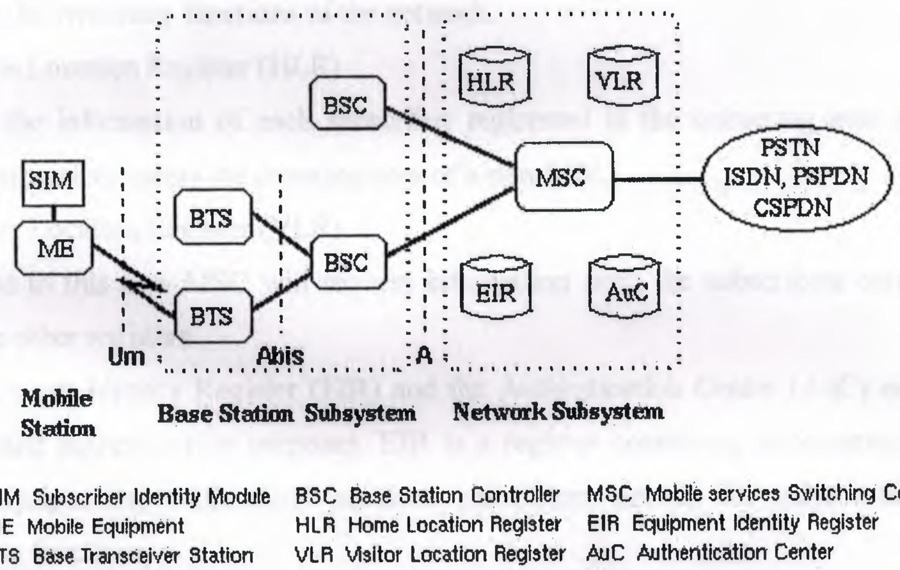


Figure 1.1 General achitecture of a GSM network

1.4. Mobile Station

The terminal consists of the mobile equipment and a SIM (Subscriber Identity Module) card. The SIM provides personal mobility so that the user can have access to subscribed services at any terminal. The mobile equipment is identified by the International Mobile Equipment Identity (IMEI), and the subscriber by the International Mobile Subscriber Identity (IMSI). A secret key is used for authentication.

1.4.1. Base Station Subsystem

The Base Station Subsystem is composed of two parts, the Base Transceiver Station (BTS) and the Base Station Controller (BSC). The BTS corresponds to the transceivers and antenna used in each cell of the network, and the BSC conrtols a group of BTS and manages their radio rescources.

1.4.2. Network Subsystem

The main role of the Network Subsystem is to manage the communication between the mobile users and other users in fixed or mobile environments.

The Mobile services Switching Center (MSC)

performs the switching functions of the network.

The Home Location Register (HLR)

contains the information of each subscriber registered in the coevering area of a MSC. When a subscriber enters the covering area of a new MSC

the Visitor Location Register (VLR)

associated to this new MSC will request information from the subscribers corresponding HLR The other registers

the Equipment Identity Register (EIR) and the Authentication Center (AuC) are used for security and authentication purposes. EIR is a register containing information about the mobile equipments, while AuC provides parameters needed for authentification and encryption functions.

1.5. Spectrum for GSM

The International Telecommunication Union (ITU) allocated the bands 890-915 MHz and 935-960 MHz for mobile networks in Europe. Because this range was already in use by the analog system of the day (early 1980's), CEPT reserved the top 10 MHz of each band for GSM. Eventually the entire 2x25 MHz bandwidth will be allocated GSM. By using these bandwidths GSM provide connectivity to as many users as possible. The method used is a combination of Time- and Frequency- Division Multiple Access (TDMA/FDMA). Because the possiblity of radiowaves bouncing o_ everything at the 900

MHz range, GSM provides a multipath equalisation which extract everything but the desired signal.

1.5.1. Network aspects

In addition GSM have network aspects as radio resources management, which controls the setup, maintenance, and termination of radio and fixed channels, including handover; mobility management which manages the location updating and registration procedures, as well as security and authentication; and connection management which handles general call control, the supplementary services and the short message service (SMS) (Scourias 1995).

1.6. UMTS

Future successful developers will be those design services to adapt to whatever networks and whatever terminals the user will be using at any particular time or place. (UMTS-Forum 2000)

1.6.1. Objectives

Universal Mobile Telecommunications System (UMTS) is a part of the family of 3G mobile communications systems, and will play a key role in creating the future mass market for high-quality wireless multimedia communications (Baumgarten & a.o. 2000). UMTS o_ers (Baumgarten & a.o. 2000) (Bjørnland & Lauritzen 1995) (Maile 2000):

- low user and service cost and ease of use
- a wide range of terminals
- optimized mobile multimedia service delivery (graphics, video, music etc...)
- enabling of multiple users to be supported through a single subscription
- high quality speech together with advanced data and information services
- support for datarates up to 2Mbit/s
- internet protocol (IP) support
- quality of service to suit services
- virtual connectivity at all times
- alternative ways of billing

- universal connectivity wherever and whenever (global terminal roaming capability)
- satellite and terrestrial based coverage
- integration of fixed and mobile networks
- teminal mobility and personal mobility (allowing standard terminals

like printers e.g. to be directly connected the mobile terminal)

1.6.2. History of UMTS

In 1986 the International Telecommunications Union (ITU) initiated the Future Public Land Mobile Telecommunications Systems (FPLMTS). After several years of feasibility studies 230MHz of spectrum in the 2GHz band should be reserved for FPLMTS. At the same time the European Telecommunications Standards Institute (ETSI) worked on a European implementation of FPLMTS. UMTS was initiated in late 1991. The UMTS reasearch phase (technological research) and concept phase (objectives) were concluded in 1995, while the specification phase were finished in 1998 (Bjørnland & Lauritzen 1995). Bjørnland & Lauritzen (1995) states that the current date of introduction of UMTS is set to 1. january 2001, further says Baumgarten & a.o. (2000) that the basic deployment phase is beginning in 2002, while the full commercial phase with performance and capability enhancements, and the introduction of new sophisticated UMTS services is set to 2002-2005. Figure 3 is shown in Cisco Systems 'GPRS White Paper' and indicates the timeline of third generation wireless technology (Cisco-Systems 2000).

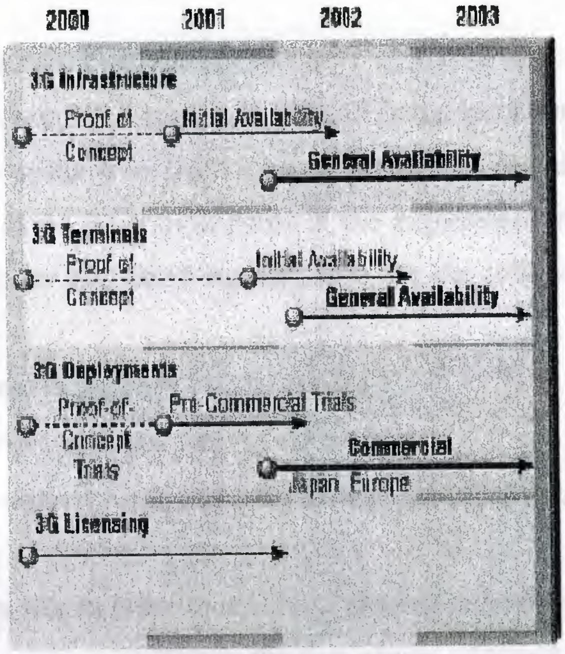


Figure 1.2 3G Timeline

1.6.3. Technological features of UMTS

The UMTS o_ers-list indicates that UMTS support for datarates up to 2Mbit/s, and that is true, but UMTS terminals might not be able to operate at the highest data rates at all times. 14 radio operational environments have been identified that are going to a_ect the relative speed between the terminal and the radio port and user tra_c conditions. These include business, neighbourhood and home and indoor environments, urban vehicular, urban pedestrian and rural outdoor environment, a local high bitrate environment and several satelite indoor and outdoor environments. The highest bitrate o_ered is 1920 kbit/s, and the lowest userbitrates is 1.2 kbit/s (Bjørnland & Lauritzen 1995).

1.6.4. Spectrum for UMTS

In 1992, the World Administrative Radio Conference (WARC'92) identi-fied the frequency bands 1885-2025 MHz and 2110-2200 MHz for use by FPLMTS (Bjørnland & Lauritzen 1995). Studies carried out by the UMTS Forum highlighted that multimedia mobile will require additional spectrum for both satelite and terrestrial services of about 160 MHz (Baumgarten & a.o. 2000). These spectrum are not exclusively reserved for FPLMTS or UMTS.

1.6.5. Migration From GSM system to UMTS

In order to reduce the cost of introducing UMTS in the market and to ease the transition of the existing mobile systems to UMTS, reuse of parts of the already existing physical infrastructure will be done. Migration paths is the expression which describes the way GSM can evolve towards full GSM support, and has the following steps (Bjørnland & Lauritzen 1995):

- new radio access technology will be needed
- multi-mode GSM terminals will be required
- integration to support a more flexible mechanism for service creation and control is required.

Priscoli (1996) suggest that in order to acheive a smooth migration from the GSM network to the third generation system, at least in the first phases of transition, most of the existing technologies and infrastructures already implemented in GSM should be reused.

1.7. Bluetooth

1.7.1. History

Bluetooth technology was first invented by Ericsson Mobile Communications AB in Lund, Sweden, in 1994 (Haartsen 1998). Ericsson wanted to investigate the feasability of a low-power, low-cost radio interface between mobile phones and their accessories. Later it gained the support of Nokia, IBM, Toshiba, Intel and many other manufacturers. In the time of this writing there are 2018 members of the Bluetooth Special Interest Group (SIG) (Bluetooth-Special-Interest-Group 2000). The Bluetooth Special Interest Group was formed by the five promoters in 1998 mentioned earlier and is comprised of leaders in telecommunication, computing, and network industries. The purpose of the group is to establish a de facto standard for the air interface and the software that controls it. They are driving the development of the technology and bringing it to the market.

1.7.2. Technological Features of Bluetooth

Bluetooth is a universal radio interface in the 2.45 GHz frequency band that enables portable electronic devices to connect and communicate wirelessly via short-range, ad-hoc networks. The technology eliminates the need for wires, cables and connectors for and between cordless or mobile phones, PDA's, printers, computers and so on. Infrared links (IrDA) have so far been the typical wireless connection between di_erent types of devices. Infrared transceivers are also inexpensive but they have some limitations compared to radio transceivers:

- They have a limited range (typically one to two meters).
- They are sensitive to direction and therefore they require a direct line-of-sight.
- They can in principle only be used between two devices at the same time.

By contrast, radiosignals havemuch greater range. Radios can propagate around objects and through various materials, and they can connect to many devices simultaneously. Another advantage is that they do not require user interaction. This means that your device will be recognized and connected to the other device, such as a printer, without first have to connect the devices to each other manually (Haartsen 1998).

1.7.3. The Bluetooth Air Interface

Before the Bluetooth air interface could be designed there were some requirements that had to be met:

- The system must operate worldwide. Because the system must operate globally, the frequency band had to be licens-free and open to any radio system. Therefore they chose the Industrial-Scientific- Medical (ISM) band. The ISM band operates in the 2.45 GHz range. Because only parts of the band is available in some countries the band can operate worldwide given that the radio tranceivers cover the frequency band between 2,400 and 2,500 MHz.
- The connection must support voice (mobile phones with wireless headsets) and data (for example multimedia applications).
- The radio tranceivers must be small and operate at low power.
  The reason for that is that they should fit into small portable devices such as mobile phones, headsets and personal digital assistants (PDA's).

Bluetooth radios use frequency-hop (FH) spread spectrum. Frequencyhop systems divide the frequency band into di_erent channels. Since many bluetooth-components can connect to the same source, there have to be a way to avoid collisions on the same frequency. There is, as mentioned earlier, 100 di_erent frequencies to choose from (2,400-2,500).
When more than one device wants to connect to for example a printer, the radio tranceivers hop from one channel to another in a random order. This hopping avoids collisions, or more specific, interference. From time to time two devices will choose the same frequency and causing interference between to signals. The packets have a fixed format ,see figure 1.3

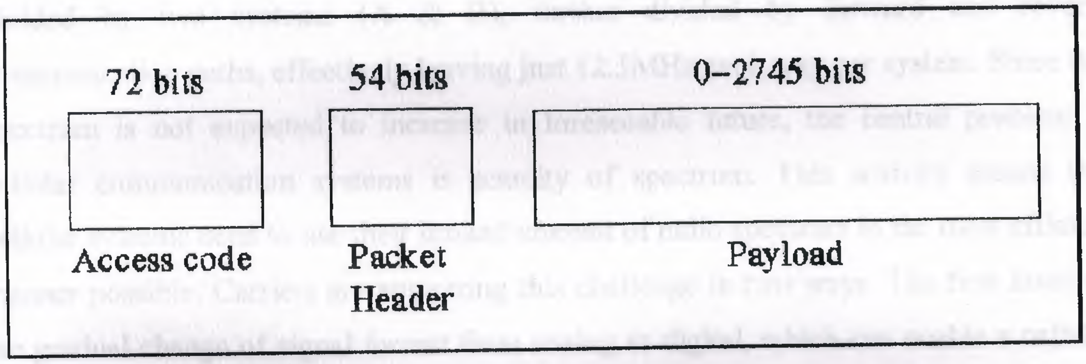


Figure 1.3 Bluetooth fixed packet format

- Each packet begins with a 72 bits access code that is unique for the channel. Recipients compare the incoming signals with the acces code. If these do not match, the recieved packet is considered invalid on the channel and the rest of its contents are ignored. The access code is also used for synchronization.
- The access code is followed by a 54 bits header. The header contains important information such as: a three-bit media-access-control (MAC) adress, packet type, flow control bits, bits for the automaticretransmission-query (ARQ) scheme and a header-error-check (HEC) field.
- The last part of the packet contains the payload where the lenght varies from 0 to 2,745 bits. The payload contains the specific data that you want to exchange.

2. TIME DIVISION MULTIPLE ACCESS

2.1. Overview

Wireless communications have shown a profound effect on our daily life. In less than ten years, cellular telephones have attracted more than a hundred million subscribers in the United States, Europe, and Asia. Since mobile personal communications have been introduced, the service providers have been limited by short-term capacity solutions offered by both technology of industry and the frequency real estate relinquished by FCC.

At the beginning, cellular service providers were given 50 MHz of channel spectrum, divided by two systems (A & B), further divided by forward and reverse communication paths, effectively leaving just 12.5MHz each way per system. Since this spectrum is not expected to increase in foreseeable future, the central problem of cellular communication systems is scarcity of spectrum. This scarcity means that cellular systems need to use their limited amount of radio spectrum in the most efficient manner possible. Carriers are answering this challenge in two ways. The first involves the gradual change of signal format from analog to digital, which can enable a cellular system to employ fewer base stations. The second method employs digital phase modulation to enable a group of users to employ the same radio frequency channel simultaneously. Here comes multiple access.

2.2. Definition

TDMA (Time Division Multiple Access) is a second-generation technology used in digital cellular telephone communication, which divides each cellular channel into individual time slots in order to increase the amount of data that can be carried. Several different mutually incompatible implementations of TDMA technologies are in use worldwide, the most prolific being GSM (Global System for Mobile Communications). However, the implementation that is commonly referred to as TDMA is that defined by IS-136 by the Telecommunication Industries Association (TIA).

TDMA forms part of the evolution from first-generation analog systems to second- and then third-generation digital systems. It builds upon the original analog Advanced Mobile Phone Service (AMPS), using the same frequency band of 800MHz, but also operates in the Personal Communication Services (PCS) band of 1,900MHz in the US. Although TDMA could be considered as the least technologically advanced of the second-generation mobile systems, it has proven very popular in the US and developing world as a simple upgrade from analog to digital services. As of December 1999, there were approximately 36 million TDMA subscriptions, accounting for 9% of the digital market.Although TDMA is currently incompatible with other second-generation systems, there is now a common upgrade path to IMT-2000, which should become the world-wide standard for third-generation mobile communication.

2.3. Multiple Access

The goals of multiple access communications systems, meaning cellular and PCS, are:

- Near-wireline quality voice service
- Near-universal geographical coverage
- Low equipment cost, both subscriber stations and fixed plant
- Minimum number of fixed radio sites

The implementations of cellular systems having hundreds of channels became practical with the availability of compact, low-cost frequency synthesizers. Besides, microprocessor control permits complex control message dialogs that implement sophisticated call control protocols. There are three widely used types of multiple access today, Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA). The following figure shows the basic idea of these technologies.

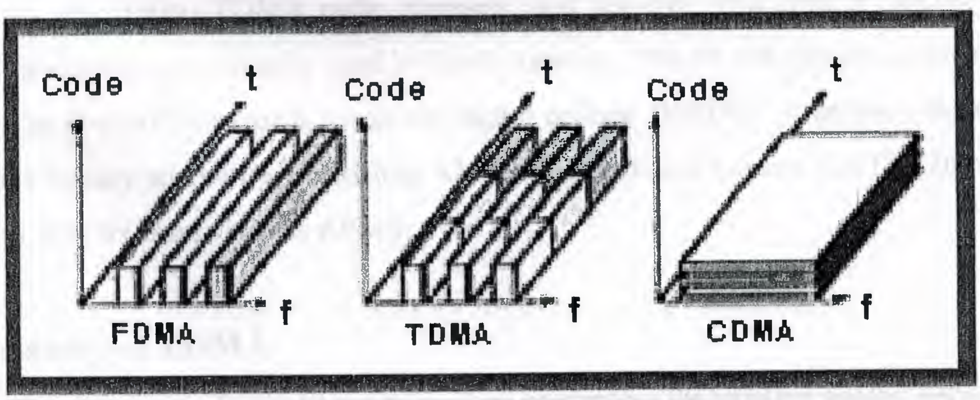


Figure 2.1 Methods of multiple access

2.4. What is TDMA

Time division multiple access (TDMA) is digital transmission technology which allows a number of users to access a single radio frequency channel without interference by allocating unique time slots to each user within each channel. The TDMA digital transmission scheme multiplexes three signals over a single channel.

The current TDMA standard for cellular divides a single channel into six time slots, with each signal using two slots, providing a 3 to 1 gain in capacity over Advanced Mobile Phone Service (AMPS). Each caller is assigned a specific time slot for transmission. The major technology of TDMA in Europe is GSM, in Japan is PDC, and in North America it is referred as IS-136 based Digital AMPS.

Tablel 2.1 TDMA standards

TDMA Standards	Channel Width	Time Slots
North American Digital Cellular (IS-54,IS-136)	30KHz	3
Japanese Digital Cellular (PDC)	25KHz	3
Global System for Mobile Communication (GSM)	200KHz	8

IS-136 is the TDMA Digital AMPS (D-AMPS) specification. It uses TDMA system, combines new digital TDMA radio channels, and features with AMPS functionality. The IS- standards are primarily used in North America. The IS-136 system is sometimes referred as D-AMPS or North American digital cellular (NADC). A primary feature of IS-136 is its easy adaptation to existing AMPS system due to the fact that IS-136 retains the same 30KHz bandwidth as APMS.

2.5. History of TDMA

The wireless industry began to explore converting the existing analog network to digital as a means of improving capacity back in the late 1980s.

In 1988, the Cellular Telecommunications Industry Association (CTIA) developed a guideline for the next generation of cellular technology called User performance Requirements, and Telecommunication Industry Association (TIA) used this guideline to create a TDMA digital standard, called IS-54. The first version of IS-54 specification identified the basic parameters (for example, time slot structure, type of radio channel modulation, message formats) needed to begin designing TDMA cellular equipment. But IS-54 lacks some basic features that were introduced in the first commercial TDMA phones. Soon, IS-54 REV A was born to correct error and add some basic features (such as call id) to the TDMA standard.

In 1991, IS-54 REV B added features such as authentication, voice privacy, and a more capable caller ID with great benefit to the user. Digital TDMA still evolve beyond IS-54 REV B, so a new standard is needed to cover specification of all these features. That is IS-136. IS-136 concentrates on what were not present in the earlier IS-54 TDMA system. These include longer standby time, short message service functions, and support for small private or residential system that coexist with the public systems. In addition, IS-136 defines a digital control channel allows a mobile telephone to operate in a single digital-only mode.

During the development of IS-136, many new features were influenced by or borrowed from the GSM specification. The overall control channel signaling processes are very similar to that of GSM.

2.6. TDMA Technologies

IS-136 is the United States standard for TDMA for both the cellular (850 MHz) and PCS (1.9 GHz) spectrums.

The data is transmitted via radio carrier from a base station to several active mobiles in the downlink. In the reverse direction (uplink), transmission from mobiles to base station is time sequenced and synchronized on a common frequency for TDMA.

2.7. Architecture

The D-AMPS 800/1900 system architecture consists of four major parts:

The Switching System controls call processing and subscriber- related functions.

The Base Station performs radio-related functions.

The Operation and Support System supports the operation and maintenance activities required in the network.

The Mobile Station is the end-user device which supports the use of voice and data communications as well as short message services.

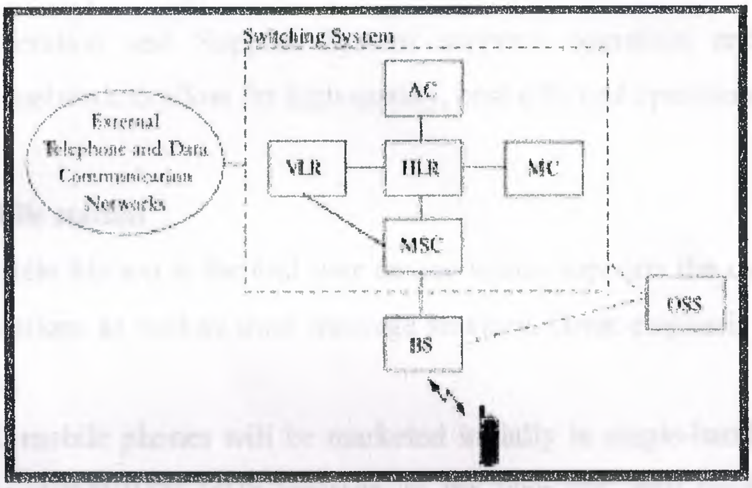


Figure 2.2 D-AMPS 800/1900 system architecture.

2.7.1. The switching system

The Switching System contains five main functional entities:

The Mobile Switching Center (MSC) performs the telephony switching functions for the network. It controls calls to and from other telephone and data communications networks such as Public Switched Telephone Networks (PSTN), Integrated Services Digital Networks (ISDN), Public Land Mobile Networks (PLMN), Public Data Networks and various private networks.

The Visitor Location Register (VLR) database contains all temporary subscriber information needed by the MSC to serve visiting sub-scribers.

The Home Location Register (HLR) database stores and manages subscriptions. It contains all permanent subscriber information including the subscribers service profile, location information and activity status.

The Authentication Center (AC) provides authentication and encryption parameters that verify the users identity and ensure the confidentiality of each call. This functionality protects network operators from common types of fraud found in the cellular industry today. The Message Center (MC) supports numerous types of messaging services, for example voice mail, fax mail and E- mail.

2.7.2. The base station

The Base Station is the radio equipment needed to serve each cell in the network. One base station site may serve more than one cell.

2.7.3. The operation and support system

The Operation and Support System supports operation and maintenance activities in the network to allow for high-quality, cost-efficient operation.

2.7.4. The mobile station

The Mobile Station is the end user device which supports the use of voice and data communications as well as short message services. Great emphasis is put on user-friendly phones.

D-AMPS 1900 mobile phones will be marketed initially in single-band 1900 MHz as well as dual-band 800/1900 MHz versions. In the long run, dual-band versions may prove themselves able to replace single-band versions at both 800 and 1900 MHz. The D-AMPS 1900 dual-band phones will also provide dual-mode capabilities for the 800 MHz band and will support both AMPS and D-AMPS technologies.

2.8. TDMA Frame Structure

In a TDMA system, each carrier is split into consecutive frames, where each frame is subdivided into a number of time slots. In D-AMPS, each TDMA frame consists of six timeslots (see Figure 3). One speech channel allocates two slots per frame, e.g. time slot 1 and 4, 2 and 5, 3 and 6, one for mobile unit to base station (uplink), and one for base station to mobile unit (downlink) transmission. Three users thus share one carrier. This is called full-rate traffic. In the future, with improved speech-codec algorithms of lower bit rate, it may be sufficient to allocate only one slot per speech channel. This will double the capacity. In a TDMA/frequency division duplex (FDD) system, a nearly identical frame structure is used for both the uplink and the downlink transmission, but the carrier frequencies are different for the two links. Uplink (1850-1865 or 824-849 MHz) and downlink (1930-1945 or 869-894 MHz) frequencies are separated enough to prevent cross-talk between the two links. Generally, in a TDMA/FDD system a delay (or offset) of several time slots is intentionally induced between the uplink and downlink time slots of each particular user to avoid the use of duplexers in the mobile unit.

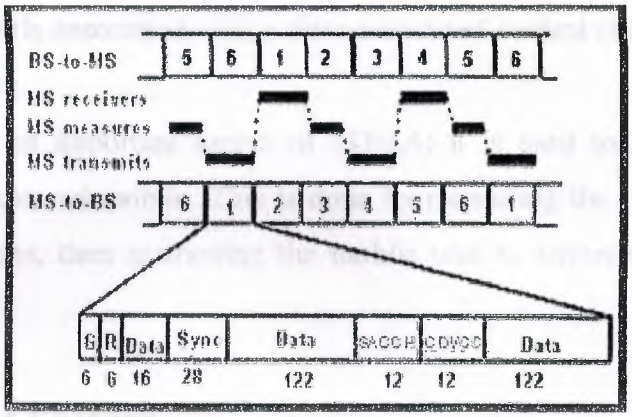


Figure 2.3 Frame structure of DAMPS traffic channel

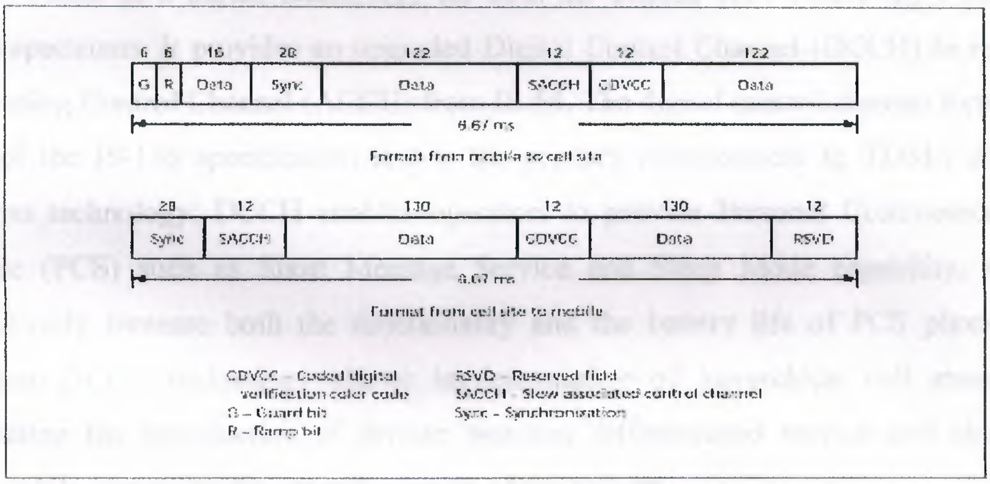


Figure 2.4 Time slot structure for DAMPT-1900

By looking at Figure 2.3, we can see that the mobile station has an idle time period between transmission and reception. Assume, for example, a user on a full-rate traffic channel, e.g. slot 1 and 4. The timing of the MS-to-BS transmission is offset by approximately one time slot relative to the BS-to-MS transmission. Thus the transmission and reception in the mobile station do not overlap. In addition, there is an idle time period between the BS-to-MS and MS-to-BS transmissions. For a user on time slots 1 and 4 this idle time period corresponds to the time when time slot 2 is transmitted in the BS-to-MS direction (which is the same as time slot 3 in the MS-to-BS direction). In Figure 2.3, the transmit-receive-measure cycle is indicated for the mobile station. The idle time period in a TDMA system automatically gives support for both intra- and inter-frequency Mobile Assisted Hand-Off (MAHO), as it allows for the mobile to carry out measurements on other channels/carriers.

The time slot structure for DAMPS-1900 is shown in Figure 4, where each traffic channel is permanently associated with a slow associated control channel (SACCH) for non-urgent messages.

Synchronization is an important aspect of TDMA; it is used to allow for the time alignment of the base and mobile. This is done by measuring the time delay from the synchronization codes, then instructing the mobile unit to advance or slow down its transmission rates.

2.8.1. IS-136 TDMA Channels

As mentioned earlier, the IS-136 version of TDMA has been specified in the United States as a digital technology for both the cellular (850 MHz) and PCS (1.9 GHz) spectrums. It provides an upgraded Digital Control Channel (DCCH) to replace the Analog Control Channel (ACCH) from IS-54. The digital control channel forms the core of the IS-136 specification and is the primary enhancement to TDMA digital-wireless technology. DCCH enables operators to provide Personal Communications Service (PCS) such as Short Message Service and Sleep Mode capability, which dramatically increase both the functionality and the battery life of PCS phones. In addition, DCCH technology allows implementation of hierarchical cell structures, facilitating the introduction of private systems, differentiated service and charging areas, while increasing the overall capacity of the system.

IS-136 systems contain 4 types of channels:

- Analog Control Channel (ACC)
- Analog Voice Channel (AVC)
- Digital Control Channel (DCCH)
- Digital Traffic Channel (DTC)

These channels allow for digital systems to grow within analog systems. Signaling has been added to the AMPS channels to allow a mobile to switch between digital and analog channels to find the channel that will provide the best service.

PCS phones receive pages, send originations, and communicate with the system on the DCCH. After receiving a page or performing a call origination, a traffic channel is then designated for the call, and the phone will hand off from cell to cell as it moves around the system. At call completion, the phone returns to the DCCH to await further interaction.

2.8.2. The Dual-Band/Dual-Mode Operation

In D-AMPS, digital and analog channels can co-exist in the same network, so *that a digital system can grow within an analog system, and users can be given seamless service access across both analog and digital modes, via dual-mode phones.*

D-AMPS is also a dual-band standard, so that access on 800MHz and access on 1900MHz bands can if required be integrated to provide seamless services across both bands.

The combination of dual-mode and dual-band operation in a single portable phone opens the door to roaming agreements with any AMPS or D-AMPS network operator, whether on 800MHz or 1900MHz bands.

There's another way of looking at the dual-banding capability. A network operator with a local or regional license on one of the newer 1900MHz bands can set up roaming agreements with other operators on 1900MHz or 800MHz, to provide customers with added value.

D-AMPS has all the functions and features required for Personal Communication Services. The big attraction is that with D-AMPS, these PCS services need not be limited to any particular frequency band. Subscribers can be given PCS services with a common look and feel, on 1900MHz or 800MHz.

On a wider scale, subscribers can be given global roaming not only to countries with D-AMPS networks, but also countries with AMPS networks. Advanced security features including automatic authentication on a call-by-call basis ensure that cloning fraud is virtually impossible in an IS-136 network. For these reasons, D-AMPS IS-136 has achieved tremendous momentum, with the active support of leading wireless network *operators, vendors and others, and a fast-growing global user base.*

2.8.3. Hand-Off

A hand-off is the process of passing a user from a voice channel in one cell to a new voice channel in another cell as the user moves throughout the network. So the call can be "handed-off"" from the old cell to the new cell without an interruption in service. Analog systems assign the new channel, regardless of its quality, and handoff can be rough if the new channel is poor. With TDMA, Mobile Assisted Handoff (MAHO) is used to decrease the number of dropped calls and minimize operational delay. In TDMA, transmission and reception are performed only during part of the frame. The mobile utilizes the time slots between transmitting and receiving for measurements on other frequencies (see Figure 2.5). Measurements can be obtained both in the uplink and the downlink on all frequencies. Therefore, during a conversation, the mobile station measures the signal strengths from the neighboring cells and reports the results to the system. By using the measurement results, in conjunction with other relevant information, e.g. mobile station speed, cell layer preference and user-specific information, the system decides when to hand-off the mobile station to another cell. The measurements are evaluated to find good candidates for hand-off. The system then chooses the best cell for the mobile. Before the hand-off is executed, the target cell verifies the measurement values obtained from the mobile station.

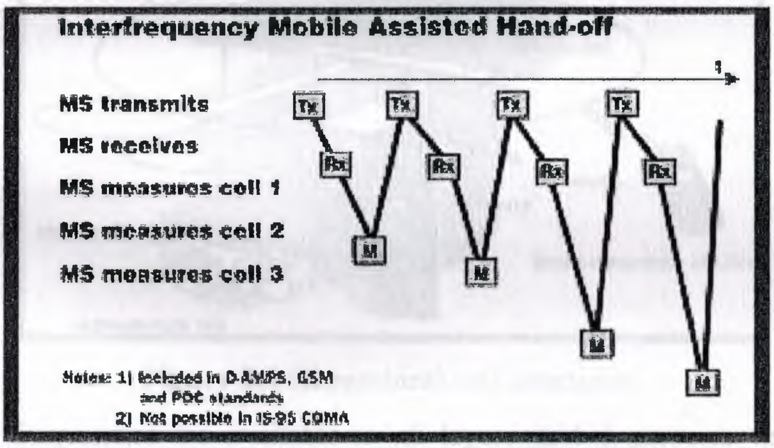


Figure 2.5 Mobile Assisted Hand-off

The hand-off process can be briefed as following four steps:

- Triggering: The hand-off could be triggered by the following conditions: Signal strength is too low; Interference or bit error rate is too high.
- Screen: The mobile unit uses the MAHO to measure the signal strengths from the surrounding cells and report the results to the switch.
- Select: Before selecting a target cell, the switch must decide if better choice is available, and if a hand-off is worthwhile.
- Hand-off: After selecting the target location to hand-off the call, the switch sets up a new voice path. The mobile then acknowledges the new path and jumps to the new voice channel without interrupting the conversation.

2.9. Hierarchical Cell Structures

The D-AMPS standard can support very large numbers of subscribers, and capacity can be increased wherever it is needed in the network. The key to this is the Hierarchical Cell Structure (HCS). Hierarchical cell structures allow the combined use of macro, micro and pico cells within the same area to achieve high capacity and seamless coverage throughout the network. Within the hierarchical cell structures of a D-AMPS network, macro cells can cover large geographical areas where subscriber densities may be low, and handle fast-moving mobiles. Micro and pico cells serve locations where subscriber densities are higher. For example, A micro cell may serve a single street. A pico cell may serve a single building such as a shopping mall or a single floor of a skyscraper. Such a layer system is shown in Figure 2.6

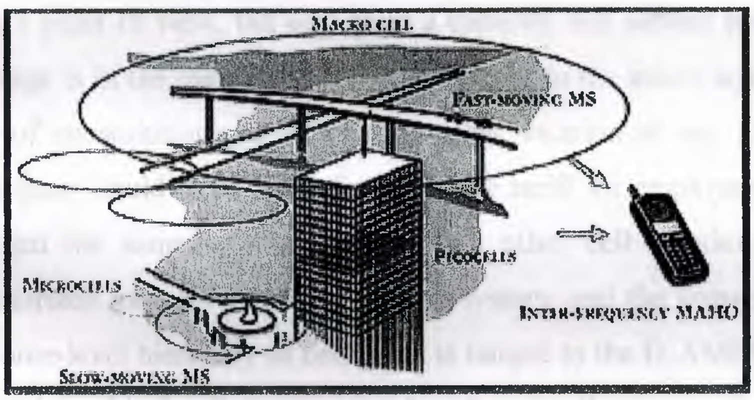


Figure 2.6 Hierarchical cell structures.

Basically, all frequencies are available in all layers, and it prevents the layers from interfering with each other by regionally separating the frequencies between the layers. Certain cells can be identified as "preferred", so that the user's phone always checks to see if a preferred cell is available, and if so connects the user to that cell.

This function allows phones to be programmed to treat all pico and micro cells as preferred, so that traffic is largely kept down at these levels, freeing up wireless capacity in the macro cells. When traffic demands increase, adaptive channel allocation makes it is easy to put up a new site where needed. Such flexibility is also offered in the short term by load sharing: a nearby sector will take on the overflow traffic of a fully loaded sector. Therefore the number of costly macrocell sites can be kept low and used mainly for wide area coverage and coverage between different microcells. Microcells can be created using small, low-power micro base stations that can be mounted on walls or lamp posts for example, thus requiring a minimum of infrastructure support.

The only way to implement HCS is to not force hand-offs between sectors or layers. It must be possible to be connected to a cell without disturbing the rest of the system even though another cell might exist which offers better signal strength. However, hand-offs should be done when deemed appropriate by the system, for example when the mobile starts to move faster. The inter-frequency Mobile Assisted Hand-off (MAHO) measurements are very useful for HCS (see Figure 2.5).

Hierarchical Cell Structures is a flexible tool to handle non-homogeneous traffic. Base stations can be located exactly where the traffic demands are. When reducing cell size to expand capacity, the cells will become very small and frequent hand-offs create a heavy load in the access network. With HCS, the fast-moving mobiles, those who do most of the hand-offs, are moved to the macro layer. Similarly, slow-moving mobiles are kept in the microcells. The system chooses the best cell for the mobile not only from a signal strength point of view, but also from a capacity and service point of view. In this way, coverage is in the macro layer, and capacity is in the micro layer. HCS allows differentiation of subscriptions based on subscriber location at any given time. For example, a company could have picocells where the tariff for employee phone calls is lower than when the same mobiles are used in other cell locations. The system recognizes authorized mobiles belonging to this system, and the correct tariff will be applied. This three-level hierarchy of cell types is unique to the D-AMPS standard. The combination of hierarchical cell structures and preferred cell selection functions gives a D-AMPS network virtually unlimited capacity. For comparison, in IS-95 CDMA, measurements on other frequencies are not possible since the receiver is occupied at all times. It is only possible to evaluate the base stations transmitting on the same 1.25 MHz band. This makes it impossible to have Hierarchical Cell Structures in IS-95 CDMA.

2.9.1. Enhanced TDMA

The full digital capabilities of IS-136 introduce an enhanced set of services: message waiting indicator, calling number identification, sleep mode, voice privacy, authentication, data communications, short message services (paging), closed user groups, and others.

TDMA substantially improved upon the efficiency of analog cellular. However, like FDMA, it had the weakness that it wasted bandwidth: the time slot was allocated to a specific conversation whether or not anyone was speaking at that moment. Hughes'

TDMA also provides the user with extended battery life and talk time since the mobile is only transmitting a portion of the time (from 1/3 to 1/10) of the time during conversations.TDMA installations offer substantial savings in base-station equipment, space, and maintenance, an important factor as cell sizes grow ever smaller.

TDMA is the most cost-effective technology for upgrading a current analog system to digital.

TDMA is the only technology that offers an efficient utilization of hierarchical cell structures (HCSs) offering pico, micro, and macrocells. HCSs allow coverage for the system to be tailored to support specific traffic and service needs. By using this approach, system capacities of more than 40-times AMPS can be achieved in a cost-efficient way. Because of its inherent compatibility with FDMA analog systems, TDMA allows service compatibility with the use of dual-mode handsets. Dual band 800/1900 MHz offers the following competitive advantages:

- Identical applications and services are provided to subscribers operating in both bands.
- Carriers can use the same switch for 800– and 1900–MHz services.
- Seamless interworking between 800– and 1900–MHz networks through dual-band/dual-mode phones.
- Using dual-mode, dual-band phones, subscribers on a TDMA 1,900 channel can hand off both to/from a TDMA channel on 800 MHz as well as to/from an analog AMPS channel.

2.10.2. The Disadvantages of TDMA

One of the disadvantages of TDMA is that each user has a predefined time slot. However, users roaming from one cell to another are not allotted a time slot. Thus, if all the time slots in the next cell are already occupied, a call might well be disconnected. Likewise, if all the time slots in the cell in which a user happens to be in are already occupied, a user will not receive a dial tone.

Another problem with TDMA is that it is subjected to multipath distortion. A signal coming from a tower to a handset might come from any one of several directions. It might have bounced off several different buildings before arriving (see Figure 2.5) which can cause interference.

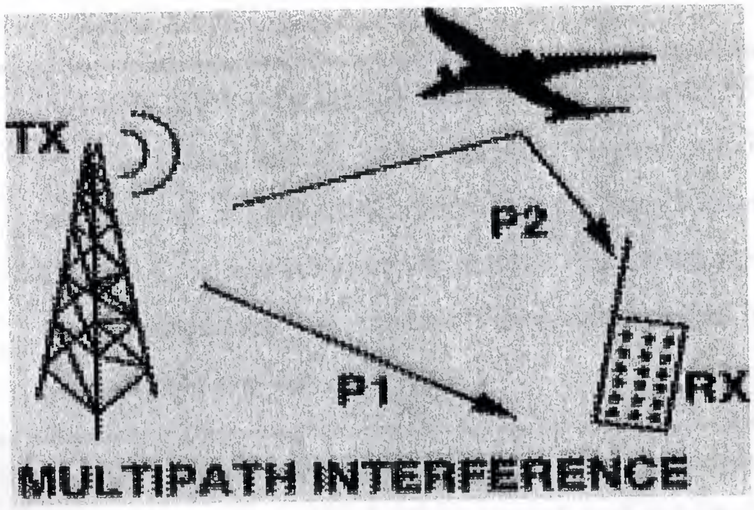


Figure 2.7 Multipath Interference

2.11. TDMA versus CDMA

Since the introduction of CDMA in 1989, the wireless world has been occupied by a debate over the relative merits of TDMA and CDMA.

The supporters of CDMA have claimed bandwidth efficiency of up to 13 times that of TDMA and between 20 to 40 times that of analog transmission. Moreover, they note that its spread-spectrum technology is both more secure and offers higher transmission quality than TDMA because of its increased resistance to multipath distortion. One of the key players in CDMA business is Qualcomm, a San Diego company.

The supporters of TDMA, on the other hand, point out that to date there has been no successful major trial of CDMA technology that supports the capacity claims. Moreover, they point out that the theoretical improvements in bandwidth efficiency claimed for CDMA are now being approached by enhancements to TDMA technology. The evolution of TDMA will allow capacity increases of 20 to 40 folds over analog in the near future. This combined with the vastly more expensive technology needed for CDMA ($300,000 per base station compared with $80,000 for TDMA) calls into question what real savings CDMA technology can offer. So far, IS-136 TDMA is the proven leader as the most economical digital migration path for an existing AMPS network. Ericsson is a strong advocate of TDMA. In a recent paper, they compared their D-AMPS 1900 system, the CMS 8800, with the 1900 MHz version of IS-95 CDMA. They conclude (see Table 2) that D-AMPS 1900 system has both financial and technological advantages over IS-95 CDMA.

Table 2.2 Advantage of TDMA over CDMA

Coverage	D-AMPS offers substantially better coverage than IS-95 CDMA: For the 8 kbps speech coder rate, the allowed maximum path loss (attenuation) of D-AMPS 1900 is 2 dB higher than that of IS-95 CDMA. Coverage refers to the number of sites required to adequately cover a given area. The number of sites is determined by the maximum allowed path loss and other factors.
Hand-off Techniques	D-AMPS 800/1900 uses MAHO. The combination of timing information in the hand-off command and extremely fast hand-off algorithms results in a secure, accurate and seamless hand-off. No additional hardware for hand-off is required. Due to the 1-cell reuse of frequencies, IS-95 CDMA is forced to use a soft hand-off algorithm, and it is extremely sensitive to interference at cell borders.
Cost	The D-AMPS infrastructure costs up to 50% less than IS-95 CDMA: With the 13 kbps variable rate speech coder IS-95 CDMA would require 65% more base stations compared to D-AMPS 1900. Besides, TIA research shows, at any given time in an IS-95 CDMA system, due to the use of soft hand-off, 30% of the calls are in two-way and 10% are in three-way soft hand-off. This results in an overall additional requirement for 50% more channels (and transmission link) for IS-95 CDMA
Capacity	Using an 8 kbps full-rate speech coder, the basic D-AMPS technology offers more than 6 times the capacity of AMPS. And with hierarchical cell structures capacity is virtually unlimited.
Voice Quality	The D-AMPS speech quality outperforms IS-95 CDMA under all conditions
Compatibility	The D-AMPS 1900 mobile is compatible with analog AMPS system as well as D-AMPS 800 MHz. IS-95 CDMA does not even support a hand-off from AMPS to IS-95 CDMA on 800 MHz.

2.11.1. Present Status and Future Trend

TDMA was a boon to the market early in 1988. It has remained as the sole multiple access scheme in three of the top fourteen cellular providers, including AT&T Wireless, the largest cellular carrier at 78.7 million Points of Presence (POPs). Other two providers in the top fourteen coexist with CDMA. TDMA has a presence in half of the top fourteen PCS service providers as the PCS 1900 standard, the American version of GSM. The most significant of these is Atlantic Personal Communication's Washington-Baltimore market that successfully began commercial business in November of 1995.

On the other hand, since the world's first commercial CDMA system was launched in Hong Kong successfully, CDMA's US market share is increasing rapidly. Most significant was the choice by Sprint Spectrum, formerly known as Sprint Telecommunications Venture, to use CDMA. Sprint Spectrum currently holds about 163.3 million POPs, making it the largest provider of PCS markets.

It's hard to say which technology will win the battle. Though the current rate of development for CDMA is fast, TDMA is a proven technology that has already been widely implemented and supported. It's very likely TDMA will beat CDMA if all of its new features are implemented successfully. TDMA is also strongly represented in the international market to implement (or upgrade) full D-AMPS systems for developing countries. For these reasons it seems clear that for the near future, at least, TDMA will remain the dominant technology in the wireless market.

3. CODE DIVISION MULTIPLE ACCESS

3.1. Overview

CDMA is an advanced digital wireless transmission technology that uses the principle of spread spectrum communication. Instead of using frequencies or time slots, as do traditional technologies, CDMA uses mathematical codes to transmit and distinguish between multiple wireless conversations.

The intent of CDMA technology is to provide increased bandwidth in a limited frequency system, but has also other advantages including extended range and more secure communications. In a CDMA system, a narrowband message signal is multiplied by a spreading signal, which is a pseudo-noise code sequence that has a rate much greater than the data rate of the message. CDMA uses these code sequences as a means of distinguishing between individual conversations. All users in the CDMA system use the same carrier frequency and may transmit simultaneously.

CDMA is a driving technology behind the rapidly advancing personal communications industry. Because of its greater bandwidth, efficiency, and multiple access capabilities, CDMA is becoming a leading technology for relieving the spectrum congestion caused by the explosion in popularity of cellular mobile phones, fixed wireless telephones, and wireless data terminals. Since becoming an officially recognized digital cellular protocol, CDMA is being rapidly implemented in the wireless communications networks of many large communications corporations.

3.2. History of CDMA

3.2.1. The Cellular Challenge

The world's first cellular networks were introduced in the early 1980s, using analog radio transmission technologies such as AMPS (Advanced Mobile Phone System). Within a few years, cellular systems began to hit a capacity ceiling as millions of new subscribers signed up for service, demanding more and more airtime. Dropped calls and network busy signals became common in many areas.

To accommodate more traffic within a limited amount of radio spectrum, the industry developed a new set of digital wireless technologies called TDMA (Time Division Multiple Access) and GSM (Global System for Mobile). TDMA and GSM used a time-sharing protocol to provide three to four times more capacity than analog systems. But just as TDMA was being standardized, an even better solution was found in CDMA.

3.2.2. Commercial Development

The founders of QUALCOMM realized that CDMA technology could be used in commercial cellular communications to make even better use of the radio spectrum than other technologies. They developed the key advances that made CDMA suitable for cellular, then demonstrated a working prototype and began to license the technology to telecom equipment manufacturers.

The first CDMA networks were commercially launched in 1995, and provided roughly 10 times more capacity than analog networks - far more than TDMA or GSM. Since then, CDMA has become the fastest-growing of all wireless technologies, with over 100 million subscribers worldwide. In addition to supporting more traffic, CDMA brings many other benefits to carriers and consumers, including better voice quality, broader coverage and stronger security.

3.2.3. Current Cellular Standards

Different types of cellular systems employ various methods of multiple access. The traditional analog cellular systems, such as those based on the Advanced Mobile Phone Service (AMPS) and Total Access Communications System (TACS) standards, use Frequency Division Multiple Access (FDMA). FDMA channels are defined by a range of radio frequencies, usually expressed in a number of kilohertz (kHz), out of the radio spectrum.

For example, AMPS systems use 30 kHz "slices" of spectrum for each channel. Narrowband AMPS (NAMPS) requires only 10 kHz per channel. TACS channels are 25 kHz wide. With FDMA, only one subscriber at a time is assigned to a channel. No other conversations can access this channel until the subscriber's call is finished, or until that original call is handed off to a different channel by the system.

A common multiple access method employed in new digital cellular systems is the Time Division Multiple Access (TDMA). TDMA digital standards include North American Digital Cellular (know by its standard number IS-54), Global System for Mobile Communications (GSM), and Personal Digital Cellular (PDC).

TDMA systems commonly start with a slice of spectrum, referred to as one "carrier". Each carrier is then divided into time slots. Only one subscriber at a time is assigned to each time slot, or channel. No other conversations can access this channel until the subscriber's call is finished, or until that original call is handed off to a different channel by the system.

For example, IS-54 systems, designed to coexist with AMPS systems, divide 30 kHz of spectrum into three channels. PDC divides 25 kHz slices of spectrum into three channels. GSM systems create 8 time-division channels in 200 kHz wide carriers.

3.2.4. The CDMA Cellular Standard

With CDMA, unique digital codes, rather than separate RF frequencies or channels, are used to differentiate subscribers. The codes are shared by both the mobile station (cellular phone) and the base station, and are called "pseudo-Random Code Sequences." All users share the same range of radio spectrum.

For cellular telephony, CDMA is a digital multiple access technique specified by the Telecommunications Industry Association (TIA) as "IS-95."

In March 1992, the TIA established the TR-45.5 subcommittee with the charter of developing a spread-spectrum digital cellular standard. In July of 1993, the TIA gave its approval of the CDMA IS-95 standard.

IS-95 systems divide the radio spectrum into carriers which are 1,250 kHz (1.25 MHz) wide. One of the unique aspects of CDMA is that while there are certainly limits to the number of phone calls that can be handled by a carrier, this is not a fixed number. Rather, the capacity of the system will be dependent on a number of different factors. This will be discussed in later sections.

3.3. Principles of CDMA

THE GOAL OF SPREAD SPECTRUM is a substantial increase in bandwidth of an information-bearing signal, far beyond that needed for basic communication. The bandwidth increase, while not necessary for communication, can mitigate the harmful effects of interference, either deliberate, like a military jammer, or inadvertent, like co-channel users. The interference mitigation is a well-known property of all spread spectrum systems. However the cooperative use of these techniques in a commercial, non-military, environment, to optimize spectral efficiency was a major conceptual advance.

SPREAD SPECTRUM systems generally fall into one of two categories: frequency hopping (FH) or direct sequence (DS). In both cases synchronization of transmitter and receiver is required. Both forms can be regarded as using a pseudo-random carrier, but they create that carrier in different ways.

FREQUENCY HOPPING is typically accomplished by rapid switching of fast-settling frequency synthesizers in a pseudo-random pattern. The references can be consulted for further discussions of FH, which is not a part of commercial CDMA. CDMA uses a form of direct sequence. Direct sequence is, in essence, multiplication of a more conventional communication waveform by a pseudonoise (PN) +1 binary sequence in the transmitter.

We are taking some liberties with the details. In reality spreading takes place prior to any modulation, entirely in the binary domain, and the transmitted signals are carefully bandlimited. A second multiplication by a replica of the same +1 sequence in the receiver recovers the original signal.

The noise and interference, being uncorrelated with the PN sequence, become noise-like and increase in bandwidth when they reach the detector. The signal-to-noise ratio can be enhanced by narrowband filtering that rejects most of the interference power. It is often said, with some poetic license, that the SNR is enhanced by the so-called processing gain W/R, where W is the spread bandwidth and R is the data rate. This is a partial truth. A careful analysis is needed to accurately determine the performance. In IS-95A CDMA W/R = 10 log(1.2288 MHz/9600Hz) = 21 dB for the 9600 bps rate set.Show me the math!To get this right, you have to bite the bullet, and go do some math! We've tried to present it in as simple a fashion as possible.

3.4. CDMA Definition

Code Division Multiple Access (CDMA) is a digital wireless transmission technology for mobile communications. CDMA is one of a number of approaches to implementing widely distributed digital mobile voice and data networks. It is viewed as a competing technology to European de facto mobile digital wireless technology GSM (Global System for Mobile communication).

As with the majority of wireless transmission and communication network technologies, CDMA uses a hand held transceiver, which transmits calls to a localised base station. The CDMA standard defines 64 channels transmitted from base station and can support a maximum of 63 simultaneous users per 1.25-MHz frequency. Designed as an improvement on analogue cellular and Time Division Multiplexing Access (TDMA) telephony, CDMA is being promoted by some industry actors as the next mobile data networking technology.

CDMA uses a technology called direct sequence spread spectrum transmission. This is a form of multiplexing where the transmitter (the mobile phone) encodes the signal using a pseudo-random code sequence that the receiver (base station) also knows. The receiver uses this code to decode the received signal. Each different random sequence corresponds to a different communication channel.

3.5. Application

CDMA technologies form the basis of mobile communication services in the United States and other parts of the world. In the US, a group called P.C.S. PrimeCo, that includes NYNEX, Bell Atlantic, US-West and Air-touch Communications, have developed personal communications systems (PCS) that use CDMA.

CDMA is the equivalent of 2nd generation GSM in Europe, and the emerging CDMA1 is equivalent to the emerging 3rd generation GSM.

3.5.1. Signaling Applications in the CDMA System

We will discuss the end-to-end call flow for some typical basic and supplementary services. These end-to-end call flows are synthesized for examination of the various standards and do not appear in any one document within the standard We trace call flows from a mobile station to a base station, to the MSC, and to other network elements. The flows are based on the TR-45/TR-46 reference model and A-interface (the interface between the base station and the MSC supporting signaling and Traffic) based on the Integrated Services Digital Network

3.5.2. Basic Services

Before a mobile station can originate or receive a call, it will register with the wireless system. An exception is made for emergency (911) calls. During the registration process, the MS is given a temporary mobile station identity (TMSI) that is used for all subsequent call processing

(1) Registration

Registration is the means by which a mobile station informs a service provider of its presence in the system and its desire to receive service from that system. The MS may initiate registration for several different reasons. A mobile station registering on an access channel may perform any of the following registration types:

Distance-Based Registration is down when the distance between the current base station and the base station where the MS last registered exceeds a threshold. Ordered Registration is done when the system sets parameters on the forward paging channel to indicate that all or some of the MSs must register. Parameter Change Registration is done when specific operating parameters in the MS are changed Power-Down Registration is done when the mobile station is switched off. This allow the network to deregister a mobile station immediately upon its power-down Power-up Registration is done when power is applied to the mobile station and is used to notify the network that the MS is now active and ready to place or receive calls. Time-Based Registration is done when a timer expires in the mobile station. Zone-Based Registration is done whenever an MS enters a new area of the same system. Two other forms of registration occur when the mobile station takes certain actions:

Implicit Registration occurs when a mobile station successfully communicates with the base station for a page response or an origination. Traffic Channel Registration occurs when the mobile station is assigned a traffic channel. The base station can notify the MS that it is registered.

(2) Call Origination

Call origination is the service wherein the MS user calls another telephone on the world-wide telephone network. It is a cooperative effort among the MSC, the VLR, and the base station.

(3) Call Termination

Call termination is the service wherein an MS user receives a call from other telephones in the world-wide telephone network. The following discussion is for calls terminating to a MS registered at its home MSC. Calls terminating to roaming MSs will be discussed in section of Roaming. Call termination is a cooperative effort among the MSC, the VLR, and the base station.

(4) Call Clearing

When either party in a conversation wishes to end a call, then the call clearing function is invoked. The exact call flows depend on which side ends the call first. It is a cooperative effort among the MSC, the VLR, and the base station.

3.6. Multiple-Access

Wireless systems transmit and receive signals over a common resource: the air. This may lead to conflicts if several users want to transmit at the same time. Multiple accesses mean that multiple, simultaneous users can be supported. In other words, a large number of users share a common pool of radio channels and any user can gain access to any channel (each user is not always assigned to the same channel). A channel can be thought of as merely a portion of the limited radio resource which is temporarily allocated for a specific purpose, such as someone's phone call. A multiple access method is a definition of how the radio spectrum is divided into channels and how channels are allocated to the many users of the system.

The original system was called the Advanced Mobile Phone System, or AMPS. It is the system we use throughout North America. Similar systems, with slight variations, are Nordic Mobile Telephone (NMT) in Scandinavia, and Total Access Communications System (TACS) used in the United Kingdom, China, and other countries. Spectral allocations are in the 800-900 MHz region.

Several hundred channels are available within the spectrum allocation. One channel of one base station is used for each conversation. Upon handoff, the subscriber station is directed via messaging to discontinue use of the old channel and tune to the new one, on which it will find the new cell.

3.6.1. Frequency Reuse

The concept of frequency reuse is quite central to the cellular concept. Although there are hundreds of channels available, if each frequency were assigned to only one cell, total system capacity would equal to the total number of channels, adjusted for the Erlanger blocking probability: only a few thousand subscribers per system. By reusing channels in multiple cells the system can grow without geographical limits.

Reuse is critically dependent upon the fact that the electromagnetic field attenuation in the cellular bands tends to be more rapid with distance than it is in free space. Measurements have shown repeatedly that typically the field intensity decays like R-n, with 3 < n < 5. In free space n = 2. In fact, it is easily shown that the cellular concept fails completely due to interference that grows without bound if the propagation is exactly free space. Typical cellular reuse (pre-CDMA) is easily rationalized by considering an idealized system. If we assume that propagation is uniformly R-n, and that cell boundaries are at the equisignal points, then a planar service area is optimally covered by the classical hexagonal array of cells

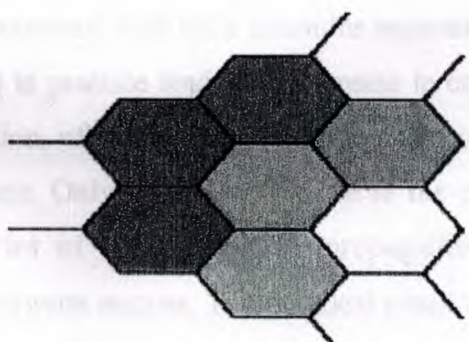


Figure 3.1 Seven sets of channels are used, one set in each colored cell. This seven-cell unit is then replicated over the service area.

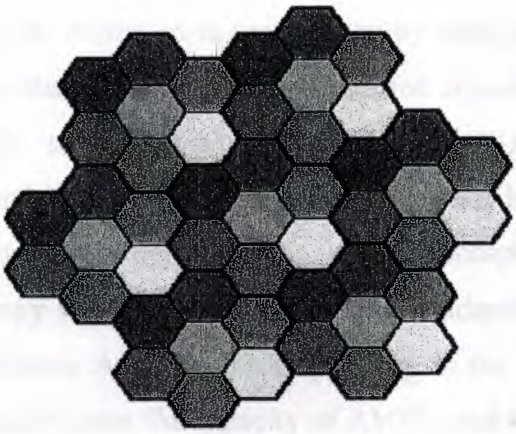


Figure 3.2 There are approximately 57 channels available per cell.

No similarly colored cells are adjacent, and therefore there are no adjacent cells using the same channel. While real systems do not ever look like these idealized hexagonal tailings of a plane, the seven-way reuse is typical of that achieved in practice. The capacity of a K-way reuse pattern is simply the total number of available channels divided by K. With K=7 and 416 channels, there are approximately 57 channels available per cell. At a typical offered load of 0.05 Erlangs per subscriber, each site supports about 1140 subscribers.

3.6.2. Antenna Sectorisation

The pictures above assume that the cells are using omni directional antennas. It might be expected that system capacity could be increased by antenna sectorization. The operators, usually three-ways, in fact sectorize sites. That is, each site is equipped with three sets of directional antennas, with their azimuths separated by 120°. Unfortunately the sectorization does not in practice lead to an increase in capacity. The reason is that the sector-to-sector isolation, often no more than a few dB, is insufficient to guarantee acceptably low interference. Only in part is this due to the poor front-to-back ratio of the antennas. The vagaries of electromagnetic propagation in the real world also conspire to mix signals between sectors. The practical result of sectorization is only an increase in coverage because of the increased forward gain of the directional antenna. Nothing is gained in reuse. The same seven-way cell reuse pattern applies in sectored cells as in omni directional cells. Viewed from the standpoint of sectors, the reuse is K = 7 *3 = 21, instead of 7.

CDMA assigns each subscriber a unique "code" to put multiple users on the same wideband channel at the same time. Both the mobile station and the base station to distinguish between conversations use the codes, called "pseudo-random code sequences". The signals are separated at the receiver by using a correlator that accepts only signal energy from the desired channel. Undesired signals contribute only to the noise.The IS-95 CDMA standard was adopted by the TIA (Telecommunications Industry Association) and became a digital cellular standard in 1992. The J-STD-008 standard for personal communications services was also accepted by ANSI. CDMA is the first digital technology which meets the exacting standards of the CTIA (Cellular Telecommunications Industry Association). Depending on the level of mobility of the system, it provides 10 to 20 times the capacity of AMPS, and 4 to 7 times the capacity of TDMA. CDMA is the only one of the three technologies that can efficiently utilize spectrum allocation and offer service to many subscribers without requiring extensive frequency planning.

3.7. CDMA Concepts

CDMA stands for "Code Division Multiple Access." It is a radically new concept in wireless communications. It is a form of spread-spectrum, an advanced digital wireless transmission technique. The core principle of spread spectrum is the use of noise-like carrier waves, and, as the name implies, bandwidths much wider than that required for simple point-to-point communication at the same data rate.

Instead of using frequencies or time slots, as do traditional technologies, CDMA uses mathematical codes to transmit and distinguish between multiple wireless conversations. Its bandwidth is much wider than that required for simple point-to-point communications at the same data rate because it uses noise-like carrier waves to spread the information contained in a signal of interest over a much greater bandwidth. However, because the conversations taking place are distinguished by digital codes, many users can share the same bandwidth simultaneously.

CDMA changes the nature of the subscriber station from a predominately analog device to a predominately digital device. Commercial applications became possible because of two evolutionary developments. One was the availability of very low cost, high density digital integrated circuits, which reduce the size, weight, and cost of the subscriber stations to an acceptably low level. The other was the realization that optimal multiple access communication requires that all user stations regulate their transmitter powers to the lowest that will achieve adequate signal quality. The advanced methods used in commercial CDMA technology improve capacity, coverage and voice quality, leading to a new generation of wireless networks.

Old-fashioned radio receivers separate stations or channels by filtering in the frequency domain. CDMA receivers do not eliminate analog processing entirely, but they separate communication channels by means of a pseudo-random modulation that is applied and removed in the digital domain, not on the basis of frequency. Multipleusers occupy the same frequency band. This universal frequency reuse is not fortuitous. On the contrary, it is crucial to the very high spectral efficiency that is the hallmark of CDMA.

Handoff is a very important concept in wireless communications. It occurs when a call has to be handed off from one cell to another as the user moves between cells. In a traditional "hard" handoff, at the very least, the person will hear some static or a glitch of some sort because the transmission had to be placed on a new carrier wave. This is relatively acceptable, except in cases when there are no more channels available to any mobile. In this case the call is just dropped, i.e.: the connection to the current cell is broken, and then the connection to the new cell is made. This is known as a "break-before-make" handoff.

Since all cells in CDMA use the same frequency, it is possible to make the connection to the new cell before leaving the current cell. As the mobile nears the boundary of a neighboring cell, it receives transmissions from both cells. The mobile will receive some message from one cell, and some from the other until it has moved into one or the other cells. This is known as a 'make-before-break" or "soft handoff" because the user never experiences any glitch and certainly never a dropped call. Soft handoffs require less power, which reduces interference and increases capacity.

3.8. Coding and modulation

Coding and modulation provide the means of mapping information into waveforms such that the receiver (with an appropriate demodulator and decoder) can recover the information in a reliable manner. The simplest model for a communication system is that of an additive white Gaussian noise (AWGN) system. In this model a user transmits information by sending one of M possible waveforms in a given time, period T, with a given amount of energy. The rate of communication, R, in bits per second is log2(M)/T. The signal occupies a given bandwidth W Hz. The normalized rate of communications is R/W measured in bits/second/Hz. The received signal is the sum of the transmitted signal and white Gaussian noise (noise occupying all frequencies). The optimum receiver for deciding which of the M signals was transmitted filters the received waveform to remove as much noise as possible while retaining as much signal as possible. For a fixed amount of energy, the more waveforms (the larger M) the harder it is for the receiver to distinguish which waveform was transmitted. There is a fundamental tradeoff between the energy efficiency of a communication system and the bandwidth efficiency. This fundamental tradeoff is shown in Fig. 3.3. In this figure the possible normalized rate of transmission (measured in bits per second per Hz) is shown as a function of the received signal-to-noise ratio Eb/N0 for arbitrarily reliable communication. Here, Eb is the amount of energy received per information bit while N0 is the power spectral density of the noise. The curves labeled AWGN place no restrictions on the type of transmitted waveform except that the average energy must be constrained so that the received signal energy per bit is Eb. The curve labeled BPSK restricts the modulation (but not the coding) to binary phase shift keying. The curve labeled QPSK is for quaternary phase shift keying and the 8-PSK curve is for 8-ary phase shift keying. Clearly at low rates and low Eb/N0 there is virtually no loss in using QPSK modulation with the best coding compared to the best modulation and coding. Also shown in the figure is what can be achieved with certain coding schemes. While these curves show the best possible transmission rate for a given energy, no restrictions are placed on the amount of delay incurred and on the complexity of implementation. It has been the goal of communication researchers and engineers to achieve performance close to the fundamental limits with small complexity and delay.

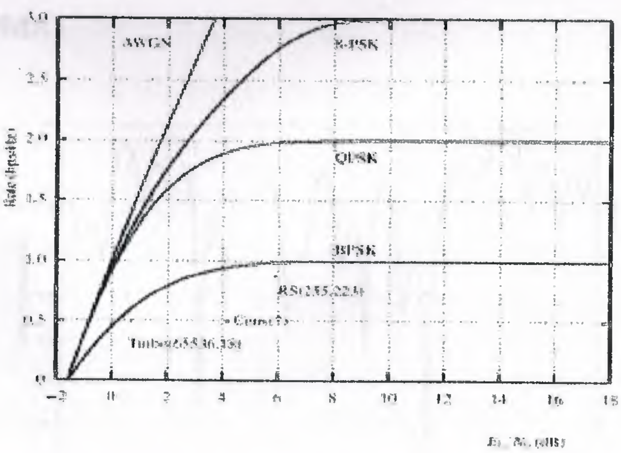


Figure 3.3 Possible transmission rates versus signal-to-noise ratios for an additive white Gaussian noise channel.

For a wireless communications system, the AWGN model is much too simplistic. In a wireless communication system the transmitted signal typically propagates over several distinct paths before reaching the receiving antenna. Depending on the relative phases of the received signal the multiple signals could interfere in a destructive manner or in a constructive manner. The result of the multiple paths is that the received signal amplitude is sometimes attenuated severely when the signals from different paths cancel destructively, while sometimes the signal amplitude becomes relatively large because of constructive interference. The nature of the interference is, in general, time varying and frequency dependent. This is generally called time and frequency selective fading. A typical time response for a multipath fading channel is shown in Fig. 3.4 .The received signal varies more quickly as the vehicle speed increases. In the original analog cellular systems in order to compensate for the multipath fading, the transmitter increased or decreased the amount of transmitted power. As with the additive white Gaussian noise channel, there are fundamental limits on the rate of transmission for a given average received energy-to-noise ratio (Eb/N0). In the simplest model the received signal energy is modeled as a Rayleigh distributed random variable, independent from symbol to symbol. With this assumption the transmissions rates possible, as a function of the average received signal-to-noise ratio, are shown in Fig. 3.5 The gray curves represent the performance possible in an additive white Gaussian noise channel while the dark curves represent the performance with Rayleigh fading. The assumption in this figure is that the channel bandwidth is very narrow and so the result of fading is to only change the amplitude of the signal and not distort the signal in any other way. This is clearly not valid for many communication systems (especially wide bandwidth systems like direct-sequence CDMA).

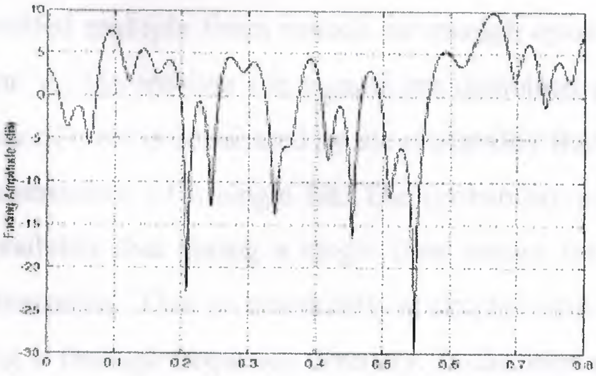


Figure 3.4 Received signal strength as a function of time for vehicle velocity 10 mph.

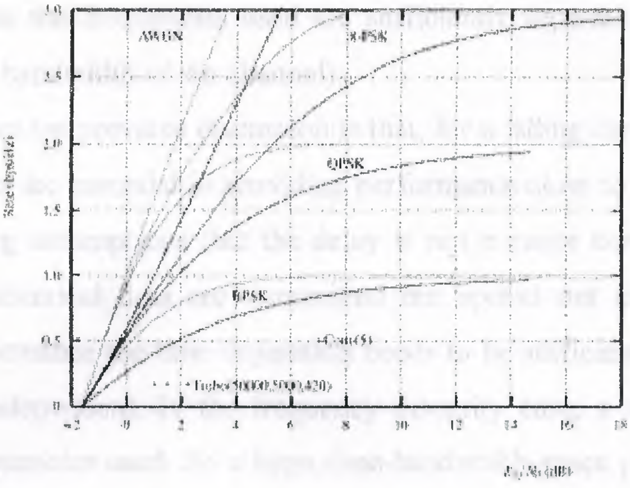


Figure 3.5 Possible transmission rates versus signal-to-noise ratios for a Rayleigh fading channel.

A key observation from this figure is that there is not a significant loss in performance between what is possible in an additive white Gaussian noise channel and what is possible in a fading channel. For example for transmission rates less than 1/2 bps/Hz the loss in performance due to fading is less than 2 dB with the optimal coding and with BPSK modulation. However, for BPSK alone (without coding), the loss in performance compared to white Gaussian noise channels is on the order of 40 dB when the desired error probability is 10-5. This is a huge loss and is due to the fluctuations of the signal amplitude. Basically the fading process sometimes attenuates the signal so that the conditional error probability is close to 1/2. Sometimes the fading accentuates the signal so that the conditional error probability is virtually zero. The average error probability then is dominated by the probability that the fading level is small. This can be overcome with one or a combination of several techniques. Antenna arrays whereby the received signal at different antennas fades independently is one such technique Another technique is time diversity through coding. In the simplest realization of this, information is transmitted multiple times spaced far enough apart (in time) so that the fading is independent. At the receiver the signals are combined appropriately. In this manner the probability of error is dominated by the probability that the fading processes attenuate all the transmissions of a single bit. The probability of this event is much smaller than the probability that during a single time instant the fading process will cause significant attenuation. This is essentially a simple form of coding. Another simple form of coding is through frequency diversity. In this case the same information is transmitted over several different frequencies simultaneously. Because the channel is frequency selective not all the frequencies fade simultaneously. In this way diversity is achieved as long as the frequencies used are sufficiently separated (separation larger than the coherence bandwidth of the channel).

The conclusion from the previous discussion is that, for a fading channel, coding and/or diversity techniques are essential in providing performance close to optimal. As before, there are underlying assumptions that the delay is not a major constraint. In the time diversity system, identical data are transmitted but spread out in time. In order to achieve good performance the time separation needs to be sufficiently large so that the fading is nearly independent. In the frequency diversity case, a similar argument is made with the frequencies used. So a large time-bandwidth-space product is needed in order to achieve reasonable performance. In a wireless system, error control, coding and modulation are used to protect the data not only against the effects of fading but interference as well. Interference will be discussed in the multiple access section.

In 1993 a new coding technique (known as turbo codes) was shown to have exceptional performance in an additive white Gaussian noise environment, coming within 0.7 dB of the fundamental limit for a Gaussian channel with a code with block length on the order of 65,000 bits (Berrou et al. 1993). Since that discovery was made, considerable effort has begun on investigating these codes on other channels and with different block lengths. For an ideal Rayleigh fading channel (independent fades for each symbol) turbo codes with block length 50,000 approach within about 1.5 dB of the fundamental limit when the channel is known perfectly. For the white Gaussian noise channel, low density parity check codes are within 0.01 dB of the fundamental limit when the block length is very large. When the block length is shorter (as required by delay constraints in many applications) then the performance of turbo codes deteriorates to the point that traditional convolutional codes perform better. Third generation cellular systems will employ turbo codes for relatively long (e.g., larger than 300 bits) block length messages. Many different modulation schemes are used in current wireless systems, among these binary phase shift keying (BPSK), Gaussian-filtered minimum shift keying (GMSK), $\pi/4$ DPSK, offset quadrature phase shift keying (OQPSK), and orthogonal frequency division multiplexing (OFDM) (multicarrier). There are a couple key issues when designing a modulation technique. One of these issues is whether the technique uses a constant envelope or a nonconstant envelope. Constant envelope modulation techniques can cope with amplifier nonlinearities but have larger bandwidth than nonconstant envelope modulation techniques. On the other hand, a power amplifier is most energy efficient when operating in the nonlinear region. Nonconstant envelope techniques have smaller bandwidth but need a very linear amplifier to avoid generating both in-band distortion and adjacent channel power. The goal is to have bandwidth efficiency and power efficiency simultaneously. However, with current amplifier designs there is a tradeoff between these two conflicting objectives.

Another key issue when dealing with modulation is intersymbol interference. A wireless channel generally has multipath fading, which causes intersymbol interference if the data symbol duration is the same magnitude or smaller than the delay spread of the channel. As the data rate increases, the amount of (number of symbols affected by) intersymbol interference increases. This generally increases the complexity of the receiver. One method to avoid this is to transmit information on many different carrier frequencies simultaneously. This makes the symbol duration on each carrier much longer (by a factor equal to the number of carriers) and thus decreases the amount of intersymbol interference. However, multicarrier modulation techniques have a particularly high fluctuation of the signal envelope; and thus to avoid generating unwanted signals (in-band or adjacent channel) an amplifier with high backoff (low input drive level) is required, which means that the energy efficiency will be very small.

Another approach to dealing with multipath fading is to use wide bandwidth modulation techniques, generally referred to as spread-spectrum techniques. Because of the frequency and time selective nature of the wireless channel, a narrowband signal might experience a deep fade if the phases from multiple paths add up in a destructive manner at the receiver. These deep fades generally need extra protection to prevent errors by either increasing the power or adding additional redundancy for error control coding. On the other hand, if the signal has a wide bandwidth (relative to the inverse of the delay spread) then not all the frequencies in a given band will simultaneously be in a deep fade. As such the signal from the part of the spectrum that is not faded can still be recovered. One realization of this idea is that of a direct-sequence system that uses a Rake receiver to "collect" the energy from several paths (at different delays). The probability of all of the paths fading simultaneously becomes much smaller than the probability of one of the paths fading. Because of this the performance is significantly improved compared to a narrow-band system. However, the performance is limited by the bandwidth available.

3.9. CDMA Process Gain

One of the most important concepts required in order to understand spread spectrum techniques is the idea of process gain. The process gain of a system indicates the gain or signal to noise improvement exhibited by a spread spectrum system by the nature of the spreading and dispreading process. The process gain of a system is equal to the ratio of the spread spectrum bandwidth used, to the original information bandwidth. Thus, the process gain can be written as:

$$Gp = \frac{BW_{RF}}{BW_{info}}$$

Where BWRF is the transmitted bandwidth after the data is spread, and BWinfo is the bandwidth of the information data being sent.

Figure 3.6 shows the process of a CDMA transmission. The data to be transmitted

(a) Is spread before transmission by modulating the data using a PN code. This broadens the spectrum as shown in (b) In this example the process gain is 125 as the spread spectrum bandwidth is 125 times greater the data bandwidth. Part (c) Shows the received signal. This consists of the required signal, plus background noise, and any interference from other CDMA users or radio sources. The received signal is recovered by multiplying the signal by the original spreading code. This process causes the wanted received signal to be despread back to the original transmitted data. However, all other signals that are uncorrelated to the PN spreading code become more spread. The wanted signal in (d) is then filtered removing the wide spread interference and noise signals.

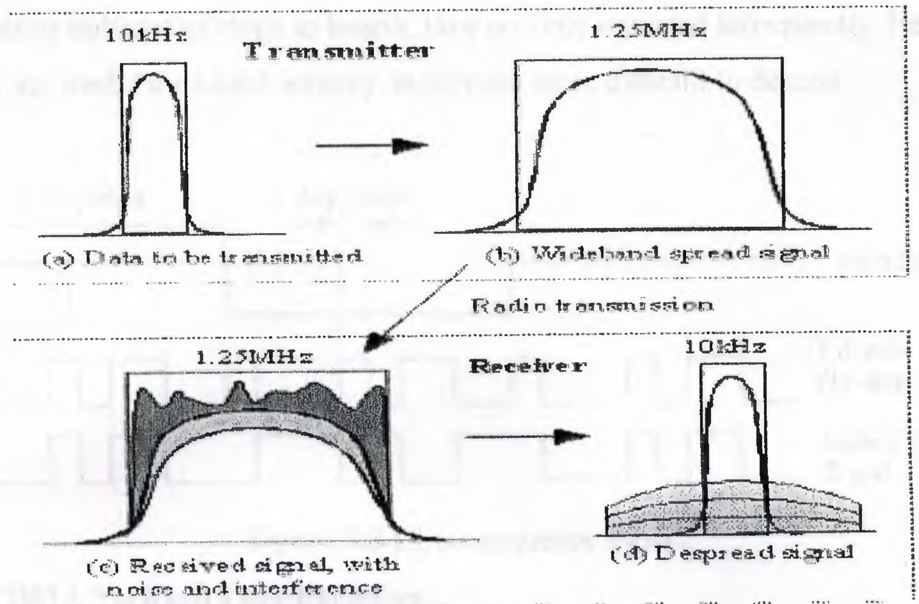


Figure 3.6 Basic CDMA transmissions.

3.9.1. CDMA Generation

CDMA is achieved by modulating the data signal by a pseudo random noise sequence (PN code), which has a chip rate higher then the bit rate of the data. The PN code sequence is a sequence of ones and zeros (called chips), which alternate in a random fashion. Modulating the data with this PN sequence generates the CDMA signal. The CDMA signal is generated by modulating the data by the PN sequence. The modulation is performed by multiplying the data (XOR operator for binary signals) with the PN sequence. Figure 3.7 shows a basic CDMA transmitter.

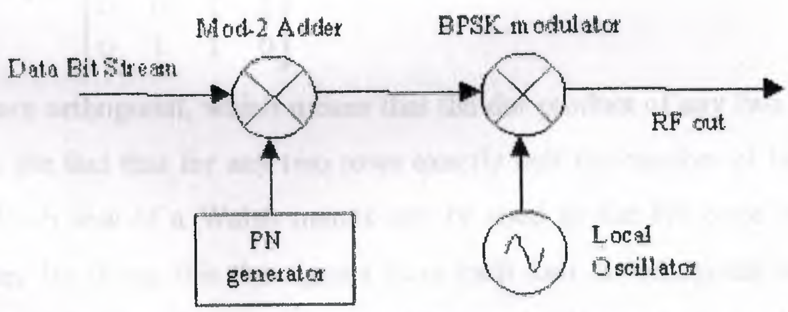


Figure 3.7 Simple direct sequence modulator

The PN code used to spread the data can be of two main types. A short PN code (typically 10-128 chips in length) can be used to modulate each data bit. The short PN code is then repeated for every data bit allowing for quick and simple synchronization of the receiver. Figure 3.8 shows the generation of a CDMA signal using a 10-chip length short code. Alternatively a long PN code can be used. Long codes are generally thousands to millions of chips in length, thus are only repeated infrequently. Because of this they are useful for added security as they are more difficult to decode.

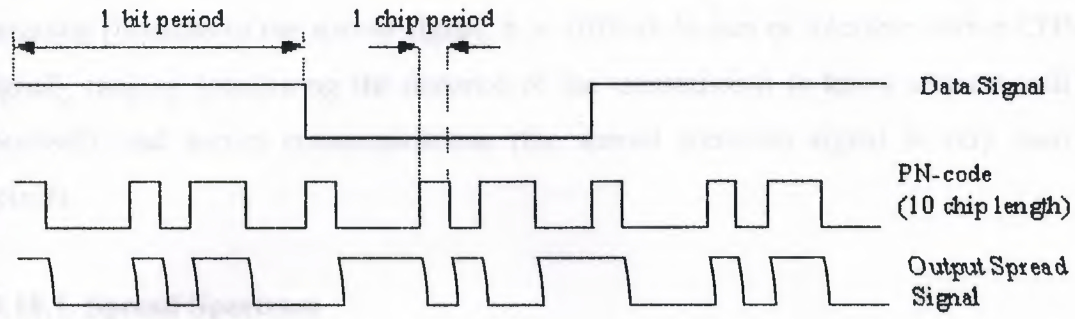


Figure 3.8 Direct sequence signals

3.9.2. CDMA Forward Link Encoding

The forward link, from the base station to the mobile, of a CDMA system can use special orthogonal PN codes, called Walsh codes, for separating the multiple users on the same channel. These are based on a Walsh matrix, which is a square matrix with binary elements and dimensions that are a power of two. It is generated from the basis that Walsh(1) = W1 = 0 and that:

$$W_{2n} = \begin{bmatrix} W_n & W_n \\ W_n & \overline{W_n} \end{bmatrix}$$

Where Wn is the Walsh matrix of dimension n. For example:

$$W_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \quad W_4 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

Walsh codes are orthogonal, which means that the dot product of any two rows is zero. This is due to the fact that for any two rows exactly half the number of bits match and half do not. Each row of a Walsh matrix can be used as the PN code of a user in a CDMA system. By doing this the signals from each user is orthogonal to every other user, resulting in no interference between the signals. However, in order for Walsh codes to work the transmitted chips from all users must be synchronized. If the Walsh code used by one user is shifted in time by more than about 1/10 of chip period, with respect to all the other Walsh codes, it looses its orthogonal nature resulting in inter-user interference. This is not a problem for the forward link as signals for all the users originate from the base station, ensuring that all the signal remain synchronized.

3.10. CDMA Technology

Though CDMA's application in cellular telephony is relatively new, it is not a new technology. CDMA has been used in many military applications, such as anti-jamming (because of the spread signal, it is difficult to jam or interfere with a CDMA signal), ranging (measuring the distance of the transmission to know when it will be received), and secure communications (the spread spectrum signal is very hard to detect).

3.10.1. Spread Spectrum

CDMA is a "spread spectrum" technology, which means that it spreads the information contained in a particular signal of interest over a much greater bandwidth than the original signal.

A CDMA call starts with a standard rate of 9600 bits per second (9.6 kilobits per second). This is then spread to a transmitted rate of about 1.23 Megabits per second. Spreading means that digital codes are applied to the data bits associated with users in a cell. These data bits are transmitted along with the signals of all the other users in that cell. When the signal is received, the codes are removed from the desired signal, separating the users and returning the call to a rate of 9600 bps.

Traditional uses of spread spectrum are in military operations. Because of the wide bandwidth of a spread spectrum signal, it is very difficult to jam, difficult to interfere with, and difficult to identify. This is in contrast to technologies using a narrower bandwidth of frequencies. Since a wideband spread spectrum signal is very hard to detect, it appears as nothing more than a slight rise in the "noise floor" or interference level. With other technologies, the power of the signal is concentrated in a narrower band, which makes it easier to detect.

Increased privacy is inherent in CDMA technology. CDMA phone calls will be secure from the casual eavesdropper since, unlike an analog conversation, a simple radio receiver will not be able to pick individual digital conversations out of the overall RF radiation in a frequency band.

3.10.2. Synchronization

In the final stages of the encoding of the radio link from the base station to the mobile, CDMA adds a special "pseudo-random code" to the signal that repeats itself after a finite amount of time. Base stations in the system distinguish themselves from each other by transmitting different portions of the code at a given time. In other words, the base stations transmit time offset versions of the same pseudo-random code. In order to assure that the time offsets used remain unique from each other, CDMA stations must remain synchronized to a common time reference.The Global Positioning System (GPS) provides this precise common time reference. GPS is a satellite based, radio navigation system capable of providing a practical and affordable means of determining continuous position, velocity, and time to an unlimited number of users.

3.10.3. The Balancing Act

CDMA cell coverage is dependent upon the way the system is designed. In fact, three primary system characteristics-Coverage, Quality, and Capacity-must be balanced off of each other to arrive at the desired level of system performance.In a CDMA system these three characteristics are tightly inter-related. Even higher capacity might be achieved through some degree of degradation in coverage and/or quality. Since these parameters are all intertwined, operators cannot have the best of all worlds: three times wider coverage, 40 times capacity, and "CD" quality sound. For example, the 13 kbps vocoder provides better sound quality, but reduces system capacity as compared to an 8 kbps vocoder.

3.10.4. CDMA Benefits

When implemented in a cellular telephone system, CDMA technology offers numerous benefits to the cellular operators and their subscribers. The following is an overview of the benefits of CDMA:

- Capacity increases of 8 to 10 times that of an AMPS analog system and 4 to 5 times that of a GSM system
- Improved call quality, with better and more consistent sound as compared to AMPS systems
- Simplified system planning through the use of the same frequency in every sector of every cell
- Enhanced privacy
- Improved coverage characteristics, allowing for the possibility of fewer cell sites
- Increased talk time for portables

- Bandwidth on demand

3.11. The Objectives of CDMA

CDMA will enable new wireless business models. Greater network capacity means less reliance on usage-based pricing and more use of advertising-subsidized and e-commerce-based models. CDMA's robust data performance leads the way to a plethora of enhanced services. This course provides a technical and business overview of current and coming CDMA technologies, starting with a review of CDMA fundamentals and the 2G IS-95 standard. It then offers detailed explanations of the prominent 3G wideband CDMA implementations, including TIA cdma2000 and ETSI/ARIB W-CDMA, so that you and your organization can be ready to meet the coming challenges. Since the new 3G-CDMA standards are constantly evolving, this course prepares the technical professional to understand and interpret virtually any CDMA standard that is defined or that may emerge.

3.12. Spread Spectrum and CDMA

3.12.1. Curriculum of the CDMA

1. Importance of optimal signal choice in a system design concise historical survey.

2. Classical reception procedures and signal design problems. Detection, recognition, parameter estimation in relation with the problem of optimal signal choice. Spread spectrum (SS) signals. Independence of detection and binary recognition of signal modulation. Attractiveness and necessity of SS signal application in M-ary data transmission, time-frequency measuring and signal resolution.

3. Advantages of spread spectrum: jamming and interference immunity. High immunity of SS signals to CW/narrow-band jamming and bandpass noise interference. Compatibility of SS systems with the traditional ones and each other. SS as the only way to design "covert" systems and to provide low interception probability. Feasibility of time diversity and multi-path fading suppression with the aid of SS.

4. Advantages of spread spectrum: multi-user network capacity. Multiple access problem within limited time-frequency resource and maximal number of users

(users capacity). Equivalence of all orthogonal division modes (FDMA, TDMA and synchronous CDMA) in users capacity. Asynchronous and overloaded synchronous CDMA: gain in capacity in networks with cellular geometry.

3.12.2. The Euro-Asian Alternative of GSM

Analysts consider Qualcomm's major competitive disadvantage to be its lack of access to the European market now controlled by Global System for Mobile communications (GSM). The wireless world is now divided into GSM (much of Western Europe) and CDMA (North America and parts of Asia).
Bad timing may have prevented the evolution of one, single global wireless standard. Just two years before CDMA's 1995 introduction in Hong Kong, European carriers and manufacturers chose to support the first available digital technology - Time Division Multiple Access (TDMA). GSM uses TDMA as its core technology. Therefore, since the majority of wireless users are in Europe and Asia, GSM has taken the worldwide lead as the technology of choice.
Mobile Handset manufacturers ultimately split into two camps, as Motorola, Lucent, and Nextel chose CDMA, and Nokia and Ericsson eventually pushed these companies out and became the dominant GSM players.

3.12.3. Advantages of GSM

GSM is already used worldwide with over 450 million subscribers. International roaming permits subscribers to use one phone throughout Western Europe. CDMA will work in Asia, but not France, Germany, the U.K. and other popular European destinations. GSM is mature, having started in the mid-80s. This maturity means a more stable network with robust features. CDMA is still building its network. GSM's maturity means engineers cut their teeth on the technology, creating an unconscious preference. The availability of Subscriber Identity Modules, which are smart cards that provide secure data encryption give GSM m-commerce advantages. In brief, GSM is a "more elegant way to upgrade to 3G," says Strategis Group senior wireless analyst Adam Guy.

3.13. CDMA Architecture

Several CDMA receiver architectures have been proposed. One of these new receivers consists of LMS architecture and can adapt to varying channel characteristics. More recently, we proposed the use of coding techniques to improve the performance of the CDMA receiver. In this paper, we analyze the resources required to implement both the matched and LMS filter structures. We calculate the overhead necessary to achieve the improved performance using the LMS structures. Next we analyze the overhead necessary to add coding to the receiver structure. We demonstrate that with minimal resource overhead, the convolutionally-coded system has significantly improved signal to noise ratio over a conventional CDMA receiver.

The simplest code division multiple access (CDMA) receiver utilizes a matching filter to separate the appropriate output signal from the received baseband signal. Two problems exist with wireless CDMA systems: the near-far effect and the multipath problem. These problems greatly increase the bit error rate of the data demodulated by a conventional CDMA receiver. A solution to these problems is the use of adaptive filter receivers . The adaptive filter receiver has the capability to adapt to varying channel characteristics. More recently we proposed the addition of coding within the CDMA filter receiver to further improve the filter performance . We know that error correction codes can improve the performance of digital systems by lowering the required signal-to-noise ratio while increasing the required bandwidth. In fact, with very low rate convolutional codes in additive white Gaussian noise channels, it is possible to achieve the ultimate channel capacity. By using convolutional codes within the CDMA filter receiver we were able to demonstrate improved bit error rates (BERs) at equivalent signal-to-noise ratios.

In this paper we analyze the resource requirements of the receiver architectures needed to implement the CDMA receiver models. We begin by analyzing the matched filter and LMS filter implementations. With the LMS structure it is possible to achieve BERs that are not possible with the matched filter structure. We calculate the overhead necessary to reach this performance level. Furthermore, the use of coding substantially improves performance for both the LMS and matched filter structures. We demonstrate that this additional performance comes at very minimal cost especially when compared to the cost of the LMS structure.

3.13.1. CDMA Models

The structures of the matched filter and the adaptive filter CDMA receivers are well known . In this section, we briefly describe the additional blocks needed within these structures to support convolutionally coded signals.

The convolutionally coded baseband CDMA transmitter is shown in Fig.1. In this model, the data source produces the transmitted data stream. A k bit input is shifted into the convolutional encoder and an n bit output symbol is produced (rate k/n coder). Here k=1,and n=2. We used a rate ½ encoder with 4 states. Each bit of the coded symbol spans one complete PN (pseudo-noise) sequence period.. Demodulation of coded CDMA signals is conventionally achieved with a matched filter receiver, as shown in Figure 3.10

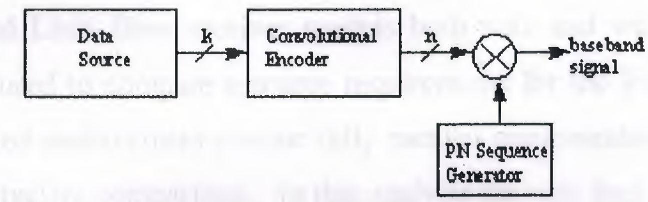


Figure 3.10 Convolutionally coded CDMA transmitter.

The adaptive LMS filter receiver for the convolutionally coded CDMA system is shown in Figure 3.11 The receiver consists of an LMS filter and a Viterbi decoder.

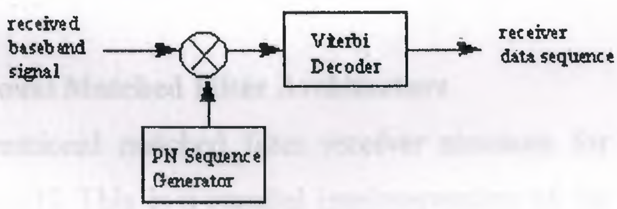


Figure 3.11 conventional receivers for the convolutionally coded CDMA system.

Here, we use an N-tap adaptive LMS filter receiver to minimize the mean squared error (MSE) between the desired signal and the received signal when N is the length of the PN sequence. We assume that the receiver has the knowledge of the PN sequence.

Figure 3.12 Adaptive LMS filter receiver for the convolutionally coded CDMA system.

We have shown in that an adaptive LMS filter receiver in a CDMA system has significantly better BER than that achieved by using a conventional matched filter receiver. With the addition of forward error correction capability this performance can be enhanced even more. In we have shown that for K=6 users, and Npath=4 multipaths and PN sequence length N=127 with rate ½ convolutional code, one can achieve about 2 dB coding gain by using the adaptive LMS filter receiver in AWGN channel. In a

Rayleigh fading channel, for the same parameters, one can achieve 7 dB coding gain. So, it is shown that by using adaptive LMS filter receiver instead of conventional matched filter receiver one can enhance the performance of the CDMA system. In this section we will calculate the resources needed to implement the adaptive LMS filter receiver for the CDMA system. There are four different architectures that we will look at: matched filter receiver, matched filter receiver with Viterbi decoder, LMS filter receiver, and LMS filter receiver with Viterbi decoder.

In the next few sections, we present several architectures used to implement the matched filter and LMS filter receiver models both with and without coding. These architectures are used to compare resource requirements for the four different models. All of the presented architectures assume fully parallel implementations. This is simply to provide an equivalent comparison. In this analysis we only look at the area required by each model. The parallel implementations have similar latency requirements for each model and will be analyzed in a future paper. Additional improvements to the area and throughput requirements for each architecture can be made by using bit-serial architectures or by using pipelining , or unfolding .

3.13.2. Conventional Matched Filter Architecture

The conventional matched filter receiver structure for a CDMA receiver is shown in Figure 3.12 This is a parallel implementation of the conventional matched filter Receiver. To compare the matched filter receiver architecture with the convolutionally coded CDMA system architecture, we need to define some parameters. We assume that the input signal width is a bits and the PN sequence chip width is b bits. Then the system in Fig.4 needs Naxb bit multipliers and (N-1)c bit adders. We will fix a, b, and c later in the paper. The superscripts are used throughout the paper to show the size of the adders and the multipliers.

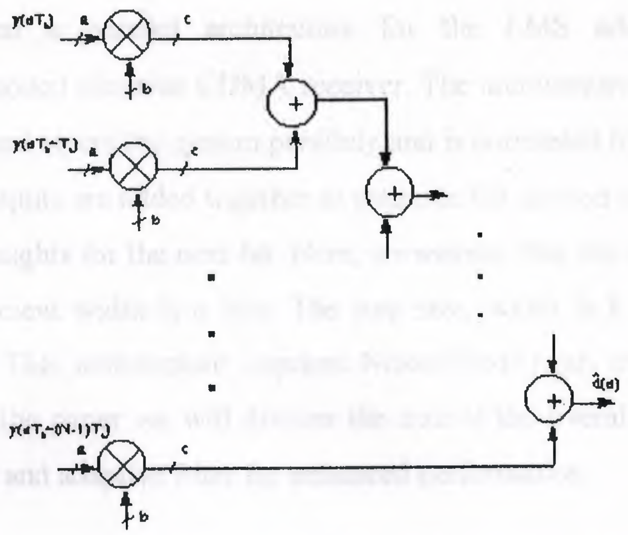


Figure 3.13 Conventional matched filter receiver.

3.13.3. Adaptive LMS Filter Architecture

The LMS adaptive filter structure for a CDMA receiver is shown in Figure 3.13 The purpose of the adaptive filter is to find the best tap weights, W's necessary to minimize the desired error, e. The error equation and the update equation of the LMS adaptive filter are defined as: $e[n] = d[n] - \hat{d}[n]$

Where $\hat{d}[n] = y^T[n]w[n]$, $w[n] = [W_1, W_2, \cdots, W_N]^T$

And $y[n] = [y(nT_b), y(nT_b + T_C), \cdots, y(nT_b + (N-1)T_C)]^T$ where Tb is the bit period, Tc is the chip period, and N is the processing gain defined as Tb/ Tc. As we can see from Figure 3.14 is the input signal to the adaptive filter, and is the step-size parameter.

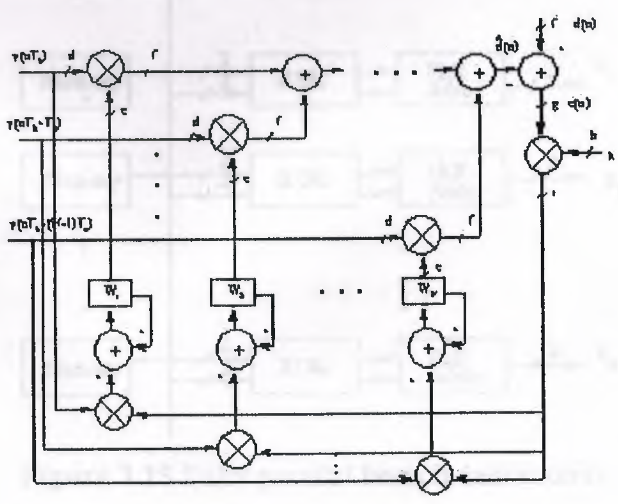


Figure 3.14 Parallel adaptive LMS filter architecture

We have chosen a parallel architecture for the LMS adaptive filter for the convolutionally coded adaptive CDMA receiver. The architecture of the filter is shown in Fig.5. The signal enters the system parallely and is correlated by the filter tap weights parallely. The outputs are added together to estimate the desired signal which is used to update the tap weights for the next bit. Here, we assume that the input signal width is d bits, filter coefficient width is e bits. The step size, width is h bits. The error signal width is g bits. This architecture requires Ndxe+Nexi+1gxh multipliers and Ne+Nf adders. Later in the paper we will discuss the size of the overall architecture together with the decoder and adaptive filter for enhanced performance.

3.13.4. Hard Decision Viterbi Decoder

The hard decision Viterbi decoder architecture is shown in Figure 3.14-3.15 This is a parallel hardware implementation of the Viterbi algorithm. Fig.6 shows the architecture of a branch metric unit (BMU). The BMU iteratively calculates the hamming distance between the received codewords and all possible codewords. The architecture for the BMU consists of 24 XOR gates, 8 AND gates, and 8 memory elements. The size of the BMU is fixed for a fixed encoder design. In our case we used a rate ½ convolutional encoder with generators 58 and 78. For a hard decision Viterbi decoder the size of the BMU is fixed and depends only on the number of states for the encoder and the number of possible outputs from each state. In our case the number of states is 4 and there are 2 possible outputs from each state.

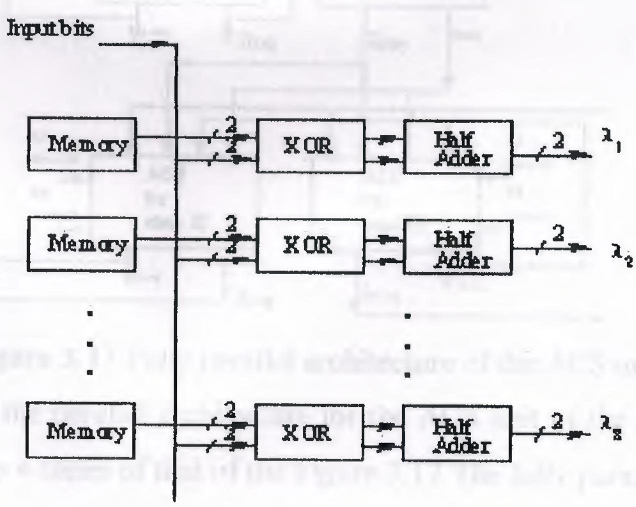


Figure 3.15 Fully parallel branch metric units

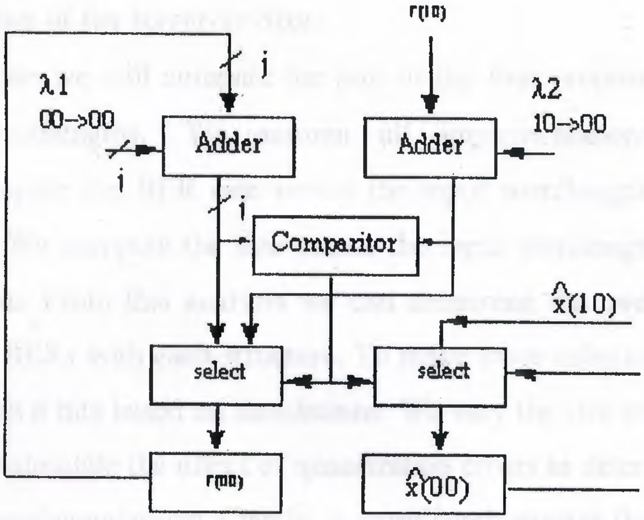


Figure 3.16 Add-Compare-Select Unit

Figure 3.16 shows the architecture of an add, compare and select unit (ACSU) for state 00. The size of the ACSU depends on the length of the trace back path that defines the size of the comparitor, the multiplexes, the registers and the adders. In our design we chose the trace back path to be 15. The encoder had L=3 memory elements, so the trace back path can be chosen as 5*L=15 which is sufficient to decode the received bits. The ACSU consists of 2 full adder (j bits), 2 comparators (j bits), 2 select units (2:1 2j bit multiplexer) and 2 storage elements of size 2j.

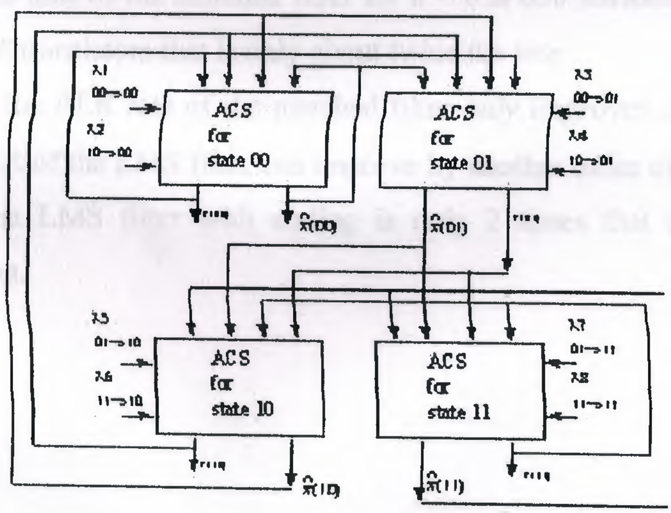


Figure 3.17 Fully parallel architecture of the ACS unit.

Figure 3.17 shows the parallel architecture for the ACS unit of the decoder. The total size of the ACSU is 4 times of that of the Figure 3.17 The fully parallel Viterbi decoder requires 9.5Ktransistors. This is quite small compared to the size of the matched filter and the LMS filter receiver.

3.13.5. Computation of the Receiver Size

In this section we will compare the size of the four proposed architectures for varying input wordlengths. We assume all implementations use fixed-point structures. We compute the BER rate versus the input wordlength for each structure using simulations. We compute the size versus the input wordlength of each structure through calculations. From this analysis we can determine the overhead necessary to achieve improved BERs with each structure. To make these calculations, we assume b is implemented with 6 bits based on simulations. We vary the size of a and c in tandem. In Figure 3.18, we simulate the effect of quantization errors to determine when they no longer affect the implementations. Clearly, a wordlength greater than 4 is required. In Figure 3.18 we show the affects of BER versus wordlength. The BER was determined using simulation. In Figure 3.19 we show the size of the receiver structures versus wordlength. The size of the receiver structures is determined based on the analysis in Sections 3, 4 and 5. The gate count for each functional block has been translated to a transistor count assuming a CMOS implementation. Clearly the LMS filter without coding provides substantial improvement over the matched filter. For example at a wordlength of a= 8 the BER rate for the matched filter is 0.03 and for LMS filter the BER is 0.0018. Thus the LMS filter provides an order of magnitude improvement. Meanwhile the size of the matched filter for a = 8 is 638 Ktransistors and for the LMS filter is 1304 Ktransistors that is only about twice the size.

With coding, the BER rate of the matched filter only improves slightly. However with coding the BER of the LMS filter can improve by another order of magnitude. However the size of the LMS filter with coding is only 2 times that of the matched filter implementation.

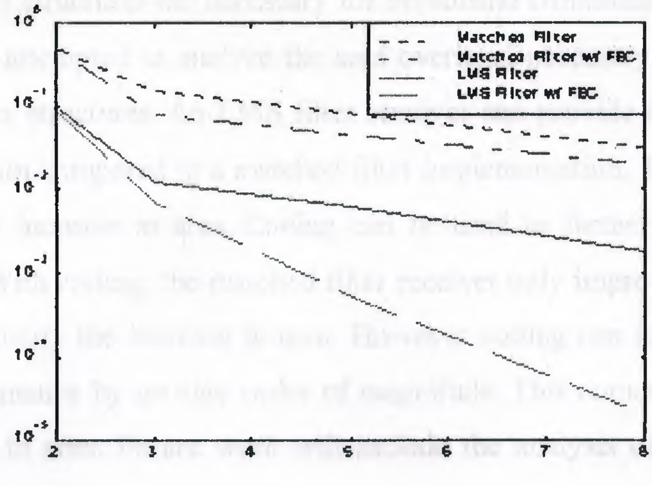


Figure 3.18 BER vs. word size for a CDMA system.

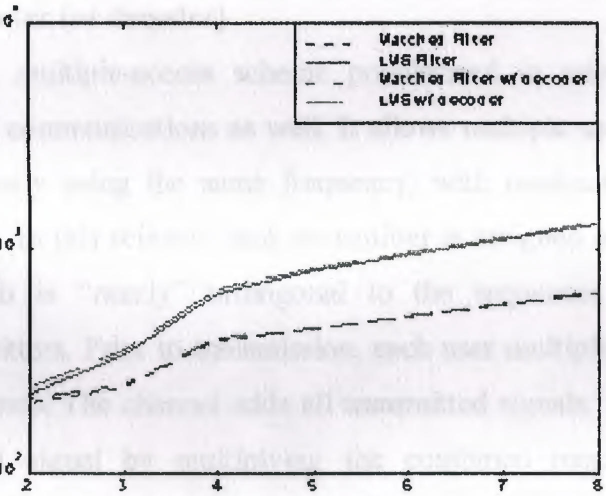


Figure 3.19 Receiver size vs. word length for four different architectures.

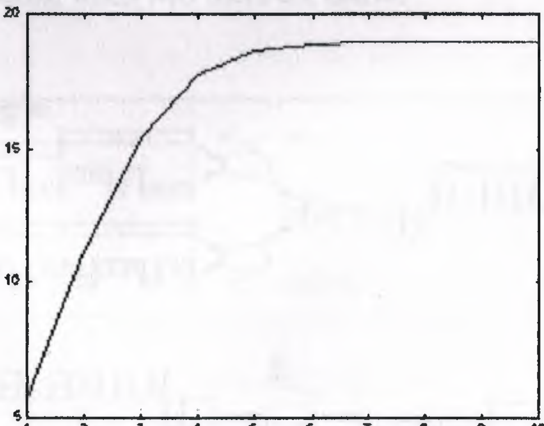


Figure 3.20 Signal to noise ratio at the output vs. number of quantization levels.

CDMA receiver structures are necessary for broadband communication systems. In this paper we have attempted to analyze the area overhead necessary to implement various CDMA receiver structures. An LMS filter receiver can provide an order of magnitude performance gain compared to a matched filter implementation. This comes at a cost of only a 2 times increase in area. Coding can be used to further improve the receiver performance. With coding, the matched filter receiver only improves by a small amount and does not justify the increase in area. However coding can improve the LMS filter receiver performance by another order of magnitude. This comes at a cost of only a 2 times increase in area. Future work will include the analysis of throughput for these filter structures.

3.13.6. CDMA Encoder (or decoder)

CDMA is a multiple-access scheme popularized in wireless channels, but applicable to optical communications as well. It allows multiple users to "coexist" and transmit simultaneously using the same frequency, with minimal interference under favorable conditions. In this scheme, each transmitter is assigned a unique sequence of short "chips" which is "nearly" orthogonal to the sequences assigned to other simultaneous transmitters. Prior to transmission, each user multiplies its data signal by its "chipping" sequence. The channel adds all transmitted signals. But the decoder can retrieve the desired signal by multiplying the combined received signal by the "signature" of the desired transmitter. The following illustration, from "Computer Networking…" by J. F. Kurose and K. W. Ross is a useful description of the encoding/decoding process, when two users are active.

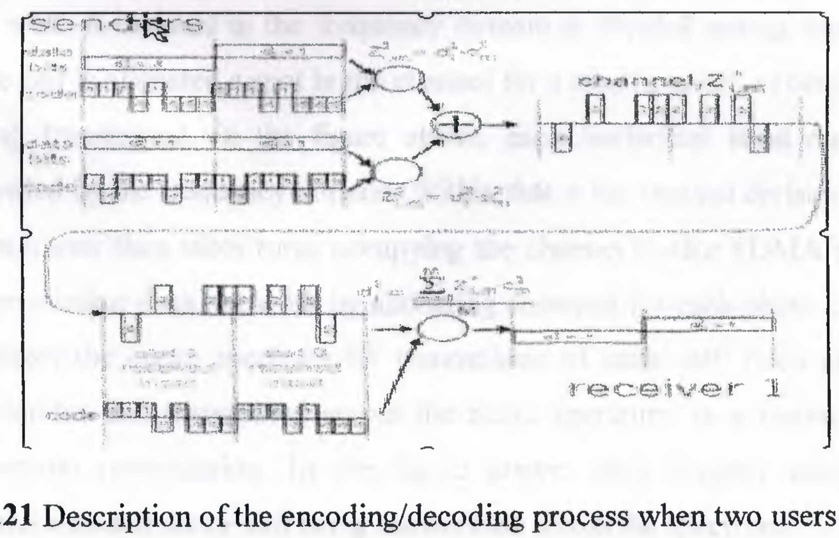


Figure 3.21 Description of the encoding/decoding process when two users are active.

In any CDMA application, the encoder (which works almost identically as a decoder) plays a central role. Below is a schematic diagram of how this can be done in an optical domain. . (Zhang, ET. Al (1998)). The "bubbles" represent optical buffers, which delay the original ultra-short optical pulse, giving rise to a pulse sequence representing an optical CDMA signature.

3.14. FDMA TDMA and CDMA: What's the difference?

Three of the more common transmission schemes include FDMA (Frequency Division Multiple Access), TDMA (Time Division Multiple Access), and CDMA (Code Division Multiple Access).

To better understand CDMA and how it is different, let's compare the three transmission schemes FDMA divides the given spectrum into channels by the frequency domain. Each phone call is allocated one channel for the entire duration of the call. In the figure above, each band represents one call.

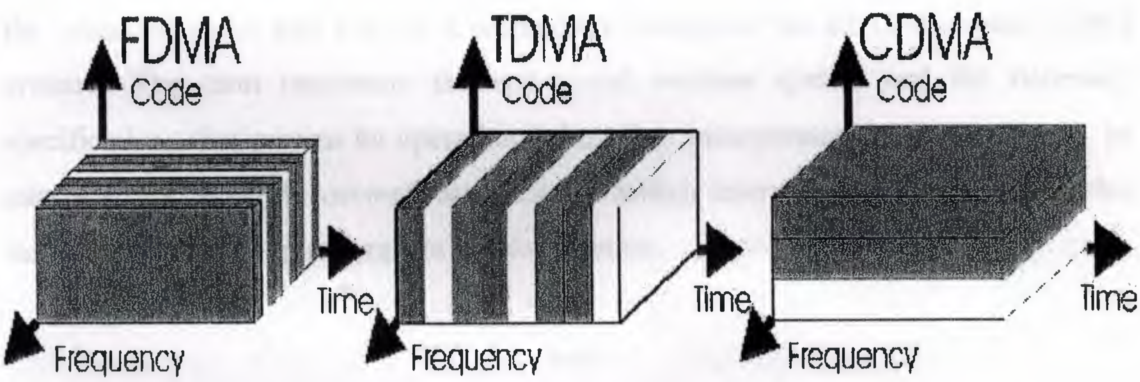
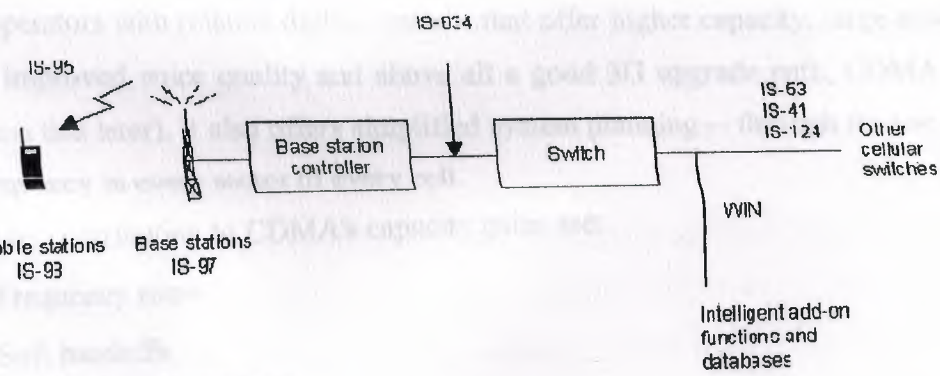


Figure 3.22 FDMA, TDMA, and CDMA

TDMA enhances FDMA by further dividing the spectrum into channels by the time domain as well. A channel in the frequency domain is divided among multiple users. Each phone call is allocated a spot in the channel for a small amount of time, and "takes turns" being transmitted. In the figure above, each horizontal band represents the channel divided by the frequency domain. Within that is the vertical division in the time domain. Each user then takes turns occupying the channel.Unlike FDMA and TDMA, CDMA transmission does not work by allocating channels for each phone call. Instead, CDMA utilizes the entire spectrum for transmisson of each call. Each phone call is uniquely encoded and transmitted across the entire spectrum, in a manner known as spread spectrum transmission. In the figure above, each brightly colored pattern represents the encoded phone call being transmitted across the spectrum.

3.14.1. (CDMA) Technology (IS-95) (cdmaOne)

The CDMA technology used in North America is based on the IS-95 protocol standard first developed by QUALCOMM. CDMA differs from the other two technologies by its use of spread spectrum techniques for transmitting voice or data over the air. Rather than dividing RF spectrum into separate user channels by frequency slices or time slots, spread spectrum technology separates users by assigning them digital codes within the same broad spectrum. Advantages of CDMA technology include high user capacity and immunity from interference by other signals. Like TDMA IS-136, CDMA operates in the 1900-MHz band as well as the 800 band. Work on developing the CDMA standard is conducted mainly by the CDMA Development Group (CDG), a consortium of the main CDMA manufacturers and operators formed to standardize and promote CDMA technology. Whilst work to develop CDMA as a third-generation technology has attracted a great deal of attention over recent months, the CDG has also been working to improve the current performance of CDMA as a second-generation technology. The CDMA Development Group (CDG) has formally adopted the cdmaOne name and logo as a technology designator for all IS-95-based CDMA systems. The term represents the end-to-end wireless system and the necessary specifications that govern its operation. cdma One incorporates the IS-95 CDMA air interface, the ANSI-41 network standard for switch interconnection and many other standards that make up a complete wireless system.



Source: CDMA Development Group

Figure 3.23 The CDMA Development Group (CDG) has formally adopted the cdmaOne name and logo as a technology designator for all IS-95-based CDMA systems.

The CDMA technology, used in the Interim Standard IS-95, maximizes spectrum efficiency and enables more calls to be carried over a single 1.25 MHz channel. In a CDMA system each digitized voice is assigned a binary sequence that directs the proper response signal to the corresponding user. The receiver demodulates the signal using the appropriate code. The resulting audio signal will contain only the intended conversation, eliminating any background noise. This allows more calls to occupy the same space in the communication channel, thereby increasing capacity. As a simple, example let us assume a user is talking into a mobile phone on a CDMA network. The transmitted portion of a voice signal has frequency components from approximately 300~3400 Hz. This analog signal is digitally encoded, using QPSK (Quadrature Phase Shift Keying), at 9600 bps. The signal is then spread to approximately 1.23 Mbps using special codes that add redundancy. Some of these codes include a device ID that is unique to the phone (like a serial number). Next the signal is broadcast over the channel. When broadcast, the signal is added to the signals of the other users in the channel. On the receiving end, the same code is used to decode the incoming signal. The 9600 bps signal is obtained and the original analog signal is reconstructed. When the same code is used on another user's signal, the redundancy is not removed and the signal remains at 1.23 Mbps. The problems are the quality of reception and voice squeakiness. To address this major PCS carriers are using 13 kbps vocoders instead of 10 kbps. This improves quality but at the cost of capacity. The technology has been widely adopted by major cellular and PCS carriers in the United States and also internationally. CDMA networks provide operators with reliable digital systems that offer higher capacity, large coverage area and improved voice quality and above all a good 3G upgrade path, CDMA 2000 (I'll discuss this later). It also offers simplified system planning -- through the use of the same frequency in every sector of every cell.

Factors contributing to CDMA's capacity gains are:

- Frequency reuse
- Soft handoffs
- Power control,
- Variable rate vocoders

Some of the benefits of using cdmaOne are:

- Capacity gains of eight to ten times that of AMPS analog systems

- Improved call quality, with better and more consistent sound as compared to AMPS systems
- Simplified system planning through the use of the same frequency in every sector of every cell
- Enhanced privacy through the spreading of voice signals
- Improved coverage characteristics, allowing for fewer cell sites
- Increased talk-time for portables

cdmaOne technology improves quality of service through the use of soft handoffs, which greatly reduce the number of dropped calls and ensure a smooth transition between cells. In soft handoff, a connection is made to the new cell while maintaining the connection with the original cell. This transition between cells is one that is almost undetectable to the subscriber. cdmaOne technology also takes advantage of multipath fading to enhance communications and voice quality. Using a rake receiver and other improved signal-processing techniques, each mobile station selects the three strongest multipath signals and coherently combines them to produce an enhanced signal.

The cdmaOne data capabilities are based on IS-95A, which can provide data speeds of 14.4kbit/s. IS-95B and IS-95C are designed to enhance CDMA's data capability. IS-95B can provide data speeds of up to 64kbit/s by aggregating existing channels. IS 95-B can provide these enhanced data rates through software upgrades only. IS-95C aims to offer a minimum of 24.4kbit/s per channel and aggregated data speeds of more than 115kbit/s. It is expected that IS-95C will define CDMA's capability as a third-generation system. CDMA already supports asynchronous data and faxing (IS-99) and has standardized packet data (IS-657).

The major development initiatives being taken by the CDG for 2G CDMA systems enhancements include Enhanced roaming enables transparent roaming across cellular and PCS networks, with selection of networks and location services. Enhanced roaming will provide roaming between CDMA systems similar to that on GSM: registration, authentication and credit-checking are automatically carried out between the networks without users having to do anything more than switch on their mobiles. Roaming agreements will still be needed between operators.

3.15. Features of CDMA

3.15.1. Multi-path

One of the amazing things about CDMA is that many of its benefits occur in urban environments where they are needed the most. One such feature is CDMA's use of a Rake correlator, which actually allows CDMA implementations to benefit from multi-path signal propagation, which often occurs when signals bounce off of and between buildings. This is an important benefit because it allows CDMA phones to have lower power output; this lengthens battery life but more importantly allows for more cells to be crammed into urban areas where there is a greater need for more capacity. A Rake correlator works by taking advantage of the way that pseudo-random codes are almost orthogonal to slightly delayed versions of themselves. This means that a receiver can take a matched filter and sift it through the received signal to find where the signal peaks. Then the receiver sums the signals from the various paths and thus the signal strength from each of the multi-paths adds to the signal strength instead of the noise. In traditional cellular implementations, the signals that are not direct usually contribute to the combined noise and thus lower overall signal to noise ratio; SNR actually improves for CDMA in a multi-path environment.

3.15.2. Power Control/Variable Power Output

Although not intrinsically tied to CDMA, most implemented versions of CDMA also feature a dynamically variable power output. Basically what happens is the phone sends a predetermined signal pattern to the tower. The tower then takes the inverse transform of the signal it receives and transmits it to the handset, which applies it to its power output. This causes the handset to have an extremely non-constant power output. The result is that the received power by the tower which has gone through the forward transform of the channel is now flat. The phone is in essence trying to cancel out the effects of the channel by applying an inverse transform first. This equalization of power received from each handset allows a system to maximize the capacity of each cell.

3.15.3. Frequency Reuse

This brings us to another major benefit of CDMA, higher frequency reuse. In general, most traditional wireless implementations only allow each cell to use about 1/6 the total bandwidth allotted to the wireless carrier. This is because a cell cannot use the same frequencies as the any of the cells directly next to it because they would interfere with the transmissions in the neighboring cell. Since CDMA phones have lower power output and because CDMA uses orthogonal codes, even if it does receive a signal from the neighboring cell in the same frequencies, when it multiplies the input by its orthogonal chip, all the other signals cancel out so it's as if they didn't exist. This allows for about twice the frequency reuse rate of traditional implementations. That means about 1/3 the total spectrum allotted to the carrier can be used in each cell.

3.15.4. Capacity Dependent on Number of Users/Soft Capacity

An overall consequence of the many benefits of CDMA is that there is not a sheer cutoff in the number of users that it can support unlike TDMA or traditional cellular. In CDMA, the limiting criteria on the number of users that can be supported, ultimately depends on how much noise you're willing to tolerate. Since pseudo-random codes are not in reality perfectly orthogonal, each additional signal added onto the channel does contribute slightly to the noise level. Eventually if you add enough calls, the noise level gets too high and impedes efficient communication. The practical effect of this is the introduction of static into the voice signal because of the increase in the bit error rate. This means that the number of calls that can be handled is dependent on how much noise can be tolerated. This is useful if a carrier decides that they would rather suffer more static during peak hours in exchange for enabling their network to handle more calls. This is also beneficial during handoffs from one tower to another. With traditional cellular and TDMA, if the receiving tower does not have the capacity for another call, the call must be dropped. With CDMA, the receiving tower can decide to accept the call at a lower quality and then raise the quality back up when it is handling fewer calls.

3.15.5. Vocoder

The vocoder in CDMA not only allows for more efficient transmission of the voice signal by using an adaptive bit rate. It also reduces the background noise in the process. This occurs because the vocoder sets its data rate thresholds higher depending on the background noise level. The higher the background noise level, the higher the threshold is moved. This allows the vocoder to only go to the higher bit rates when someone is talking into the phone as opposed to when the background noise level increases. This also has the side benefit of removing a good deal of ambient noise from the voice signal which improves voice quality.

3.15.6. Privacy and Security

Now that we've seen how CDMA can provide cheap, clear, and energy efficient wireless communication, let's look at how CDMA can prevent others from listening in on our conversation. CDMA by its very nature is more cryptic than both traditional analog cellular and TDMA. Encoding and decoding CDMA is rather computationally complex, especially considering that this encoding has to be done by a little battery powered phone. When the idea of using orthogonal codes first was developed, it was probably more realistic to view it as an encryption algorithm than a transmission scheme. This is in stark contrast to analog cellular where all that's needed is a broad range tuner that's available at Radio Shack. In order to pick off a CDMA conversation, it is necessary to know the codes being used which could probably be looked up in a book. Further more a computer is needed to do the decoding. This might not seem like such a difficult task since it was just mentioned that decoding is currently done with little battery powered phones. However, it cannot be overlooked that CDMA handsets implement encoding and decoding in HARDWARE and someone trying to pick off a CDMA conversation would have to do the decoding on their home computer in SOFTWARE, hardware being several orders of magnitude faster than software. As we discovered while doing this project, although one might think an Ultra 10 is fast, it still can't do CDMA encoding or decoding in real time (on Matlab, it might have been able to do it if we wrote the programs in C). Furthermore, we have completely overlooked the fact that in actuality, when CDMA is used, the digital signal being transmitted is encrypted. This means that in order pick off a CDMA phone call, one would have to some how find the encryption key in addition to doing all the things we've just mentioned. The empirical evidence to the effectiveness of CDMA's security is that currently, there are few if any reports of people listening in on other people's conversations or of air-time fraud like there was when analog cellular was most popular.

3.16. The Advantages of CDMA

Low power spectral density. As the signal is spread over a large frequency-band, the Power Spectral Density is getting very small, so other communications systems do not suffer from this kind of communications. However the Gaussian Noise level is increasing. Interference limited operation. In all situations the whole frequency-spectrum is used. Privacy due to unknown random codes. The applied codes are - in principle - unknown to a hostile user. This means that it is hardly possible to detect the message of an other user. Applying spread spectrum implies the reduction of multi-path effects. Random access possibilities. Users can start their transmission at any arbitrary time.

1- Capacity increases of 8 to 10 times that of an AMPS analog system, and 4 to 5 times GSM.

Because of CDMA's unique spread spectrum technology, many users can share the same carrier frequency, and without time-sharing. This means that mobile phone service providers can handle more customers on a CDMA network than on a GSM network.

2- Improved call quality, with better and more consistent sound.

CDMA systems use precise power control—that is, the base station sends commands to every mobile phone currently involved in a call, turning down the power on the nearby ones, and increasing the power of those further away. The result is a nice , even noise level across the carrier, with lower overall power levels and no spiky interference. In this civilized atmosphere, each station can easily pick out its own coded data frames, decode them and deliver a clean end result. Dropped calls are minimized by CDMA's unique ability to keep every sector of every cell on the same frequency, so handoffs are "soft" as the mobile phone moves from one area to the next. (There is no hole in the signal as one cell is dropped and another is acquired.) CDMA decoders interpret constant sounds, such as road noise, as having no useful content, and ignore them as much as possible.

3- Simplified system planning through the use of the same frequency in every sector of every cell.

Other types of systems (analog, GSM, etc.) need to break up their frequency spectrum allotments so that each cell uses a different frequency. And since no two adjoining cells can use the same frequency, a given cell has to be surrounded by a circle of six other cells, all of which have to be on different frequencies. This translates to frequency re-use of only 1 in 7, and if you change one (by adding a cell for example), the effects ripple through the system. CDMA providers have no such planning headaches, since every sector of every cell uses the same frequency.

4- Enhanced privacy. Privacy is inherent in the way CDMA works.

Each call is spread over the entire 1.25 MHz carrier—much wider bandwidth than is needed for a single call. The data bits used to convey real information are mixed with digital coding that is known only to the base station and the individual mobile phone. To an eavesdropper, the call looks like unintelligible noise. CDMA was originally developed by the military for this very reason.

5- Improved coverage characteristics, allowing for the possibility of fewer cell sites.

This comes from the accurate power control of all mobile phones using the site, and the fact that individual sites don't interfere with each other, since they are all on the same frequency.

6- Increased talk time for mobile phones.

Again a function of power control among other built-in efficiencies. A mobile phone only uses the amount of power required at the moment—it's not a full-power-or off situation. When a mobile phone is collecting data bits to be coded and sent off to the base station, it can actually ignore the silences in human speech (as much as 65 percent counting the time the caller is listening to the other party speak) and not send those. Less useless data transmitted means less power used, more capacity for other callers, and generally more efficient use of spectrum.

7- Bandwidth on demand.

The wide-band carrier that all users share is kind of a "bandwidth pool" that can be dipped into by each mobile phone for whatever purpose—voice, data, fax, etc. When one mobile phone is using less bandwidth, more is available for others. This approach is much more flexible than tying up an entire channel or time slot until the call is over.

3.17. CDMA has the disadvantage

CDMA systems are interference limited. However, this limitation can be overcome by proper multiuser detection (MUD). We propose a MUD based on recurrent neural networks (RNN). This algorithm provides a performance which is close to the optimum MUD, while keeping the computational complexity low. Furthermore, the regular structure of the algorithm facilitates a hardware (HW) implementation utilizing distributed computation. The HW platform we target at are field programmable gate arrays (FPGA). Compared to application specific integrated circuits, FPGAs allow a much faster and more flexible hardware implementation. We have implemented the algorithm with a fixed point arithmetic and investigated the minimum number of binary digits required so that the performance of the algorithm does not degrade substantially. Furthermore an efficient implementation of the tanh nonlinearity is presented.

• Implementation complexity: 2- layer modulation scheme of either frequency hopping or direct sequencing increases power consumption

• Power control: required to maximize the number of users in a cell

3.17.1. Business Disadvantage

CDMA devices have proved unsuccessful within Europe. GSM is established and already outperforms TDMA and analogue cellular (the original target markets for CDMA). GSM is designed to support data as well as voice transmissions. Current CDMA network implementations do not offer data communications services.

3.18. What Is Orthogonal Multi-Carrier CDMA?

There are many equivalent ways to describe MC-CDMA:

MC-CDMA is a form of CDMA or spread spectrum, but we apply the spreading in the frequency domain (rather than in the time domain as in Direct Sequence CDMA). MC-CDMA is a form of Direct Sequence CDMA, but after spreading, a Fourier Transform (FFT) is performed. MC-CDMA is a form of Orthogonal Frequency Division Multiplexing (OFDM), but we first apply an orthogonal matrix operation to the user bits. There for , MC-CDMA is sometimes also called "CDMA-OFDM".

MC-CDMA is a form of Direct Sequence CDMA, but our code sequence is the Fourier Transform of a Walsh Hadamard sequence. MC-CDMA is a form of frequency diversity. Each bit is transmitted simultaneously (in parallel) on many different subcarriers. Each sub carrier has a (constant) phase offset. The set of frequency offsets form a code to distinguish different users.

3.18.1. What Are The Advantages Of MC-CDMA?

Compared to Direct Sequence (DS) CDMA ,DS-CDMA is a method to share spectrum among multiple simultaneous users. Moreover, it can exploit frequency diversity, using RAKE receivers. However, in a dispersive multipath channel, DS-CDMA with a spread factor N can accommodate N simultaneous users only if highly complex interference cancellation techniques are used. In practice this is difficult to implement. MC-CDMA can handle N simultaneous users with good BER, using standard receiver techniques Possible Transmitter Implementation.

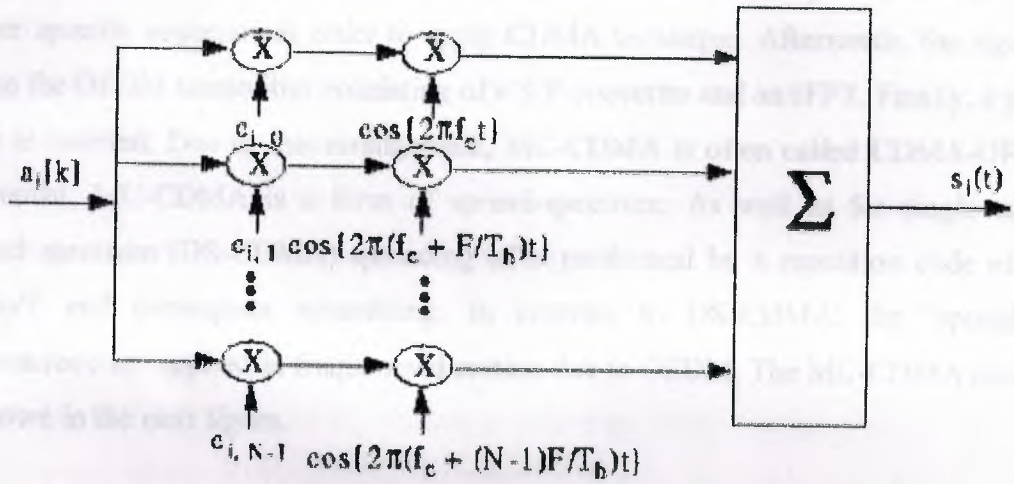


Figure 3.24 possible implementation of a Multi-Carrier spread-spectrum transmitter. Each bit is transmitted over N different subcarriers. Each subcarrier has its own phase offset, determined by the spreading code.

MC-Code Division Multiple Access systems allow simultaneous transmission of several such user signals on the same set of subcarriers. In the downlink multiplexer, this can be implemented using an Inverse FFT and a Code Matrix.

3.18.2. Principle of Multi carrier Code-Division-Multiple-Access (MC-CDMA)

There exist many equivalent ways to interpret MC-CDMA, the one we prefer is shown in the following figure

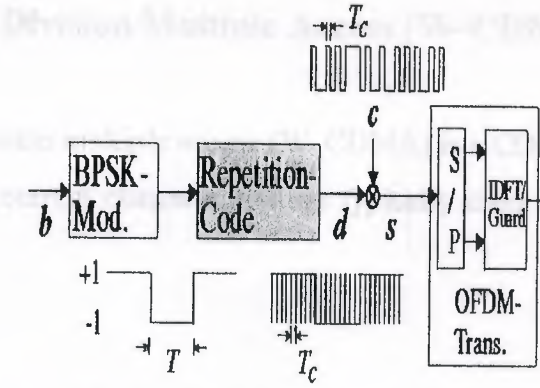


Figure 3.25 MC-CDMA transmitters

In this context, the data is encoded by a repetition code and subsequently scrambled by a user specific sequence in order to apply CDMA technique. Afterwards, the signal is fed to the OFDM transmitter consisting of a S/P converter and an IFFT. Finally, a guard time is inserted. Due to this arrangement, MC-CDMA is often called CDMA-OFDM. Moreover, MC-CDMA is a form of spread-spectrum: As well as for single carrier spread spectrum (DS-CDMA) spreading of is performed by a repetition code of rate R=Tc/T and subsequent scrambling. In contrast to DS-CDMA, the "spreading" sequencies c are applied in frequency direction due to OFDM. The MC-CDMA receiver is shown in the next figure.

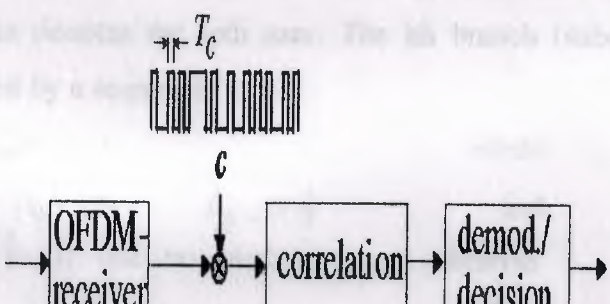


Figure 3.26 MC-CDMA receivers

After OFDM reception, the signal is multiplied with the user-specific sequence, afterwards, correlation is performed. The correlation can be interpreted as decoding of the repetition code. Finally, demodulating and hard decision results to the received data samples. Note that due to the transmission direction, i.e. uplink or downlink, different scrambling sequences with different correlation properties can be used. For the synchronous downlink one can apply orthogonal Walsh-Hadamard sequences leading to the well known user separation for MC-CDMA. On the other hand, in the asynchronous uplink scenario, Pseudo-Noise-Sequences are used with the drawback of high Multiple-Access-Interference (MAI).

3.19. Wideband Code Division Multiple Access (W–CDMA)

3.19.1. Definition

Wideband code division multiple access (W–CDMA) is a CDMA channel that is four times wider than the current channels that are typically used in 2G networks in North America.

3.19.2. Overview

In January 1998, European Telecommunications Standards Institute (ETSI) decided to choose the W–CDMA technology to be the multiple access techniques for the third-generation mobile telephone system. For a mobile communication system, a key parameter is the system capacity. A number of methods to increase system capacity in a W–CDMA network are discussed. This tutorial presents results from different antenna pattern parameters and sectorization techniques for optimizing the maximum number of active subscribers.

3.19.3. Transmitter Model

Shown in Fig.1 is the transmitter model of an WMC-CDMA system. The input data symbols, am(k) of duration Tb, are assumed to be binary antipodal where k denotes the kth bit interval and m denotes the mth user. The ith branch (subcarrier) of the parallel stream is multiplied by a sequence,

$c_m(i)g_m^i(t-iT_c)$, where

$g_m^i(t) \in \{h_0(t), h_1(t), \cdots, h_{N-1}(t)\}$ and

$c_m(i) \in \{-1, 1\}$, and then modulated to a subcarrier

and then modulated to a subcarrier spaced apart from its neighbouring subcarriers by F/Tb where F is an integer number. Cm(0), cm(1), ..., cm(N-1) represents the Pseudo-Random code of the mth user with Tc as chip duration. The property of the codes that is desired is for the codes of different users to be orthogonal, i.e.,

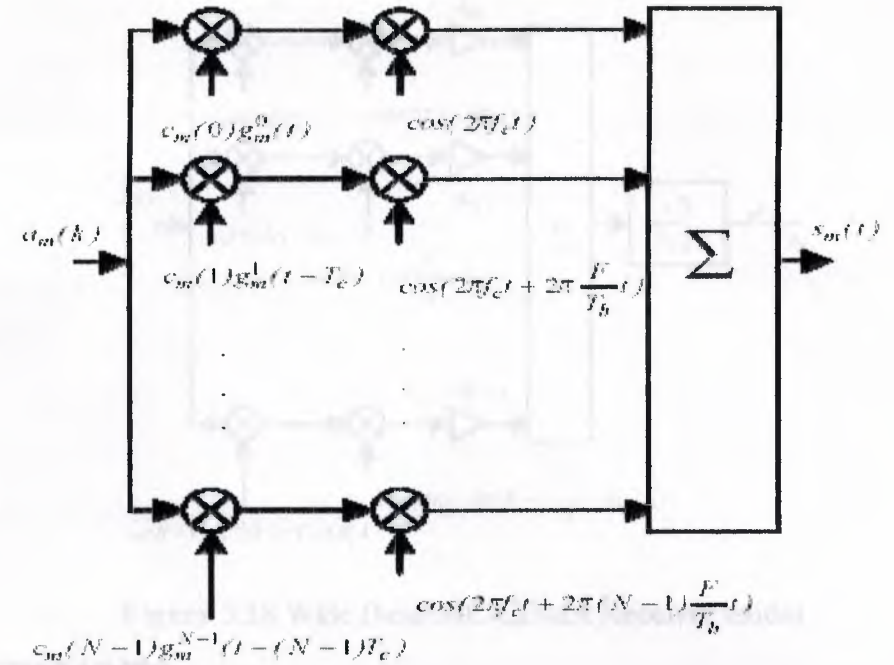


Figure 3.27 the W-MC-CDMA Transmitter Model

3.16.4. Receiver model of w-CDMA

When there are M active users, the received signal is

$$r(t) = \sum_{m=0}^{M-1} \sum_{i=0}^{N-1} p_{mi} a_m(k) c_m(i) g_m^i(t - iT_c - \tau_m)$$
$$\times \cos\left[(2\pi f_c + 2\pi i \frac{F}{T_b})(t - \tau_m) + \theta_{mi}\right] + n(t)$$

where the effects of the channel have been included in n(t) is an AWGN with one-sided power spread spectral density of N0. Each user, m, is
Delayed with respect to the desired user m=0. Thereafter, it is assumed that.

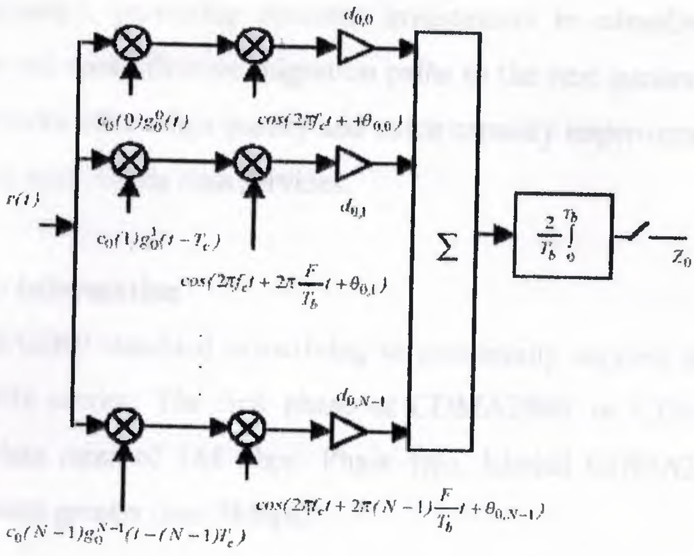


Figure 3.28 Wide Band MC-CDMA Receiver model

3.20. CDMA2000

CDMA2000 is the 3rd Generation solution based on IS-95. Unlike some 3G standards, It is an evolution of an existing wireless standard. CDMA2000 supports 3G services as defined by the International Telecommunications Union (ITU) for IMT-2000. 3G networks will deliver wireless services with better performance, greater cost-effectiveness and significantly more content. The goal is access to any service, anywhere, anytime from one terminal - true converged, mobile services.

CDMA2000 is one solution for wireless operators who want to take advantage of the new market dynamics created by mobility and the Internet. CDMA2000 is both an air interface and a core network solution for delivering the services that customers are demanding today. These services are sometimes referred to as 3G. CDMA2000 and 3G are synonymous.

CDMA2000 is one mode of the Radio Access "Family" of Air interfaces agreed upon by the Operators Harmonization Group for promoting and facilitating convergence of third generation (3G) networks. One goal of the harmonization effort is to provide seamless global roaming between the different modes of CDMA 3G -- CDMA2000 and WCDMA. Ericsson's use of common core technologies allows us to easily support the whole family of 3G CDMA modes. The CDMA Systems Ericsson Business Unit in San Diego is the champion unit from Ericsson for the development of CDMA2000-capable 3G infrastructure products. CDMA2000 is designed to mitigate risks, protect investments and deliver significant performance boosts to operators as they evolve their networks to offer 3G services. CDMA2000 networks are backward compatible to cdmaOne deployments, protecting operator investments in cdmaOne networks and providing simple and cost-effective migration paths to the next generation. In addition, CDMA2000 networks offer voice quality and voice capacity improvements, and support for high speed and multimedia data services.

3.20.1. Technical Information

The CDMA2000 standard is evolving to continually support new services in a standard 1.25 MHz carrier. The first phase of CDMA2000, or CDMA2000 1X will deliver average data rates of 144 kbps. Phase two, labeled CDMA2000 1xEV, will provide for data rates greater than 2Mbps.

3.20.2. CDMA2000 1X

The IS-2000 standard (CDMA2000 1X) was completed early this year and published by the Telecommunications Industry Association (TIA). 1X offers approximately twice the voice capacity of cdmaOne, average data rates of 144 kbps, backward compatibility with cdmaOne networks, and many other performance improvements. 1X refers to CDMA2000 implementation within existing spectrum allocations for cdmaOne - 1.25 MHz carriers. The technical term is derived from N =1 (i.e. use of same 1.25 MHz carrier as in cdmaOne) and the 1x means one times 1.25 MHz.

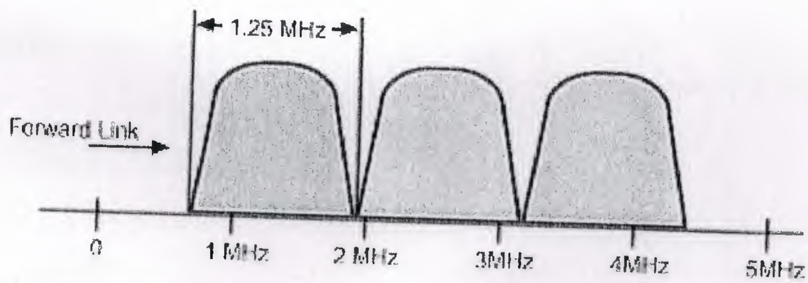


Figure 3.29 CDMA2000 implementation within existing spectrum allocations for cdma one - 1.25 MHz carriers

CDMA2000 1X can be implemented in existing spectrum or in new spectrum allocations. A CDMA2000 1X network will also introduce simultaneous voice and data services, low latency data support and other performance improvements. The backward compatibility with cdmaOne provided by Ericsson's CDMA2000 solution, further ensures investment protection.

CONCLUSION

Wireless Communication is in the process of revolutionising telecommunications services and the way in which people use them. Overall growth in the cordless and cellular markets during recent years has exceeded exceptations. There is widespread anticipation that customer demand for wireless telecommunication will continue to expand for the foreseeable future. This is reflected by the high level of engineering activity and standards development worldwide. There are many different views on what the future will bring in terms of wireless capabilities and designs. However, one things is clear wireless communication has achieved "mainstream" status and will be the major force in driving the development of telecommunications systems and services.

This project laid some light on one of the most aspects in wireless communications studying the history and developements evolved upto date.this project aslo discussed the multiple access methods which refer to the method of creating multiple channels for each transmission direction. And the types of multiple access methods.

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