NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

SIMULATION AND STUDY OF MULTIPLE ACCESS TECHNOLOGY

Graduation Project
EE- 400

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Firstly I shall show my all respect and thanks for ALLAH for helping me to complete this work and keep me safe.

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*I am grateful to my parents, **Mr. and Mrs. Abuawwad**, for the tremendous amount of inspiration and moral support they have given me from my childhood without which I would not have reached this position. I would like to express thanks to my brothers and sisters for the love and support they have given me at times I needed the most.*

*My deepest LOVE and GRATITUDE belong to **NADINE (NADOO)** her unconditional SUPPORT and LOVE was vital also for me and for this project.*

I also thank Eng. Ezzat Natsheh, Eng. Bassam Barham, for their help in my work and all my other friends at NEU and out of NEU who helped me indirectly in my Graduation.

ABSTRACT

Multiple Access Control (MAC) solves the problem of the allocation of a common channel for multiple users. It is the technology behind products like cell phone, wireless LAN and Bluetooth. This paper describes the MAC and studies three main techniques, TDMA (Time Division Multiple Access), FDMA (Frequency Division Multiple Access), and CDMA (Code Division Multiple Access); where I show the definitions, operation, features, and applications of each technique.

In this paper, also MATLAB codes is written for every technique, where the sender and receiver for each one are simulated.

INTRODUCTION

Wireless telecommunications has dramatically increased in popularity, resulting in the need for technologies that allow multiple users to share the same frequency. This is called "Multiple Access Control."

The three main techniques of Multiple Access Control system are:

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

These access techniques allow sharing the available bandwidth in wireless communication. These techniques can be classified into narrowband and wide band systems depending upon how the available bandwidth is allocated to users.

The purpose of this project is to study and simulate the MAC (Multiple Access Control) and its techniques TDMA, FDMA, and CDMA by details, discuss their uses and problems, and show the plot diagrams for sending and receiving for every technique.

Chapter one represents the Multiple Access Control Technology (MAC), where I discussed the history and the access techniques which Multiple Access contains, such as TDMA, FDMA, CDMA, and CSMA/ CA. And I talked briefly about these techniques. In TDMA (Time Division Multiple Access) technique I showed the history of this techniques, definitions, and features (advantages and disadvantages for this technique). In FDMA (Frequency Division Multiple Access) technique I discussed the use of this technique. And I discussed the features of FDMA advantages and disadvantages. About CDMA (Code Division Multiple Access) technique I showed the history of this technique, definitions, and features (advantages and disadvantages for this technique). Finally in this chapter I introduced CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance).

Chapter two represents the study for TDMA with more details, where I discussed definition of TDMA, TDMA works, Enhanced TDMA, Signal and system structures for TDMA,

TDMA Applications, TDM (Time Division Multiplexing), and Mechanism of TDM (Time division multiplexing).

Chapter three shows FDMA Definition, FDMA Operations, Basic system operation, where I discussed the following operations, Wireless FDMA operation, and Power control in wireless FDMA systems, FDMA Features, and FDM Definition (Frequency Division Multiplexing), and in FDM I studied, OFDM Principles (Orthogonal Frequency Division Multiplexing), OFDM Generation, and the Benefits of OFDM and Performance Criteria.

Chapter four represents CDMA Technique studies; here I discussed the possible CDMA Definitions, CDMA Techniques, where I represented the following techniques of CDMA, Direct Sequence CDMA, Frequency Hopping CDMA, Time Hopping CDMA, and Hybrid Systems. Then I studied CDMA in 3G Wireless Systems, Forward CDMA channel, Reversed CDMA channel, CDMA Features; CDMA Advantages, Common CDMA problems, and Possible Technical Difficulties. And Receiver Structures for CDMA Systems; such as Correlation Receiver, RAKE Receiver, Multiuser Receivers, and Sub-optimal Receiver.

During this study for MAC and MAC techniques I prepared simulations for each technique of MAC sender and receiver for each one, and I show the plots and the queue for those simulations in Chapter five. And the code for Matlab simulations could be found in Appendix A for every technique.

CHAPTER ONE

MULTIPLE ACCESS CONTROL (MAC)

1.1 Multiple Access Systems

Multiple Access Technologies History

The origins of multiple access date back to Marconi's early experiments. In 1900, he was awarded Patent No. 7777 for the "Tuned Circuit," which was the enabling technology for Frequency Division Multiple Access (FDMA). In fact however, the first experiments probably involved Frequency Division Multiplexing (FDM). The difference is that FDM refers to transmission of multiple sources from a single location by modulating each on a separate carrier separated sufficiently in frequency. Each receiver contains one, or several "tuned circuits" or more generally frequency filters, each of which isolates one of the received multiple sources and sends it to a demodulator to recover the desired source signal. FDMA operates on the same principle as FDM, except that the sources and their respective modulated carriers emanate from different transmitters, generally not co-located. Multiple Accesses is a term often used for both forms, but FDM is somewhat simpler because from a single transmitter the frequency separation of carriers is easily maintained, while FDMA with separate transmitters must carefully control carrier frequencies, particularly for moving users whose frequency is changing due to the Doppler Effect. In any case, FDM and FDMA are the only multiplexing and multiple access techniques which can handle both Analog and digital transmissions.

MULTIPLE ACCESS CONTROL (MAC)

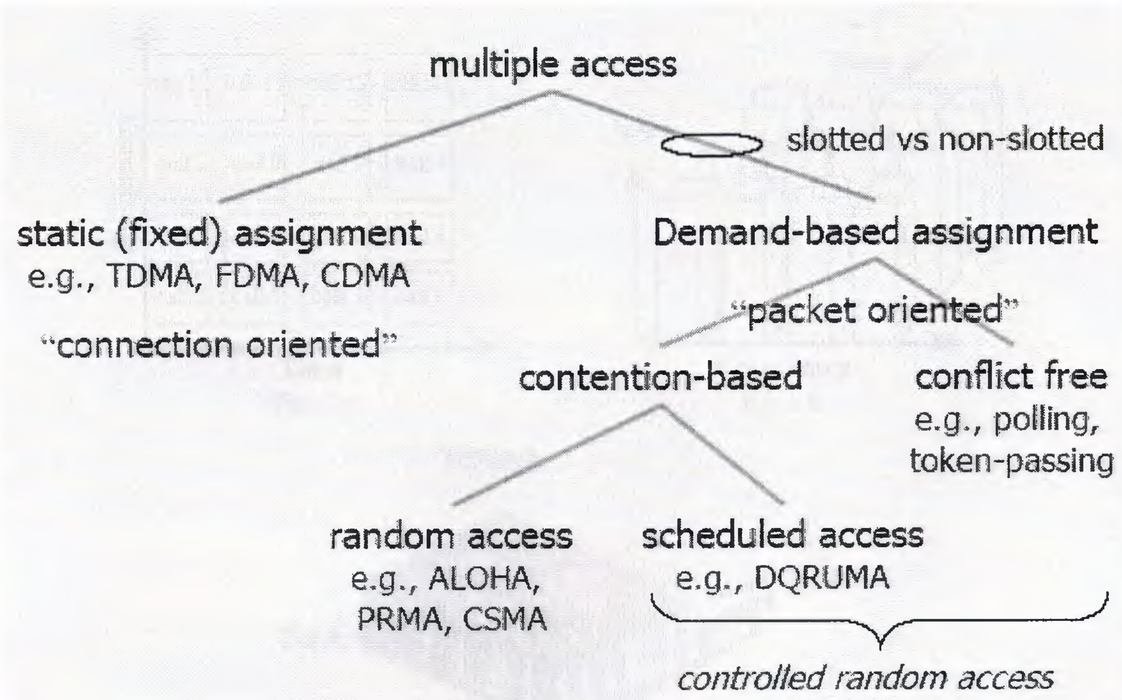

Figure1.1: Multiple Access Control diagram

Types of Multiple Access System

1. Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)
2. Time Division Multiple Access (TDMA)
3. Frequency Division Multiple Access (FDMA)
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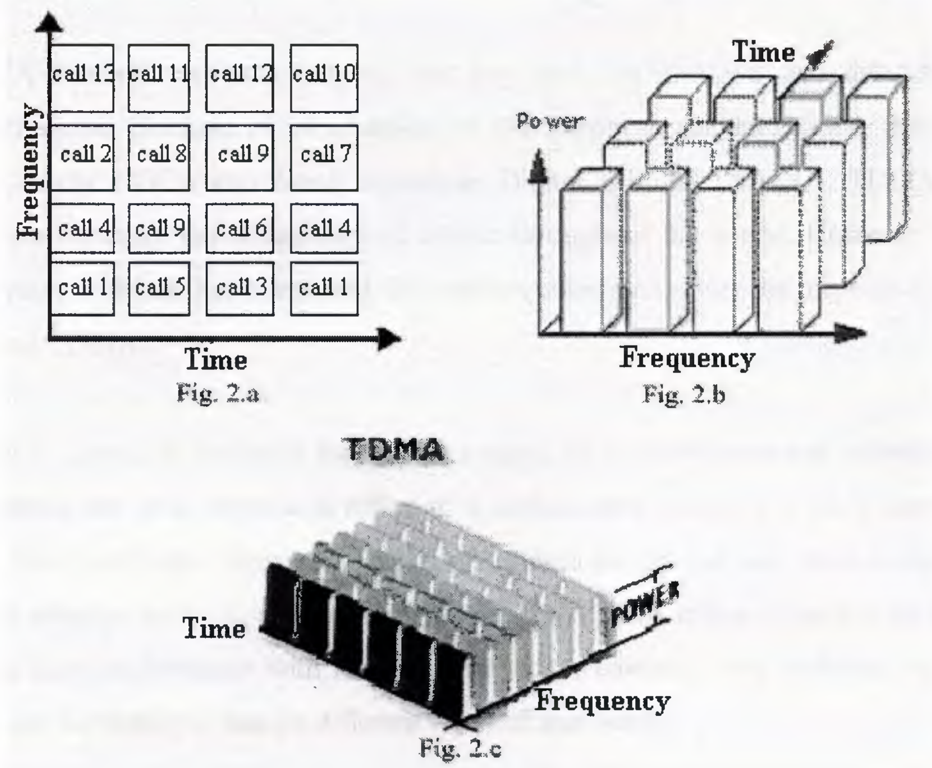

Figure1.3: The frequency vs. time vs. power representation

1.2 Overview

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 1989, the Cellular Telecommunications Industry Association (CTIA) chose TDMA over Motorola's frequency division multiple accesses (FDMA) (today known as narrowband analog mobile-phone service [NAMPS]) narrowband standard as the technology of choice for existing 800 MHz cellular markets and for emerging 1.9-GHz markets. With the growing technology competition applied by Qualcomm in favor of code division multiple accesses (CDMA) and the realities of the European global system for mobile communications (GSM) standard, the CTIA decided to let carriers make their own technology selection. The two major (competing) systems that split the RF are TDMA and CDMA. CDMA is a spread-spectrum technology that allows multiple frequencies to be used simultaneously. CDMA codes every digital packet it sends with a unique key.

A CDMA receiver responds only to that key and can pick out and demodulate the associated signal. Because of its adoption by the European standard GSM, the Japanese Digital Cellular (JDC), and North American Digital Cellular (NADC), TDMA and its variants are currently the technology of choice throughout the world. However, over the last few years, a debate has convulsed the wireless community over the respective merits of TDMA and CDMA.

The TDMA system is designed for use in a range of environments and situations, from hand portable use in a downtown office to a mobile user traveling at high speed on the freeway. The system also supports a variety of services for the end user, such as voice, data, fax, short message services, and broadcast messages. TDMA offers a flexible air interface, providing high performance with respect to capacity, coverage, and unlimited support of mobility and capability to handle different types of user needs.

1.3 Time Division Multiple Access

TDMA History

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 and 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 errors and to add some basic features (such as call id) to the TDMA standard. In 1989, CTIA chose TDMA over Motorola's FDMA (today known as Narrowband Analog Mobile-Phone Service [NAMPS]) narrowband standard as the technology of choice for existing 800 MHz cellular markets and for emerging 1.9-GHz markets. With the growing technology competition applied by Qualcomm in favor of CDMA and the realities of the European global system for mobile communications standard, the CTIA decided to let carriers make their own technology selection. Because of its adoption by the European standard, the Japanese Digital Cellular (JDC) and North American Digital Cellular (NADC), TDMA and its variants are currently the technology of choice throughout the world. However, over the last few years, a debate has convulsed the wireless community over the respective merits of TDMA and CDMA.

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Definitions of TDMA

TDMA users share a common frequency channel, but use the channel for only a very short time. They are each given a time slot and only allowed to transmit during that time slot. When all available time slots in a given frequency are used, the next user must be assigned a time slot on another frequency. The important factor to be considered while designing is that these time slices are so small that the human ear does not perceive the time slicing. TDMA works by chopping up the channel into sequential time slices. Only one person is actually using the channel at any given moment, but he or she only uses it for short bursts. He then gives up the channel momentarily to allow the other users to have their turn. This is very similar to how a computer with just one processor can seem to run multiple applications simultaneously. The following figures 2a, 2b and 2c show the

frequency vs. time vs. power representation of TDMA. Fig 2c is a three dimensional representation, and we could easily find that how the each channels are sliced into time slots in TDMA technology.
The capacity of TDMA is about 2 to 5 times as that of FDMA. There are actually three different flavors of TDMA in the PCS market. The most complex implementation is that of GSM. IS-136 is another form for TDMA, and it is this implementation that people generically refer to as TDMA. IDEN is a proprietary Motorola technology that no other company seems to participate in. Only Motorola makes IDEN phones, and only Motorola makes IDEN infrastructure equipment.

TDMA systems still rely on the switch to determine when to perform a handoff. Unlike the old analog system however, the switch does not do this in a vacuum. The TDMA handset constantly monitors the signals coming from other sites, and it reports this information to the switch without the caller being aware of it. The switch then uses this information to make better handoff choices at more appropriate times.
In TDMA the entire channel bandwidth is used just by the useful signals, as no guard band s are employed. But TDMA requires strict signaling and synchronization. As in case of FDMA, TDMA also wastes bandwidth as transmission continues on even when no conversation occurs.

TDMA is a digital technology that allows more than one person access one radio frequency channel, because the channel is divided into small packages and delegate a time slot to each package. The packages are then transmitted in synchronization of bursts. For example, in a TDMA system 3 conversations uses only one channel, oppose to using three different channels under an analog system. However, one of the disadvantages of TDMA is that it still wastes bandwidth in the radio-frequency channel because the bandwidth is still used though nothing is transmitted (a caller is listening to the conversation, thus the caller's phone is transmitting silence to the person on the other end).

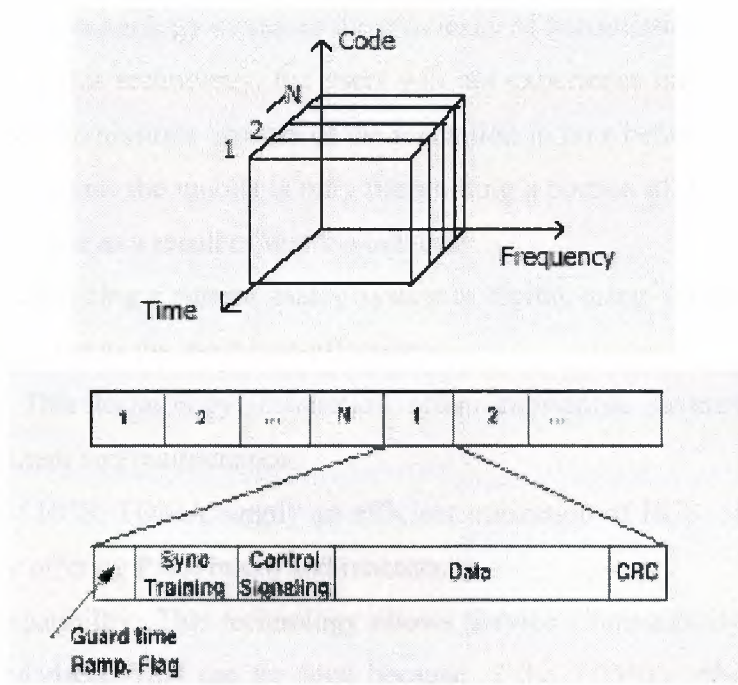

Figure1.5: Divide radio spectrum into time slots

1 Only 1 user allowed either transmitting or receiving in a slot.
2 Slots assigned cyclically.
3 Non-continuous transmission: buffer and burst.
4 Digital data and modulation must be used.
5 Guard time allows for different prop delays bet mobile and BS.
6 30 % of data rate is overhead.
7 Tradeoffs in overhead, size of data payload, and latency.
8 Divide radio spectrum into time slots

TDMA Features

Advantages

1 Personal Communication: Services such as SMS - short message data, fax, voice band data, and also multimedia, video-conferencing, which is bandwidth-intensive application. All of these can be supplied by the TDMA because of the ability to carry data rates of 64 Kbps to 120 Mbps.

2 Efficiency: This technology increases the efficiency of transmission.

3 Interference: In this technology, the users will not experience interference from other simultaneous transmissions because of the separation in time between different users.

4 Battery life: Because the mobile is only transmitting a portion of the time, this extends the battery life and as a result of that the talk time.

5 Cost: While upgrading a current analog system to digital, using TDMA is the advisable technology for that as the most cost-effective.

6 Installation: This technology installation offers substantial savings in base-station space, equipment and maintenance.

7 Utilization of HCS: TDMA supply an efficient utilization of HCS - Hierarchical Cell Structures by offering Pico, micro and macrocells.

8 Service Compatibility: This technology allows Service Compatibility with the use of dual-mode handsets. This can be done because of the TDMA's inherit compatibility with FDMA analog system.

Disadvantages

1. Predefined Time Slot: Each user has a predefined time slot, but the users are not allocated a time slot while they are roaming from one cell to another - this might cause a call to be disconnected in case that all time slots in the next cell are already occupied. Another problem with predefined timeslots is that a fixed and predefined number of users will have channel access. Thus, if all time slots are already occupied, new users wishing to transmit and get access rights won't be able to do so (their call will be disconnected).
2. Multipath Distortion: This technology is subject to Multipath distortion - An Interference might be caused in case that a signal which is coming from a tower to a handset might also come from any one of several directions and will be bounced off several different buildings before arriving to it's target.

1.4 Frequency Division Multiple Access

Though it could be used for digital systems, is exclusively used on all analog cellular systems. Each FDMA subscriber is assigned a specific frequency channel. No one else in the same cell or a neighboring cell can use the frequency channel while it is assigned to a user. This reduces interference, but severely limits the number of users. Essentially, FDMA splits the allocated spectrum into many channels. In current analog cell systems, each channel is 30 kHz. When a FDMA cell phone establishes a call, it reserves the frequency channel for the entire duration of the call. The voice data is modulated into this channel's frequency band (using frequency modulation) and sent over the airwaves. At the receiver, the information is recovered using a band-pass filter. The phone uses a common digital control channel to acquire channels.

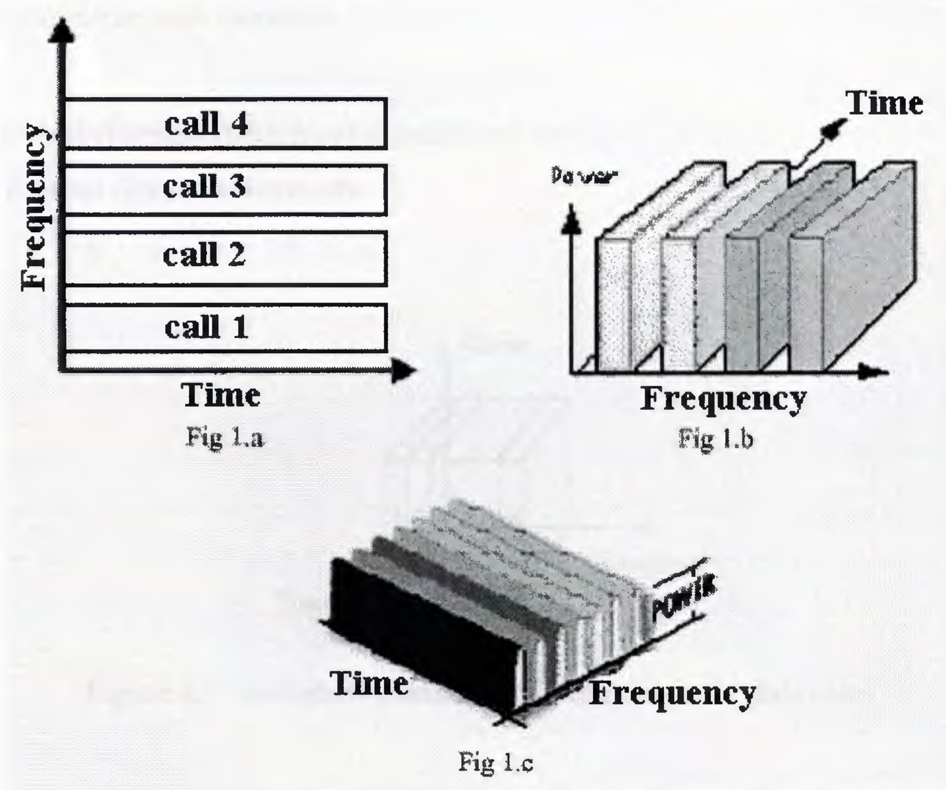

Figure 1.6: Three dimensional view of FDMA signal.

FDMA systems are the least efficient cellular system since each analog channel can only be used by one user at a time. Not only are these channels larger than necessary given modern digital voice compression, but they are also wasted whenever there is silence during the cell phone conversation. Analog signals are also especially susceptible to noise and there is no way to filter it out. Given the nature of the signal, analog cell phones must use higher power (between 1 and 3 watts) to get acceptable call quality. Given these shortcomings, it is easy to see why FDMA is being replaced by newer digital techniques.

FDMA divides the frequency spectrum into small slices, which are assigned to the subscribers. Since the radio spectrum is limited and subscribers do not free their assigned frequency until they are completely finished with it, the number of subscribers in the system can be quickly limited. As the number of subscribers increases, the required frequency spectrum also increases.

1 Individual channels (frequency) to individual users.

2 On demand channel assignment.

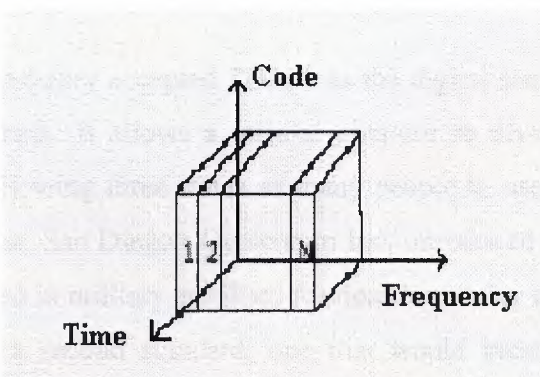

Figure 1.7: Individual channels (frequency) to individual users

FDMA Features

1. If channel not in use, sits idle.
2. Channel bandwidth relatively narrow (30 kHz), i.e., usually narrowband systems.

3. Symbol time >> average delay spread => little or no Equalization required.
4. Simplest.
5. Best suited for analog links.
6. Continuous transmission implies no framing or synchronization bits needed.
7. Requires tight filtering to minimize interference.
8. Usually combined with FDD for duplexing.

1.5 Code Division Multiple Access

History of CDMA

1985 The ITU sets up Interim Working Group 8/13 to determine the overall objectives for future public land mobile telecommunications systems or FPLMTS. The purpose is to integrate terrestrial and satellite components to provide seamless, high-bandwidth access for mobile phones across global networks, while facilitating delivery of fixed wireless access to the developing world.

1989 The U.S. cellular industry accepted TDMA as the digital standard that would replace the analog AMPS standard. It allows a cellular operator to divide up the signal in tiny fractions of a second, allowing three times as many people to use the system at the same time. Later that same year, San Diego's Qualcomm Inc. introduced CDMA, a new flavor of an idea that has been used in military satellites for decades. After three years of testing, the industry accepted it as a second standard, one that would increase the capacity of the system 10 to 20 times. 1992 The TIA established the TR-45.5 subcommittee with the charter of developing a spread-spectrum digital cellular standard. 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. 1994 FPLMTS is renamed IMT-2000. 1996 The ITU holds the first World Telecommunications Forum to explore regulatory policies raised by the overlapping of satellite and national mobile communications systems.

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INTRODUCTION

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The three main techniques of Multiple Access Control system are:

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
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CHAPTER ONE

MULTIPLE ACCESS CONTROL (MAC)

1.1 Multiple Access Systems

Multiple Access Technologies History

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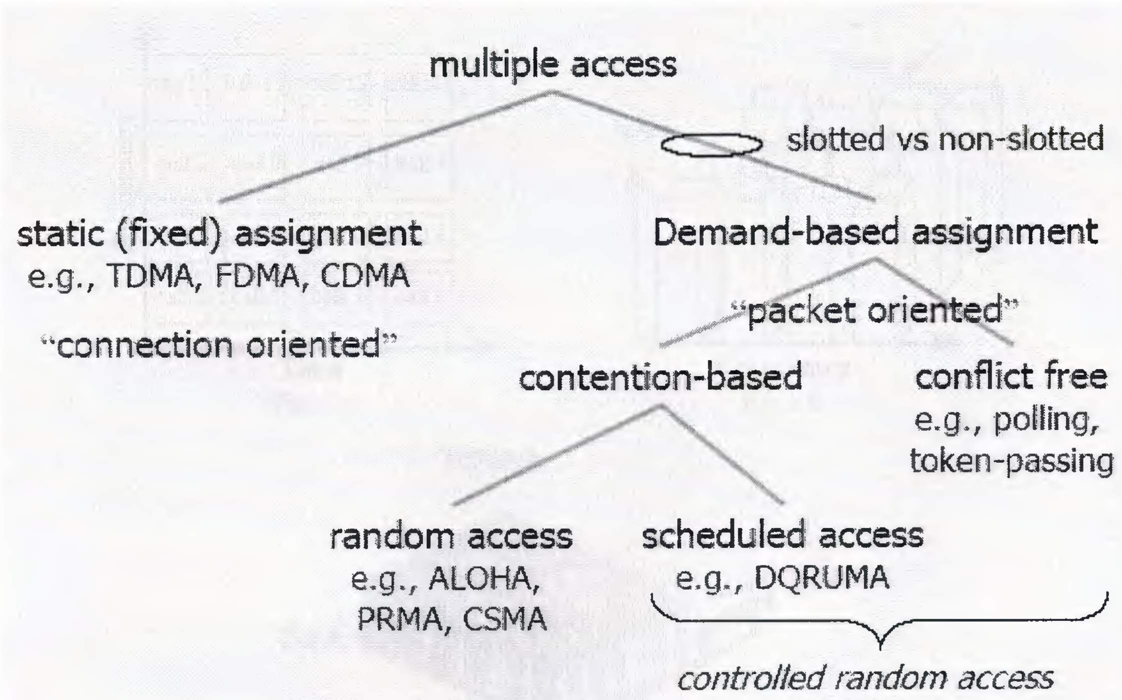

Figure1.1: Multiple Access Control diagram

Types of Multiple Access System

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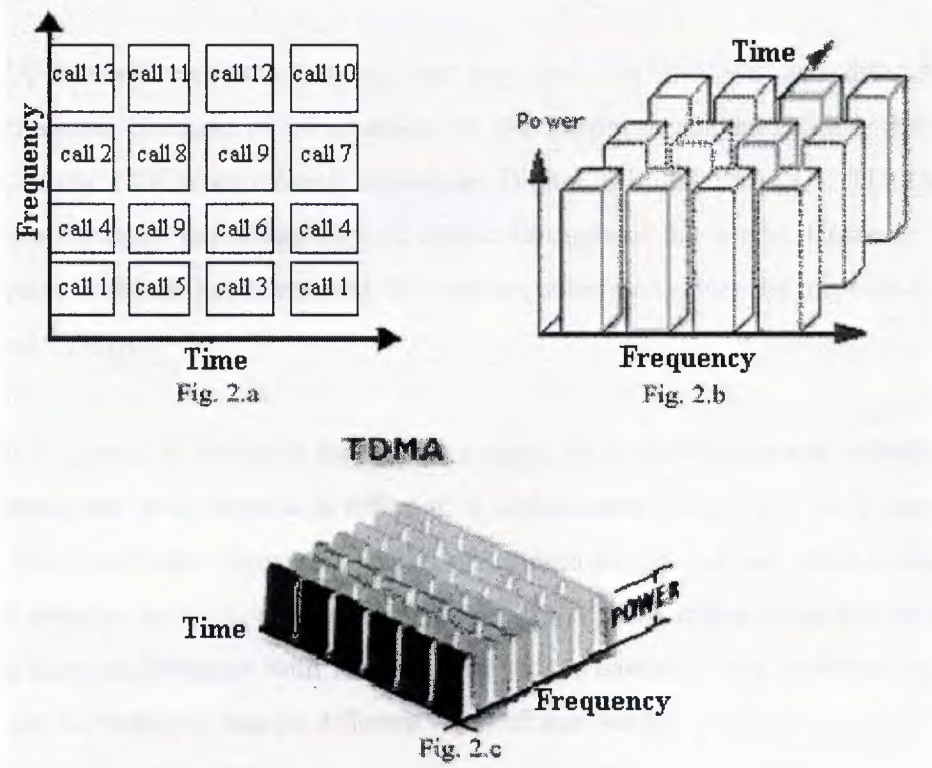

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TDMA users share a common frequency channel, but use the channel for only a very short time. They are each given a time slot and only allowed to transmit during that time slot. When all available time slots in a given frequency are used, the next user must be assigned a time slot on another frequency. The important factor to be considered while designing is that these time slices are so small that the human ear does not perceive the time slicing. TDMA works by chopping up the channel into sequential time slices. Only one person is actually using the channel at any given moment, but he or she only uses it for short bursts. He then gives up the channel momentarily to allow the other users to have their turn. This is very similar to how a computer with just one processor can seem to run multiple applications simultaneously. The following figures 2a, 2b and 2c show the frequency vs. time vs. power representation of TDMA. Fig 2c is a three dimensional representation, and we could easily find that how the each channels are sliced into time slots in TDMA technology.

The capacity of TDMA is about 2 to 5 times as that of FDMA. There are actually three different flavors of TDMA in the PCS market. The most complex implementation is that of GSM. IS-136 is another form for TDMA, and it is this implementation that people generically refer to as TDMA. IDEN is a proprietary Motorola technology that no other company seems to participate in. Only Motorola makes IDEN phones, and only Motorola makes IDEN infrastructure equipment.

TDMA systems still rely on the switch to determine when to perform a handoff. Unlike the old analog system however, the switch does not do this in a vacuum. The TDMA handset constantly monitors the signals coming from other sites, and it reports this information to the switch without the caller being aware of it. The switch then uses this information to make better handoff choices at more appropriate times.

In TDMA the entire channel bandwidth is used just by the useful signals, as no guard band s are employed. But TDMA requires strict signaling and synchronization. As in case of FDMA, TDMA also wastes bandwidth as transmission continues on even when no conversation occurs.

TDMA is a digital technology that allows more than one person access one radio frequency channel, because the channel is divided into small packages and delegate a time slot to each package. The packages are then transmitted in synchronization of bursts. For example, in a TDMA system 3 conversations uses only one channel, oppose to using three different channels under an analog system. However, one of the disadvantages of TDMA is that it still wastes bandwidth in the radio-frequency channel because the bandwidth is still used though nothing is transmitted (a caller is listening to the conversation, thus the caller's phone is transmitting silence to the person on the other end).

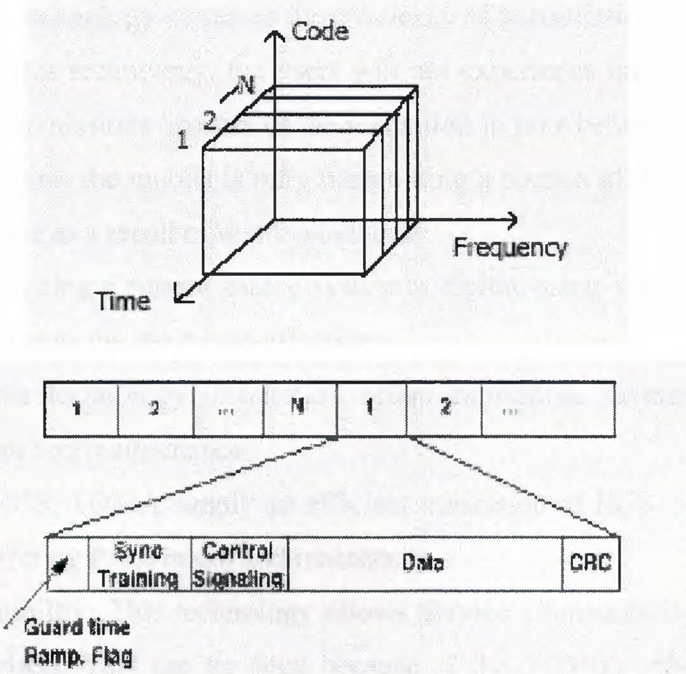

Figure1.5: Divide radio spectrum into time slots

1 Only 1 user allowed either transmitting or receiving in a slot.
2 Slots assigned cyclically.
3 Non-continuous transmission: buffer and burst.
4 Digital data and modulation must be used.
5 Guard time allows for different prop delays bet mobile and BS.
6 30 % of data rate is overhead.
7 Tradeoffs in overhead, size of data payload, and latency.
8 Divide radio spectrum into time slots

TDMA Features

Advantages

1 Personal Communication: Services such as SMS - short message data, fax, voice band data, and also multimedia, video-conferencing, which is bandwidth-intensive application. All of these can be supplied by the TDMA because of the ability to carry data rates of 64 Kbps to 120 Mbps.

2 Efficiency: This technology increases the efficiency of transmission.

3 Interference: In this technology, the users will not experience interference from other simultaneous transmissions because of the separation in time between different users.

4 Battery life: Because the mobile is only transmitting a portion of the time, this extends the battery life and as a result of that the talk time.

5 Cost: While upgrading a current analog system to digital, using TDMA is the advisable technology for that as the most cost-effective.

6 Installation: This technology installation offers substantial savings in base-station space, equipment and maintenance.

7 Utilization of HCS: TDMA supply an efficient utilization of HCS - Hierarchical Cell Structures by offering Pico, micro and macrocells.

8 Service Compatibility: This technology allows Service Compatibility with the use of dual-mode handsets. This can be done because of the TDMA's inherit compatibility with FDMA analog system.

Disadvantages

1. Predefined Time Slot: Each user has a predefined time slot, but the users are not allocated a time slot while they are roaming from one cell to another - this might cause a call to be disconnected in case that all time slots in the next cell are already occupied. Another problem with predefined timeslots is that a fixed and predefined number of users will have channel access. Thus, if all time slots are already occupied, new users wishing to transmit and get access rights won't be able to do so (their call will be disconnected).
2. Multipath Distortion: This technology is subject to Multipath distortion - An Interference might be caused in case that a signal which is coming from a tower to a handset might also come from any one of several directions and will be bounced off several different buildings before arriving to it's target.

1.4 Frequency Division Multiple Access

Though it could be used for digital systems, is exclusively used on all analog cellular systems. Each FDMA subscriber is assigned a specific frequency channel. No one else in the same cell or a neighboring cell can use the frequency channel while it is assigned to a user. This reduces interference, but severely limits the number of users. Essentially, FDMA splits the allocated spectrum into many channels. In current analog cell systems, each channel is 30 kHz. When a FDMA cell phone establishes a call, it reserves the frequency channel for the entire duration of the call. The voice data is modulated into this channel's frequency band (using frequency modulation) and sent over the airwaves. At the receiver, the information is recovered using a band-pass filter. The phone uses a common digital control channel to acquire channels.

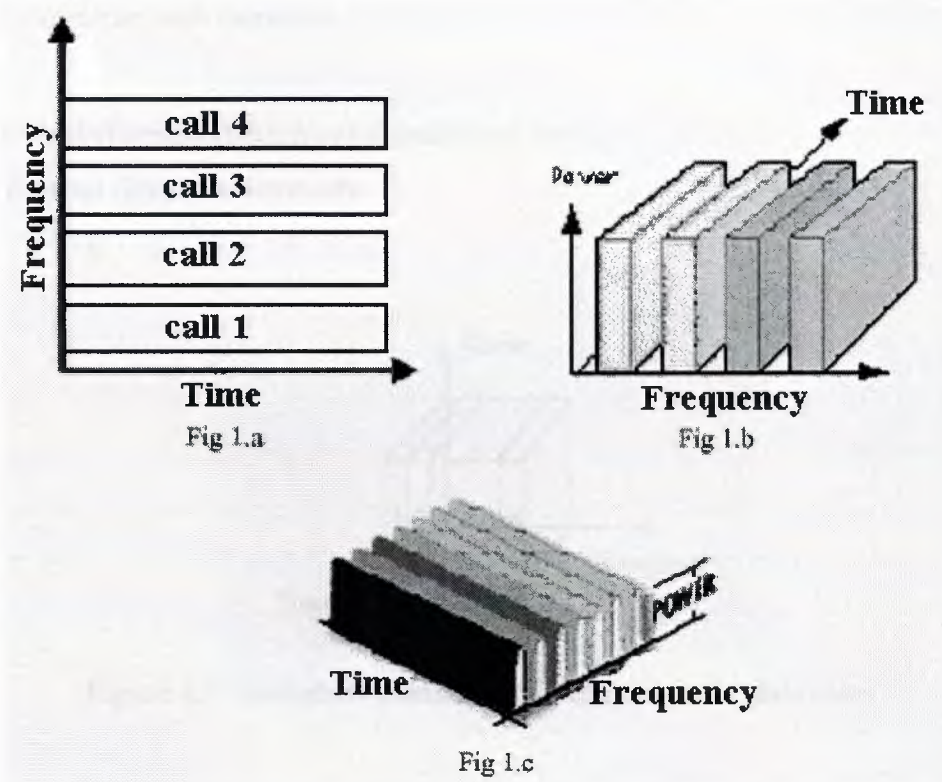

Figure 1.6: Three dimensional view of FDMA signal.

FDMA systems are the least efficient cellular system since each analog channel can only be used by one user at a time. Not only are these channels larger than necessary given modern digital voice compression, but they are also wasted whenever there is silence during the cell phone conversation. Analog signals are also especially susceptible to noise and there is no way to filter it out. Given the nature of the signal, analog cell phones must use higher power (between 1 and 3 watts) to get acceptable call quality. Given these shortcomings, it is easy to see why FDMA is being replaced by newer digital techniques.

FDMA divides the frequency spectrum into small slices, which are assigned to the subscribers. Since the radio spectrum is limited and subscribers do not free their assigned frequency until they are completely finished with it, the number of subscribers in the system can be quickly limited. As the number of subscribers increases, the required frequency spectrum also increases.

1 Individual channels (frequency) to individual users.

2 On demand channel assignment.

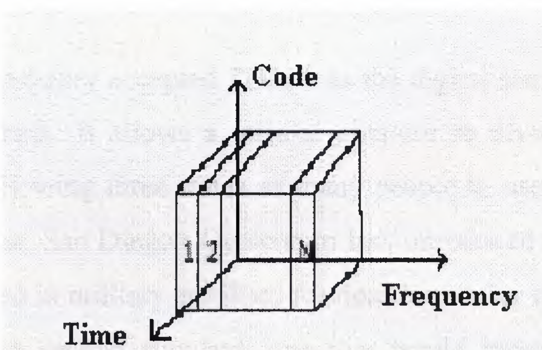

Figure 1.7: Individual channels (frequency) to individual users

FDMA Features

1. If channel not in use, sits idle.
2. Channel bandwidth relatively narrow (30 kHz), i.e., usually narrowband systems.

3. Symbol time >> average delay spread => little or no Equalization required.
4. Simplest.
5. Best suited for analog links.
6. Continuous transmission implies no framing or synchronization bits needed.
7. Requires tight filtering to minimize interference.
8. Usually combined with FDD for duplexing.

1.5 Code Division Multiple Access

History of CDMA

1985 The ITU sets up Interim Working Group 8/13 to determine the overall objectives for future public land mobile telecommunications systems or FPLMTS. The purpose is to integrate terrestrial and satellite components to provide seamless, high-bandwidth access for mobile phones across global networks, while facilitating delivery of fixed wireless access to the developing world.

1989 The U.S. cellular industry accepted TDMA as the digital standard that would replace the analog AMPS standard. It allows a cellular operator to divide up the signal in tiny fractions of a second, allowing three times as many people to use the system at the same time. Later that same year, San Diego's Qualcomm Inc. introduced CDMA, a new flavor of an idea that has been used in military satellites for decades. After three years of testing, the industry accepted it as a second standard, one that would increase the capacity of the system 10 to 20 times. 1992 The TIA established the TR-45.5 subcommittee with the charter of developing a spread-spectrum digital cellular standard. 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. 1994 FPLMTS is renamed IMT-2000. 1996 The ITU holds the first World Telecommunications Forum to explore regulatory policies raised by the overlapping of satellite and national mobile communications systems.

1997 IS-95B standard complete; includes 64 kbps data. The ITU adopts a recommendation for guidelines for evaluating radio transmission technologies and requests candidate RTT proposals. CDMA One brand name launched for IS-95 CDMA. 1998 TIA endorses sideband CDMA One (aka cdma2000) for ITU 3G solution. LG Telecom launches first CDMA data services. 1999 IMT-2000 licenses will be offered in Europe and the United Kingdom. CDMA One reaches 33,621,544 worldwide subscribers Operators across North America, Korea and Japan begin launching CDMA One Internet and information services. 2000. WRC will identify additional spectrum for IMT-2000.

Definitions of Code Division Multiple Access

TDMA proves to be much more efficient than the analog system it was still wasting and width. As a result, Code Division Multiple Access (CDMA) reduces the waste in bandwidth. Again, speech is transformed into a digital stream and a frequency is made which depends on the speech. If there is no speech, because the caller is not talking then the bandwidth is reduced. Furthermore, CDMA increases the caller's privacy because it makes it difficult for other people to replicate the frequency that is used. The only person that can intercept the frequency is the person on the other end of the conversation who is programmed with the same frequency code.

1. All users use same frequency and may transmit simultaneously.
2. Narrowband message signal multiplied by wideband spreading signal, or codeword.
3. Each user has its own pseudo-codeword (orthogonal to others).
4. Receivers detect only the desired codeword. All others appear as noise.
5. Receivers must know transmitter's codeword.

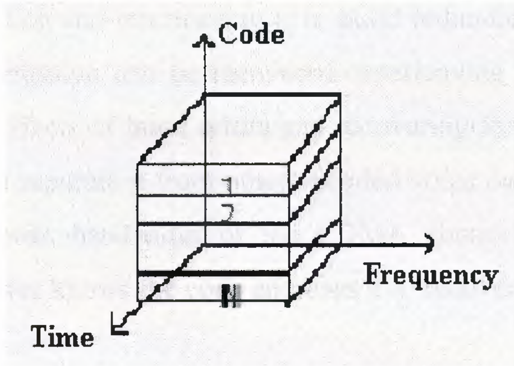

Figure 1.8: Code Division Multiple Access CDMA

CDMA uses codes to convert between analog voice signals and digital signals. CDMA also uses codes to separate (or divide) voice and control data into data streams called "channels". The generation of CDMA signals can be classified into 5 steps:

1. Analog to digital conversion
2. Vocoding
3. Encoding and Interleaving
4. Channelizing the signals
5. Conversion of the digital signal to a RF signal.

The general block diagram of CDMA generation is given in figure 3c. The first step of CDMA signal generation is analog to digital conversion, sometimes called A/D conversion. CDMA uses a technique called Pulse Code Modulation (PCM) to accomplish A/D conversion.

The second step of CDMA signal generation is voice compression. CDMA uses a device called a vocoder to accomplish voice compression. The term "vocoder" is a contraction of the words "voice" and "code". Vocoders are located at the BSC and in the phone.

People pause between syllables and words when they talk. CDMA takes advantage of these pauses in speech activity by using a variable rate vocoder. Encoders and interleaver are built into the BTS and the phones.

The purpose of the encoding and interleaving is to build redundancy into the signal so that information lost in transmission can be recovered. Interleaving is a simple but powerful method of reducing the effects of burst errors and recovering lost bits. The encoded voice data is further encoded to separate it from other encoded voice data. Encoded symbols are then spread over the entire bandwidth of the CDMA channel. This process is called channelization. The receiver knows the code and uses it to recover the voice data.

CDMA Features

1. Soft capacity limit: system performance degrades for all users as number of users increase.
2. Wide frequency spectrum reduces fading.
3. Rake receiver: Separate Multipath signals of different delays by "chip" unit.
4. Cell frequency reuses No frequency planning.
5. Soft Handover increases capacity.
6. "Make before break" vs. "break before make".
7. Utilization of voice activity (talk spurts).
8. Power control necessary for mitigating near-far problem.
9. Tradeoff between precision of power control and capacity.
10. Complex network support for implementing soft handoff.
11. Self-jamming problem due to spreading sequences not being exactly orthogonal.
12. Inappropriate for ultra high rate wireless access.
13. Tremendous width of BW necessary.
14. Hardware complexity.

1.6 CSMA/CA

CSMA/CA stands for (Carrier Sense Multiple Access/Collision Avoidance) is the channel access mechanism used by most wireless LANs in the ISM bands. A channel access mechanism is the part of the protocol which specifies how the node uses the medium when to listen, when to transmit.

The basic principles of CSMA/CA are listening before talk and contention. This is an asynchronous message passing mechanism (connectionless), delivering a best effort service, but no bandwidth and latency guarantee. Its main advantages are that it is suited for network protocols such as TCP/IP, adapts quite well with the variable condition of traffic and is quite robust against interferences.

CSMA/CA is fundamentally different from the channel access mechanism used by cellular phone systems; CSMA/CA is derived from CSMA/CD (Collision Detection), which is the base of Ethernet. The main difference is the collision avoidance: on a wire, the transceiver has the ability to listen while transmitting and so to detect collisions (with a wire all transmissions have approximately the same strength). But, even if a radio node could listen on the channel while transmitting, the strength of its own transmissions would mask all other signals on the air. So, the protocol can't directly detect collisions like with Ethernet and only tries to avoid them.

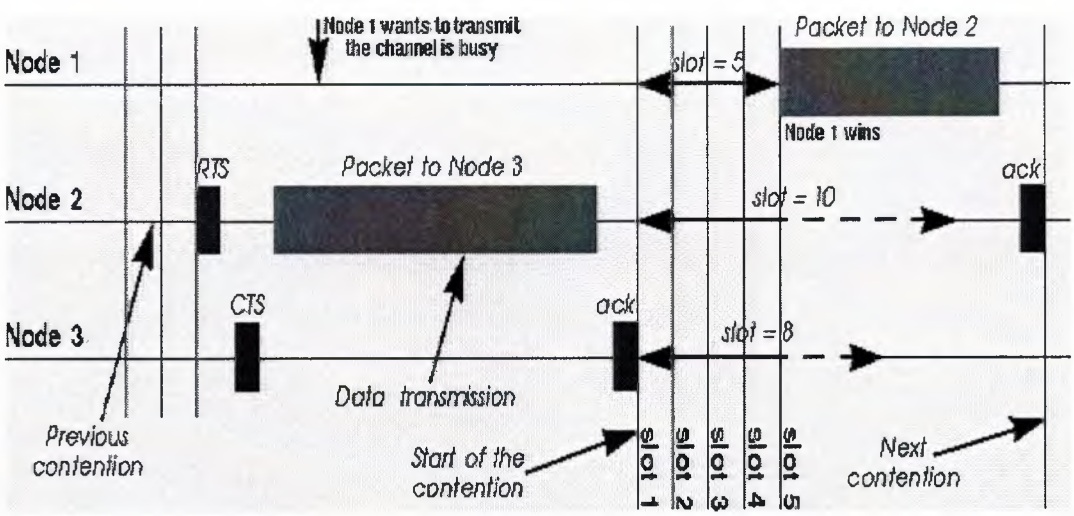

Figure 1.4: CSMA/CA channel Access Mechanisms

The protocol starts by listening on the channel (this is called carrier sense), and if it is found to be idle, it sends the first packet in the transmit queue. If it is busy (either another node transmission or interference), the node waits the end of the current transmission and then starts the contention (wait a random amount of time). When its contention timer expires, if the channel is still idle, the node sends the packet. The node having chosen the shortest contention delay wins and transmits its packet. The other nodes just wait for the next contention (at the end of this packet). Because the contention is a random number and done for every packets, each node is given an equal chance to access the channel (on average - it is statistic). As we have mentioned, we can't detect collisions on the radio, and because the radio needs time to switch from receive to transmit, this contention is usually slotted (a transmission may start only at the beginning of a slot: 50 µs in 802.11 FH and 20 µs in 802.11 DS). This makes the average contention delay larger, but reduces significantly the collisions (we can't totally avoid them).

CHAPTER TWO

TIME DIVISION MULTIPLE ACCESS (TDMA)

2.1 Definition of TDMA

TDMA is a common multiple access technique employed in digital cellular systems. It allows a number of users to access a single frequency channel by allocating unique time slots to each user within each channel.

2.2 TDMA works

Time division multiple access (TDMA) takes advantage of the digitization of the signals in order to accommodate information from several users within one frequency channel. Nyquist's sampling theorem assures that if a band limited signal with bandwidth W is sampled at rate of at least Ws=2*W then the signal can be fully reconstructed from its samples and no information is lost. Thus, the signal's samples can be transmitted instead of the signal itself. But now, the time between transmitted samples can be utilized to transmit samples of other signals in order to increase the capacity of the frequency channel. This is a simplified conceptual description of how TDMA works.

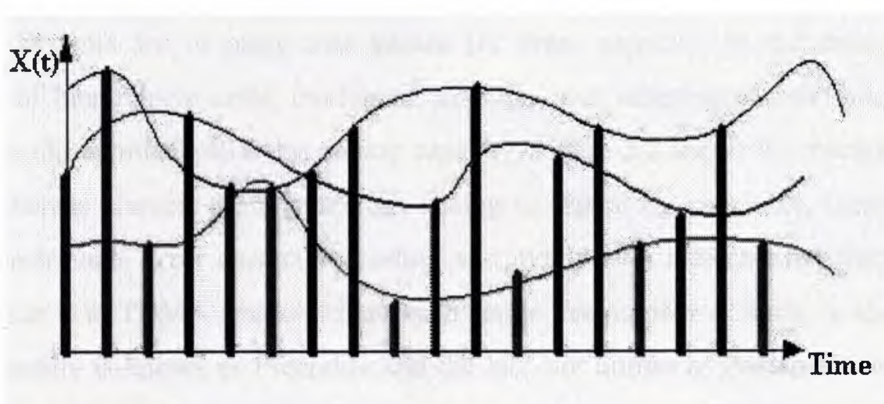

Figure 2.1: TDMA signal.

More elaborately, when a user wishes to transmit an analog signal (voice), the signal is sampled, quantized and digitized in a process that is called PCM-Pulse Code Modulation (If the signal is already digitized (data signal) this is unnecessary). As a result the signal is converted into a stream of digital information. The stream is compressed by a digital speech code into bursts 1/n of their original length. The burst takes only 1/n of the airtime required to transmit the original audio signal, leaving n-1/n of the time for the other u. The digital burst is then modulated into the channel's frequency and in the time slot that was allocated for the user the burst is transmitted. The channel's frequency and the allocated time slot for the user are informed to the mobile user by the base station when the call is set up via a control channel.

TDMA is a store and burst system. Incoming user traffic is stored in memory and when a user's turn comes up, this accumulated traffic is transmitted in a digital burst. In TDMA, the transmission is divided to frames, which contain several time slots. In each time slot, a different user transmits his digital burst. This method of multiplexing that combines data streams by assigning each stream a different time slot in a set is called Time Division Multiplexing (TDM) (this technique is also used in T1/E1 channels).
The number of time slots in a frame (n) is standard dependent. Effectively, TDMA implementations that use n:1 multiplexing (i.e. divide the channel's given bandwidth into n time slots) increase capacity by n. North American cellular standards IS-54 and IS-136, for example, triple the capacity of cellular frequencies by dividing a 30-kHz channel into three time slots, enabling three different users to occupy it at the same time.
Currently, systems are in place that allows six times capacity. In the future, with the utilization of hierarchical cells, intelligent antennas, and adaptive channel allocation, the capacity should approach 40 times analog capacity. Figure 2.2 shows the mechanism of the TDMA, whereas convert the signal from analog to digital by converter, compression by digital speech code, error correction coding and modulation into channel frequency, and finally divide it to TDMA frames where each frame has number of slots, in the frame the first slot usually is knows as Preamble and the last slot knows as Postamble and the slots which com between is the transmitted message.

TIME DIVISION MULTIPLE ACCESS (TDMA)

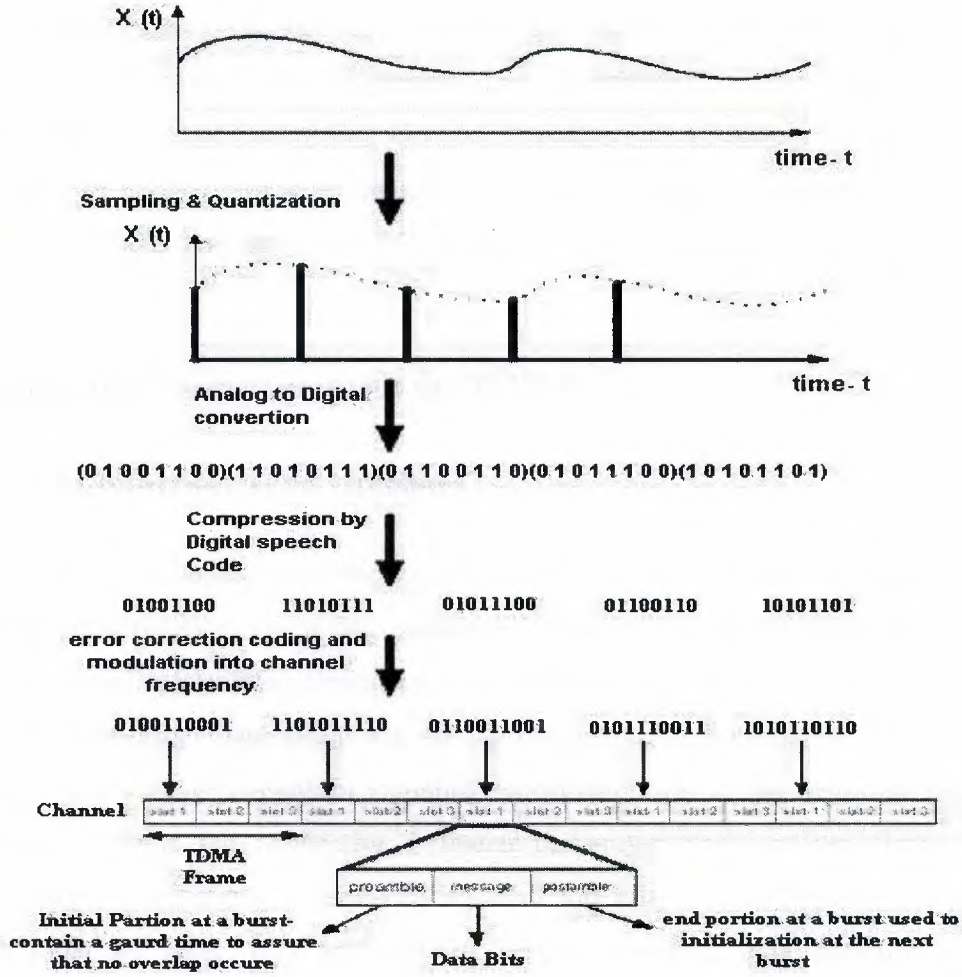

Figure 2.2: TDMA Mechanism

2.3 Enhanced TDMA

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.

An enhanced version of TDMA (ETDMA) improves the bandwidth utilization by assigning time slots to users dynamically instead of waiting to determine whether a user is transmitting. ETDMA sends data through those pauses which normal speech contains. When a user has something to transmit, he puts one bit in a buffer queue. The system scans the buffer, notices that the user has something to transmit, and allocates bandwidth accordingly. If a user has nothing to transmit, he is skipped. So, instead of being arbitrarily assigned, time is allocated according to need. If partners in a phone conversation do not speak over one another, these techniques can almost double the bandwidth utilization efficiency of TDMA, making it almost 10 times as efficient as analog transmission.

2.4 Signal and system structures for TDMA

Physical layer subscriber signal structures

The physical layer subscriber signals carry the data sequences, which shall be transmitted to the receiver. These data sequences consist of encoded subscriber data, which can be any type of information stemming from higher layers, i.e. layers above the physical layer. These subscriber data could e.g. be digitally encoded speech. The physical layer subscriber signals have to contain signaling information which are required to set up, maintain and release the connection between transmitter and receiver. Since mobile communication is considered, a time-varying Multipath channel with an unknown impulse response must be taken into account. To support coherent data detection, channel estimation must be carried out at least once per subscriber time slot. This channel estimation is based on training sequences, which are part of the aforementioned signaling Information and which must therefore be embedded in the physical layer subscriber signals. Furthermore, the physical layer subscriber signals are concluded by guard periods of duration Tg in order to guarantee a reasonable separation between consecutive physical layer subscriber signals.

As illustrated in Sect. 2 and Tab. 1, TDMA allows a subscriber to be active only for a short time before the next period of activity occurs in the next TDMA frame. A typical duration of a subscriber time slot, Tu, is about 0.5 ms whereas a TDMA frame comprises of several subscriber time slots and has a typical duration, Tfr, in the order of 5 ms. Hence, the physical layer subscriber signals have a finite duration of Tu. Such signals are usually termed bursts.

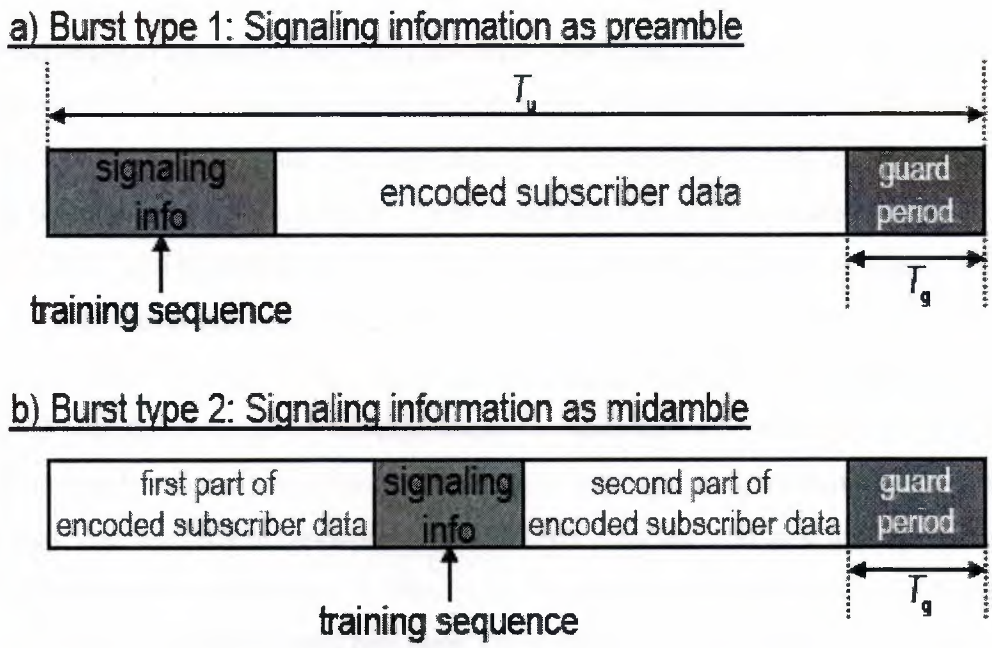

Figure 2.3: Burst types for TDMA

- Burst type 1: Signaling information as preamble
- Burst type 2: Signaling information as midamble

When a preamble is used, the aforementioned channel estimation can take place at the beginning of the signal reception. The channel estimate, which is based on noisy samples, is affected by estimation errors due to noise in the received signal. Owing to these estimation errors, the data detection can only be quasi-coherent. The noisy channel estimates are fed into the quasi-coherent data detector, which carries out the data detection based on the sample values obtained after the reception of the preamble. Ideally, this quasi-coherent data detection can be carried out without having to store any sample values. However, in the case of a low correlation time of the mobile radio channel, i.e. at high mobile velocities, the true channel impulse response varies over the duration Tu of the subscriber signals.

The error between the noise channel estimate and the true channel impulse response increases nonlinearly with increasing distance from the preamble. In the case of long bursts this effect leads to considerable systematic errors resulting in dramatic degradations of the quasi-coherent data detection, i.e. of the bit error ratio at a given Eb/N0. In order to alleviate this effect, midambles are used instead of preambles, cf. Fig. 2b. In this case, the data are divided in two parts, usually of equal size and half as long as the data carrying part shown in Fig. 2a. The signaling information is located between these two parts. Then, the effect of the above-mentioned systematic errors on the bit error ratio is considerably smaller. However, in order to carry out quasi-coherent data detection, at least those samples associated with the first part of encoded subscriber data has to be stored before the channel estimation can be carried out. Nevertheless, thanks to high integration densities in CMOS technology, memory ICs or embedded on-chip memories are available at a reasonably low price alleviating this drawback. A third possibility, using a postamble, suffers from all drawbacks of the aforementioned two burst types without having further advantages. To the knowledge of the author, this third possibility has not yet been implemented and will not be further considered in this communication

2.5 TDMA Applications

There are three primary versions of TDMA RF technology: North American TDMA (IS-136), European TDMA (GSM), and Japanese TDMA (PHS/PDC). The IS-136 version of TDMA provides the foundation for a global TDMA platform of enhanced, scaleable mobile services and will evolve based on the increasing number of wireless transnational service requirements in the global mobility marketplace.

1. North American TDMA (IS – 136 also called D-AMPS)
2. European TDMA (GSM)
3. Japanese TDMA (PDC)

North American TDMA (IS-136 D-AMPS)

The IS-136 evolved from the TDMA standard IS-54. The IS-54 standard identified the critical parameters (e.g. time slot structure, type of radio channel and modulation) and included like calling number identity, voice privacy, message waiting indicator etc. In order to include further features such as enhanced battery life, the digital control channel at the IS-136 series were developed. Because of the evolution process IS-136 phones can operate in an analog or digital environment. Digital traffic channels are divided into frames with six time slots. Every communications channel consists of two 30-Khz wide channels (from the cell site to the mobile phone [forward] and vice versa). The time slots between the forward and reverse channels are related so that the mobile phone cannot simultaneously transmit and receive.

Advantages of TDMA D-AMPS

IS-136 makes migration from analog to digital services easier because of these competitive advantages:

1. The top carriers report that 50 percent of their markets are already built out with TDMA.

   TDMA is cost-effective - as your capacity needs increase you can ramp as needed. You never have to buy more capacity than you need.
2. A single network system covers a full range of digital in-building (including fixed wireless) to extend and complement traditional outdoor macro-cellular services.
3. Seamless interworking with all Advanced Mobile Phone Service (AMPS)-based analog systems (60 percent of current worldwide cellular services today).
4. Ubiquitous spectral coverage and full subscriber mobility across multiple radio bands, based on a single dual mode, dual band wireless terminal.
5. Support for subscriber pre-subscription and carrier selection options for competitive telecom service markets.
6. Cost: IS-136 allows analog AMPS and TDMA networks to co-exist, using the same frequencies, radio channels and dual-mode phones. IS-136 allows the operator to assign digital services to previous analog channels or new digital growth channels based on actual market demand - "just-in-time" digital provisioning.
7. Timing: IS-136 allows digital services to be assigned to previous analog channels or new digital growth based on actual market demand.

8. Flexibility: The increased capacity of TDMA digital can be introduced by the operator wherever needed in the network, to support a broad range of demand forecasts and strategies for modernization--including all-digital TDMA deployment when required, while avoiding unnecessary holding costs for inventory of spectrum not put into service.

European TDMA (GSM)

The Global System for Mobile communications (GSM) is a European digital cellular standard that uses a different form of TDMA at the IS- 136.
A primary feature of the GSM system is its use of a single type of digital radio channel. Each 200-Khz wide GSM digital radio channel is divided into frames with eight time slots. Every GSM channel consists of radio channels, a forward channel and a reverse channel. Again the mobile cannot transmit and receive simultaneously. The GSM system also uses portable Subscriber Identity Module (SIM) cards that contain the identity of the customer.

Japanese TDMA (PDC)

PDC is a cordless communications standard, developed in Japan to provide high quality, cheap and flexible communications solutions. PDC uses a micro-cell configuration with a base station range of 100-300 meters in diameter. Because of the low transmit power, smaller and lighter handsets with longer talk and standby times are supported. PDC also supports a 32kbits/sec data link, which enables fixed-line quality voice and high rate data services.

2.6 TDM (Time Division Multiplexing)

It's often practical to combine a set of low-bit-rate streams, each with a fixed and pre-defined bit rate, into a single high-speed bit stream that can be transmitted over a single channel. This technique is called time division multiplexing (TDM) and has many applications, including wire line telephone systems and some cellular telephone systems. The main reason to use TDM is to take advantage of existing transmission lines. It would be very expensive if each low-bit-rate stream were assigned a costly physical channel (say, an entire fiber optic line) that extended over a long distance.

Consider, for instance, a channel capable of transmitting 192 kbit/sec from Chicago to New York. Suppose that three sources, all located in Chicago, each have 64 kbit/sec of data that they want to transmit to individual users in New York. As shown in Figure 7-2, the high-bit-rate channel can be divided into a series of time slots, and the time slots can be alternately used by the three sources. The three sources are thus capable of transmitting all of their data across the single, shared channel. Clearly, at the other end of the channel (in this case, in New York), the process must be reversed (i.e., the system must divide the 192 kbit/sec multiplexed data stream back into the original three 64 kbit/sec data streams, which are then provided to three different users). This reverse process is called demultiplexing.

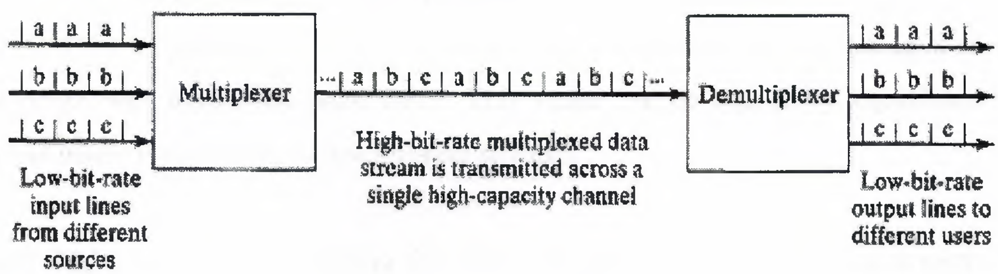

Figure 2.4: Time division multiplexing

Choosing the proper size for the time slots involves a trade-off between efficiency and delay. If the time slots are too small (say, one bit long) then the multiplexer must be fast enough and powerful enough to be constantly switching between sources (and the demultiplexer must be fast enough and powerful enough to be constantly switching between users). If the time slots are larger than one bit, data from each source must be stored (buffered) while other sources are using the channel. This storage will produce delay. If the time slots are too large, then a significant delay will be introduced between each source and its user. Some applications, such as teleconferencing and videoconferencing, cannot tolerate long delays.

Mechanism of TDM (Time division multiplexing)

TDM (Time division multiplexing) is based on fixed slot assignments to each of the low-bit-rate data streams. In other words, each stream has predefined slot positions in the combined stream, and the receiver must be aware which slots belong to which input stream. Both transmission ends, the transmitter and the receiver, must be perfectly synchronized to the slot period. For this reason, the technique is usually called synchronous TDM.

There is another important version of TDM, usually referred to as statistical TDM. Statistical TDM is useful for applications in which the low-bit-rate streams have speeds that vary in time. For example, a low-bit-rate stream to a single terminal in a computer network may fluctuate between 2 kbit/sec and 50 kbit/sec during an active connection session (we've all seen variable speeds during Internet connections, for instance). If we assign the stream enough slots for its peak rate (that is, for 50 kbit/sec), then we will be wasting slots when the rate drops well below the peak value. This waste can be especially significant if the system has many variable-speed low-bit-rate streams.

Statistical TDM works by calculating the average transmission rates of the streams to be combined, and then uses a high-speed multiplexing link with a transmission rate that is equal to (or slightly greater than) the statistical average of the combined streams. Since the transmission rates from each source are variable, we no longer assign a fixed number of time slots to each data stream. Rather, we dynamically assign the appropriate number of slots to accommodate the current transmission rates from each stream. Because the combined rate of all the streams will also fluctuate in time between two extreme values, we need to buffer the output of the low-bit-rate streams when the combined rate exceeds the transmission rate of the high-speed link. With statistical TDM, we are no longer relying on synchronized time slots with fixed assignments for each input stream, as we did with synchronous TDM. So how does the demultiplexer in statistical TDM know which of the received bits belongs to which data stream? Prior to transmission, we divide each stream of bits coming from a source into fixed-size blocks. We then add a small group of bits called a header to each block, with the header containing the addresses of the source and intended user for that block. The block and the header are then transmitted together across the channel. Combined, the block and header are called a packet. Figures 2.5 present the statistical TDM technique.

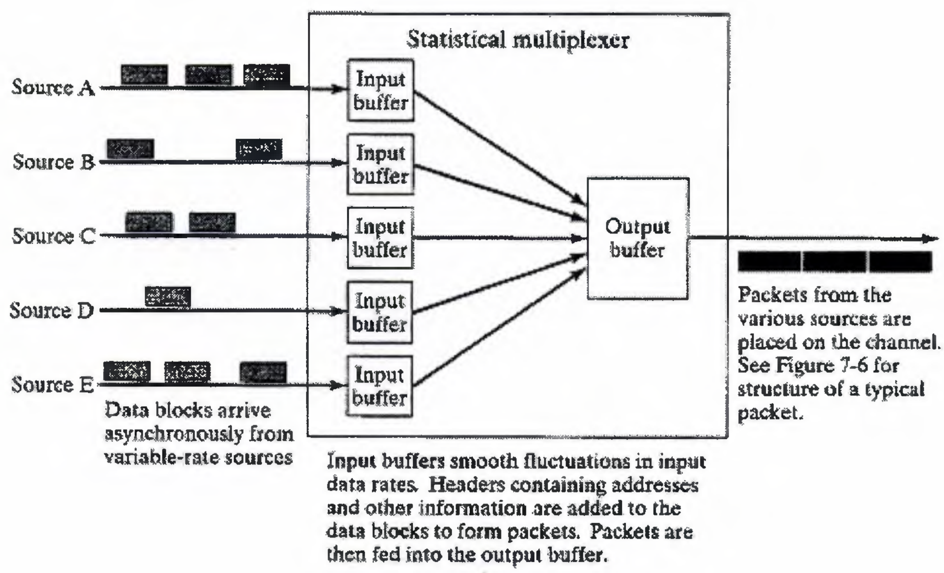

Figure 2.5: Statistical TDM.

Actually, the header may contain other information besides the source and user addresses, such as extra bits for error control or additional bits for link control (used, for example, to indicate the position of a particular block in a sequence of blocks coming from the same user, or to indicate priority level for a particular message). Extra bits can also be added to the beginning and end of a block for synchronization; a particular pattern of bits, called a start flag, can be used in the header to mark the start of a block, and another particular pattern of bits, called an end flag, can be used to conclude the block. Each block transmitted across the channel thus contains a group of information bits that the user wants, plus additional bits needed by the system to ensure proper transmission. These additional bits, while necessary to system operation, reduce the effective transmission rate on the channel. Figures 2.6 present the structure of a typical packet.

Start flag	Address field	Control field	Information bits	Error control	End flag

Figure 2.6: Structure of a typical statistical TDM packet.

CHAPTER THREE

FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

3.1 FDMA Definition

FDMA (Frequency Division Multiple Access) is one of the earliest multiple-access techniques for cellular systems when continuous transmission is required for analog services. In this technique the bandwidth is divided into a number of channels and distributed among users with a finite portion of bandwidth for permanent use as illustrated in figure 3.1. The vertical axis that represents the code is shown here just to make a clear comparison with CDMA (discussed later in this chapter). The channels are assigned only when demanded by the users. Therefore when a channel is not in use it becomes a wasted resource. FDMA channels have narrow bandwidth (30 KHz) and therefore they are usually implemented in narrowband systems. Since the user has his portion of the bandwidth all the time, FDMA does not require synchronization or timing control, which makes it algorithmically simple. Even though no two users use the same frequency band at the same time, guard bands are introduced between frequency bands to minimize adjacent channel interference. Guard bands are unused frequency slots that separate neighboring channels. This leads to a waste of bandwidth. When continuous transmission is not required, bandwidth goes wasted since it is not being utilized for a portion of the time. In wireless communications, FDMA achieves simultaneous transmission and reception by using Frequency division duplexing (FDD). In order for both the transmitter and the receiver to operate at the same time, FDD requires duplexers. The requirement of duplexers in the FDMA system makes it expensive.

Both fixed and dynamic frequency allocation is possible. Radio frequencies are a good example of a fixed allocation though often this will be combined with SDM as frequencies are reused in different geographical areas. Even within demand-driven allocation we have a pure FDMA scheme where channels are assigned the same frequency at all times and a combined scheme with TDMA where channels may change frequencies according to a

pattern. The second scheme may involve frequency hopping where a hopping pattern, agreed between sender & receiver, to minimize narrowband interference.
Often, a duplex channel will exist to allow simultaneous two-way communication e.g. between a base station and a mobile station. Frequency division duplex (FDD) provides different frequencies for the uplink and downlink. The diagram below is based on the GSM standard for 900 MHz. Uplinks use frequency band between 890.2 and 915 MHz, downlinks use 935.2 to 960 MHz. The base station allocates a frequency for uplink with the downlink frequency a fixed increment away e.g. 45 MHz.

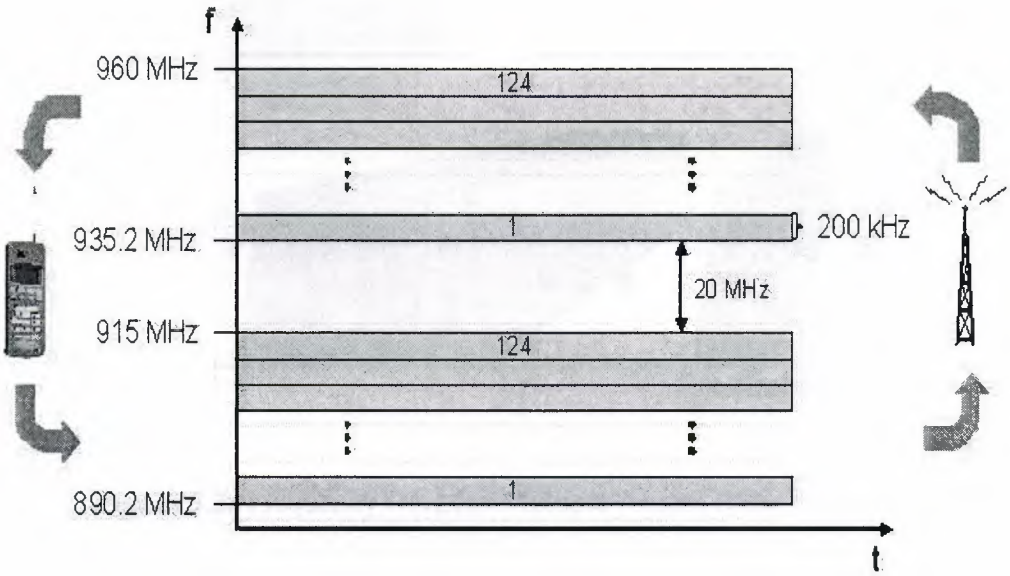

Figure 3.1: Bandwidth is divided into a number of channels

3.2 FDMA Operations

Basic system operation

Frequency division multiplexing was used extensively in the early telephone and wireless multi-user communication systems, and is perhaps the most intuitive form of resource sharing. If a channel, such as a cable, has a transmission bandwidth W Hz, and individual users require B Hz to achieve their required information rate, then the channel in theory should be able to support W/B users simultaneously. This is made possible by using bandpass modulation (i.e. ASK, FSK and PSK) and placing each user in an adjacent slot of the available bandwidth. Immediately, we see that the efficiency of frequency multiplexing is governed by how effectively the transmission bandwidth is constrained by each user. It is also dependent on how good (selective) the 'de-multiplexing' system is at filtering out the modulation corresponding to each user.

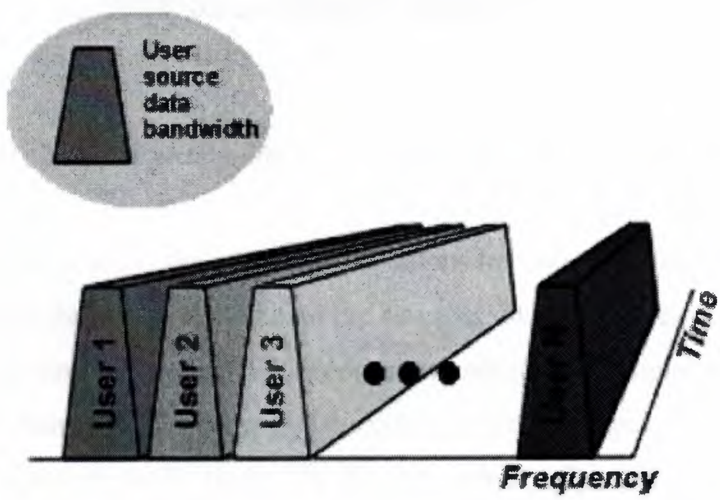

Figure 3.2: Frequency Division Multiple Access Basic System Operation

With frequency division multiplexing, the data rate and hence modem design for each user remains unchanged by the requirement to operate a multi-user system, and the only additional circuitry is for frequency conversion to the assigned slot. The user will typically be assigned the frequency slot for the duration of the message.

Wireless FDMA operation

FDMA is widely used in wireless communications systems where the radio environment creates several challenges for any multiple access method owing to the unpredictable and time varying nature of the communications channel.

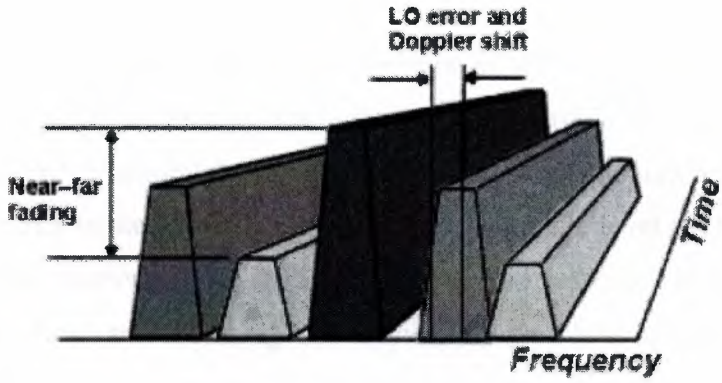

Figure 3.3: Frequency Division Multiple Access Wireless Operation

One of the biggest challenges is the very large variations in received signal power that arise from users in different frequency slots due to the so-called near-far effect. A radio user that is very near to a base-station receiver will produce a much stronger signal than that from a distant (far) user operating on the extreme of the communication range.

Typical variations in power can be up to 100 dB. If the strong signal is producing any out-of-band radiation in the slot occupied by the weak signal, this can easily swamp the weak signal corrupting the communications. Controlling the bandwidth and side-lobe energy of digital modulation formats, such as Continuous Phase Frequency Shift Keying (CPFSK) and on designing modulation formats that are not overly sensitive to amplifier distortion, such as $\pi/4$ Quadrature Phase Shift Keying ($\pi/4$ QPSK), are all driven by this near-far problem in the wireless application.

Other challenges in the radio environment include dealing with the frequency uncertainty for any individual user caused by Doppler shift and local oscillator error. This inevitable error requires guard-bands to be allocated between frequency slots, thus sacrificing some of the efficiency of the FDMA scheme.

3.3 Power control in wireless FDMA systems

As the near-far problem can be so dominant in wireless FDMA operation, it is worth looking briefly at techniques for alleviating the problem. The most effective technique over and above maximizing the filtering and spectral shaping within the modem and improving linearity in the TX/RX subsystems is to attempt to level out the signal power from each user at the receiver site. If each user were able to fully control the output power from its own transmitter, and assuming that it knew the path loss to the receiver, then it could adjust its own power to ensure a fixed minimum (yet sufficient) level from all users at the receiving site.

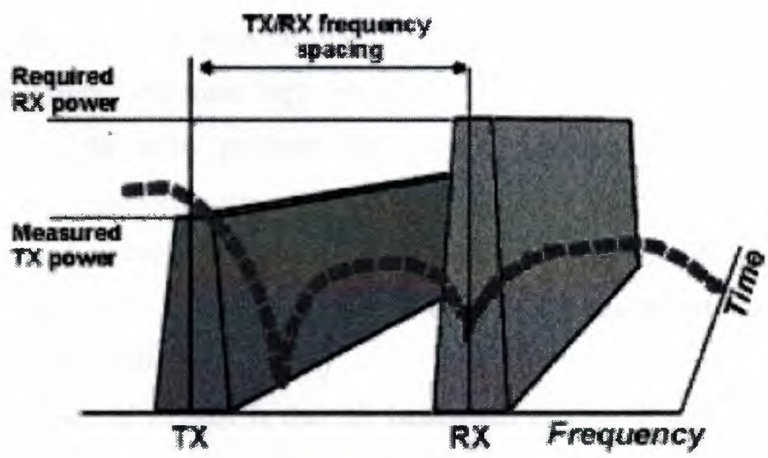

Figure 3.4: Power control issues with selective fading

Determining the path loss is the key problem. Certainly it is possible in a duplex link for the remote user to measure the power received from the base-station site and hence calculate the path loss in the 'downlink'. However, unless the user is stationary and operating on the same frequency for transmits and receives, this does not necessarily translate to the path loss in the 'uplink' direction. For example, the remote user could be receiving in a frequency selective fade, in which case the unit would overestimate the path loss involved. Alternatively the uplink could be subject to a frequency selective fade and the unit not generate sufficient transmit power. A solution to this problem is to operate a closed loop power control system whereby the base-station unit monitors the signal power from each remote unit and issues commands to increase or decrease TX power accordingly. This can, however, incur a high signaling overhead in the system. It turns out that power control is very critical in CDMA and to a lesser extent TDMA operation, and closed loop power control is common in CDMA applications.

3.4 FDMA Features

Advantages

Traditionally FDMA has been favored for:-

1. To be use in radio systems, where the path delays introduced by Multipath propagation give rise to intersymbol interference effects which become significant when the differential path delay becomes a significant part of the symbol period. By keeping the symbol duration high, which implies M-ary signaling over narrow frequency slots, the delay problem can often be ignored. (With modern signal processing, the implementation of channel equalization techniques has meant that this delay spread problem need no longer constrain the symbol rate used, allowing much faster data rates over air and hence opening up the possibility of TDMA solutions as an alternative to FDMA.)
2. Another advantage of FDMA is that the bandwidth of the TX and RX circuitry is kept to a minimum (particularly the bandwidth over which power amplifiers are to be made linear), and the signal processing task for data generation and detection is kept as simple as possible.

Disadvantages

A disadvantage that has often been leveled at FDM/FDMA is inflexibility to accommodate variable user data rates within a fixed bandwidth frequency slot. This claim is nowadays unfounded for two reasons. Firstly, it is practical to vary the data rate in a given frequency slot by increasing the number of symbol states used. Secondly, it is possible to assign a user more than one frequency slot, or introduce the concept of a variable bandwidth slot in order to vary the user data rate. Both of these solutions rely heavily on the advent of powerful digital signal processing devices that can implement adaptive rate multi-symbol modems (these are now commonplace in line modem cards), and variable bandwidth matched channel filters – again a simple function for today's DSP devices.

Figure 3.5: Frequency selective fading

Frequency stability and the need for guard-bands has traditionally been a bigger problem for FDMA use, requiring very costly and high stability oscillators in the modems if the guard-bands are to be kept to a minimum. In recent years, the use of a broadcast off-air reference has been exploited to allow designers to dispense with these costly oscillator components and achieve much greater stability than hither too possible. (Today, it is possible to buy watches that take their timing reference 'off-air' for millisecond precision accuracy.) The major disadvantage of FDMA in a wireless environment is the susceptibility of any individual narrow frequency slot to frequency selective fading which can cause loss of signal for that user – usually on a temporary basis.

3.5 FDM Definition

Frequency Division Multiplexing (FDM) is a technique the carrier bandwidth is divided into sub-channels of different frequency widths, each carrying a signal at the same time in parallel. Each channel is 30 kHz. All the signals may be amplified, conducted, translated in frequency and routed toward a destination as a single signal, resulting in economies which are the motivation for multiplexing. Receivers at the receiving end separates the multiplexed signals by means of frequency passing or rejecting filters, and demodulates the results individually, each in the manner appropriate for the modulation scheme used for that band or group.

FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

Wavelength Division Multiplex (WDM) and Frequency Division multiplex (FDM) are both based on the same principles but WDM applies to digitized wavelengths of light in optical fiber while FDM is used in analog transmission such as twisted pair telephone line, cable access, cellular, radio and TV communications. TDMA and CDMA are always used in combination with FDMA, i.e., a given frequency channel may be used for either TDMA or CDMA independently of signals on other frequency channels.

Where frequency division multiplexing is used as to allow multiple users to share a physical communications channel, it is called frequency division multiple access (FDMA). FDMA analog transmissions are the least efficient networks since each analog channel can only be used one user at a time. Analog channels don't take full advantage of band-width. Not only are these FDMA channels larger than necessary given modern digital compression, but they are also wasted whenever there is silence during communication. Analog signals are especially susceptible to noise and the extra noise cannot get filtered out.

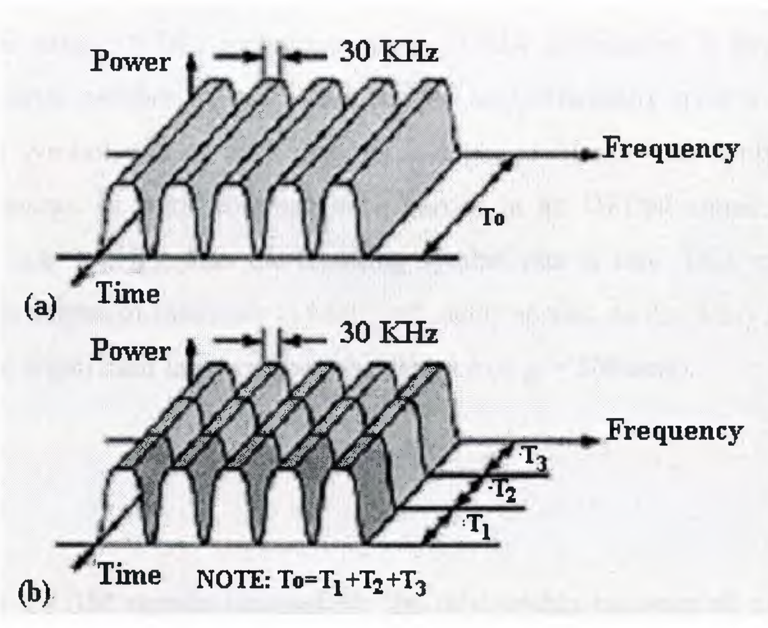

Figure 3.6: FDM: Frequency Division Multiplex and FDMA

3.6 OFDM Principles

(OFDM) Orthogonal Frequency Division Multiplexing is a multicarrier transmission technique used in applications catering to both Wired and Wireless Communications. However, in the wired case, the usage of the term Discrete Multi-Tone is more appropriate. The OFDM technique divides the frequency spectrum available into many closely spaced carriers, which are individually modulated by low-rate data streams. In this sense, OFDM is similar to FDMA (The bandwidth is divided into many channels, so that, in a multi-user environment, each channel is allocated to a user). However, the difference lies in the fact that the carriers chosen in OFDM are much more closely spaced than in FDMA (1kHz in OFDM as opposed to about 30kHz in FDMA), thereby increasing its spectral usage efficiency. The orthogonality between the carriers is what facilitates the close spacing of carriers.

The orthogonality principle essentially implies that each carrier has a null at the center frequency of each of the other carriers in the system while also maintaining an integer number of cycles over a symbol period.

The motivation for using OFDM techniques over TDMA techniques is twofold. First, TDMA limits the total number of users that can be sent efficiently over a channel. In addition, since the symbol rate of each channel is high, problems with Multipath delay spread invariably occur. In stark contrast, each carrier in an OFDM signal has a very narrow bandwidth (i.e. 1 kHz); thus the resulting symbol rate is low. This results in the signal having a high degree of tolerance to Multipath delay spread, as the delay spread must be very log to cause significant inter-symbol interference (e.g. > 500usec).

Orthogonality

To generate OFDM signals successfully the relationship between all carriers must be carefully controlled in order to maintain orthogonality. Shown below is the frequency spectrum depicting the various carriers/channels (used interchangeably). Rectangular windowing of transmitted pulses results in a sinc-shaped frequency response for each channel. As can be seen, whenever any particular carrier frequency attains peak amplitude, the remaining carriers have a null point.

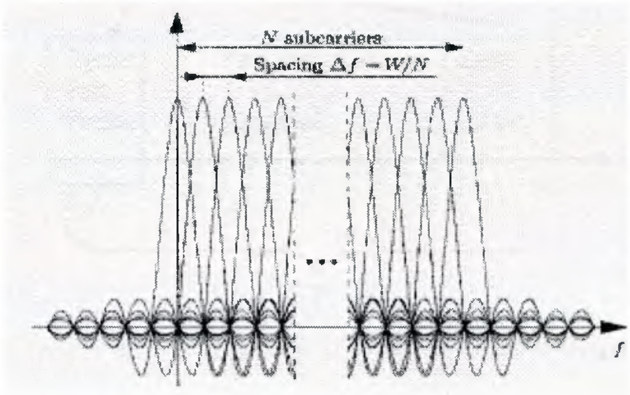

Figure 3.7: Frequency spectrum showing N channels for an OFDM system with N carriers over a bandwidth W

OFDM Generation

The spectrum required is first chosen based on the input data and the modulation scheme used (typically Differential BPSK, QPSK or QAM). Data to be transmitted is assigned to each carrier that is to be produced. Amplitudes and phases of the carriers are calculated based on the chosen scheme of modulation. The required spectrum is then converted back to its time domain signal by employing Inverse Fourier Transform algorithms like the Inverse Fast Fourier Transform (Cooley-Tukey Algorithm)
The next step is that of adding a guard period to the symbol to be transmitted. This ensures robustness against Multipath delay spread. This step can be achieved by having a long symbol period, which minimizes intersymbol interference. The level of robustness can be further increased by the addition of a guard period between successive symbols. The most popular and effective method of doing this, is the addition of a cyclic prefix. A cyclic prefix is a copy of the last part of the OFDM symbol, which is prepended to the transmitted symbol. This makes the transmitted signal periodic and does not affect the orthogonality of the carriers. Further, this also plays a decisive role in avoiding inter-symbol and inter-carrier interference.

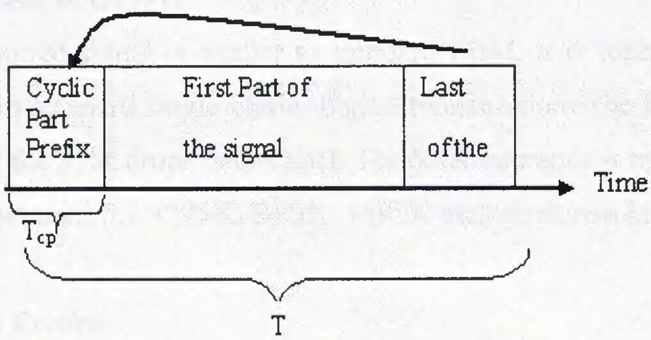

Figure 3.7: The Cyclic Prefix is a copy of the last part of the OFDM signal

A cyclic prefix does however introduce a loss in the signal-to-noise ratio, but this effect is usually negligible as compared to its effect on mitigating interference.
A schematic diagram is shown next and a mathematical model of a base band OFDM system is now developed.

3.7 Benefits of OFDM and Performance Criteria

The main criteria for evaluating the performance of the OFDM system are tolerance to peak power clipping, channel noise and time synchronization errors. The performance of different OFDM systems under varied channel conditions, keeping in mind the above criteria is now discussed.

Peak Power Clipping:

The OFDM signal showed high degrees of tolerance (BER is not affected adversely) even if it was heavily clipped. The clipping distortions mostly arise from the Power Amplifier transmitting the signal. The signal can be clipped by as high as 9dB without a significant effect on the BER. This could be used to our advantage, meaning, the OFDM signal could be clipped by up to 6dB so that the Peak-to-RMS ratio can be reduced, thus allowing an increased transmitted power.

Gaussian Noise Tolerance of OFDM

Since the transmitted signal is similar to standard FDM, it is found that the SNR performance is similar to standard single carrier digital transmission. The BER is found to be adversely affected, if the SNR drops below 6dB. The SNR tolerance is mostly dependant on the kind of modulation used (i.e. QPSK, BPSK, 16PSK etc.) as shown in the plot.

Time-Synchronization Errors

The Synchronization factor in an OFDM system is the most critical one. When the receiver is initially turned on, it is not in synchronization with the transmitter. For this reason, data transmission in an OFDM system might need data to be sent in frames. At the beginning of each frame a null symbol is transmitted, so that the receiver can detect incoming data using simple envelope detection techniques. However, the noise in the signal might interfere with the envelope detection process. In general, it has been found that the receiver synchronizes itself with the transmitter in a time interval less than or equal to the guard interval.

CHAPTER FOUR

CODE DIVISION MULTIPLE ACCESS (CDMA)

4.1 Overview

Code Division Multiple Access was born from spread spectrum technology. Spread Spectrum systems were developed to combat unauthorized access and prevent jamming of signals while operating at least external interference, low spectral density and providing multiple access capability. In this project we simulated an asynchronous direct sequence spread spectrum CDMA system and studied the effect on bit error probability by varying number of users and processing gain of the system. The transmitter and receiver are assumed to be synchronized perfectly. The performance of the system with multiple access interference and noise were analyzed. The probability of bit error versus various numbers of users for different Eb/No was computed. The effect of varying processing gain was observed on BER for fixed number of users and a particular Eb/No. Also, BER performance for interfering power of other user in neighboring environment was studied for a fixed Eb/No. Further a simple scheme for Adaptive Transmitter power control in closed loop configuration was simulated, attempt was also made to simulate a Rayleigh fading channel and observe the effect of Multipath on BER.

Direct-Sequence Spread Spectrum was chosen because of its simplicity in simulation and also as DS-SS systems perform well in multi-user environments of today. Spread Spectrum techniques are characterized by the following properties:

1. Transmitted signal occupies a bandwidth, which is many times greater than the message bandwidth.
2. Carrier signal is pseudo-random in nature. Modulating the output of a pseudo-random sequence generator with the message signal produces the transmitted signal.
3. Message detection involves correlating the received signal with the same pseudo-random spreading signal. This operation is called dispreading. Thus, the receiver

has to be able to generate a time-synchronized copy of the same pseudo-random sequence as in the transmitter.

The core principle of CDMA (or spread spectrum in general) is the use of noise-like carrier waves, where the signals are directly multiplied with assigned code (Pseudo random code). This results in wider bandwidths than simple point-to-point communication at the same data rate. Even though CDMA was proposed in 1950's, the practical applications for civilian mobile communications did not take place until 40 years later.

4.2 CDMA Definition

Let us consider the situation where two people conversing over dinner at a crowded restaurant in a foreign country. Although surrounded by the crowd carrying on conversation in many different languages, these people are able to tune out the other conversations and understand each other because they are speaking the same language or there exists a correlation between them. This theme was used in CDMA where language shared by the two diners can be considered as the code and the signal can be recovered by the use of correlation technique. It allows many conversations to occur simultaneously, while only its intended recipients understand each conversation.

CDMA uses spread spectrum technique to provide multiple access communications. Each user in a CDMA system occupies the entire allocated spectrum, using a direct sequence spread spectrum waveform. Each user is assigned a unique pseudo-random code. A large number of users share the same frequency at the same time using their own pseudo-random code. Each pseudo-random code has low autocorrelation and low cross-correlation with all other pseudo-random code. The low correlation between the codes is used to achieve near orthogonality between signals of different users. Note that while FDMA and TDMA are perfectly orthogonal multiple access techniques, in practice, asynchronous CDMA cannot be perfectly orthogonal, since we cannot generate a large number of PN sequences with zero cross-correlation. A correlation receiver for CDMA decodes the received signal by multiplying it by the PN sequence of the desired user.

4.3 CDMA Techniques

Direct Sequence CDMA

In Direct Sequence CDMA, the modulated information signal is directly modulated by a code signal. The code signal is digital while the data signal can be either digital or analog. If the information signal is also digital, then it can be directly multiplied with the code signal, and the resulting signal modulates the wideband carrier. The rate of the code signal is called the chip rate. If the code chip rate is 10 times the data rate, it means that the processing gain is equal to 10.

At the other end, the receiver dispreads the spread spectrum signal using the same code sequence obtained from a local generator. This code sequence must also be synchronized to that of the received signal. A synchronization/tracking block performs this operation. The block diagrams of the SSMA transmitter and receiver are shown below, along with the spectrum diagram of the signal at the transmitting and the receiving ends.

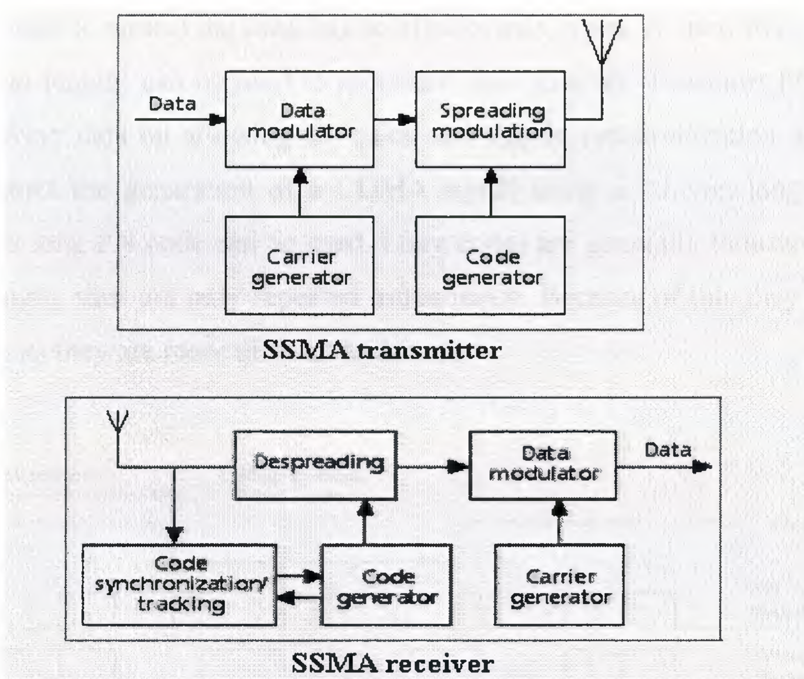

Figure 4.1: The block diagrams of the SSMA transmitter and receiver

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 4.1 shows a basic CDMA transmitter.

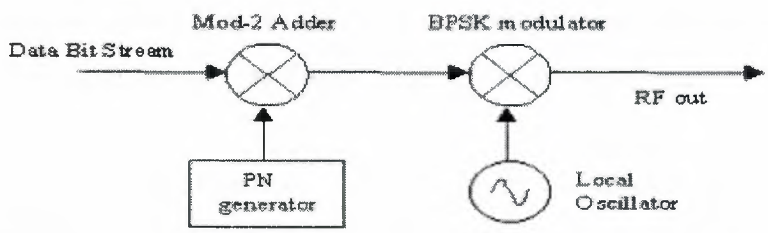

Figure 4.2: Simple direct sequence modulator

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 4.2 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.

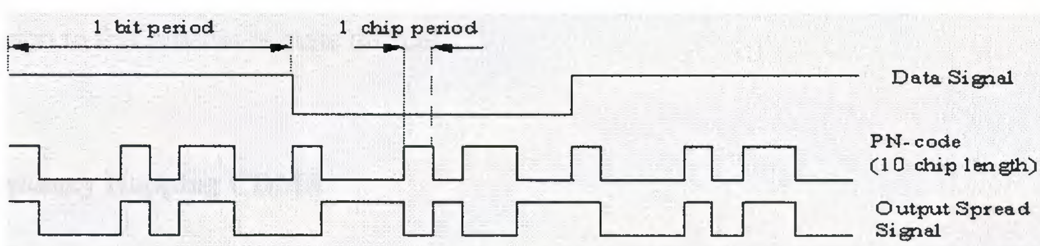

Figure 4.3: Direct sequence signals

The four important properties of DS-CDMA are:

1. Multiple Accesses: Even if multiple users use the bandwidth at the same time, the coherent demodulation puts only very little of the interfering signal power in the information bandwidth. This is because the cross correlation of the codes used by various users is very small.
2. Multipath Interference: If the code sequence has an ideal autocorrelation function, then the correlation function outside the time interval [-Tc, Tc] is 0, where Tc is the chip duration. This means that if the time difference between the desired signal and any delayed version is greater than twice the chip duration, then the delayed version is treated as interference, and very little of its power is put in the information bandwidth.
3. Narrowband interference: At the receiver, coherent detection involves multiplication of the received signal with the code sequence. If there is narrowband interference, then its spectrum will be spread and therefore its power in the information bandwidth is decreased by a factor equal to the processing gain. This is illustrated in the figure below.
4. Low Probability of Interception: In DS-CDMA, the complete spectrum is used all the time. The transmitted power per hertz is therefore very low, and is quite close to the noise level. This makes the detection of a DS-CDMA signal very difficult.

There are also some disadvantages of this technique. Synchronization between the locally generated code sequence and the received code sequence must be a fraction of the chip time. This places a limit on the bandwidth that can be used. Another major problem of this technique is the near-far effect. Since all users use the full spectrum, users close to the base station create a lot of interference for the users who are far from the base station. The solution to this process is quite difficult.

Frequency Hopping CDMA

In Frequency Hopping CDMA, the carrier signal of the modulated information signal is not constant, but I vary according to a pattern, that is determined by the code signal. The set of frequencies that this carrier can attain is called the hop-set. The frequency occupation of the FH-CDMA signal is quite different from that of the DS-CDMA signal though they both transmit the same power in the frequency band on the average. The difference is illustrated below.

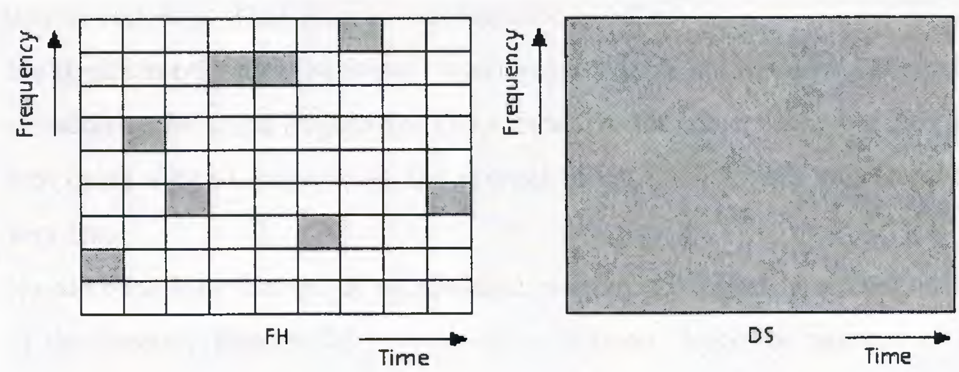

Figure 4.4: Difference between FH-CDMA & DS-CDMA

The block diagrams of the transmitter and the receiver of the FH-CDMA system are given below. The working of the system is easily understood from the block diagram.

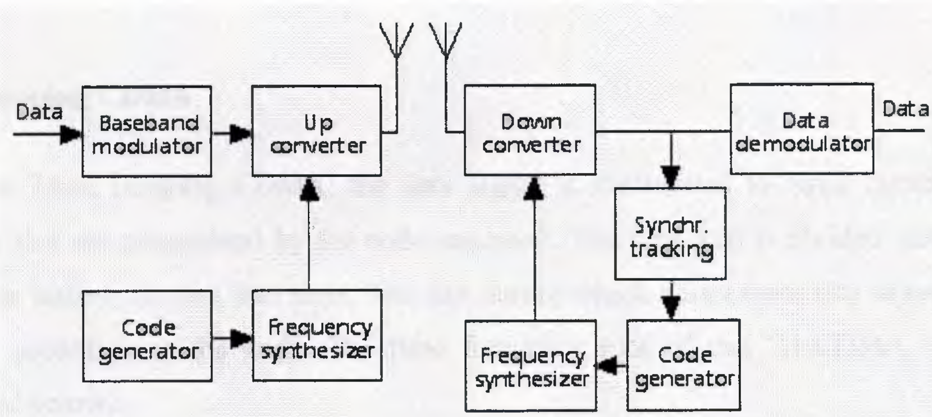

Figure 4.5: FH-CDMA system

FH-CDMA is further classified into slow frequency hopping (S-FH) and fast frequency hopping (F-FH) CDMA. If the frequency-hopping rate is much greater than the symbol rate, then it is called F-FH CDMA. If the hopping rate is (much) smaller than the symbol rate, then it is called S-FH CDMA.

The discussion for the various properties of the FH-CDMA system is given below.

1. Multiple Access: If the cross correlation between various codes is very less, then the probability that two users will be transmitting on the same frequency at the same time is very less. Thus multiple accesses are obtained.
2. Multipath Interference: Multipath interference effects are frequency dependent, and are additive for some frequencies and subtractive for some. Since the information is sent using a lot of frequencies, the average effect of Multipath interference will be very less.
3. Narrowband Interference: A narrowband interference signal interferes only on one of the hopping frequencies present in the hop-set. Since the number of hopping frequencies is equal to the processing gain, the probability that the narrowband interference signal will affect the transmission is equal to the reciprocal of the processing gain.
4. Low Probability of Interception: Since the frequency at which the signal is being transmitted is unknown and constantly changing, the probability of it being intercepted for extended periods of time is very remote.

Time Hopping CDMA

In Time Hopping CDMA, the data signal is transmitted in rapid bursts at time intervals that are determined by the code sequence. The time axis is divided into frames, which are further divided into slots. The slot during which a user transmits in each frame changes according to the code. The time frequency plot of the TH-CDMA system is illustrated below.

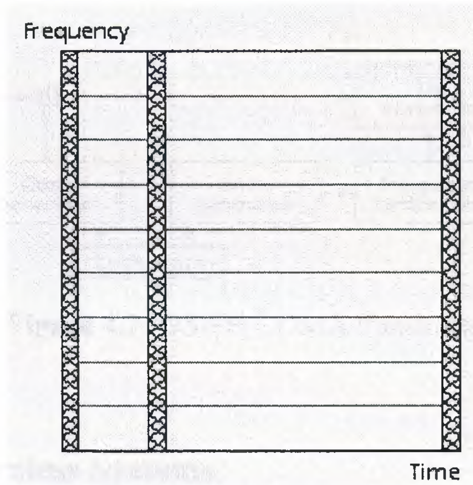

Figure 4.6: TH-CDMA system

The properties of the TH-CDMA system are discussed below.

1. Multiple Access: If the cross correlation between different codes is less, then the probability of two users transmitting at the same time is less. In the event that a simultaneous transmission occurs, then error-correcting codes are used to extract the correct data.
2. Multipath rejection: No gain is obtained with respect to this phenomenon.
3. Narrowband Interference: Since the time of transmission is reduced by a factor equal to the reciprocal of the processing gain, the interference effects are also felt only in this reduced time.

Hybrid Systems

Since different techniques of CDMA have their own advantages and disadvantages, hybrid systems that combine various techniques have been proposed and implemented. Some of them are DS/FH CDMA, DS/TH CDMA and so on. Some gains are obtained in the characteristics at the cost of increased complexity of the transmitters and receivers. The block diagram of DS/FH CDMA transmitter is given below.

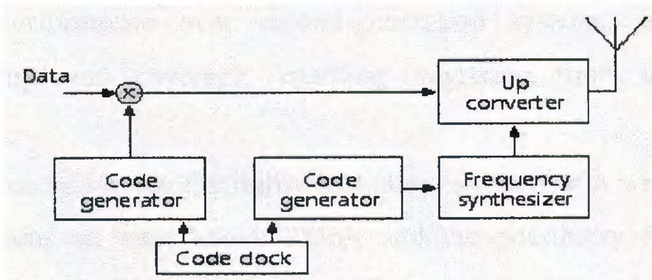

Figure 4.7: DS/FH CDMA transmitter

4.4 CDMA in 3G Wireless Systems

The standards being defined for 3G air interface based on CDMA can be classified as network synchronous or network asynchronous. In network asynchronous schemes, the base stations need not be synchronized. The European standard WCDMA is an example of an asynchronous scheme. On the other hand, in the synchronous scheme, the base stations need to synchronize to each other within a few microseconds. The US standard, cdma2000 is a synchronous scheme. Some of the advanced characteristics of the various wideband CDMA proposals are:

1. Provision of Multirate services
2. Support for packet data
3. Seamless interfrequency handover
4. Optional multiuser detection

Wideband CDMA has a bandwidth of 5MHz or more. This is needed in order to support the 3G objectives of data rates of 144 Kbps and 384 Kbps. A lot of performance enhancement in terms of separation of more Multipaths in this bandwidth. Higher bandwidths of 10, 15 and 20 MHz have been proposed to support higher data rates more effectively. The higher data rates are required for Internet access; multimedia services etc. 2Mbps connectivity for certain constrained mobility is also recommended.

Key W-CDMA Features

Some of the key features of the W-CDMA air interface are discussed. The key properties emphasized in W-CDMA are:

1. Improved performance over second-generation systems, including: improved capacity, improved coverage, enabling migration from a second-generation deployment.
2. A high degree of service flexibility including: support of a wide range of services with maximum bit rates above 2Mb/s and the possibility for multiple parallel services on one connection. A fast and efficient packet-access scheme.
3. Packet data can be transmitted either using a common channel (for short data packets) or on dedicated channels (for longer transmissions).
4. A high degree of operator flexibility, including: support of asynchronous inter-base-station operation, Efficient support of different deployment scenarios, including hierarchical cell structure (HCS) and hot-spot scenarios, Support of evolutionary technologies such as adaptive antenna arrays and multi-user detection.

Performance Improvements

Capacity improvements – The wide bandwidth of W-CDMA gives an inherent performance gain over previous cellular systems, since it reduces the fading of the radio signal. In addition, W-CDMA uses coherent demodulation in the uplink, a feature that has not previously been implemented in cellular CDMA systems. Also, fast power control on the downlink will give improved performance, especially in indoor and low-speed outdoor environments at low Doppler. In total, for a speech service, these improvements are expected to increase the cell capacity of W-CDMA by at least a factor of two (3 dB).

Coverage and Link Budget Improvements – The coverage demonstrated for W-CDMA shows that it is possible to reuse GSM1800 cell sites when moving from GSM to W-CDMA supporting high-rate UMTS services.

Service Flexibility – One of the most important characteristics of W-CDMA is that power is common shared resource for users. In the downlink, the total transmitted power of an RF carrier is shared between the users transmitting from the base station by code-division multiplexing (CDM). In the uplink, there is a maximum tolerable interference level at the base station receiver. This maximum interference power is shared between the transmitting mobile stations in the cell, each contributing to the interference.

Power as the common resource makes W-CDMA very flexible in handling mixed services and services with variable bit rate demands. Radio resource management is done by allocation power to each user (call) to ensure that the maximum interference is not exceeded. Reallocation of codes, time slots, and so on is normally not needed as the bit rate demand changes, which means that the physical channel allocation remains unchanged even if the bit rate changes. Furthermore, W-CDMA requires no frequency planning, since one cell reuse is applied.

Operator Flexibility – An important flexibility aspect is the incorporation of link improvements. If a technique to improve the link-level performance is introduced such as multi-user (joint) detection, downlink antenna diversity, or adaptive antennas, there is an immediate improvement for all users. The reason is that if the link performance is improved even for only some of the links, the required power levels (and generated interference) for these links is immediately reduced. With the common shared power resource, and since there is single-cell reuse, this has an immediate impact in reduced interference for all users. The reduced interference can be utilized as higher capacity, better range, or improved link quality.

1. Asynchronous Base Station Operation: In contrast to second-generation narrowband CDMA systems, W-CDMA does not require tight inter-base-station synchronization. This means, for example, there is no requirement that each base station should be capable of reliable Global Positioning System (GPS) reception. This will significantly reduce the deployment efforts, especially in indoor environments.
2. Interfrequency Handover: The interfrequency handover is a key feature of W-CDMA. Two methods for interfrequency measurement are considered, dual receiver and slotted mode.
3. Support for Adaptive Antenna Arrays: W-CDMA supports full utilization of adaptive antennas through the use of dedicated pilot symbols on both uplink and downlink.

WCDMA logical channels

The common control channels are:

1. Broadcast Control Channel (BCCH) carries system and cell specific information.
2. Paging Channel (PCH) for messages to the mobile stations in the paging area.
3. Forward Access Channel (FACH) for messages from the base station to the mobile in one cell.

In addition there are two dedicated channels:

1. Dedicated Control Channel (DCCH)
2. Dedicated Traffic Channel (DTCH)

4.5 Forward CDMA channel

The forward CDMA channel is the cell-to-mobile direction of communication. It carries traffic, a pilot signal and overhead information. The pilot is spread, but otherwise unmodulated. The pilot and overhead channels establish the system timing and station identity. The pilot channel is also used in the mobile-assisted hand-off (MAHO) process signal strength reference.

4.6 Reversed CDMA channel

In general, the reversed channel is almost similar to the forward channel; in terms of demodulation (OQPSK) traffic channel, soft handoff, and rate.... However, the parameters are a little different. Two rate sets are proposed below. Again, first one is used for cellular IS-95 standards and the second set is used by J-STD-008 PCS services.

There is only one type of overhead channel in the Reverse CDMA channel: the Access Channel.

Access Channel: acts as a vehicle for communicating with mobile stations when they are not assigned to traffic channel. Its primary purpose is to service origination and page responses by the mobile stations.

4.7 CDMA Features

CDMA Advantages

The preceding discussions of CDMA originally were more applicable to military communications; where security and anti-jamming are prime importance. However, commercial CDMA will focus a lot more on bandwidth efficiency as its primary concern. We wish to accommodate as many users as possible and not degrade the system as much. CDMA will potentially enable the system to provide significant capacity advantages. An analog system would require a seven times frequency re-use pattern. Our current TDMA system requires a four-cell re-use pattern and stations in every cell. Our CDMA upgrades would provide significant advantages in a fundamental way, reducing the number of cell stations as well as frequency planning.

CDMA changes the nature of the subscriber station from a predominantly analog device to a predominantly digital device. Old-fashioned radio receivers separate stations or channels by filtering in the frequency domain. DCMA receivers do not eliminate the 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.

A very important factor in cellular communication as well as wireless is the frequency allocation and frequency reuse. This requires that RF engineers must be very careful in assigning specific frequency bands to certain channels to avoid interference from other channels such as co-channel interference, adjacent channel interference and inter symbol interference (ISI). CDMA allows all users share the same spectrum. Therefore frequency planning can be avoided or greatly simplified. CDMA is altering the face of commercial wireless communications by:

1. Dramatically improving the telephone traffic capacity
2. Dramatically improving the voice quality and eliminating audible effects of Multipath fading.
3. Providing high voice quality.
4. Providing low probability of intercept (LPI), anti-jamming, therefore giving users more privacy.
5. Reducing incidents of dropped calls due to hand-off failures

6. Providing reliable transport mechanism for data communications, such as facsimile and internet traffic.
7. Reducing the number of sites needed to support any given amount of traffic.
8. Reducing deployment and operating costs because fewer cell sites are needed.
9. Reducing average transmitted power.
10. Reducing interference to other electronics devices and potential heath risks

Common CDMA problems

The two problems which discussed are:-

1. Near-far effect: This happens when the users closer to base station having more power than ones with further distance from the base station. The propagation path loss difference among extreme cases could be many tens of dB, degrading the signal quality greatly. However, we do have solution for the problem; and it is called power control. Rather than using constant power, the transmitter can be controlled in such a way that the received powers from all users are roughly equal.
2. Multi-path effect: This happens when the transmitted signal travels many paths before it gets to the receiver. Multipath is a major problem for analog technologies.

CDMA is less affected by this effect. We can build a Rake receiver to deal with Multipath problem.

Possible Technical Difficulty

1. CDMA is subject to Multipath effect, fading.
2. Complexity of the systems
3. Multi-stage Rake receivers should be used to increase performance for multi-users. (difficult to implement)
4. Partial-correlation of codes

Current technology statistics show that the problems faced by CDMA are much less than the advantages and benefits that CDMA offers.

4.8 Receiver Structures for CDMA Systems

Correlation Receiver

The following receiver is a correlation receiver at the base station of a CDMA cellular system. At the base station, there is a separate receiver for each user, and all receivers are

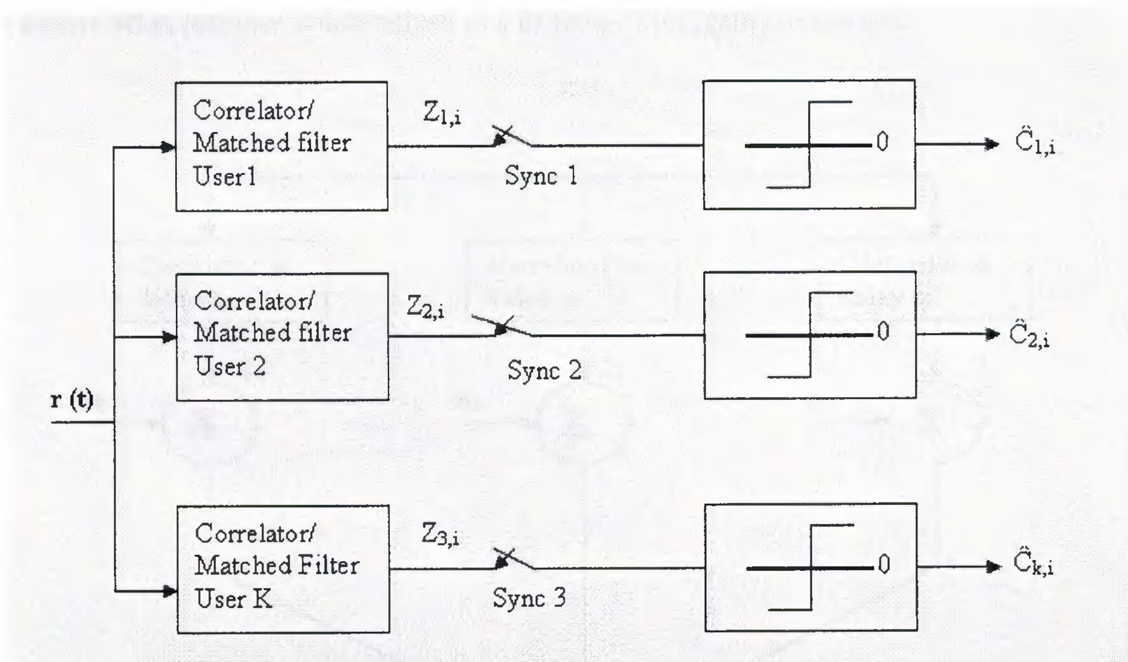

Figure 4.8: Correlation Receiver.

Presented with the same incoming signal r(t), which is the sum of the signals of all users and the noise(AWGN). Each receiver correlates the incoming signal with a synchronized copy of the desired PN code to generate a decision statistic which is used to estimate the transmitted data stream. Thus, conventional correlation detectors operate by enhancing the desired user, and treat the MAI which is inherent in CDMA as additive noise. This would work well if the MAI were truly uncorrelated with the desired signal. Unfortunately, some correlation between the codes cannot be avoided, and this cause significant degradation. As a result, capacities for single cell CDMA systems employing a correlation receiver can be significantly lower than those for FDMA or TDMA systems which are truly orthogonal. Moreover, if an interferer is significantly stronger than the desired user it will dominate performance due to the near-far effect. This would limit the utility of the CDMA system to applications where each user's received power is approximately the same.

RAKE Receiver

A Rake receiver allows DS/SS to exploit Multipath. Each "finger" of Rake receiver is a correlation receiver synchronized to a different Multipath component.

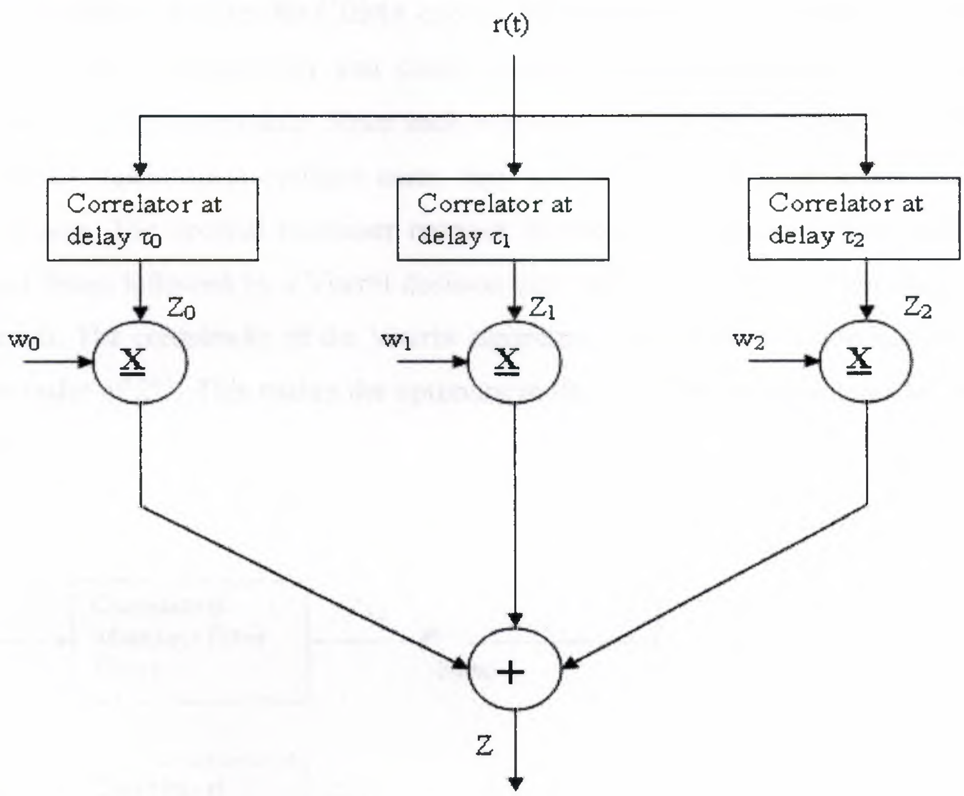

Figure 4.9: RAKE receiver

When a signal travels through a practical channel, it undergoes reflection and scattering off objects in its path. The Multipath components could interfere either constructively or destructively, depending on their relative phases. This causes inter-symbol interference which limits the data rate of unequalized narrow-band systems (because delays are much smaller than the bit period). In wide band signaling, however, the duration of the transmitted symbols is small compared to the Multipath delay introduced by the channel. This provides an inherent time diversity in case of wide band signals. Multipath can be used to advantage in CDMA by using a RAKE receiver. The RAKE receiver exploits the time diversity by using information in Multipath components in the decision process.

Multiuser Receivers

Multiuser receivers for CDMA exploit the fact that the base station receives signals from all users simultaneously and could potentially share information to make better decisions on the received data. Since such receivers work on the principle of simultaneous reception of signals from multiple users, they are suited for the base station of a cellular radio system. The optimal multiuser receiver shown in the figure, consists of a bank of matched filters followed by a Viterbi decision algorithm for maximum likelihood sequence estimation. The complexity of the Viterbi algorithm is exponential in the number of users (on the order of 2^K). This makes the optimum multiuser receiver to complex to implement in practice.

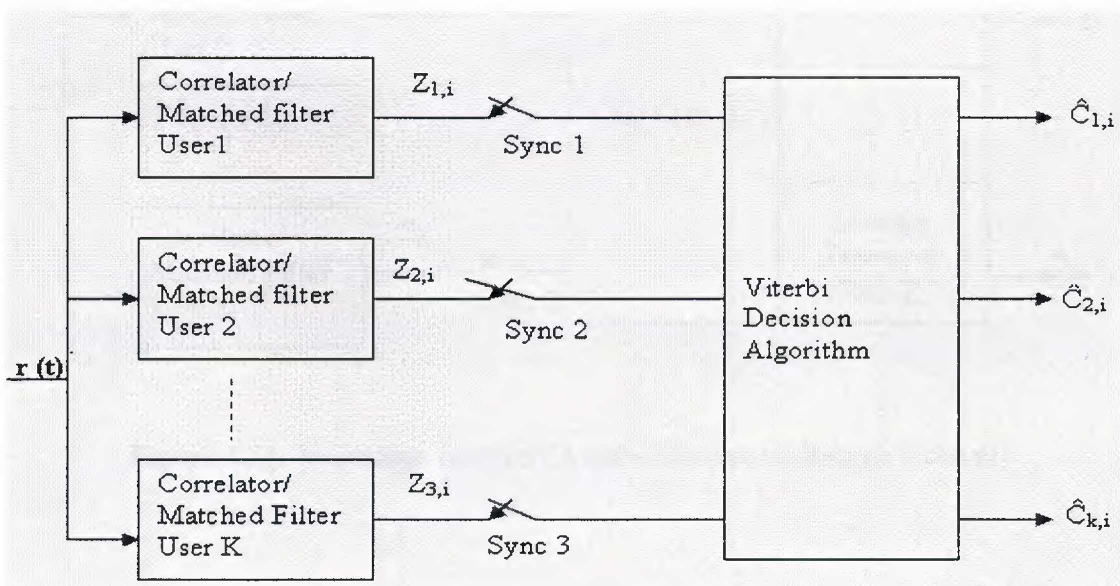

Figure 4.10: Optimal Multiuser Receiver.

Sub-optimal Receiver

For the very complexity of the optimum multiuser receiver, research has focused on sub-optimal receivers which achieve significant performance improvement with reasonable complexity. In sub-optimal receiver, detector consists of a bank of K matched filters followed by a bank of K M-stage processors. The first stage is a conventional CDMA detector and provides a decision statistics for each user from the received signal. Then, M stages of processing are performed on the decision statistic, where each stage processes the decision statistic obtained from the previous stage. Such a receiver exhibits significant performance improvement over the conventional receiver, and a-approaches the performance and near far resistance of an optimum receiver.

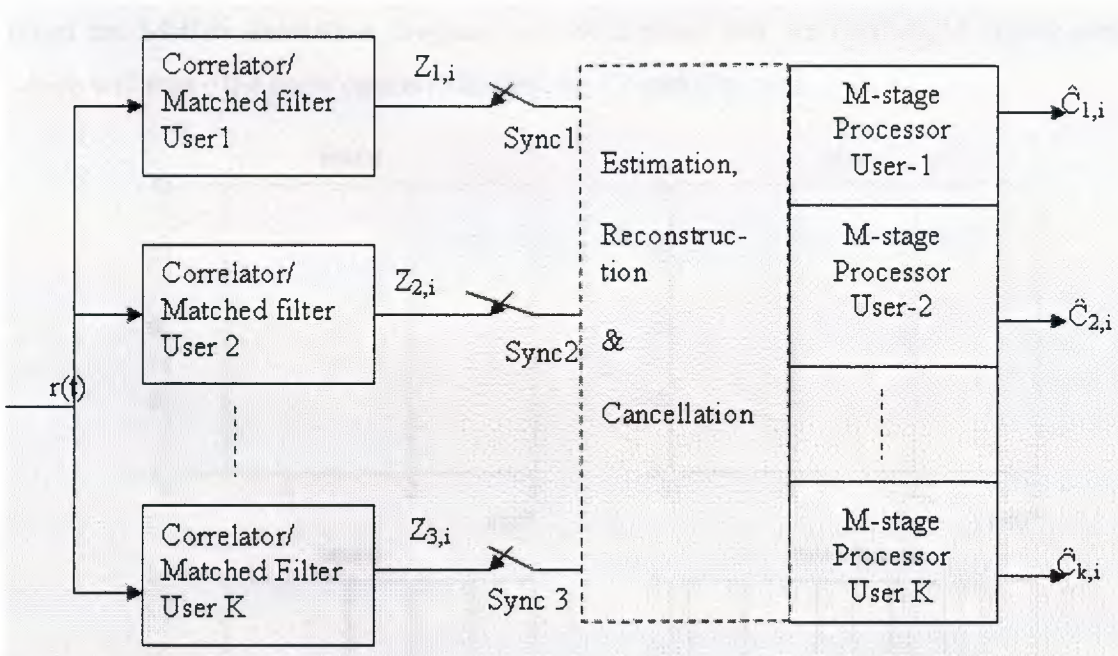

Figure 4.11: Multistage receiver (A sub-optimum multistage receiver)

CHAPTER FIVE

SIMULATING MULTIPLE ACCESS TECHNIQUES

5.1 Simulation of TDMA

In the TDMA simulation, a TDMA system with 3 users was simulated. In this simulation program I have used 3 inputs users created randomly and then I add them to TDMA channel user by user on the time vector. We can see the TDMA channel plotted in the figure. After the channel, the inputs are separated to get the users data.

From the Matlab simulation program we can noticed that we used PCM signal creator which will make the users data are random, its 1's and 0's.

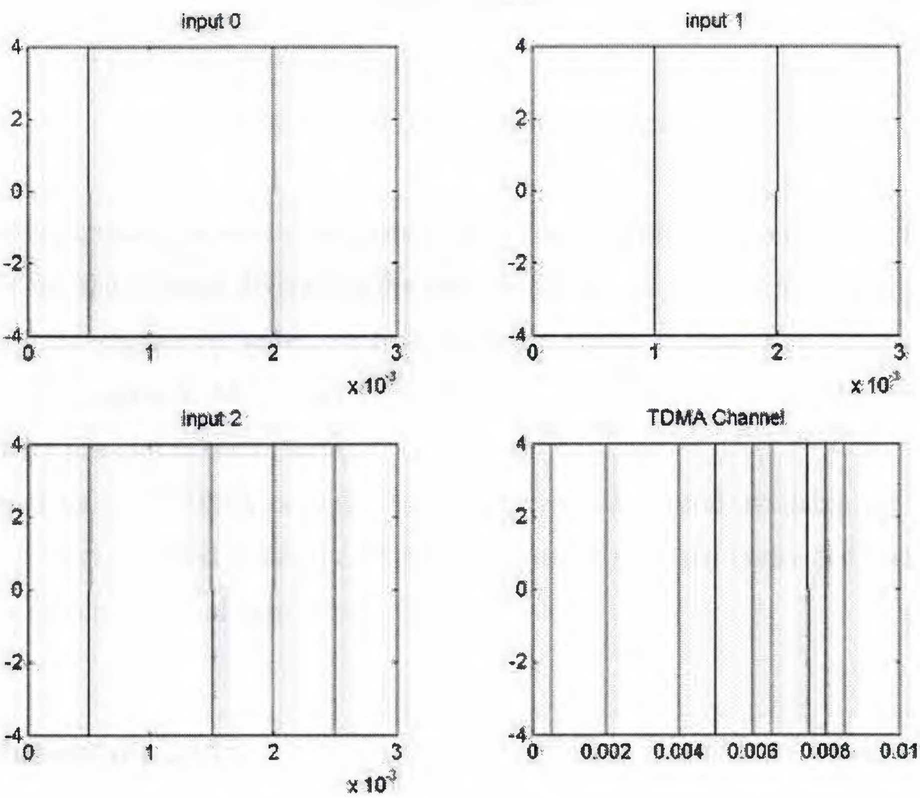

Figure 5.1: TDMA for 3 inputs and 6 bits each user

In TDMA uplink channel, the base station divides the channel into time periods called Frames. In each frame, each mobile station transmits only once and starts waiting for its turn in the next frame. The time period in which the mobile station transmits is called Slot. The Number of bits transmitted in each slot is specified in a protocol.

The figure below is TDMA example for the uplink channel. The part Preamble (Pr. In Figure 5.2) is the part in which the base station signals the mobile units that the frame started and gives any other information it wants to give.

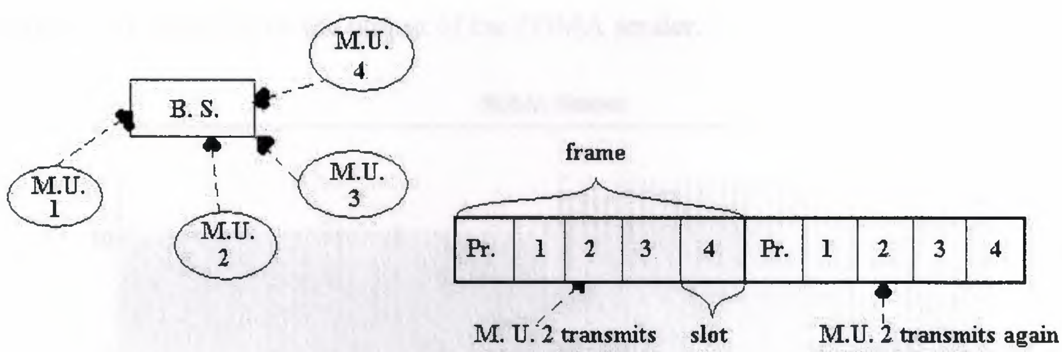

Figure 5.2: TDMA Uplink channel

For a downlink channel in which the mobile units don't transmit but receive signals from the base station, the channel division is the same as figure 5.2. in such a channel, the base station sends the signals by order, so first M.U. 1's signal is sent, then M.U.2, M.U.3, M.U.4, and back again to M.U. 1 in the next frame. Each mobile unit listen to the base station only for one slot in each frame.

If the channel used in TDMA occupies the whole frequency band available for the base station, the system is called wideband TDMA, whereas if the band is divided into smaller channels the system is called narrowband TDMA.

5.2 Simulation of FDMA

In the FDMA simulation, a FDMA system with 3 users and 6 bits was simulated. We can see the FDMA sender channel plotted in the Figure 5.3. After the channel figure, the inputs are separated to get the users data by using the FDMA receiver, and we can see the inputs user for the plotted channel below in Figures 5.4 & 5.5.

In the simulation FDMA sender program I designed PCM signals as input signals randomly and I filter it using LPF filter that has cutoff frequency of 10khz, when I got the filtered output (convoluted signal) I modulated it with cosine modulator of amplitude 1 and frequency as indicated with the equation below:-

Fc= 45 kHz * n

The figure 5.3 below show the output of the FDMA sender.

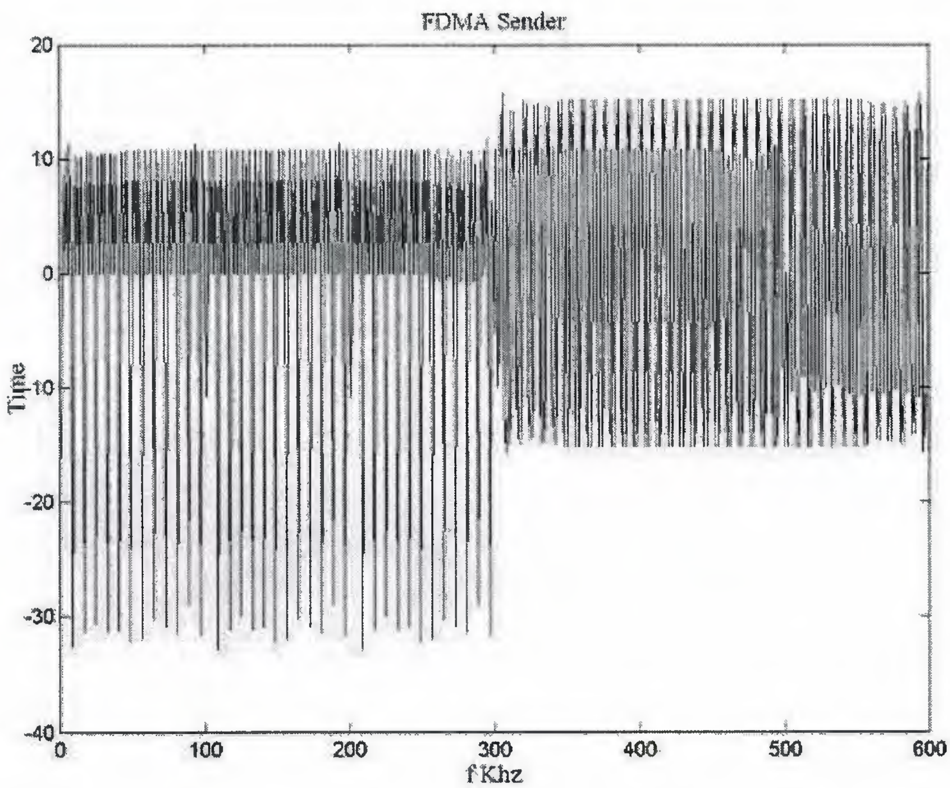

Figure 5.3: FDMA sender 3 inputs 6 bits each user

In the figures 5.4 below it's the outputs of the FDMA receive, where it was the inputs of the FDMA receiver, where firstly I modulate the same channel above in figure 5.3 with the same cosine modulators which had been used in the FDMA sender, the results which I got from modulation I filtered it using the same LPF filter which used in FDMA sender, then I got the inputs signals (users) to the FDMA sender.

From figure 5.4 we can notice the users or inputs not clear as much as the real inputs, that's refers to the noise which happened through modulation and receiver filtering.

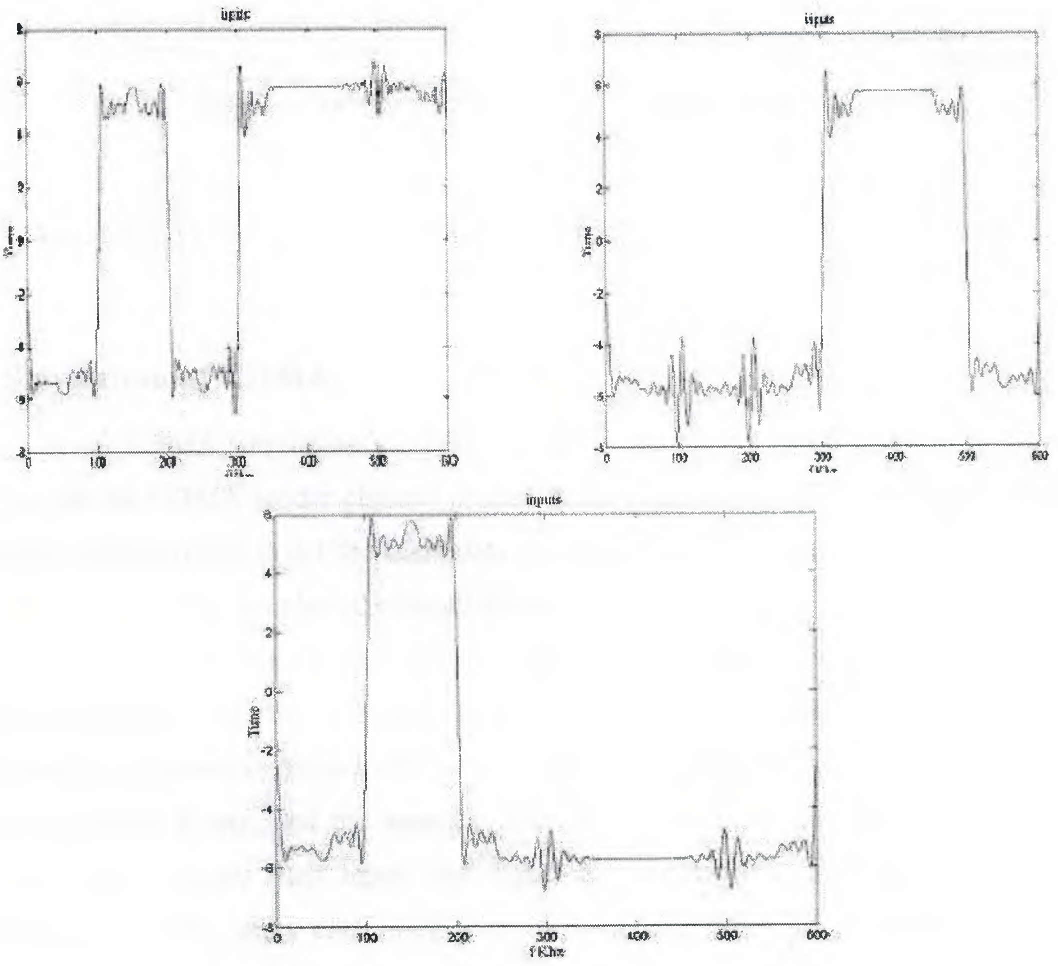

Figure 5.4: FDMA receiver inputs 1, 2 & 3 for the same channel above1

In frequency division multiple access, the band is divided in the frequency domain. Each mobile unit gets a specific carrier frequency (in addition to a lower and upper limit) and transmits and receives only in that part. This way no interference happens between different users. FDMA is illustrated in figure 5.5 below. The channel shown below could either be forward or reverse channels.

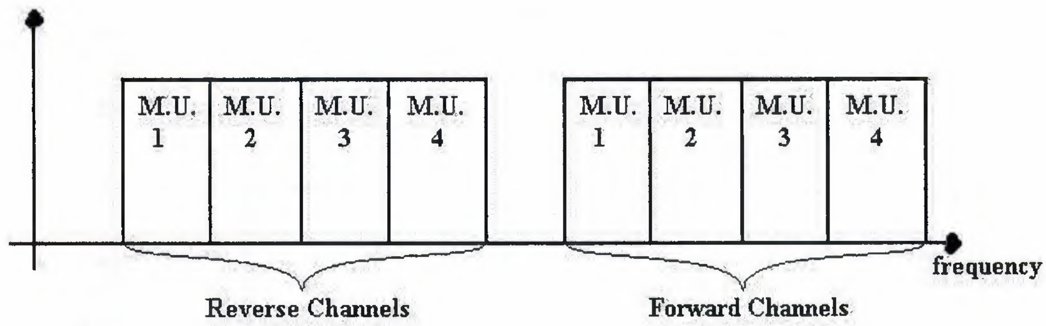

Figure 5.5: FDMA forward and reverse channel for system with 4 mobile units

5.3 Simulation of CDMA

In the CDMA simulation, a CDMA system with 4 users and 6 bits was simulated. We can see the CDMA sender channel plotted in the Figure 5.6. After the channel figure, the inputs are separated to get the users data by using the CDMA receiver, and we can see the inputs user bits for the plotted channel above.

In the simulation CDMA sender program I designed PCM signals as input signals randomly done, I created the chips for each user and these chips are orthogonal with each other as a condition for the chips in order to be correct chips, where the chip used in this sender is 6 times the signaling rate, and the sampling rate used is 10 times the chip rate, for that I designed long chip for each input user signal by repeat the chip to use the chips in modulation with the users each user with its own chip after the modulation I got 4 modulated result I added all the results together then I got the CDMA channel as in figure 5.6 below.

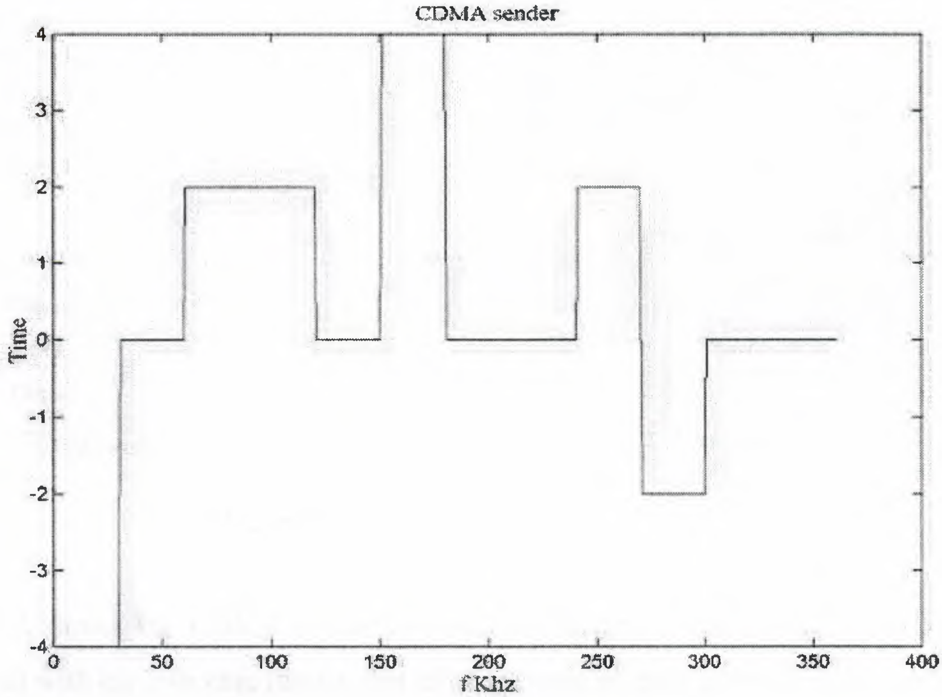

Figure 5.6: CDMA sender for 4 inputs users and 6 bits

In CDMA receiver I used the same chips which I used in the CDMA sender to modulate each chip with the same channel above in figure 5.6, then I sum the result of each bit together then I made for loop to check the result whether its greater or less than zero so if its greater so the original bit must be 1, but if it less than zero the original bit is -1, and I repeated this operation for all result of each modulated channel with separated chip after I repeated for all chips the result must be the same as the input users to the which used to get the channel above, so the CDMA receiver gives user bits for the above channel are:

Input 1: -1 1 1 -1 -1 -1
Input 2: -1 -1 -1 -1 -1 -1
Input 3: -1 -1 -1 -1 1 -1
Input 4: -1 -1 -1 -1 -1 -1

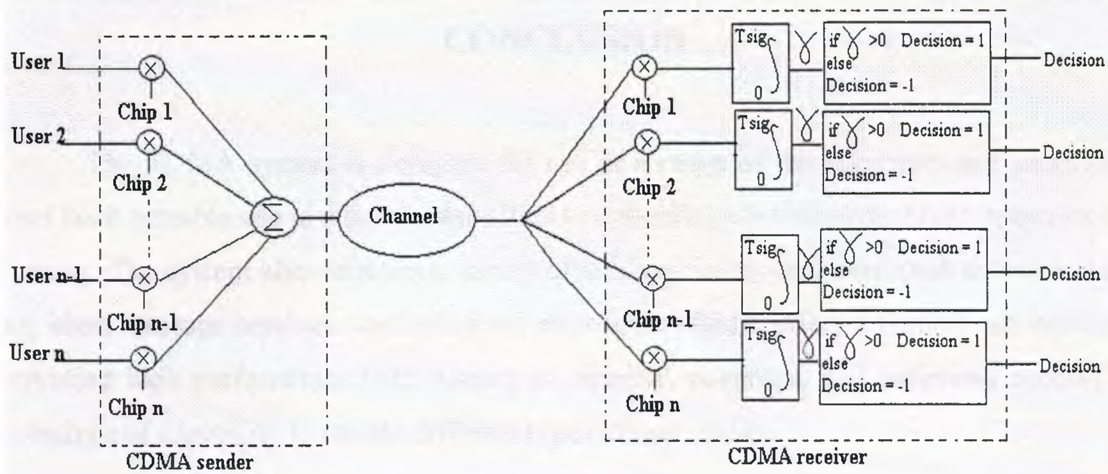

Figure 5.7: CDMA sender and receiver

Figure 5.7 shows the CDMA sender and receiver diagram, each user in this system is modulated with his own chip (notice that all chips must be orthogonal with each other). The modulated signals resulting will be added together to be sent as a channel to the receiver.

In the receiver part the channel will be modulated again with every chip, in each result a correlation must be done to each signaling rate, and the result of each correlation compare with zero, if it greater the zero the bit will be one, other wise it will be -1. After repeating this operation for each chip we will be able to get the input users of the system.

CONCLUSION

The TDMA system is designed for use in a range of environments and situations, from hand portable use in a downtown office to a mobile user traveling at high speed on the freeway. The system also supports a variety of services for the end user, such as voice, data, fax, short message services, and broadcast messages. TDMA offers a flexible air interface, providing high performance with respect to capacity, coverage, and unlimited support of mobility and capability to handle different types of user needs.

Frequency division Multiple Access can allow several users to share the bandwidth in a channel at the same time without one user's channel interfering with the channel of another user. However, the number of users using the channel varies at any given time. When there are a small number of users, the channel is divided into only a few different bands. This relatively large bandwidth, in conjunction with the guard bands placed between each users allotted frequencies, makes it very difficult for two unique signals to interfere with one another. However, for a large number of users, we are faced with the prospect of dividing up our channel into several small bands, making the likelihood of interference much larger.

Nowadays, CDMA is getting very popular for mobile wireless applications. Commercial applications became possible because of two evolutionary developments. One is the availability of very low cost, high-density digital integrated circuits and DSP chips that can perform highly sophisticated calculations at a high speed and reliable accuracy. This helps to reduce the size, weight and cost of subscriber stations to an acceptably low level. The other development is the realization that optimal multiple access communication requires all user stations regulates their transmitter powers to the lowest that will achieve adequate signal quality.

From the simulations of the Multiple access Techniques TDMA, FDMA, and CDMA, the simulation codes for TDMA and FDMA was not complex which show that TDMA is the simple technique, but CDMA was a complex system where I used to simulate, which show the reason of being the most complex system at reality.

I simulated the sender and receiver for each system but I didn't apply noise in every one in the channels. So for future works the simulation can be done with showing the noise, the effects on the channel and the receiver.

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APPENDIX

A. Plotting Pulse Code Modulation (PCM)

```
function out=makePcm(A,fsig,bc, fs)
% pulse code modulation
%function out=makepcm(A,fsig,bc,fs)
if (nargin<4)
   fs=(fsig*100);
end
%if number of input argument is less than 4 do.
tbit=0:1/fs:(1/fsig-1/fs);
pcmSignal=[];
for n=1:bc
   bit=round(rand);
   % creat a random vector have elements as number of bit count bc
   % and then round the elements of the vector
   if (bit==0)
      pcmSignal=[pcmSignal,-A*ones(1,length(tbit))];
   else
      pcmSignal=[pcmSignal,A*ones(1,length(tbit))];
   end
end
t=0:1/(fsig*100):1/fsig*bc-1;
out=pcmSignal;
plot(out)
```

B. Plotting Time Division Multiple Access (TDMA)

```
function out=TDMAPlot(A,fsig,bc)
% function out=TDMAPlot0(A,fsig,bc)
T=1/fsig; % time period
out0=makePcm(A,fsig,bc);
out1=makePcm(A,fsig,bc);
out2=makePcm(A,fsig,bc);
% In the above 3 steps i call the PCM ready prgram
tout=0:1/(fsig*100):bc/fsig;
tout=tout(1:length(tout)-1);
subplot(2,2,1); plot(tout,out0); title ('input 0')
subplot(2,2,2); plot(tout,out1); title ('input 1')
subplot(2,2,3); plot(tout,out2); title ('input 2')
% i plot the 3 inputs which i use it as TDMA system users
tdma=[out0,out1,out2];
% here i creat a TDMA channel and plot it in the next step
tout=0:1/(fsig*100):bc*T*3;
tout=tout(1:length(tout)-1);whos
subplot(2,2,4); plot(tout,tdma); title ('TDMA Channel')
```

C. Frequency Division Multiple Access (FDMA)

- **Plotting the Frequency Division Multiple Access Sender**

```
function out=fdmasender(n,bc,fsig);
% function out=fdmasender(n,bc,fsig);
% fsig<10kHz and n<5
T=1/fsig;
fs=200e3;
load fdafilt.mat;
% by using this command i load the filter to use it in
% filtering the PCM inputs.
for i=1:n;
  pcms(i,:)=makePcm(10,fsig,bc,fs);% to call makePCM matlab program.
  temp=conv(pcms(i,:),fdmafilter);
  y(i,:)=temp(51:end-51);
end;
% in this loop i made a convolution for each PCM input
% with the filter by using the (( conv )) command.
tmod=0:1/fs:length(y)/fs;
tmod=tmod(1:end-1);
% i defined this time period to equalize the dimentions of
% the cosine function and the filtered signals to
% to modulated with each other
for i=1:n;
  m(i,:)=cos(2*pi*25e3*i*tmod).*y(i,:);
end
% in this for loop i modulate the cosine function with the
% filtered inputs
out=zeros(1,length(m(i,:)));
for i=1:n;
  out=out+m(i,:);
```

```
end;
% here in this last for loop i join the all modulated inputs
% as FDMA channel by adding them with each other
% whether in TDMA we put the modulated signals
% by series at the time axis
plot(out)
```

- **Plotting the Frequency Division Multiple Access Receiver**

```
function out=fdmareceiver(chan,n,bc,fsig);
% function out=fdmareceiver(chan,n,bc,fsig);
T=1/fsig;
fs=200e3;
load fdafilt.mat;
t=0:1/fs:length(chan)/fs;
t=t(1:end-1);
for i=1:n;
   m(i,:)=cos(2*pi*25e3*i*t).*chan ;
end;
% in the step above i modulate the channel with the cosine modulator
for i=1:n;
   temp=conv(m(i,:),fdmafilter);
   y(i,:)=temp(51:end-51);
   figure; plot(y(i,:));
end;
% in the step above i filtered the result from the modulation using same
% filter i used in FDMAsender
whos
```

D. Code Division Multiple Access (CDMA)

- **Plotting the Code Division Multiple Access Sender**

```
function out=CDMAsender(A,n,bc,fsig)
% function out=tryCDMA(A,n,bc,fsig)
% the reminder of n/4 must equal to zero
% where n is the number of input ships

T=1/fsig;
fs=60*fsig;
t=0:1/fs:2*T;
t=t(1:end-1);
pcm=[];
for i=1:n;
   pcms(i,:)=makePcm(1,fsig,bc,fs);% to call makePCM matlab program.
end
%for i=1:n
%    subplot(n,1,i);plot(pcms(i,:));
%end
chips=hadamard(n);
finalChips=[];
for i=1:n
  c=[];
   allOne=ones(1,floor(length(t)/length(chips(i,:))));
   for j=1:length(chips)
      c=[c,chips(i,j)*allOne];
   end
   c=[c(1:end),chips(i,j)*ones(1,(length(t)-length(c)))];
   finalChips(i,:)=c;
end
chip=finalChips;
```

```
while(length(chip)<length(pcms))
   chip=[chip,finalChips];
end
mod=zeros(1,length(pcms));
chan=[];
for i=1:n;
   chan=[(pcms(i,:).*chip(i,:))];
   mod=mod+chan;
end
plot(mod);
out=mod
xlabel({'f Khz'},'FontName','Times','Fontsize',12)
ylabel({'Time'},'FontName','Times','Fontsize',12)
title({'CDMA sender'},'FontName','Times','Fontsize',12)
```

- **Code Division Multiple Access receiver**

```
function out=CDMAreceiver(channel,A,n,bc,fsig);
% function out=tryCDMA(A,n,bc,fsig)
% the reminder of n/4 must equal to zero
% where n is the number of input ships
T=1/fsig;
fs=60*fsig;
t=0:1/fs:T;
t=t(1:end-1);
chips=hadamard(n);
finalChips=[];
for i=1:n
   c=[];
   allOne=ones(1,floor(length(t)/length(chips(i,:))));
   for j=1:length(chips)
```

```
        c=[c,chips(i,j)*allOne];
    end
    c=[c(1:end),chips(i,j)*ones(1,(length(t)-length(c)))];
    finalChips(i,:)=c;
end
chip=finalChips;
while(length(chip)<length(t)*bc)
    chip=[chip,finalChips];
end
addmod=[];
dec=[];
for i=1:n;
    demod(i,:)=channel.*chip(i,:);
    for j=1:bc;
        dec=sum(demod(i,((j-1)*length(t)+1):(j*length(t))));
        if dec>0
            out(i,j)=1;
        else
            out(i,j)=-1;
        end
    end
end
```