NATIONAL OPEN UNIVERSITY OF NIGERIA

SCHOOL OF SCIENCE AND TECHNOLOGY

COURSE CODE: CIT755

COURSE TITLE: Wireless Communication I

COURSE GUIDE

CIT755
WIRELESS COMMUNICATION I

Course Team A. J. Ikuomola (Developer/Writer) - AUOA
Prof. H.O.D Longe (Editor) - UNILAG
Prof. Obidairo (Programme Leader) - NOUN
A.A. Afolorunso (Coordinator) - NOUN

NATIONAL OPEN UNIVERSITY OF NIGERIA

National Open University of Nigeria
Headquarters
14/16 Ahmadu Bello Way
Victoria Island
Lagos

Abuja Office
No. 5 Dar es Salaam Street
Off Aminu Kano Crescent
Wuse II, Abuja
Nigeria

e-mail: centralinfo@nou.edu.ng
URL: www.nou.edu.ng

Published By:
National Open University of Nigeria

First Printed 2011

ISBN: 978-058-537-0

CONTENTS **PAGE**

Introduction

Introduction to Wireless Communication 1 is a 3-unit post graduate course in Information Technology.

Wireless communication is the transfer of information over a distance without the use of electrical conductors or "wires". The distances involved may be short (a few meters as in television remote control) or long (thousands or millions of kilometers for radio communications). When the context is clear, the term is often shortened to "wireless".

Wireless communication is generally considered to be a branch of telecommunications.

It encompasses various types of fixed, mobile, and portable two-way radios, cellular telephones, personal digital assistants (PDAs), and wireless networking. Other examples of wireless technology include GPS units, garage door openers, wireless computer mice, keyboards and headsets, satellite television and cordless telephones

This course introduces you to the most important new technology in wireless communication system. To provide wireless communications to the whole world was a dream before the development of cellular concept. With the development of highly reliable, miniature, solid-state radio frequency hardware, the wireless communication era came into existence. The recent exponential growth in cellular radio and personal communication systems throughout the world has been possible because of the new technologies developed. Further, the future growth of consumer-based mobile and portable communication system will be coupled closely to the allocations of radio spectrum which support new technologies advancement in signal process.

What You Will Learn in this Course

This Course Guide is the starting point for this course. It tells you briefly what the course is about, what course materials you will be using and how you can work your way through these materials. It also gives you guidance on your tutor-marked assignments as well as describes what you need to do in order to pass this course. There will be regular tutorial classes that are related to the course. It is advisable for you to attend these tutorial sessions. The course will prepare you for the challenges you will meet in the field of wireless communication.

Course Aims

The aim of this course is to provide you with an understanding of wireless communication, its use, application and the technology behind it; it also aims to provide you with solutions to problems in wireless/cellular communication system. This will be achieved by:

- introducing you to what the wireless communication is and what it consists of
- explaining to you the basic technology underlying the wireless communication
- explaining to you the cellular design concept
- helping you to understand the various modulation, diversity and multiple access techniques.

Course Objectives

To achieve the aims set out above, the course has a set of objectives.

Each unit has specific objectives which are included at the beginning of each unit. You should read these objectives before you study the unit. You may wish to refer to them during the study to check on your progress. On successful completion of this course, you should be able to:

- explain the concept and evolution of wireless communication
- identify the various cellular system generations and the mechanism for capacity increase in a cellular system
- discuss the three basic radio propagation mechanism
- explain the concept of radio wave propagation: Large scale path loss model, small scale fading and shadowing
- describe various modulation techniques
- discuss on the types of diversity techniques
- categorise the multiple access techniques and state their application areas
- solve practical problems in wireless communication.

Working through this Course

To complete this course you are required to read each study unit, the textbooks, related materials you find on the internet and other materials which may be provided by the National Open University of Nigeria.

Each unit contains self-assessment exercises, and at a point in the course, you are required to submit assignments for assessment purposes.

At the end of this course there is a final examination. The course will take about 18 weeks to complete. Below, you will find listed all the components of the course, what you have to do and how you should allocate your time to each unit in order to complete the course successfully on time.

Course Materials

The main components of the course are:

1. The Course Guide
2. Study Units
3. Presentation Schedule
4. Assignment
5. References/Further Reading

Study Units

There are 21 study units in this course. Each unit should take you 2-3 hours to work through. The 21 units are divided into four modules.

Three modules contain 5 units each while the last module contains 6 units. This is arranged as follows: The study units in this course are as follows:

Module 1 Introduction

Unit 1 Overview and History of Wireless Communication
Unit 2 Modern Wireless Communication System
Unit 3 Wireless Data Network
Unit 4 The Cellular Concept
Unit 5 Improving Capacity in Cellular System

Module 2 Mobile Radio Propagation

Unit 1 Wireless Channel Model
Unit 2 Large-Scale Propagation Model
Unit 3 Radio Propagation Mechanisms
Unit 4 Path Loss Model
Unit 5 Shadowing

Module 3 Mobile Radio Propagation

Unit 1 Small Scale Fading and Multipath
Unit 2 Types of Small Scale Fading
Unit 3 Small Scale Fading: Racian, Rayleigh and Nakagami

In Module 1: The first unit focuses on the meaning, concept, differences between wired and wireless, application, brief history of wireless communication, mobile radio communication and evolution, radio and the electromagnetic spectrum, how radio signals are created, radio-wavelength, frequency and antennas, radio signal and energy. The second unit deals with the meaning of cellular system, basic cellular system and wireless communication standards generations. The third unit concentrates on various wireless data network. Unit 4 deals with the meaning of cellular communication, cell fundamentals, cell size, cellular frequency reuse, cell planning, mobile phone network, concept of cell cluster and geometry of hexagonal cells. Unit 5 discusses the advantages of cellular system, interference and system capacity, channel assignment strategies and mechanisms for capacity increase in cellular system.

In Module 2: The first five units concentrate on meaning of channel model, statistical propagation models, basic concept of path loss, causes and propagation prediction, free space propagation model, relating power to electric field, radio propagation mechanisms, empirical path loss model, practical link budget design using path loss model, and the concept of shadowing.

In Module 3: The first five units focus on the meaning and factor affecting small scale multipath propagation, multipath fading channel models, concept of doppler, types of small scale fading, mitigation, fading models: racian, rayleigh and nakagami fading, threshold crossing rate, fade duration, average fade duration, scatter function, and channel classification.

In Module 4: The first four units discuss definition, choice of modulation, how to modulate a sound wave and types of modulation techniques, Unit 5 deals with diversity techniques for fading channel and its application. Unit 6 concentrates on meaning of multiple access, multiple access in a radio cell, category, comparison and application of multiple access techniques.

Presentation Schedule

Your course materials have important dates for the early and timely completion and submission of your TMAs and attending tutorials are necessary. You should remember that you are required to submit all your assignments by the stipulated time and date. You should guard against falling behind in your work. The assignment file will be made available to you in due course. In this file, you will find all the details of the work you must submit to your tutor for marking. The marks you obtain for these assignments will count in computing the final mark you obtain for this course.

Assessment

There are three aspects to the assessment of the course: the self-assessment exercises, the tutor-marked assignments and the written examination/end of course examination.

You are advised to do the exercises. In tackling the assignments, you are expected to apply information, knowledge and techniques you gathered during the course. The assignments must be submitted to your facilitator for formal assessment in accordance with the deadlines stated in the presentation schedule and the assignment file. The work you submit to your tutor for assessment will count for 30% of your total course work.

At the end of the course you will need to sit for a final or end of course examination of about three hour duration. This examination will count for 70% of your total course mark.

Tutor-Marked Assignment (TMA)

The TMA is a continuous assessment component of your course. It accounts for 30% of the total score. You will be given four (4) TMAs to answer. Three of these must be answered before you are allowed to sit for the end of course examination. The TMAs would be given by your facilitator and returned after you have done the assignment. Assignment questions for the units in this course are contained in the Assignment File. You will be able to complete your assignments from the information and materials contained in your reading and study units, references and the internet. When you complete each assignment, send it, together with the TMAs, to your tutor. Make sure that each assignment reaches your tutor/facilitator on or before the deadline given in the presentation schedule and assignment file.

Final Examination and Grading

The end of course examination for Wireless Communication will be for about 3 hours and it has a value of 70% of the total course work. The final examination covers information from all parts of the course i.e. all areas of the course will be assessed. You might find it useful to review your Self-Assessment Exercises, Tutor-Marked Assignments and comments on them before the examination.

Course Marking Scheme

The following table lays out how the actual course marking is broken down.

Assignment	**Marks**
Assignment 1 – 4	Four assignments, best three marks of the four count at 10% each – 30% of course marks
End of course examination	70% of overall course marks
Total	**100%**

Facilitators/Tutors and Tutorials

There are 16 hours of tutorials provided in support of this course. You will be notified of the dates, times and location of these tutorials as well as the name and phone number of your facilitator, as soon as you are allocated a tutorial group.

Your facilitator will mark and comment on your assignments, keep a close watch on your progress and any difficulties you might face and provide assistance to you during the course. You are expected to mail your Tutor-Marked Assignment to your facilitator before the schedule date (at least two working days are required). They will be marked by your tutor and returned to you as soon as possible.

Do not delay to contact your facilitator by telephone or e-mail if you need assistance. The following might be circumstances in which you would find assistance necessary, hence you would have to contact your facilitator if:

- You do not understand any part of the study or the assigned readings
- You have difficulty with the self-tests or exercises
- You have a question or problem with an assignment or with the grading of an assignment.

You should try to attend the tutorials. This is the only chance to have face to face contact with your course facilitator and to ask questions which are answered instantly. You can raise any problem encountered in the course of your study.

Summary

Introduction to wireless Communication I is a course that describes communications in which electromagnetic waves or RF (rather than some form of wire) carry a signal over part or the entire communication path. Upon completing this course, you will be equipped with the basic knowledge of Wireless communication. In addition, you will be able to answer the questions.

What does wireless communication I is mean?
What are the applications areas of wireless technology?
Identify four generations of wireless communication
Explain the cell concept
Explain the three propagation mechanisms
Describe large scale path loss, small scale fading and shadowing
State the advantages of FM over Am
List six types of diversity techniques
Define the term Multiple Access.

Of course, the list of questions that you can answer is not limited to the above list. We wish you success in the course and hope that you will find it both interesting and useful and wishing you every success in your future endeavours.

Course Code	CIT755
Course Title	Wireless Communication I

Course Team	A. J. Ikuomola (Developer/Writer) - AUOA
	Prof. H.O.D Longe (Editor) - UNILAG
	Prof. Obidairo (Programme Leader) - NOUN
	A.A. Afolorunso (Coordinator) - NOUN

NATIONAL OPEN UNIVERSITY OF NIGERIA

National Open University of Nigeria
Headquarters
14/16 Ahmadu Bello Way
Victoria Island
Lagos

Abuja Office
No. 5 Dar es Salaam Street
Off Aminu Kano Crescent
Wuse II, Abuja
Nigeria

e-mail: centralinfo@nou.edu.ng
URL: www.nou.edu.ng

Published By:
National Open University of Nigeria

First Printed 2011

ISBN: 978-058-537-0

CONTENTS **PAGE**

MODULE 1 INTRODUCTION

UNIT 1 OVERVIEW AND EVOLUTION OF WIRELESS COMMUNICATION

CONTENTS

1.0 INTRODUCTION

Wireless communication is experiencing its fastest growth period in history. This has been possible because of enabling technologies that permit widespread deployment.

Wireless communication is the transfer of information over a distance without the use of electrical conductors or "wires". The distances involved may be short (a few meters as in television remote control) or long (thousands or millions of kilometers for radio communications).

Wireless communication is generally considered to be a branch of telecommunications.

It encompasses various types of fixed, mobile, and portable two-way radios, cellular telephones, personal digital assistants (PDAs), and wireless networking. Other examples of wireless technology include GPS units, garage door openers, wireless computer mice, keyboards and headsets, satellite television and cordless telephones.

Wireless communication can be via:

- radio frequency communication
- microwave communication, for example long-range line-of-sight via highly directional antennas, or short-range communication or
- infrared (IR) short-range communication, for example from remote controls or via Infrared Data Association (IrDA).

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define wireless communication
- mention examples of wireless communication equipment
- state the application area of wireless communication
- explain the history of radio communication
- identify the use of wireless technology
- state the classes of wireless.

3.0 MAIN CONTENT

3.1 Concept of Wireless Communication

Wireless is a term used to describe telecommunications in which electromagnetic waves (rather than some form of wire) carry the signal over part or the entire communication path.

3.1.1 Wireless Equipment

Common examples of wireless equipment in use today include:

- **Cellular phones and pagers**: These provide connectivity for portable and mobile applications, both personal and business
- **Global Positioning System (GPS):** Allows drivers of cars and trucks, captains of boats and ships, and pilots of aircraft to ascertain their location anywhere on earth

Cordless computer peripherals: The cordless mouse is a common example; keyboards and printers can also be linked to a computer via wireless

Cordless telephone sets: These are limited-range devices, not to be confused with cell phones

Home-entertainment-system control boxes: The VCR control and the TV channel control are the most common examples; some hi-fi sound systems and FM broadcast receivers also use this technology

Remote garage-door openers: One of the oldest wireless devices commonly use by consumers which are usually operated at radio frequencies

Two-way radios: These include amateur and citizens radio service, as well as business, marine, and military communications

Baby monitors: These devices are simplified radio transmitter/receiver units with limited range

Satellite television: Allows viewers in almost any location to select from hundreds of channels

Wireless LANs or Local Area Networks: Provide flexibility and reliability for business computer users.

3.1.2 Examples of Wireless Communication and Control

More specialised and exotic examples of wireless communications and control include:

Global System for Mobile Communication (GSM): A digital mobile telephone system

General Packet Radio Service (GPRS): A packet-based wireless communication service that provides continuous connection to the Internet for mobile phone and computer users.

Enhanced Data GSM Environment (EDGE): A faster version of the Global System for Mobile (GSM) wireless service.

Universal Mobile Telecommunications System (UMTS): A broadband, packet-based system offering a consistent set of services to mobile computer and phone users no matter where they are located in the world.

Wireless Application Protocol (WAP): A set of communication protocols to standardise the way that wireless devices, such as cellular telephones and radio transceivers, can be used for internet access.

i-Mode: The world's first "smart phone" for Web browsing, first introduced in Japan; provides colour and video over telephone sets.

3.1.3 Uses of Wireless Technology

Wireless technology is rapidly evolving, and is playing an increasing role in the lives of people throughout the world. In addition, increasing numbers of people are relying on the technology directly or indirectly.

The following situations justify the use of wireless technology:

- to span a distance beyond the capabilities of typical cabling
- to avoid obstacles such as physical structures
- to provide a backup communications link in case of normal network failure
- to link portable or temporary workstations
- to overcome situations where normal cabling is difficult or financially impractical, or
- to remotely connect mobile users or networks.

3.1.4 Classification of Wireless

Wireless can be divided into the following classes:

- **Fixed wireless**: The operation of wireless devices or systems in homes and offices, and in particular, equipment connected to the Internet via specialised modems
- **Mobile wireless**: The use of wireless devices or systems aboard motorised, moving vehicles; examples include the automotive cell phone and PCS (personal communications services)
- **Portable wireless**: The operation of autonomous, battery-powered wireless devices or systems outside the office, home, or vehicle; examples include handheld cell phones and PCS units
- **IR wireless**: The use of devices that convey data via IR (infrared) radiation; employed in certain limited-range communications and control systems

3.1.5 Applications of Wireless Technology

- **Security systems:** Wireless technology may supplement or replace hard wired implementations in security systems for homes or office buildings.
- **Television remote control:** Modern televisions use wireless (generally infrared) remote control units but now radio waves are also used.
- **Cellular telephony (phones and modems):** These instruments use radio waves to enable the operator to make phone calls from many locations world-wide. They can be used anywhere there is

a cellular telephone site to house the equipment that is required to transmit and receive the signal that is used to transfer both voice and data to and from these instruments.

WiFi: Wi-Fi (for wireless fidelity) is a wireless LAN technology that enables laptop PC's, PDA's, and other devices to connect easily to the internet. Wi-Fi is less expensive and nearing the speeds of standard Ethernet and other common wire-based LAN technologies.

Wireless energy transfer: Wireless energy transfer is a process whereby electrical energy is transmitted from a power source to an electrical load that does not have a built-in power source, without the use of interconnecting wires.

Computer interface devices: Answering the call of customers frustrated with cord clutter, many manufactures of computer peripherals turned to wireless technology to satisfy their consumer base. Originally these units used bulky, highly limited transceivers to mediate between a computer and a keyboard and mouse, however more recent generations have used small, high quality devices, some even incorporating Bluetooth

3.2 Brief History of Wireless Communications

Before the "Birth of Radio" 1867-1896

1867 - Maxwell predicts existence of electromagnetic (EM) waves

1887 - Hertz proves existence of EM waves; first spark transmitter generates a spark in a receiver several meters away

1890 - Branly develops coherer for detecting radio waves

1896 - Guglielmo Marconi demonstrates wireless telegraph to English telegraph office

"The Birth of Radio"

1897 – "The Birth of Radio" - Marconi awarded patent for wireless telegraph

1897 - First "Marconi station" established on Needles Island to communicate with English coast

1898 - Marconi awarded English patent no. 7777 for tuned communication

1898 - Wireless telegraphic connection between England and France established

Transoceanic Communication

1901 - Marconi successfully transmits radio signal across Atlantic Ocean from Cornwall to Newfoundland
1902 - First bidirectional communication across Atlantic
1909 - Marconi awarded Nobel Prize for physics

Voice over Radio

1914 - First voice over radio transmission
1920s - Mobile receivers installed in Police cars in Detroit
1930s - Mobile transmitters developed; radio equipment occupied most of Police car trunk
1935 - Frequency modulation (FM) demonstrated by Armstrong
1940s - Majority of Police systems converted to FM

Birth of Mobile Telephony

1946 - First interconnection of mobile users to public switched telephone network (PSTN)
1949 – Federal Communication Commission (FCC) recognises mobile radio as new class of service
1940s - Number of mobile users > 50,000
1950s - Number of mobile users > 500,000
1960s - Number of mobile users > 1,400,000
1960s - Improved Mobile Telephone Service (IMTS) introduced; supports full-duplex, auto dial, auto trunking
1976 - Bell Mobile Phone has 543 pay customers using 12 channels in the New York City area; waiting list is 3700 people; service is poor due to blocking

Cellular Mobile Telephony

1979 – NTT Communications Corporation Japan deploys first cellular communication system
1983 - Advanced Mobile Phone System (AMPS) deployed in US in 900 MHz band: supports 666 duplex channels
1989 - Groupe Spècial Mobile defines European digital cellular standard, GSM
1991 - US Digital Cellular phone system introduced
1993 - IS-95 code-division multiple-access (CDMA) spread-spectrum digital cellular system deployed in US
1994 - GSM system deployed in US, labelled “Global System for Mobile Communications”

PCS and Beyond

1995 - Federal Communication Commission (FCC) auctions off frequencies in Personal Communications System (PCS) band at 1.8 GHz for mobile telephony

1997 - Number of cellular telephone users in U.S. > 50,000,000

2000 - Third generation cellular system standards. Bluetooth standards.

3.3 Mobile Radio Communication

Radio is the technology and practice that enables the transmission and reception of information carried by long-wave electromagnetic radiation. Radio makes it possible to establish wireless two-way communication between individual pairs of transmitter and receiver, and it is used for one-way broadcasts to many receivers. Radio signals can carry speech, music, telemetry, or digitally-encoded entertainment.

Radio is used by the general public, within legal guidelines, or it is used by private business or governmental agencies. Cordless telephones are possible because they use low-power radio transmitters to connect without wires. Cellular telephones use a network of computer-controlled low power radio transmitters to enable users to place telephone calls away from phone lines.

Radio receivers recover modulation information in a process called demodulation or detection. The radio carrier is discarded after it is no longer needed. The radio carrier's cargo of information is converted to sound using a loudspeaker or headphones.

3.3.1 Evolution of Mobile Radio Communication

In the 19th Century, in Scotland, James Clerk Maxwell described the theoretical basis for radio transmissions with a set of four equations known ever since as Maxwell’s Field Equations. Maxwell was the first scientist to use mechanical analogies and powerful mathematical modelling to create a successful description of the physical basis of the electromagnetic spectrum. His analysis provided the first insight into the phenomena that would eventually become radio.

Not long after Maxwell’s remarkable revelation about electromagnetic radiation, Heinrich Hertz demonstrated the existence of radio waves by transmitting and receiving a microwave radio signal over a considerable distance. Hertz’s apparatus was crude by modern standards but it was important because it provided experimental evidence in support of Maxwell’s theory.

Guglielmo Marconi developed a wireless telegraphy which was able to send a long-wave radio signal across the Atlantic Ocean.

The first radio transmitters to send messages, Marconi's equipment included, used high-voltage spark discharges to produce the charge acceleration needed to generate powerful radio signals. Spark transmitters could not carry speech or music information. They could only send coded messages by turning the signal on and off using a telegraphy code similar to the landline Morse code.

Spark transmitters were limited to the generation of radio signals with very-long wavelengths, much longer than those used for the present AM-broadcast band in the United States. The signals produced by a spark transmitter were very broad with each signal spread across a large share of the usable radio spectrum. Only a few radio stations could operate at the same time without interfering with each other. Mechanical generators operating at a higher frequency than those used to produce electrical power were used in an attempt to improve on the signals developed by spark transmitters.

A technological innovation enabling the generation of cleaner, narrower signals was needed. Electron tubes provided that breakthrough, making it possible to generate stable radio frequency signals that could carry speech and music. Broadcast radio quickly became established as source of news and entertainment.

Continual improvements to radio transmitting and receiving equipment opened up the use of successively higher and higher radio frequencies.

Short waves, as signals with wavelengths less than 200m were found to be able to reach distant continents. International broadcasting on shortwave frequencies followed, allowing listeners to hear programming from around the world.

The newer frequency-modulation system, FM, was inaugurated in the late 1930s and for more than 25 years struggled for acceptance until it eventually became the most important mode of domestic broadcast radio. FM offers many technical advantages over AM, including an almost complete immunity to the lightning-caused static that plagues AM broadcasts. The FM system improved the sound quality of broadcasts tremendously, far exceeding the fidelity of the AM radio stations of the time. The FM system was the creation of E. H. Armstrong, perhaps the most prolific inventor of all those who made radio possible.

In the late 1950s, stereo capabilities were added to FM broadcasts along with the ability to transmit additional programmes on each station that could not be heard without a special receiver. A very high percentage of FM broadcast stations today carry these hidden programmes that serve special audiences or markets. This extra programme capability, called SCA for Subsidiary Communications Authorisation, can be used for stock market data, pager services, or background music for stores and restaurants.

3.3.2 Radio and the Electromagnetic Spectrum

Radio utilises a small part of the electromagnetic spectrum, the set of related wave-based phenomena that includes radio along with infrared light, visible light, ultraviolet light, x rays, and gamma rays. Radio waves travel at the velocity of electromagnetic radiation. A radio signal moves fast enough to complete a trip around the earth in about 1/7 second.

3.3.3 How Radio Signals Are Created

If you jiggle a collection of electrons up and down one million times a second, then a 1-MegaHertz radio signal will be created. Change the vibration frequency and the frequency of the radio signal will change. Radio transmitters are alternating voltage generators. The constantly changing voltage from the transmitter creates a changing electric field within the antenna. This alternating field pushes and pulls on the conduction electrons in the wire that are free to move. The resulting charge acceleration produces the radio signal that moves away from the antenna. The radio signal causes smaller sympathetic radio frequency currents in any distant electrical conductor that can act as a receiving antenna.

3.3.4 Radio – Wavelengths, Frequencies and Antennas

Each radio signal has a characteristic wavelength just as it is in sound wave. The higher the frequency of the signal, the shorter will be the wavelength. Antennas for low-frequency radio signals are long. Antennas for higher frequencies are shorter; to match the length of the waves they will send or receive.

It is a characteristic of all waves, not just radio signals, that there is greater interaction between waves and objects when the length of the wave is comparable to the object's size. Just as only selected sound wavelengths fit easily into the air column inside a bugle, only chosen frequencies will be accepted by a given antenna length. Antennas, particularly transmitting antennas, function poorly unless they have a size that matches the wavelength of the signal presented to them. The radio signal must be able to fit on the antenna as a standing wave. This condition of compatibility is called resonance. If a transmitter is able to “feed” energy into an antenna, the antenna must be resonant or it will not “take power” from the transmitter. A receiver antenna is less critical, since inefficiency can be compensated by signal amplification in the receiver, but there is improvement in reception when receiving antennas are tuned to resonance.

If an antenna’s physical length is inappropriate, capacitors or inductors may be used to make it appear electrically shorter or longer to achieve resonance.

3.3.5 Radio Signals and Energy

Energy is required to create a radio signal. Radio signals use the energy from the transmitter that accelerates electric charge in the transmitting antenna. A radio signal carries this energy from the transmitting antenna to the receiving antenna. Only a small fraction of the transmitter's power is normally intercepted by any one receiving antenna, but even a vanishingly-small received signal can be amplified electronically millions of times as required.

3.4 Differences between Wired and Wireless

The main difference between wired and wireless data communication infrastructure is the existence of physical cabling.

A wired network uses wires (cables) to connect devices whereas a wireless network uses radio waves.

Wired networks are easy to set up and troubleshoot whereas wireless networks are comparatively difficult to set up, maintain and troubleshoot.

Wired networks make you immobile while wireless ones provide you with convenience of movement.

Wired network proves expensive when covering a large area because of the wiring and cabling while wireless network do not involve this cost.

Wired networks have better transmission speeds than wireless ones.

In wired networks, a user does not have to share space with other users and thus gets dedicated speed while in wireless networks the same connection may be shared by multiple users.

4.0 CONCLUSION

This unit has introduced you to the concept, applications and origination of wireless communication. You have also been informed on how radio signals are created.

5.0 SUMMARY

The main points in this unit include the following:

- Wireless communication is the transfer of information over a distance without the use of electrical conductors or "wires"
- It encompasses various types of fixed, mobile, and portable two-way radios, cellular telephones, personal digital assistants (PDAs), wireless networking, etc.
- Radio is the technology and practice that enables the transmission and reception of information carried by long-wave electromagnetic radiation
- Marconi successfully transmits radio signal across Atlantic Ocean from Cornwall to Newfoundland
- The main difference between wired and wireless data communication infrastructure is the existence of physical cabling.

SELF ASSESSMENT EXERCISE

1. What is wireless communication?
2. Why are antennas on cell phones smaller than antenna on your radio?

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss the evolution of radio communication
2. Why are car antennas about the same size as TV antenna?
3. Mention five examples of wireless communication equipment.
4. List five uses of wireless technology
5. Briefly explain the application area of wireless communication
6. Outline the four classes of wireless

7.0 REFERENCES/FURTHER READING

Goldsmith, A. (2005). *Wireless Communications*. Cambridge University Press.

Lior, Baruch (2008). *Mobile Computing: Definition-Wireless*.

O'Brien, J. & Marakas, G. M. (2008). *Management Information Systems*. New York: McGraw-Hill Irwin.

Shea J. (2000). *Brief History of Wireless Communication.*

UNIT 2 MODERN WIRELESS COMMUNICATION SYSTEM

CONTENTS

1.0 INTRODUCTION

As you have learnt in the previous unit, the field of mobile communications has experienced various advanced developments. In fact, it can be said that mobile radio communications industry has grown up during the last ten years. There are various factors which are responsible for speedy developments in mobile or wireless communications. These factors are digital and RF fabrication improvements, new large scale circuit integration and other miniaturisation technologies.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- explain a cellular system
- state the basic components of cellular system
- discuss the wireless communication generations.

3.0 MAIN CONTENT

3.1 Introduction to Cellular System

A cellular system is a radio network made up of a number of radio cell (or just cells) each served by at least one fixed-location transceiver known as a cell site or base station. These cells cover different land areas to provide radio coverage over a wider area than the area of one cell, so that a variable number of portable transceivers can be used in any one cell and moved through more than one cell during transmission.

Cellular systems offer a number of advantages including but not limited to the following over alternative solutions:

Increased capacity
Reduced power usage
Larger coverage area
Reduced interference from other signals

3.1.1 Basic Cellular System

A basic cellular system is made up of three parts:

i. A mobile unit
ii. A cell site
iii. Mobile Telephone Switching Office (MTSO) and with connections to link the three subsystems:

Mobile Unit: A mobile telephone unit contains a control unit, a transceiver and an antenna system
Cell Site: The cell site provides interface between the MTSO and the mobile unit. It has control unit, radio cabinets, antennas, a power plant and data terminals.
MTSO: The switching office, the central coordinating element for all cell sites, contains the cellular processor and cellular switch. It interfaces with telephone company zone offices; controls call processing and handle billing activities.
Connections: As a matter of fact, the radio and high speed data links connect the three subsystems. Each mobile unit can only use one channel at a time for its communication link.

However, the channel is not fixed i.e. it can be any one in the entire band assigned by the serving area, with each site having multi-channel capabilities that can connect simultaneously to many mobile units.

In addition to the above:

The MTSO is the heart of the cellular mobile system. Its processor provides central coordination and cellular administration.
The cellular switch, which can be either analog or digital, switches calls to connect mobile subscribers to other mobile

subscribers and to the nationwide telephone network. It uses voice trucks similar to telephone company interoffice voice trucks. It also contains data links providing supervision links between the processor and the switch and between the cell sites and the processor.

The radio link carries the voice and signal between the mobile unit and the cell site.

The high-speed data links cannot be transmitted over the standard telephone trucks and therefore must use either microwave links or T-carriers (wire lines).

Microwave radio links or T-carriers carry both voice and data between the cell site and the MTSO.

3.2 Wireless Communications Standards/Generations

3.2.1 First Generation Cellular Systems

The first generation (1G) wireless communications stems use frequency division multiple access (FDMA) as the multiple access technology.

FDMA is an analog transmission technique that is inherently narrowband. As a matter of fact, the first generation cellular systems make use of analog FM scheme for speech transmission. The individual calls use different frequencies and share the available spectrum through a particular multiple access technique known as frequency-division multiplexing access (FDMA).

3.2.2 Second Generation Cellular Systems

The second generation (2G) wireless systems use digital transmission. The multiple access technology is both time division multiple access (TDMA) and code division multiple access (CDMA). Although, the second generation wireless systems offer higher transmission rates with greater flexibility than the first generation systems, they are nevertheless narrowband systems. The service offered by both 1G and 2G system is predominantly voice. The digital technology allows greater sharing of the radio hardware in the base station among the multiple users, and provides a larger capacity to support more users per base station per Megahertz (Mhz) of spectrum as compared to analog system. As a matter of fact, digital systems offer a number of advantages over analog system.

Digital systems provide:

flexibility for supporting multimedia services
flexibility for capacity expansion

reduction in Radio Frequency (RF) transmit power
encryption for communication privacy
reduction in system complexity.

3.2.3 Third Generation Cellular Systems

The third generation (3G) standard is based on CDMA as the multiple access technology. With a transmission rate of up to 2 megabits per second (Mbps), 3G systems are wideband, and are expected to support multimedia services. It is likely that the third generation cellular systems will be equipped with the infrastructure to support Personal Communications Systems (PCS). The network infrastructure support will likely include the following:

public land mobile networks (PLMNs)
mobile Internet Protocol (Mobile IP)
wireless asynchronous transfer mode (WATM) networks, and
low earth orbit (LEO) satellite network

3.2.4 Fourth Generation Cellular Systems

During the last 20 years, wireless networks have evolved from an analog, single medium (voice), and low data rate (a few kilobits per second) system to the digital, multimedia, and high data rate (ten to hundreds of megabits per second) system of today. Future systems will be based on user's demands as the fourth-generation (4G) cellular system applications which need high speed data rates to achieve them.

In July 2003, the International Telecommunications Union (ITU) made requirements for 4G system which are:

i. at a standstill condition, the transmission data rate should be 1 Gbps.
ii. at a moving condition, the transmission data rate should be 100 Mbps.

Any proposed system that can meet these requirements with less bandwidth and higher mobile speed will be considered. A potential 4G system could be used in the family of OFDM (Orthogononal Frequency Division Multiplexing), because the Wireless Metropolitan Area Network (WMAN) using OFDM can have a transmission data rate of 54-70 Mbps, which is much higher than what the Code Division Multiple Access (CDMA) system can provide.

4.0 CONCLUSION

In this unit, you have learnt the concepts of a cellular system and the generations/standard of wireless communications.

5.0 SUMMARY

The main points in this unit are:

- A cellular system is a radio network made up of a number of radio cell (or just cells) each served by at least one fixed-location transceiver known as a cell site or base station.
- A basic cellular system is made up of three parts: a mobile unit, cell site, and mobile Telephone Switching Office (MTSO) and with connections to link the three subsystems
- Wireless communications systems that have been in deployment for sometime are those of the first generation and second generation. Third generation systems are also currently under deployment, but continue to evolve.

SELF ASSESSMENT EXERCISE

Write on the Fourth Generation (4G) Systems

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss on the first, second and third generation wireless communication networks
2. What do you understand about a basic cellular system?

7.0 REFERENCE/FURTHER READING

Sharma S. (2006). *Wireless & Cellular Communications*. New Delhi: S. K. Kataria & Sons.

UNIT 3 WIRELESS DATA NETWORK

CONTENTS

1.0 INTRODUCTION

In this unit, in brief, we are going to discuss various issues related to wireless data networks.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- discuss the wireless data network
- differentiate between PAN, LAN, MAN and WAN
- illustrate with diagram wireless data network.

3.0 MAIN CONTENT

3.1 Wireless Data Networks

The wireless data network can be classified according to their coverage areas as: Personal Area Network (PAN), Local Area Network (LAN), Metropolitan Area Network (MAN) and Wide Area Network (WAN).

3.1.1 Personal Area Network (PAN)

Personal Area Network (PAN) is a computer network organised around an individual person. It is a computer network used for communication among computer devices (including telephones and personal digital assistants) close to one's person. Personal area network typically involve a mobile computer, a cell phone and/or a handheld computing device such as a PDA. You can use these networks to transfer files including email and calendar appointments, digital photos and music. The smallest coverage area, where the network is called wireless personal area network (PAN), is limited to an office. A cell of such a small size would enable connection of computers or electronic input devices. A wireless PAN network can use Bluetooth. Personal area networks generally cover a range of less than 10 meters (about 30 feet).

The channel bandwidth is 200 kHz using Quadrature Amplitude Modulation (QAM). The data rate can be 1 Mbps. It is a short wire replacement for wireless. Today, most of cell phones are equipped with Bluetooth.

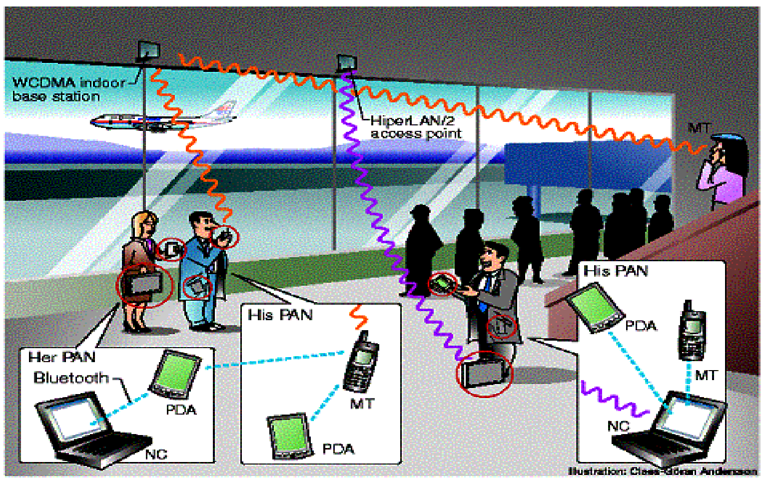


Fig. 3.1: Personal Area Network

3.1.2 Local Area Network (LAN)

Local Area Network (LAN) is a computer network covering a small physical area, like a home, office, or small group of buildings, such as a school, or an airport. Wireless local area network (LAN) connects users on a particular floor of a building. For example, two computers linked together at home are the simplest form of a LAN while several hundred computers cabled together across several buildings at school form a more complex LAN. In 1990s, wireless LANs was divided into the radio-frequency (RF) systems and infrared (IR) systems specified by the Federal Communication Commission (FCC). The RF systems are divided into the licensed non-spread-spectrum (NSS) and the unlicensed spread spectrum (SS). In the unlicensed SS, it requires a minimum of 50 and 75 hopping frequency at 910MHz and 2.5GHz, respectively, or achieved by a spread-spectrum modulation exceeding a spreading factor of 10m in direct sequence systems. LANs are usually connected with coaxial or CAT5 cable.

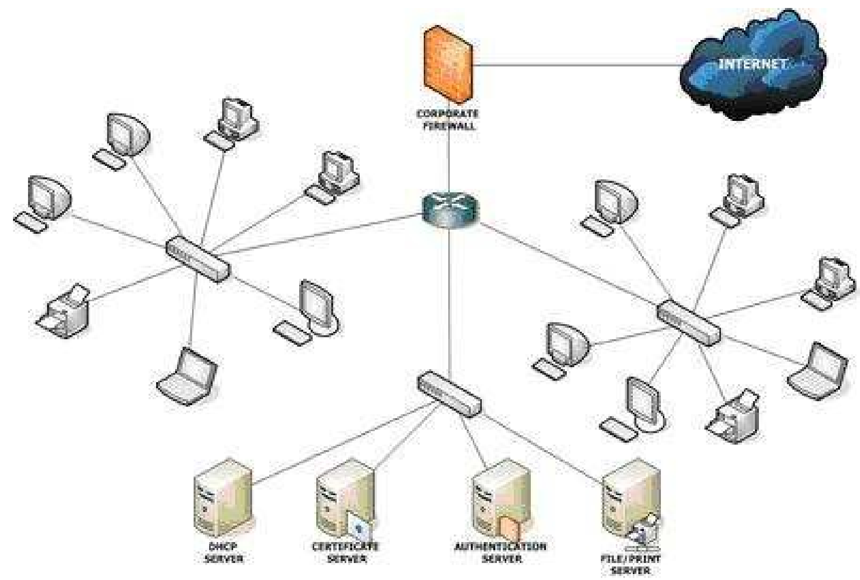


Fig. 3.2 LAN illustration. Image source: Network Elements

Source: www.networkelements.co.uk/media/lan.jpg

3.1.3 Metropolitan Area Network (MAN)

A Metropolitan Area Network (MAN) is a network that connects two or more local area networks or campus area networks together but does not extend beyond the boundaries of the immediate town/city. It connects the residents and visitors to a city. MANs are large computer networks usually spanning a city. MANs connect multiple geographically nearby LANs to one another (over an area of up to a few dozen kilometres) at high speeds. Thus, a MAN lets two remote nodes communicate as if they were part of the same local area network Routers, switches and hubs are connected to one another with high speed links (usually fibre optic cables) to create a metropolitan area network. MANs are usually connected with fibre-optic cable, microwave transceivers or leased data landlines.

There are three important features which discriminate MANs from LANs or WANs:

The network size falls intermediate between LANs and WANs. A MAN typically covers an area of between 5 and 50 km diameter. Many MANs cover an area the size of a city, although in some cases

A MAN (like a WAN) is not generally owned by a single organisation. The MAN, its communications links and equipment are generally owned by either a consortium of users or by a single network provider who sells the service to the users. This level of service provided to each user must therefore be negotiated with the MAN operator, and some performance guarantees are normally specified.

A MAN often acts as a high speed network to allow sharing of regional resources (similar to a large LAN). It is also frequently used to provide a shared connection to other networks using a link to a WAN.

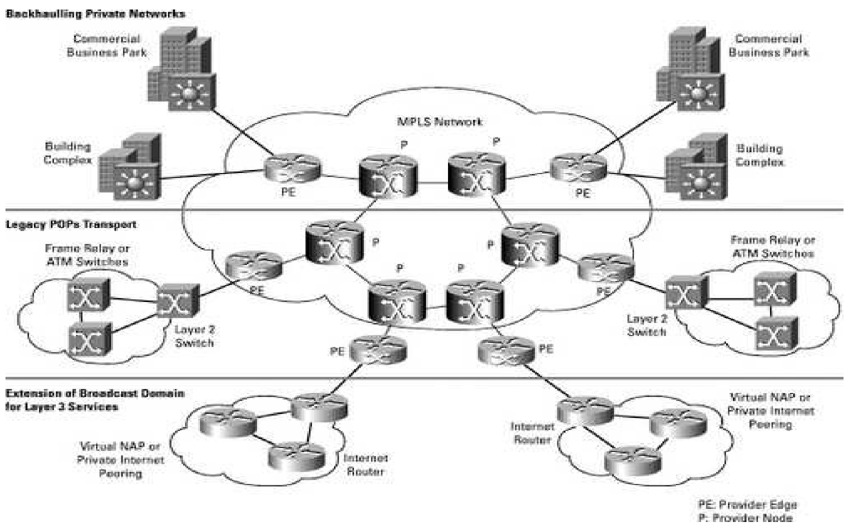
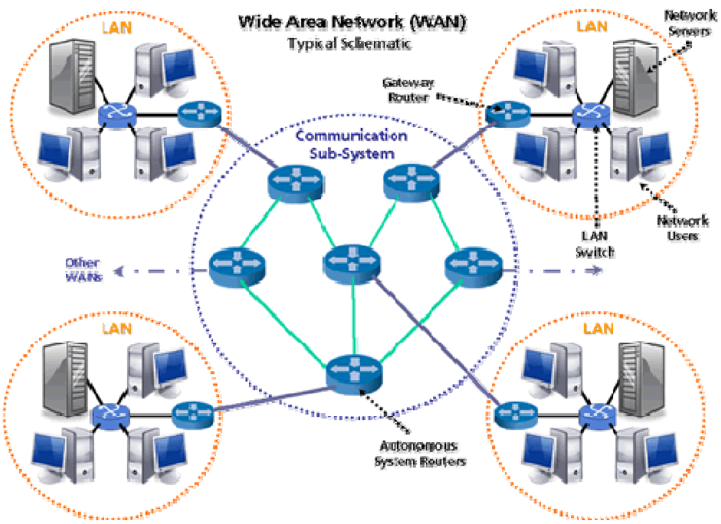


Fig. 3.3 Metropolitan Area Network

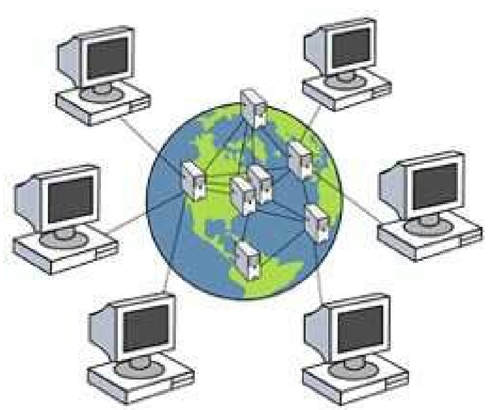
Source rkcablenet.tradeindia.com/Exporters_Suppliers

3.1.4 Wide Area Network (WAN)

Wide Area Network (WAN) is a computer network that covers a broad area (i.e., any network whose communications links cross metropolitan, regional, or national boundaries). WAN is a data communications network that covers a relatively broad geographic area (i.e. one city to another and one country to another country) and that often uses transmission facilities provided by common carriers, such as telephone companies. The largest and most well-known example of a WAN is the Internet. WANs are used to connect LANs and other types of networks together, so that users and computers in one location can communicate with users and computers in other locations. Typically, a WAN consists of two or more Local Area networks (LANs) connected by a communication sub-system, which is usually comprised of Autonomous System (AS) routers. For example, a national banking organisation may use a WAN to connect all of its branches across the country. WANs are usually connected using the Internet, ISDN landlines or satellite.



(a) Source: www.air-stream.org.au/wan



(b) Source: www.computernetworks.com/WAN.cfm

Fig. 3.4 (a & b): Wide Area Network (WAN)

4.0 CONCLUSION

The wireless data network can be classified according to their coverage areas as:

Personal Area Network (PAN)
Local Area Network (LAN)
Metropolitan Area Network (MAN)
Wide Area Network (WAN)

5.0 SUMMARY

In this unit, you have learnt that:

Personal area network (PAN) is a computer network used for communication among computer devices (including telephones and personal digital assistants) close to one's person

LAN means Local Area Network, and is generally restricted to a single building

Local area network (LAN) is a computer network covering a small physical area, like a home, office, or small group of buildings, such as a school, or an airport

MAN means Metropolitan Area Network, and usually encompasses multiple sites in the same city. It connects the residents and visitors to a city

WAN means Wide Area Network and can cover any area. It connects the entire country.

SELF ASSESSMENT EXERCISE

Mention four classifications of wireless data network

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss the wireless LAN.
2. Differentiate between MAN and WAN.
3. Illustrate with diagram a Local Area Network.

7.0 REFERENCES/FURTHER READING

Sharma, S. (2006). *Wireless and Cellular Communications*. New Delhi: S. K. Kataria & Sons.

Tse, D. & Viswanath P. (2005). *Fundamentals of Wireless Communication*. Cambridge University Press.

UNIT 4 THE CELLULAR CONCEPT

CONTENTS

1.0 INTRODUCTION

Cellular systems are widely used today and cellular technology needs to offer very efficient use of the available frequency spectrum. With billions of mobile phones in use around the globe today, it is necessary to refuse the available frequencies many times over without mutual interference of one cell phone to another. It is this concept of frequency reuse that is at the heart of cellular technology.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- explain the cell concept
- discuss the use of frequency reuse concept
- mention different types of cell
- state the importance of hexagonal cell shape over other shapes.

3.0 MAIN CONTENT

3.1 Concept of Cellular Communications

The limitation in spectral width and the maximum number of user (i.e. system capacity) that can be supported in a wireless mobile system is an important performance measure. If a single transmitter were used to cover a large geographical area (a single small area called a cell that is served by a single base station, or a cluster of cells), a very high power transmitter and very high antenna would be required. With a single high power transmitter, all users will share the same set of frequencies, or radio channels. If the same set of radio resources were assigned to serve a smaller geographical area and then reused to serve another small geographical area, it would be possible to expand the system capacity (i.e. the number of users).The geographical regions that use the same set of radio frequencies must be physically separated from each other so that the power level of the signal that spills out from one region to a neighbouring region does not produce unacceptable interference. This way of replicating identically structured and operated geographical regions gives rise to the concept of cellular communications.

3.1.1 Cell Fundamentals

A single small area is called a cell. The cell shape can be of only three types of regular polygons, equilateral triangle, square, and regular hexagon.

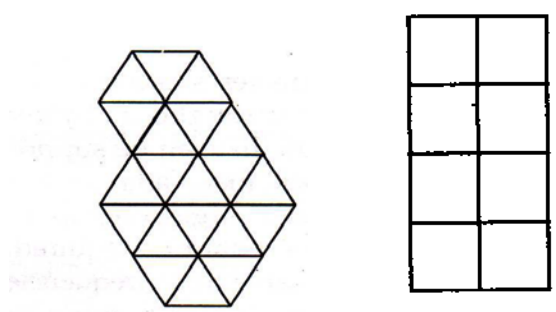


Fig. 4.1 Triangular and Rectangular Cells

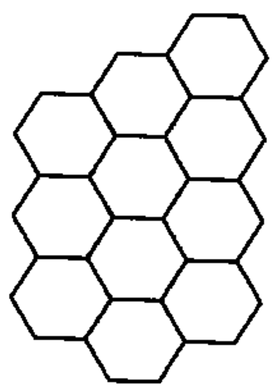


Fig. 4.2 Regular Hexagon

The hexagonal cell is the closest approximation to a circle among these three and has been used traditionally for system design. The reason being that among the three shapes mentioned, for a given radius (largest possible distance between the polygon center and its edge) the hexagon has the largest area. When using the hexagons to model coverage areas, base station transmitters are depicted as either being in the center of the cell or on three of the six cell vertices.

3.1.2 Cell Size

Even though the number of cells in a cluster in a cellular system can help govern the number of users that can be accommodated, by making all the cells smaller, it is possible to increase the overall capacity of the cellular system. However a greater number of transmitter receiver or base stations are required if cells are made smaller and this increases the cost of the operator. Accordingly, in areas where there are more users, small low power base stations are installed.

The different types of cells are given different names according to their size and function:

Macro cells: Are large cells that are usually used for remote or sparsely populated areas. These may be 10km or possibly more in diameter.
Micro cells: Are those that are normally found in densely populated areas which may have a diameter of around 1km
Pico cells: Are generally used for covering very small areas such as particular areas of buildings, or possibly tunnels where coverage from a larger cell in the cellular system is not possible. Obviously for small cells, the power levels used by the base stations are much lower and the antennas are not positioned to cover wide areas. In this way the coverage is minimised and the interference to adjacent cell is reduced.
Selective cells: May be used where full 360 degree coverage is not required. They may be used to fill in a hole in the coverage in the cellular system, or to address a problem such as the entrance to a tunnel, etc.
Umbrella cells: Is sometimes used in instances such as those where a heavily used road crosses an area where there are micro cells. Under normal circumstances this would result in a large number of handovers as people driving along the road would quickly cross the micro cells. An umbrella cell would take in the coverage of the micro cells (but use different channels to those allocated to the micro cells). However, it would enable those people moving along the road to be handled by the umbrella cell and experience fewer handovers than if they had to pass from one micro cell to the next.

Fig. 4.3 Cell Size

Decreasing cell size gives

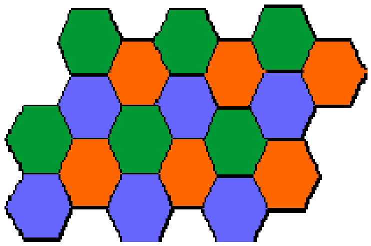
Increased user capacity
Increased number of handovers per call
Increased complexity in locating the subscriber
Lower power consumption in mobile terminal: so it gives longer talk time, safer operation

3.1.3 Cellular Frequency Reuse

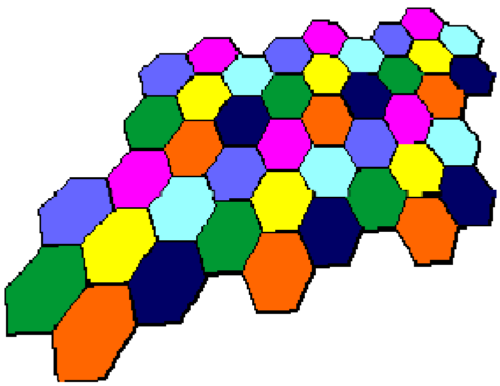
Frequency reuse is a technique of reusing frequencies and channels within a communications system to improve capacity and spectral efficiency. Frequency reuse is one of the fundamental concepts in which commercial wireless systems are based that involves the partitioning of an RF radiating area (cell) into segments of a cell. One segment of the cell uses a frequency that is far enough away from the frequency in the bordering segment that does not provide interference problems.

In the cellular concept, frequency allocated to the service are reused in a regular pattern of areas, called ‘cells’, each covered by one base station.

Every cellular base station is assigned a group of radio channels which are used within a small geographical area called a cell. The base station antennas are designed to achieve the desired coverage within a particular cell. In mobile-telephone system these cells are usually hexagonal. To ensure that the mutual interference between users remains below harmful level, adjacent cells use different frequencies. In fact, a set of C different frequencies ($f_1 \ldots f_c$) are used for each cluster of C adjacent cells. Cluster patterns and the corresponding frequencies are re-used in a regular pattern over the entire service area.

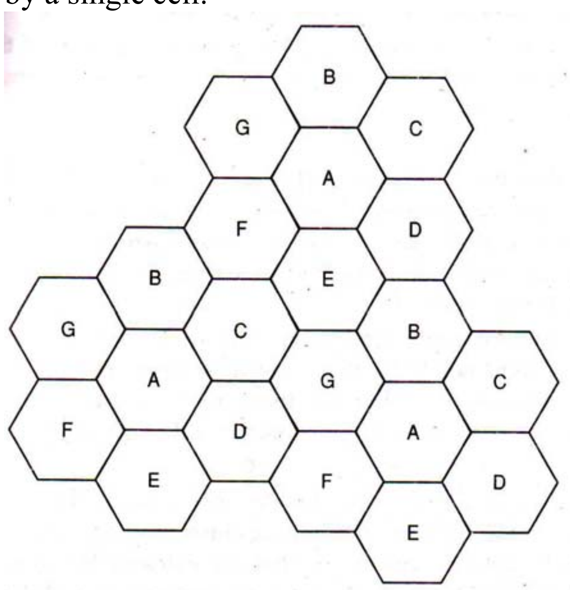


(a): Frequency reuse plan for $C = 3$, with hexagonal cells. (i=1, j =1)



(b): Frequency reuse plan for $C = 7$ (i=2, j =1).

The total bandwidth for the system is C times the bandwidth occupied by a single cell.



(c)

Fig. 4.4 (a-c): Illustration of Cellular Frequency Reuse Concept

Source: Linnartz J.M.G (1997)

3.1.4 Cell Planning

In the practice of cell planning, cells are not hexagonal as considered in the theoretical studies. However, propagation over irregular terrain leads to quite different cell shapes and cell sizes. Computer methods are being used for optimised planning of base station locations and cell frequencies. Path loss and link budgets are computed from the terrain features and antenna data. This determines the coverage of each base station and interference to other cells.

In the initial phases of operating a cellular network, the planners typically aim at maximum coverage. Subscribers should be able to reach a base station anywhere. The map of the service coverage should not contain dark spots where the service is not available. Base stations are located such that they reach as many locations as possible, e.g. typically on hill tops.

Later on, when the number of subscribers increases, there is a need to optimise the capacity. Cell size should be as small as possible to accommodate as many different cell areas as possible. The effect that hills can shield on signals and avoid propagation into other valleys can be used as advantage. It allows that frequencies are reused in nearby valleys, particularly if base station are not located at the hill tops but in the valleys.

Effect of Traffic Density

An important aspect is the distribution of traffic. Cell sizes need to be smaller in areas with more traffic. The erlang theory addresses the amount of traffic that can be carried over a given number of channels, at a given blocking rate. If a GSM operator faces blocking rates that are too large in a certain area, he could for instance

Split the cell into two cells with disjoint coverage areas, for instance by using two sectors from the same mast, or by using two separate base station locations.

Install equipment for a second GSM carrier, for 8 telephone channels. The old and new carriers have the same coverage and together provide 16 voice channels.

The first option is more efficient from a frequency scarcity point of view. In both cells, the 8 channels can carry 3.13 erlang at a blocking rate of 1%. In the second case, the 16 channels can carry 8.8 erlang at 1% blocking rate. Note that this is significantly more than 2 times 3.13 erlang.

3.1.5 Mobile Phone Networks

The most common example of a cellular network is a mobile phone (cell phone) network. A mobile phone is a portable telephone which receives or makes calls through a cell site (base station), or transmitting tower. Radio waves are used to transfer signals to and from the cell phone.

Large geographic areas (representing the coverage range of a service provider) may be split into smaller cells to avoid line-of-sight signal loss and the large number of active phones in an area. In cities, each cell site has a range of up to approximately ½ mile, while in rural areas; the range is approximately 5 miles. Many times in clear open areas, a user may receive signals from a cell site 25 miles away. All of the cell sites are connected to cellular telephone exchanges "switches", which connect to a public telephone network or to another switch of the cellular company.

As the phone user moves from one cell area to another cell, the switch automatically commands the handset and a cell site with a stronger signal (reported by each handset) to switch to a new radio channel (frequency). When the handset responds through the new cell site, the exchange switches the connection to the new cell site.

With CDMA, multiple CDMA handsets share a specific radio channel. The signals are separated by using a pseudonoise code (PN code) specific to each phone. As the user moves from one cell to another, the handset sets up radio links with multiple cell sites (or sectors of the same site) simultaneously. This is known as "soft handoff" because, unlike with traditional cellular technology, there is no one defined point where the phone switches to the new cell.

Modern mobile phone networks use cells because radio frequencies are limited and shared resource. Cell-sites and handsets change frequency under computer control and use low power transmitters so that a limited number of radio frequencies can be simultaneously used by many callers with less interference.

Since almost all mobile phones use cellular technology, including GSM, CDMA, and AMPS (analog), the term "cell phone" is used interchangeably with "mobile phone". However, satellite phones are mobile phones that do not communicate directly with a ground-based cellular tower, but may do so indirectly by way of a satellite.

There are a number of different digital cellular technologies, including: Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS), Code Division Multiple Access (CDMA), Evolution-Data Optimized (EV-DO), Enhanced Data Rates for GSM Evolution (EDGE), 3GSM, Digital Enhanced Cordless Telecommunications (DECT), Digital AMPS (IS-136/TDMA), and Integrated Digital Enhanced Network (iDEN).

3.1.6 Concept of Cell Cluster

When devising the infrastructure technology of a cellular system, the interference between adjacent channels is reduced by allocating different frequency bands or channels to adjacent cells so that their coverage can overlap slightly without causing interference. In this way cells can be grouped together in what is termed a cluster. A group of cells that use different set of frequencies in each cell is called a Cell Cluster. Let N be the cluster size in terms of the number of cells within it and K be the total number of available channels without frequency reuse. The N cells in the cluster would then utilise all K available channels. In this way, each cell in the cluster contains one-Nth of the total number of available channels. In this sense, N is also referred to as the frequency reuse factor of the cellular system.

Seven is a convenient number of cells that can be in a cluster, but there are number of conflicting requirements that need to be balanced when choosing the number of cells in a cluster for a cellular system:

Limiting interference levels
Number of channels that can be allocated to each cell site

It is necessary to limit the interference between cells having the same frequency. The topology of the cell configuration has a large impact on this. The larger the number of cells in the cluster, the greater the distance between cells sharing the same frequencies. In the ideal world it might be good to choose a large number of cells to be in each cluster. Unfortunately there are only a limited number of channels available.

This means that the larger the number of cells in a cluster, the smaller the number available to each cell, and this reduces the capacity. This means that there is a balance that needs to be made between the number of cells in a cluster, and the interference levels and the capacity that is required.

(a) Capacity Increase by Frequency Reuse Concept

Let us consider that each is allocated J channels ($J \leq K$). If the K channels are divided among the N cells into unique and disjoint channel groups, each with J channels, then we have

K = J N

N cells in a cluster use the complete set of available frequencies while K is the total number of available channel. By decreasing the cluster size N, it is possible to increase the capacity per cell. The cluster can be replicated many times to form the entire cellular communication system.

Let M be the number of times the cluster is replicated and C be the total number of channels used in the entire cellular system with frequency reuse. C is then the system capacity and is given by

C = M J N

If M is increased, the system capacity C will increase.

EXERCISE 4

Given a cellular system which has a total of 1001 radio channels available for handling traffic and given the area of a cell is 6 km^2 and the area of the entire system is 2100 km^2.

i. Calculate the system capacity if the cluster size is 7.
ii. How many times would the cluster of size 4 have to be replicated in order to approximately cover the entire cellular area?
iii. Calculate the system capacity if the cluster size is 4.
iv. Does decreasing the cluster size increase the system capacity? Explain

Solution: Given that

The total number of available channels K = 1001.
Cluster size N = 7.
Area of cell Acell = 6 km2
Area of cellular system A_{sys} = 2100 km^2

(i) The number of channels per cell is given by $J \quad \frac{K}{N}$

Then we have $J \quad \frac{1001}{7} \quad 143\, channels/cell$

Also, we know that the coverage area of a cluster is given by

$A_{cluster} \quad N \quad A_{cell} \quad 7 \quad 6 \quad 42km^2$

The number of times that the cluster has to be replicated to cover the entire system will be $M \quad \frac{A_{sys}}{A_{cluster}}$ or $M \quad \frac{2100}{42} \quad 50$

Hence, the system capacity C will be
C = M J N = 50 x 143 x 7 = 50,050 channels.

(ii) For N = 4, $A_{cluster}$ = 4 x 6 = 24 km^2

Hence $M \quad \frac{A_{sys}}{A_{cluster}} \quad \frac{2100}{24} \quad 87.5 \quad 87.$

(iii) With N = 4, $J \quad \frac{1001}{4} \quad 250\ channels/cell.$

The system capacity is then

C = 87 x 250 x 4 = 87,000 channels.

From (i) and (iii), it is obvious that a decrease in N from 7 to 4 is accompanied by an increase in M from 50 to 87, and the system capacity is increased from 50,050 channels to 87,000 channels.

Hence, decreasing the cluster size does increase the system capacity.

(iv) Cellular Layout for Frequency Reuse

Rule to Determine the Nearest Co-channel Neighbours

The following two-step rule can be used to determine the location of the nearest co-channel cell:

Step 1: Move i cells along any chain of hexagons;
Step 2: Turn 60 degrees counter clockwise and move j cells. Figure 4.5 shows the method of locating co-channel cells in a cellular system using the preceding rule for i = 3 and j= 2, where the co-channel cells are the shaded cells.

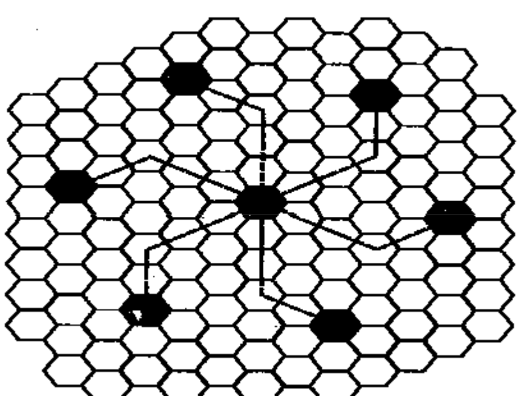


Fig. 4.5 Locating Co-Channel Cells in a Cellular System

Figure 4.6 illustrates the cluster concept and frequency reuse in a cellular network where cells with the same number use the same set of frequencies. These are co-channel cells that must be separated by a distance such that the co-channel interference is below a prescribed threshold. The parameters i and j measure the number of nearest neighbours between co-channel cells; the cluster size, N, is related to i and j by the following expression:

$$N = i^2 + ij + j^2$$

For example, if i = 1 and j = 2, then, N = 7. With a cluster size N = 7, the frequency reuse factor is seven since each cell contains one-seventh of the total number of available channels.

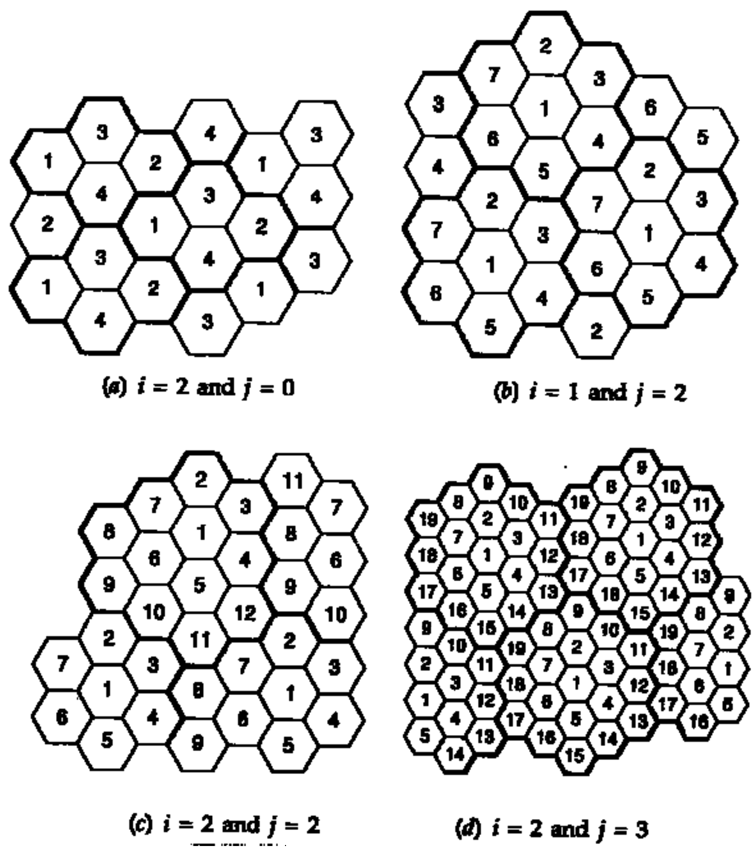


Fig. 4.6 Illustrations of Cell Clusters

3.1.7 Geometry of Hexagonal Cells

Figure 4.7 shows the geometry of an array of hexagonal cell where R is the radius of the hexagonal cell (from the center to a vertex). A hexagonal has exactly six equidistant neighbours. In the cellular array the line joining the centers of cell and each of its neighbours are separated by multiples of 60^0. It may be noted that angle 60^0 is bounded by the vertical line and the 30^0 line, which join centers of hexagonal cells. The distance between the centers of two adjacent hexagonal cells is $\sqrt{3}R$.

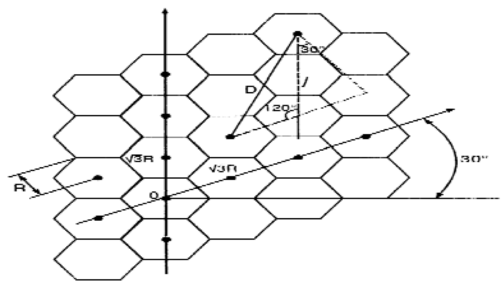


Fig. 4.7 Distance between Nearest Co-Channel Cells

The actual distance between the center of the candidate cell (the cell under consideration) and the other nearest co-channel cell is expressed as

$$D \quad D_{norm} \quad \sqrt{3}R \qquad or$$
$$D \quad \sqrt{3}R$$

For hexagonal cells, there are six nearest co-channel neighbours to each cell. Co-channel cells are located in tiers. In general, a candidate cell is surrounded by 6k cells in tier k. For cells with the same size, the co-channel cells in each tier lie on the boundary of the hexagon that chains all the co-channel cell in that tier.

4.0 CONCLUSION

Any cellular radio system mainly depends upon an intelligent assignment and reuse of channel (i.e. frequency) throughout a coverage region. Every cellular base station is assigned a group of radio channels which are used within a small geographical area called a cell.

5.0 SUMMARY

In this unit, you have learnt that:

Cell is a single small area.

Cell shape can be of only three types of regular polygons equilateral triangle, square, and regular hexagon.

Computer methods are being used for optimised planning of base station locations and cell frequencies.

A group of cells that use different set of frequencies in each cell is called a Cell Cluster.

Frequency reuse is a technique of reusing frequencies and channels within a communications system to improve capacity and spectral efficiency.

The increase in system capacity comes from the use of smaller cells, reuse of frequencies and antenna sectoring.

The actual distance between the center of the candidate cell (the cell under consideration) and the other nearest co-channel cell is expressed as:

$$D \quad D_{norm} \quad \sqrt{3}R \qquad or$$

$$D \quad \sqrt{3}R$$

SELF ASSESSMENT EXERCISE

What do you understand by hexagonal cell concept?

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand by cell
2. Mention the different types of cell
3. In the radio cell layout, in addition to the hexagonal topology, a square or an equilateral triangle topology can also be used. Given the same distance between the cell center and its farthest perimeter points, compare the cell coverage areas among the three regular polygons (hexagon, square and triangle).
4. Discuss the advantages of using the hexagonal cell shape over the square and triangle cell shape

7.0 REFERENCES/FURTHER READING

Linanartz J. M. G. (1997). *Wireless Communication*. (Online) Available at: http://wireless.per.nl/reference/about.htm

Sharma, S. (2006). *Wireless and Cellular Communications.* New Delhi: S.K. Kataria & Sons.

Walke, B. H. (2002). *Mobile Radio Networks: Networking, Protocols and Traffic Performance*. London: John Wiley and Sons.

UNIT 5 IMPROVING CAPACITY IN CELLULAR SYSTEM

CONTENTS

1.0 INTRODUCTION

In this unit, you will be exposed to the concept of cell cluster and the advantage of cellular system.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- enumerate the advantages of cellular system
- discuss the mechanism for increasing the capacity of a cellular system
- compute the size and number of cells cluster in a service area
- compute the maximum number of user in service.

3.0 MAIN CONTENT

3.1 Advantages of Cellular Systems

The advantages of operating in a cellular arrangement are listed below:

- the use of low power transmitter, and
- an allowance for frequency reuse

Frequency reuse needs to be structured so that co-channel interference is kept at an acceptable level. As the distance between co-channel cells increases co-channel interference will decrease. If the cell size is fixed, the average signal-to-co-channel interference ratio will be independent of the transmitted power of each cell. The distance between any two co-channel cells can be examined by making use of the geometry of hexagonal cells.

Exercise 5.1

Given a cellular system with a total bandwidth of 30 MHz which uses two 25 kHz simplex channels to provide full duplex voice and control channels. Assuming that the system uses a nine-cell reuse pattern and 1 MHz of the total bandwidth is allocated for control channels. (i) calculate the total available channels (ii) determine the number of control channels (iii) determine the number of voice channels per cell, and (iv) determine an equitable distribution of control and voice channels in each cell.

Solution: Given that

Total bandwidth = 30 MH

Channel bandwidth = 25 kHz x 2 = 50 kHz/duplex channel

i. The total number of available channels = $\frac{30000}{50} \quad 600$

ii. The number of control channels = $\frac{1000}{50} \quad 20$

iii. The number of voice channels per cell = $\frac{600 \quad 20}{9} \quad 64.$

iv. Since, only a maximum of 20 channels can be used as control channels, for N = 9, one way is to allocate 7 cells with 2 control channels and 64 voice channels each, and 2 cells with 3 control channels and 66 voice channels each. It may be noted that the allocation performed in part (iv) is not unique.

3.2 Interference and System Capacity

Interference is the major limiting factor in the performance of the cellular radio systems. Sources of the interference include the following cases:

Another mobile in the same cell
A call in progress in the neighbouring cell

Other base stations operating in the same frequency band
Any non-cellular system which inadvertently leaks energy into cellular frequency band.

Interference on the voice channels causes crosstalk, where the subscriber hears interference in the background due to an undesired transmission. On control channels, interference leads to missed and blocked call due to errors in the digital signaling. Interference is more severe in urban areas due to the greater radio frequency (RF) noise floor and the large number of base stations and the mobiles. Interference has been recognised as a major bottleneck in increasing capacity.

The two major types of system generated cellular interference are:

Co-channel interference
Adjacent channel interference

3.2.1 Co-Channel Interference

Frequency reuse implies that in a given coverage areas there are several cells that use the same set of frequencies. These cells are called co-channel cells and the interference between the signals from these cells is called co-channel interference. Co-channel interference or CCI is crosstalk from two different radio transmitters using the same frequency.

Co-channel radio interference is caused by the following:

Adverse weather conditions: During periods of abnormally high-pressure weather, VHF signals which would normally exit through the atmosphere can instead be reflected by the troposphere. This troposphere ducting will cause the signal to travel much further than intended; often causing interference to local transmitters in the areas affected by the increased range of the distant transmitter.

Poor frequency planning: Poor planning of frequencies by broadcasters can cause CCI, although this is rare. A very localised example is Listowel in the south-west of Ireland. The RTÉNL UHF television transmitter systems in Listowel and Knockmoyle (near Tralee) are on the same frequencies but with opposite polarization. However in some outskirts of Listowel town, both transmitters can be picked up causing heavy CCI. This problem forces residents in these areas to use alternative transmitters to receive RTÉ programming.

Overly-crowded radio spectrum: In many populated areas, there is no much room in the radio spectrum. Stations are jampacked, sometimes to the point that one can hear loud and clear two, three, or more stations on the same frequency, at once.

Co-channel interference cannot be combated by simply increasing the carrier power of transmitter. This is because an increase in carrier transmitter power increases the interference to neighbouring co-channel cells. To reduce co-channel interference co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation.

When the size of the cell is approximately the same and the base station transmit the same power the co-channel interference ratio is independent of the transmitted power and becomes a function of radius of cell and the distance between the centers of the nearest co-channel cells. By increasing the ratio of D/R the spatial separation between co-channel cells relative to the coverage distance of the cell is increased. Thus the interference is reduced from the improved isolation of the RF energy from the co-channel cell. The parameter Q called the co-channel reuse ratio is related to the cluster size. For a hexagonal geometry

$$Q = \frac{D}{R} = \sqrt{3N}$$

A small value of Q provides larger capacity since the cluster size N is small, whereas a larger value of Q improves the transmission quality due to the smaller capacity.

Exercise 5.2

The acceptable signal-to-co-channel interference ratio in a certain cellular communications situation is $\frac{S}{I} = 20\,\text{dB}$ or 100. Also, from measurements, it is determined that k = 4. What will be the minimum cluster size?

Solution:

The frequency reuse ratio can be calculated as $q = (6 \times 100)^{1/4} = 4.9494$

The cluster size is given by $N = \frac{q^2}{3} = 8.165 \approx 9$

In this case, a 9-reuse pattern is required for an S/I ratio of at least 20

dB. Since $q = \frac{D}{R}$ or $D = qR$

D can be determined, given the cell radius R, and vice versa. It may be noted that if N is less than 9, the S/I value would be below the acceptable level of 20 dB.

3.2.2 Adjacent Channel Interference (ACI)

Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference. Adjacent channel interference results from the imperfect receiver filters which allow nearby frequency to leak into the passband.

Let us consider the uplink transmission from two mobile users using adjacent channels, one very close to the base station and the other very close to the cell boundary. Without proper transmission power control, the received power from the mobile close to the base station is much larger than that from the other mobile far away. This near-far effect can significantly increase the ACI from the strong received signal to the weak received signal. Adjacent channel interference can be minimised by:

using modulation schemes which have low out-of-band radiation (e.g., MSK is better than QPSK and GMSK is better than MSK)
carefully designing the bandpass filter at the receiver front end
using proper channel interleaving by assigning adjacent channels to different cells
avoiding using adjacent channels in adjacent cells to further reduce ACI if cell cluster size is large enough and
separate the uplink and downlink properly by Time Division Duplex (TDD) or Frequency Division Duplex (FDD)

3.3 Channel Assignment Strategies

In Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) based cellular radio systems and wireless networks, channel allocation schemes are required to allocate channels to base stations and access points and to avoid co-channel interference among nearby cells. Different approaches have been tried to assign bandwidth to users in an efficient manner while minimising interference to other users.

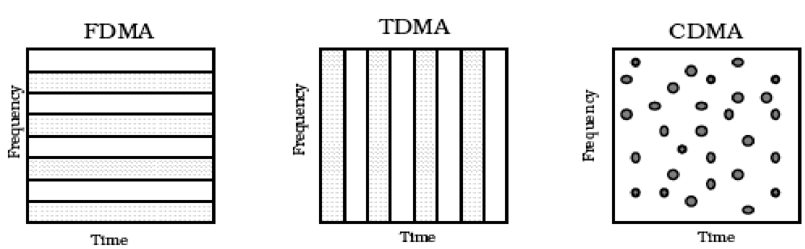
The two approaches to channel assignment are: (i) fixed channel assignment, and (ii) dynamic channel assignment.

3.3.1 Fixed Channel Assignment (FCA)

In a fixed channel assignment, each cell is allocated a predetermined set of a voice channel. Any call attempt within the cell only is served by the unused channels in that particular cell. To improve utilisation, a borrowing strategy may be considered. With the borrowing option, a cell is allowed to borrow channels from a neighbouring cell if all of its own channels are already occupied (the call is blocked and the subscriber does not receive) and the neighbouring cell has spare channels. Borrowing is supervised by the Mobile Switching Centre (MSC) because it has full knowledge of the capacity usage of the cluster of cells within its jurisdiction. Hence, the MSC is the natural subsystem to oversee function such as channel borrowing.

Three basic methods can be used to combine customers on to fixed channel radio links:

FDMA - (frequency division multiple access) analog or digital. In analog transmission, signals are commonly multiplexed using frequency-division multiplexing (FDM), in which the carrier bandwidth is divided into sub-channels of different frequency widths, each carrying a signal at the same time in parallel.
TDMA - (time division multiple access) three conversation paths are time division multiplexed in 6.7 m/sec time slots on a single carrier.
CDMA - (code division multiple access) this uses spread spectrum techniques to increase the subscriber density. The transmitter hops through a pseudo-random sequence of frequencies. The receiver is given the sequence list and is able to follow the transmitter. As more customers are added to the system, the signal of noise will gradually degrade. This is in contrast to AMPS where customers are denied access once all of the frequencies are assigned code division multiple access (digital only).



Drawback of TDMA and FDMA Systems with FCA

Fixed Channel Allocation or Fixed Channel Assignment (FCA) requires manual frequency planning, which is an arduous task in TDMA and FDMA based systems, since such systems are highly sensitive to co-channel interference from nearby cells that are reusing the same channel.

Another drawback with TDMA and FDMA systems with FCA is that the number of channels in the cell remains constant irrespective of the number of customers in that cell. This result in traffic congestion and some calls being lost when traffic gets heavy in some cells, and idle capacity in other cells.

3.3.2 Dynamic Channel Assignment (DCA)

The more efficient way of channel allocation would be Dynamic Channel Allocation or Dynamic Channel Assignment (DCA). In DCA, voice channels are not allocated to different cells on a permanent basis.

Each time a call request is made, the serving base station requests a channel from MSC. The MSC determine (dynamically) the availability of a channel and executes its allocation procedure accordingly. The MSC only allocates a given frequency (radio channel) if that frequency (radio channel) is not presently in use in the cell, or any other cell which falls within the minimum restricted distance of frequency reuse to avoid co-channel interference.

Dynamic channel assignment reduces the likelihood of call blocking, which increases the trucking capacity of the system, since all available channels under the control of the MSC are accessible to all of the cells.

Dynamic channel assignment strategies require the MSC to collect real-time data on channel occupancy, traffic distribution and radio signal quality of all channels on a continuous basis.

Merit

Dynamic Channel Assignment (DCA) and Dynamic Frequency Selection (DFS) eliminate the tedious manual frequency planning work.

DCA also handles busty cell traffic and utilises the cellular radio resources more efficiently.

DCA allows the number of channels in a cell to vary with the traffic load, hence increasing channel capacity with little costs.

3.4 Mechanisms for Capacity Increase in Cellular System

The capacity of a cellular system can be enlarged through frequency and it can also be improved based on cellular layout and antenna design. Basically, the following are the three popular mechanisms for increasing the capacity of a cellular system:

Cell Splitting

One way to perform cell splitting is to subdivide a congested cell into smaller cells, each with its own base station and corresponding reduction in antenna height and transmission power. With more cells, there will be more clusters in the same coverage area. Hence cell splitting increases the capacity of a cellular system since it increases the number of times that channels are reused. In figure 5.1, the central area is assumed to be saturated with traffic. The original large cell with radius R in the center is split into the medium cells with radius R/2 and the medium cell in the center is further split into the small cells with radius R/4. The cell splitting reduces the call blocking probability in the area, and increases the frequency with which mobiles hand off from cell to cell.

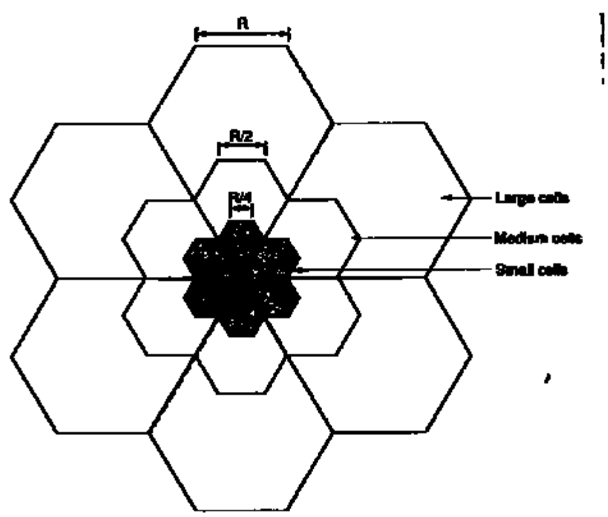


Fig. 5.1 Illustration of Cell Splitting from Radius R to R/2 and to R/4

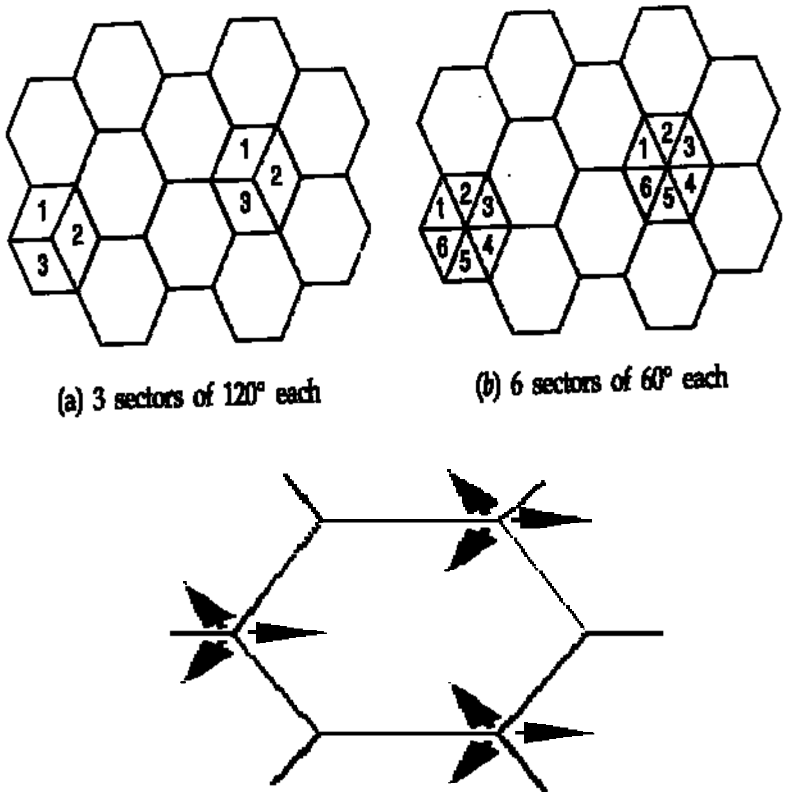
Directional Antennas (Sectoring)

One way to increase the subscriber capacity of a cellular network is replace the omni-directional antenna at each base station by three (or six) sector antennas of 120 (or 60) degrees opening. Each sector can be considered as a new cell, with its own (set of) frequency channel(s).

The base station can either be located at:

the centre of the original (large) cell, or
the corners of the original (large) cell.

The use of directional sector antennas substantially reduces the interference among co-channel cells. This allows denser frequency reuse. Sectoring is less expensive than cell-splitting, as it does not require the acquisition of new base station sites.



(c)

Fig. 5.2 (a,b,c): Antenna Sectorization

Microcell Zone

The microcell concept is based on the seven cell reuse, in which three or more zone sites are connected to a single base station and share the same radio equipment. As mobile travels within the cell, it is served by the zone with the strongest signal. As a mobile travels from one zone to another within the cell, it retains the same channel. The base station simply switches the channel to different zone site. In this way, a given channel is active only in the particular zone in which the mobile is traveling and hence the base station radiation is localised and interference is reduced.

4.0 CONCLUSION

If different cells in the entire cellular system were to use different set of frequencies, inter cell interference would be kept at minimum. However, the system capacity would be limited. In fact deployment of frequency reuse is necessary to enlarge the system capacity.

5.0 SUMMARY

In this unit, you have learnt that:

- Interference is the major limiting factor in the performance of the cellular radio systems.
- The two major types of system generated cellular interference are: Co-channel interference and adjacent channel interference.
- Co-channel interference or CCI is crosstalk from two different radio transmitters using the same frequency.
- Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference.
- Channel allocation schemes are required to allocate channels to base stations and access points and to avoid co-channel interference among nearby cells.
- The two approaches to channel assignment are: fixed channel assignment, and dynamic channel assignment.
- In a fixed channel assignment, each cell is allocated a predetermined set of a voice channel.
- In DCA, voice channels are not allocated to different cells on a permanent basis
- The three popular mechanisms for increasing the capacity of a cellular system are: cell splitting, directional antennas and microcell zone.

SELF ASSESSMENT EXERCISE

1. How can you increase the capacity of cellular system with the help of frequency reuse concept?
2. What are the advantages of cellular systems?

6.0 TUTOR-MARKED ASSIGNMENT

A cellular system has a total of 500 duplex voice channels (without frequency reuse). The service area is divided into 150 cells. The required signal-t-co-channel interference ratio is 1dB. Consider the path loss exponent k equal to 3, 4 and 5 respectively. Determine:

i. the cell cluster size
ii. the number of cell clusters in the service area and
iii. the maximum number of users in service at any instant. Discuss effects of the path loss exponent on the frequency reuse and on the transmit power (when the cell size is fixed).

7.0 REFERENCES/FURTHER READING

Linanartz J. M. G. (1997). Wireless Communication. (Online) Available at: http://wireless.per.nl/reference/about.htm

Sharma, S. (2006). *Wireless & Cellular Communications*. New Delhi: S. K. Kataria & Sons.

MODULE 2 MOBILE RADIO PROPAGATION

UNIT 1 WIRELESS CHANNEL MODEL

CONTENTS

1.0 INTRODUCTION

Mobile communication is burdened with particular propagation complications, making reliable wireless communication more difficult than fixed communication between carefully positioned antennas. The antenna height at a mobile terminal is usually very small, typically less than a few meters. Hence, the antenna is expected to have very little 'clearance', so obstacles and reflecting surfaces in the vicinity of the antenna have a substantial influence on the characteristics of the propagation path. Moreover, the propagation characteristics change from place to place and, if the terminal moves, from time to time.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- explain the term channel model
- mention the two types of communication channels
- discuss the statistical propagation models

define a path loss and state its causes
describe two propagation prediction for a path loss.

3.0 MAIN CONTENT

3.1 Chanel Model

Channel is the medium between the transmitting antenna and the receiving antenna as shown in Figure 1.1

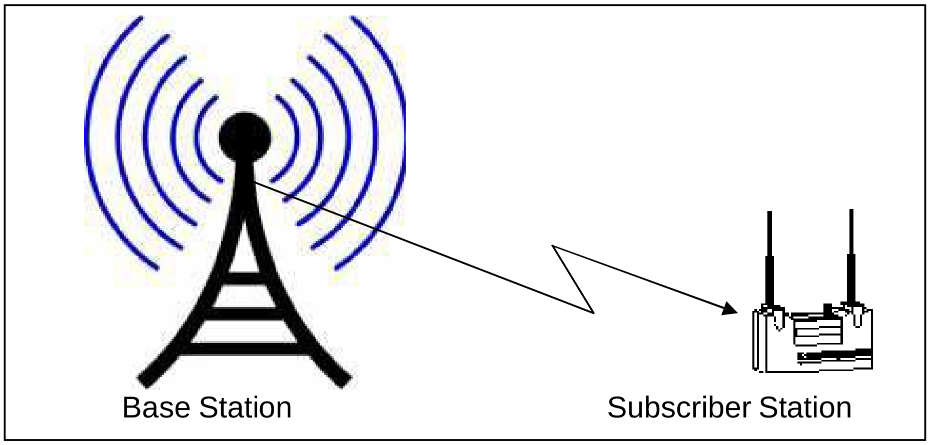


Fig. 1.1 Channel

Basically, the following are two types of communication channels:

wired channels and
radio or wireless channel

The wired channels are stationary and predictable whereas the radio channels are extremely random and do not offer easy analysis.

The characteristics of wireless signal changes as it travels from the transmitter antenna to the receiver antenna. These characteristics depend upon the distance between the two antennas, the path(s) taken by the signal, and the environment (buildings and other objects) around the path. The profile of received signal can be obtained from that of the transmitted signal if we have a model of the medium between the two. This model of the medium is called *channel model.*

A channel can be modelled physically by trying to calculate the physical processes which modify the transmitted signal. For example, in wireless communications, the channel can be modelled by calculating the reflection of every object in the environment. A sequence of random numbers might also be added in to simulate external interference and/or electronic noise in the receiver.

Statistically a communication channel is usually modeled as a triple consisting of an input alphabet, an output alphabet, and for each pair (i, o) of input and output elements a transition probability p (i, o). Semantically, the transition probability is the probability that the symbol *o* is received given that *i* was transmitted over the channel.

Statistical and physical modeling can be combined. For example in wireless communications the channel is often modeled by a random attenuation (known as fading) of the transmitted signal, followed by additive noise. The attenuation term is a simplification of the underlying physical processes and captures the change in signal power over the course of the transmission. The noise in the model captures external interference and/or electronic noise in the receiver. If the attenuation term is complex it also describes the relative time a signal takes to get through the channel. The statistics of the random attenuation are decided by previous measurements or physical simulations.

Channel models may be continuous channel models in that there is no limit to how precisely their values may be defined.

A channel model may include:

Noise model, for example, Additive White Gaussian Noise (AWGN).
Distortion model, for example non-linear channel causing intermodulation distortion (IMD).
Interference model, for example cross-talk (co-channel interference) and intersymbol interference (ISI) .
Modeling of underlying physical layer transmission techniques, for example an equivalent baseband model of modulation and frequency response.
Radio frequency propagation model.
Fading model, for example Rayleigh fading, Ricean fading, log-normal shadow fading and frequency selective (dispersive) fading.
Doppler shift model, which combined with fading results in a time-invariant system
Mobility models, which also causes a time-invariant system.

3.1.1 Statistical Propagation Models

In generic system studies, the mobile radio channel is usually evaluated from 'statistical' propagation models: no specific terrain data is considered, and channel parameters are modelled as stochastic variables.

Three mutually independent, multiplicative propagation phenomena can usually be distinguished: 'large-scale' path loss, shadowing and multipath fading.

Path-loss

The 'large-scale' effect causes the received power to vary gradually due to signal attenuation determined by the geometry of the path profile in its entirety. This is in contrast to the local propagation mechanisms, which are determined by terrain features in the immediate vicinity of the antennas.

Shadowing

This is a 'medium-scale' effect: field strength variations occur if the antenna is displaced over distances larger than a few tens or hundreds of metres.

Multipath-Propagation

Fading leads to rapid fluctuations of the phase and amplitude of the signal if the vehicle moves over a distance in the order of a wave length or more. Multipath fading thus has a 'small-scale' effect.

3.1.2 Basic Concept of Path Loss

Path Loss (or path attenuation) is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space. Path loss may be due to many effects, such as free space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption.

Path loss is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of antennas.

Path loss model describes the signal attenuation between transmitting and receiving antennas as a function of the propagation distance and other parameters. The simplest channel is the free space line of sight channel with no objects between the receiver and the transmitter or around the path between them. In this simple case, the transmitted signal attenuates since the energy is spread spherically around the transmitting antenna.

3.1.2.1 Causes

Path loss normally includes propagation losses caused by the natural expansion of the radio wave front in free space (which usually takes the shape of an ever-increasing sphere), absorption losses (sometimes called penetration losses), when the signal passes through media not transparent to electromagnetic waves, diffraction losses when part of the radio wave front is obstructed by an opaque obstacle, and losses caused by other phenomena.

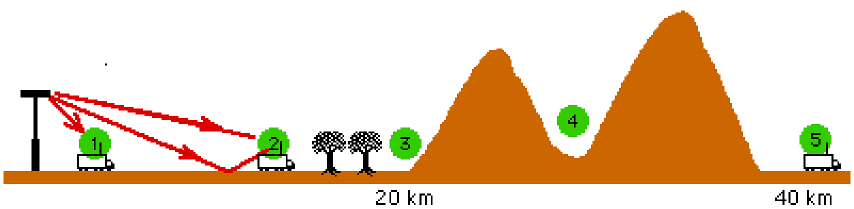
3.1.2.2 Propagation Prediction

Calculation of the path loss is usually called prediction. Exact prediction is possible only for simpler cases, such as the above-mentioned free space propagation or the flat-earth model. For practical cases the path loss is calculated using a variety of approximations.

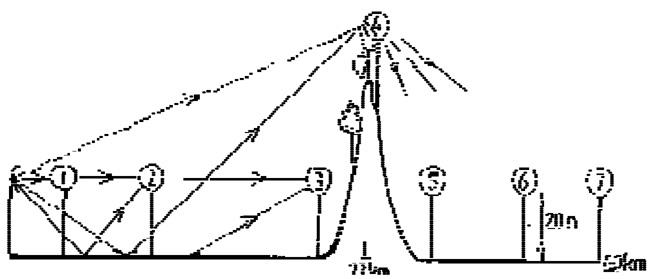
Statistical methods (also called stochastic or empirical) are based on measured and averaged losses along typical classes of radio links. Among the most commonly used methods are Okumura-Hata, the cost Hata model, W.C.Y. Lee, etc. These are also known as radio wave propagation models and are typically used in the design of cellular network. For wireless communication in the VHF and UHF frequency band (the bands used Walkie-talkies, police, taxis and cellular phones), one of the most commonly used methods is that of Okumura-Hata as refined by the COST 231 project. Other well-known models are those of Walfisch-Ikegami, W.C.Y. Lee, and Erceg . For FM radio and TV broadcasting, the ITU model is commonly used in predicting the path loss.

Deterministic methods based on the physical laws of wave propagation are also used; ray tracing is one of such methods. These methods are expected to produce more accurate and reliable predictions of the path loss than the empirical methods; however, they are significantly more expensive in computational effort and depend on the detailed and accurate description of all objects in the propagation space, such as buildings, roofs, windows, doors, and walls. For these reasons they are used predominantly for short propagation paths. Among the most commonly used methods in the design of radio equipment such as antennas and feeds is the finite-difference time-domain method.

The path loss in other frequency bands such as MW, SW, and Microwave are predicted with similar methods, though the concrete algorithms and formulas may be very different from those for VHF/UHF. Reliable prediction of the path loss in the SW/HF band is particularly difficult, and its accuracy is comparable to weather predictions.



(a)



(b)

Fig. 1.2 (a) & (b): Illustration of Path Loss

In the above path profile in Figure 1.2 (a and b), the most appropriate path loss model depends on the location of the receiving antenna:

At location 1, free space loss is likely to give an accurate estimate of path loss

At location 2 and 3, a strong line-of-sight is present, but ground reflections can significantly influence path loss. The plane earth loss model appears appropriate

At location 4, free space loss needs to be corrected for significant diffraction losses, caused by trees cutting into the direct line of sight

Path loss prediction at location 5, 6 and 7 is more difficult than at the other locations. Ground reflection and diffraction mechanisms interact.

3.1.2.3 Received Signal Power and Attenuation

Path loss is one of the mechanisms causing attenuation between the transmitter power amplifier and receiver front end. Some other effects are listed below, with an indication of the order of magnitude in a GSM-like system.

- Losses in the antenna feeder (0 .. 4 dB)
- Losses in transmit filters, particularly if the antenna radiates signal of multiple transmitters (0 .. 3 dB)
- Antenna directionality gain (0 .. 12 dB)
- Losses in duplex filter
- Fade margins to anticipate for multipath (9 .. 19 dB) and shadow losses (5 dB)
- Penetration losses if the receiver is indoors, typically about 10 dB for 900 MHz signals.

4.0 CONCLUSION

Channel model is the medium between the transmitting antenna and the receiving antenna. The three mutually independent, multiplicative propagation phenomena are ‘large-scale’ path loss, shadowing and multipath fading.

5.0 SUMMARY

In this unit, you have learnt that:

- Channel models may be continuous channel models in that there is no limit to how precisely their values may be defined
- The three mutually independent, multiplicative propagation phenomena are: 'large-scale' path loss, shadowing and multipath fading
- Path Loss (or path attenuation) is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through space
- Path loss includes propagation losses caused by the natural expansion of the radio wave front in free space, absorption losses, diffraction losses, etc
- Path loss is calculated using a variety of approximations such as statistical and deterministic methods.

SELF ASSESSMENT EXERCISE

1. What is meant by path loss?
2. What are the causes of a path loss?

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand by channel model?
2. Mention two types of communication channels
3. Describe two propagation predictions for a path loss
4. Discuss on the statistical method of propagation prediction

7.0 REFERENCES/FURTHER READING

Linnartzs, J.M.G. (1996). *Wireless Communication*. Baitzer Science Publishers.

Molisch, A. F. (2005). *Wireless Communications*. Wiley & Associates.

Rappaport, T. S. (2005). *Wireless Communication: Principles and Practice*. (2nd ed.). India: Prentice Hall.

UNIT 2 LARGE SCALE PROPAGATION MODEL

CONTENTS

1.0 INTRODUCTION

Mobile radio channel puts various limitations on the performance of wireless or mobile communication systems. The two fundamental blocks of any communication system are transmitter and the receiver. In wireless communications, the transmission path between the transmitter and receiver can vary from simple line-of-sight to one that is severely obstructed by buildings, mountains and foliage.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define an effective isotropic radiated power
- describe free space propagation model
- compute the power and the magnitude of the E-field at the receiver antenna.

3.0 MAIN CONTENT

3.1 Free Space Propagation Model for Mobile Communication

The free space propagation model is a model which is used to predict received signal strength at a particular location when the transmitter and receiver have a clear, unobstructed line-of-sight path between them. For example, satellite communication systems and microwave line-of-sight radio links, typically, undergo free space propagation. Like other large-scale radio-wave propagation models, the free space-radio propagation model predicts that the received power decays as a function of the transmitter-receiver separation distance raised to some power (i.e. a power law function). It states that power falls off proportional to distance (d).

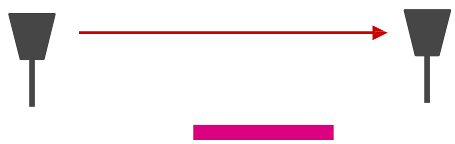


Fig. 2.1 Line-of-sight

In a radio communication system, the propagation of the modulated signal is accomplished by means of a transmitting antenna, the function of which is twofold:

To convert the electrical modulated signal into an electromagnetic field. In this capacity, the transmitting antenna acts as an "impedance-transforming" transducer, matching the impedance of the antenna to that of the free space.
To radiate the electromagnetic energy in desired directions.

At the receiver, we have a receiving antenna whose function is the opposite of that of the transmitting antenna. It converts the electromagnetic field into an electrical signal from which the modulated signal is extracted. In addition, the receiving antenna may be required to suppress radiation originating from directions where it is not wanted.

Typically, the receiver is located in the far-field of the transmitting antenna, in which case, for all practical purposes, we may view the transmitting antenna as a fictitious volumeless emitter or point source.

Let us consider an isotropic source radiating a total power denoted by P_t, measured in watts. The radiating power passes uniformly through a sphere of surface area $4\ d^2$, where d is the distance (in meters) from the source. Therefore, the power density, denoted by P(d), at any point on the surface of the sphere is given by

$$P\ d \quad \frac{P_t}{4\ d^2} watts/m^2$$

Free space (Line-of-sight) LOS without obstacles, satellite communications, microwave line-of-sight radio link.
Friis Free Space Equation: The far-field or Fraunhoher region, of a transmitting antenna may be defined as the region beyond the far field distance d_f, which is related to the largest linear

dimension of the transmitter antenna aperture and the carrier wavelength. The Fraunhofer distance can be expressed as

$d_f \quad \frac{2D^2}{\quad}$, D: the largest physical linear dimension of the antenna

Additionally, to be in the far field region, d_f must satisfy d_f >> D and d_f >>λ

The received signal power is expressed as:

$$P_r \; d \quad \frac{P_t G_t G_r \quad ^2}{4 \quad ^2 d^2 L}$$

where P_t = total power radiated by an isotropic source
G_t = transmitting antenna gain
G_r = receiving antenna gain
d = distance between transmitting and receiving antenna
λ = wavelength of the carrier signal = c/f
c = 3 x 10^8 m/s, velocity of light
f = carrier frequency
$P_t G_t$ = EIRP
L: system loss factor not related to propagation (L ≥ 1)

Due to transmission line attenuation, filter loss, antenna losses

$G \quad \frac{4 \; A_e}{2}$, A_e : antenna's effective aperture physical size of the antenna,

$\frac{c}{f} \quad \frac{2 \quad c}{w_c}$, f : carrier frequency[rad/s], c: speed of light [3 x 10^8 m/s]

Received power in Free Space

$$P_r \; d \quad P_r \; d_0 \left(\frac{d_0}{d}\right)^2 \quad , \quad d \quad d_0 \quad d_f$$

$$P_r(d)[dBm] \quad 10\log\left[\frac{P_r(d_0)}{0.001W}\right] \quad 20\log\left(\frac{d_0}{d}\right), d \quad d_0 \quad d_f$$

where $P_r(d_0)$ *is* in units of watts

Maximum radiated power:

The effective isotropic radiated power (EIRP) is defined as the product of the transmitted power, P_t, and the power gain of the transmitting antenna, G_t i.e.

The effective isotropic radiated power (EIRP) $= P_tG_t$ watts

In fact, EIRP represents the maximum radiated power available from a transmitter in the direction of maximum antenna gain, as compared to an isotropic radiator.

In dB, EIRP is equal to sum of the antenna gain, G_t (in dBi) plus the power, P_t (in dBm) into that antenna.

For example, a 12 dBi gain antenna fed directly with 15 dBm of power has an Effective Isotropic Radiated Power (EIRP) of:

12 dBi+ 15dBm = 27 dBm(500 mW).

ERP: Effective radiated power as compared to a half-wave dipole antenna

ERP = EIRP – 2.15dB

Effective Aperture (A_e) of an antenna is defined as the ratio of the power available at the antenna terminal to the power per unit area of the appropriately polarized incident electromagnetic wave.

$$A_e = \frac{\lambda^2}{4\pi} G$$

Path loss

Path loss (PL) for the free space model when antenna gains are included can be expressed as

$$PL\,dB = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{G_tG_r\lambda^2}{(4\pi)^2 d^2}\right] = -10\log_{10} G_tG_r + 10\log_{10}\left(\frac{4\pi d}{\lambda}\right)^2$$

when antenna gains are excluded,

$$PL\,dB = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right]$$

Note: Measuring in Decibels: dB, dBm, dBi

dB (Decibel) = 10 log 10 (Pr/Pt)

Log-ratio of two signal levels. Named after Alexander Graham Bell. For example, a cable has 6 dB loss or an amplifier has 15 dB of gain. System gains and losses can be added/subtracted, especially when changes are in several orders of magnitude.

dBm (dB milliWatt)

Relative to 1mW, i.e. 0 dBm is 1 mW (milliWatt). Small signals are negative (e.g.-83dBm). Typical 802.11b WLAN cards have +15 dBm (32mW) of output power. They also specified -83 dBm RX sensitivity (minimum RX signal level required for 11Mbps reception).

For example, 125mW is 21dBm and 250mW is 24dBm. (Commonly used numbers)

dBi (dB isotropic) for EIRP (Effective Isotropic Radiated Power)

The gain a given antenna has over a theoretical isotropic (point source) antenna. The gain of microwave antennas (above1 GHz) is generally given in dBi.

dBd (dB dipole)

The gain an antenna has over a dipole antenna at the same frequency. A dipole antenna is the smallest, least gain practical antenna that can be made. A dipole antenna has 2.14 dB gain over a 0 dBi isotropic antenna.

Thus, a simple dipole antenna has a gain of 2.14 dBi or 0 dBd and is used as a standard for calibration.

The term dBd (or sometimes just called dB) generally is used to describe antenna gain for antennas that operate less than 1GHz (1000Mhz).

3.1.1 Relating Power to Electric Field

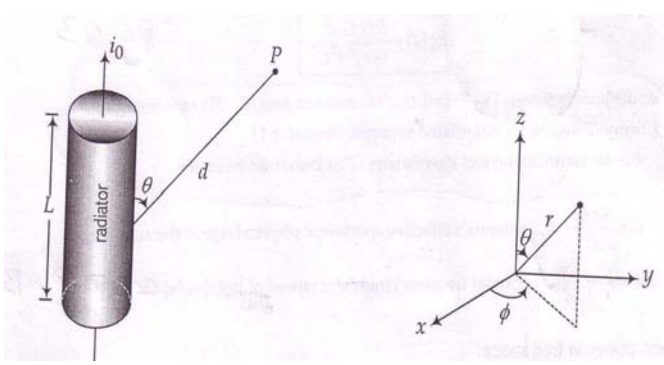


Fig. 2.2 Relating Power to Electric Field

$$E_r = \frac{I_0 L \cos\theta}{2\pi\varepsilon_0 c}\left(\frac{1}{d^2} + \frac{c}{j\omega_c d}\right)e^{j(\omega_c t - kd)}, \quad E_\theta = \frac{I_0 L \sin\theta}{4\pi\varepsilon_0 c^2}\left(\frac{j\omega_c}{d} + \frac{c}{d^2} + \frac{c^2}{j\omega_c d^3}\right)e^{j(\omega_c t - kd)}$$

$$H_\phi = \frac{I_0 L \sin\theta}{4\pi c}\left(\frac{j\omega_c}{d} + \frac{c}{d^2}\right)e^{j(\omega_c t - kd)}, \quad E_\phi = H_r = H_\theta = 0$$

$$As\ d \to \infty,\ only\ E_\theta,\ H_\phi\ be\ considered.$$

Power flux density

$$P_d\ W/m^2 = \frac{EIRP}{4\pi d^2} = \frac{P_t G_t}{4\pi d^2} = \frac{E^2}{R_{fs}} = \frac{|E^2|}{\eta_0} = \frac{E^2}{377},$$

R_{fs}: intrinsic impendence of free space, $\eta = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 376.7 \approx 120\pi$

E : electric field at the receiver

$$P_d(d)\ W = P_d A_e = \frac{|E|^2}{120\pi}A_e = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2}$$

Circuit Model for antenna system

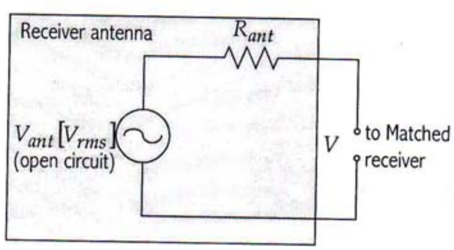


Fig.2.3 Circuit Model for Antenna System

$$P_r(d)\ W = \frac{V^2}{R_{ant}} = \frac{(V_{ant}/2)^2}{R_{ant}} = \frac{V_{ant}^2}{4R_{ant}}$$

Exercise 2.1

Compute the far field distance for an antenna with maximum dimension of 1m and operating frequency of 900MHz

Solution: Given: largest dimension of antenna, D =1m

Operating frequency f = 900MHz,

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8\ m/s}{900 \times 10^6\ Hz}m = 0.33$$

we know that the far-field distance is expressed as

$$d_f \quad \frac{2D^2}{}$$

$$d_f \quad \frac{2\,1^{\;2}}{0.33} \quad 6m$$

Exercise 2.2

If a transmitter produces 50W of power, express the transmit power in units of (a) dBm, and (b) dBW. If 50 W is applied to a unity gain antenna with a 900MHz carrier frequency, determine the received power in dBm at a free space distance of 100m from the antenna. What is P_r (10km)? Assume unity gain for the receiver antenna.

Solution: Given that

Transmitter power, $P_t \quad 50W$

Carrier frequency, f_c = 900MHz

$$\frac{c}{f} \quad \frac{3 \quad 10^8\, m/s}{900 \quad 10^6\, Hz} m \quad \frac{1}{3} \quad 0.33$$

a. We know that the transmitter power is given by

$$\mathrm{P_t\ (dBm)} \quad 10\log\left[\frac{\mathrm{P_t\,(mW)}}{\mathrm{1mW}}\right] \quad 10\log 50 \quad 10^3 \quad 47.0dBm$$

b. Transmitter power in dBW will be given by

$$P_t\,(dBW) \quad \left[\frac{P_t\,(W)}{1W}\right] \quad 10\ \log 50 \quad 17.0dBW$$

We know that the received power can be determined using the following expression:

$$P_r \ d \quad \frac{P_t G_t G_r \quad ^2}{4 \quad ^2 d^2 L} \quad \frac{50(1)(1)(1/3)^2}{(4 \quad)^2\,(100)^2\,(1)} \quad (3.5 \quad 10^{\ 6})W \quad 3.5 \quad 10^{\ 3}\ mW$$

Now, the received power in (dBm) will be given by

P_r (dBm) = 10 log P_r (mW)

= 10 log (3.5 x 10^{-3} mW) = -24.5 dBm

Further, the received power at 10km may be expressed in terms of dBm, where d_0 = 100m and d = 10km, as under:

$$P_r\,(10km) \quad P_r\,(100) \quad 20\log\left[\frac{100}{10000}\right] \quad 24.5\,dBm \quad 40\,dB \quad 64.5\,dBm$$

Exercise 2.3

Assume a receiver is located 10km from a 50W transmitter. The carrier frequency is 900MHz, free space propagation is assumed, $G_t = 1$, and $G_r = 2$, determine (a) the power at the receiver, (b) the magnitude of the E-field at the receiver antenna, (c) the rms voltage applied to the receiver input assuming that the receiver antenna has a purely real impedance of 50Ω and is matched to the receiver.

Solution: Given that

Transmitter power, $P_t = 50W$
Carrier frequency, $f_c = 900MHz$
Transmitter antenna gain, $G_t = 1$
Receiver antenna gain, $G_r = 2$
Receiver antenna resistance = 50 Ω

a. We know that the power received at distance d = 10km is given by

$$P_r(d) = 10\log\left(\frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2}\right) = 10\log\left(\frac{50\times 1\times 2\times(1/3)^2}{(4\pi)^2 (10000)^2}\right) = -91.5dBW = -61.5dBm$$

b. Again, we know that the magnitude of the received E-field is expressed as

$$|E| = \sqrt{\frac{P_r(d)\,120\pi}{A_e}}$$

$$Since\ G = \frac{4\pi A_e}{\lambda^2}\quad and\ P_r(d) = \frac{|E|^2}{120\pi}A_e$$

$$|E| = \sqrt{\frac{7\times 10^{-10}\times 120\pi}{\lambda^2 G_r/4\pi}} = \sqrt{\frac{7\times 10^{-10}\times 120\pi}{2\times 0.33^2/4\pi}} = 0.0039\,V/m$$

c Also the applied rms voltage at the receiver input (50Ω) is given by

$$V_{ant} = \sqrt{P_r(d)\times 4R_{ant}} = \sqrt{7\times 10^{-10}\times 4\times 50} = 0.374mV$$

4.0 CONCLUSION

In this unit, we have discussed the free space propagation model and the relating power to electric field.

7.0 SUMMARY

In this unit, you have learnt that:

The free space propagation model is a model which is used to predict received signal strength at a particular location when the transmitter and receiver have a clear, unobstructed line-of-sight path between them. For example, satellite communication systems and microwave line-of-sight radio links, typically, undergo free space propagation.

The free space power received by a receiver antenna situated at a particular location which is separated from a radiating transmitter antenna, by a distance d, is given by the following free space expression

$$P_r \; d \quad \frac{P_t G_t G_r \quad {}^2}{4 \quad {}^2 d^2 L}$$

SELF ASSESSMENT EXERCISE

1. What are the two basic types of communication channels?
2. Define Effective Isotropic Radiated Power (EIRP)

8.0 TUTOR-MARKED ASSIGNMENT

1. Assume a receiver is located 15m from a 55W transmitter. The carrier frequency is 900MHz, free space propagation is assumed G_t = 1, and G_r =2, find (a) the power at the receiver and (b) the magnitude of the E-field at the receiver antenna.
2. Describe free space propagation model for mobile radio wave propagation.

7.0 REFERENCES/FURTHER READING

Linnartz J. M. G. (1996). *Wireless Communication*. Baitzer Science Publishers.

Molisch, A. F. (2005). *Wireless Communications*. Wiley and Associates.

Rappaport, T. S. (2005). *Wireless Communication: Principle and Practice.* (2nd ed.), India: Prentice Hall.

Sharma, S. (2007). *Wireless and Cellular Communication*. New Delhi: S. K. Kataria & sons.

UNIT 3 RADIO PROPAGATION MECHANISMS

CONTENTS

1.0 INTRODUCTION

Singular information is transmitted with the help of electromagnetic wave. Electromagnetic wave consists of electric and magnetic fields.

As a matter of fact, the mechanisms responsible for electromagnetic wave propagation are:

reflection,
diffraction and
scattering

In case of mobile communications, operating conditions are quite severe. The reason is that most cellular radio systems operate in urban areas. In urban areas there is no direct line-of-sight path available between the transmitter and the receiver, and also, the presence of high-rise buildings creates severe diffraction loss.

Further, because of multiple reflections from various objects, the electromagnetic waves travel along different paths having variable lengths. Now, these waves interact with each other and this interaction creates the so-called multipath fading at a particular point location. As a result of this, the strengths of the waves reduce with the increase in distance between the transmitter and receiver.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- explain the three propagation mechanisms
- describe Ground Reflection Model.

3.0 MAIN CONTENT

3.1 The Three Basic Propagation Mechanisms

In order to describe radio propagation, three basic mechanisms are generally considered. These mechanisms are:

- **Reflection:** Occurs when a propagating electromagnetic wave impinges upon an object which is very large in dimensions when compared to the wavelength of the propagation wave e.g. the surface of the earth, buildings, walls, etc. These mechanisms often dominate radio propagation in indoor applications. In outdoor urban areas, this mechanism often loses its importance because it involves multiple transmissions that reduce the strength of the signal to negligible values.
- **Diffraction:** Occurs when the radio path between the Transmitter (Tx) and Receiver (Rx) are obstructed by a surface that has irregularities (edges). The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle, giving rise to a bending of waves around the obstacle, even when a line-of-sight path does not exist between transmitter and receiver. At high frequencies, diffraction, like reflection, depends on the geometry of the object, as well as the amplitude, phase, and polarization of the incident wave at the point of diffraction.
- **Scattering:** Occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength, and where the number of obstacles per unit volume is large. Scattered waves are produced by rough surfaces, small objects, or by other irregularities in the channel. In practice, foliage, street signs, and lamp posts induce scattering in a mobile communications system.

3.1.1 Reflection

Reflection = f(Fresnel reflection coefficient) = f(material property, wave polarisation, angle of incident, frequency)

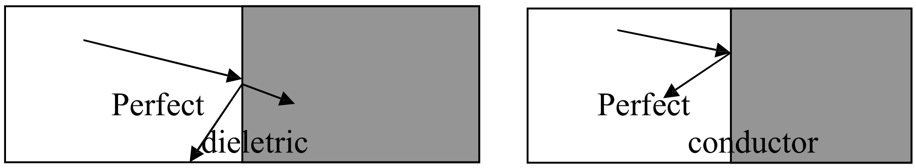
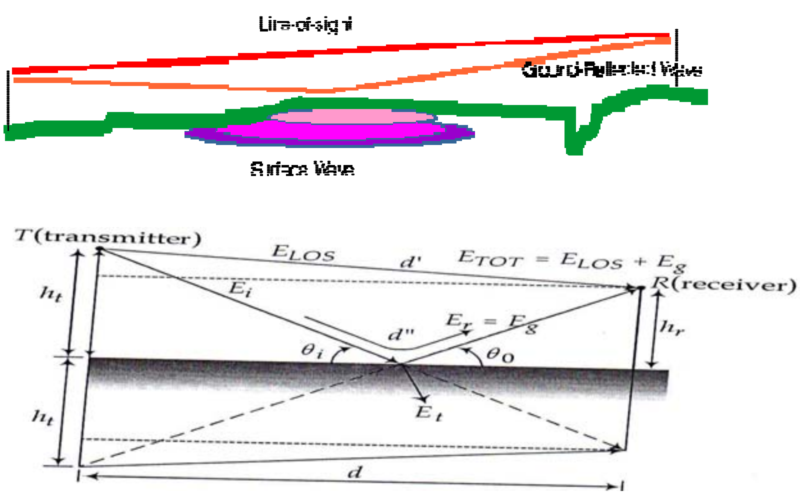


Fig. 3.1 Reflection

Ground Reflection (2-Ray) Model

Free space propagation model is inaccurate when used alone.
2-ray ground reflection model has been found to be reasonable and accurate for predicting the large-scale signal strength model over distances of several kilometers for mobile radio systems that use tall towers (height which exceed 50m) as well as for line-of-sight (LOS) microcell channels in urban environments.

a.



b. **Fig. 3.2 (a & b) The Method of Images is used to find the Path Difference between the Line-of-Sight and the Ground Reflected Paths**

The free space propagation E-field:

From figure 3.2(b), h_t is the height of the transmitter and h_r is the height of the receiver. If E_0 is the free space E-field (in units of V/m) at a reference distance d_0 from the transmitter, then for d > d_0, the free space propagating E-field is expressed

$$E(d,t) \quad \frac{E_0 d_0}{d} \cos\left[{}_c\left(t \quad \frac{d}{c}\right)\right] \qquad (d \quad d_0)$$

here $|E(d,t)| \quad \frac{E_0 d_0}{d}$ denotes the envelope of the E-field at d meters from the transmitter. Two propagating waves arrive at the receiver: the direct wave which travels a distance d', and the reflected wave which travels a distance d''. The E-field because of the line-of-sight component at the receiver will be given by

$$E_{LOS}(d',t) \quad \frac{E_0 d_0}{d'} \cos\left[{}_c\left(t \quad \frac{d'}{c}\right)\right]$$

and the E-field for the group reflected wave, which has a propagation distance of d", will be given by

$$E_g(d'',t) \quad \frac{E_0 d_0}{d''} \cos\left[{}_c\left(t \quad \frac{d''}{c}\right)\right]$$

According to laws of reflection in dielectrics, we have ${}_i \quad {}_0$ and $E_g \quad E_i$, $E_t \quad (1 \quad)E_i$ where is the reflection coefficient for ground. For small values of ${}_i \Rightarrow E_g \quad E_i$ perfect ground reflection $1,\ E_t \quad 0$

$$E_{TOT}(d,t) \quad \frac{E_0 d_0}{d'} \cos\left[{}_c\left(t \quad \frac{d'}{c}\right)\right] \quad (\ 1)\frac{E_0 d_0}{d''} \cos\left[{}_c\left(t \quad \frac{d''}{c}\right)\right]$$

Path difference between the LOS and the ground reflected paths will be given by

$$d'' \quad d' \quad \sqrt{(h_t \quad h_r)\ d^2} \quad \sqrt{(h_t \quad h_r)\ d^2}$$

$$if\ d \quad h_t \quad h_r\ , h_t \quad h_r\ (1 \quad x^2)^{1/2} \quad 1 \quad \frac{1}{2}x^2$$

If d is very large:

$$d'' \quad d' \quad \frac{2h_t h_r}{d} \Rightarrow \qquad 2 \qquad \frac{c}{c}, \text{ and } \quad _d \quad \frac{}{c} \quad \frac{}{2\ f_c}$$

It must be noted that as d becomes large, the difference between the distances d' and d" become very small, and the amplitudes of E_{LOS} and E_g are virtually identical and differ only in phase i.e.

$$\left|\frac{E_0 d_0}{d}\right| \quad \left|\frac{E_0 d_0}{d'}\right| \quad \left|\frac{E_0 d_0}{d''}\right|$$

If the received E-field is evaluated at some time, say at t = d"/c

$$E_{TOT}(d, t \quad \frac{d''}{c}) \quad \frac{E_0 d_0}{d'} \cos\left[\ _c \left(\frac{d'' \quad d'}{c} \right) \right] \quad (\quad 1) \frac{E_0 d_0}{d''} \cos(0^0)$$

$$\frac{E_0 d_0}{d'} \cos \qquad \frac{E_0 d_0}{d''} \qquad \frac{E_0 d_0}{d'} \cos \qquad 1$$

if d>>$h_t h_r$ and 1, cos 1

$$E_{TOT}(d) \quad \frac{E_0 d_0}{d} \cos \qquad \frac{E_0 d_0 \ 2 \quad 2h_t h_r}{d \qquad d} \quad \frac{1}{d^2} \left(\frac{E_0 d_0 4 \quad h_t h_r}{} \right) \quad \frac{k}{d^2} \ V/m$$

$$P_r(d) \quad \left[\frac{|E_{TOT}|^2}{120} A_e \qquad \frac{16 \quad ^2 h_t^2 h_r^2 d_0^2 \quad |E_0|^2 A_e}{^2 d^4 \qquad 120} \right]$$

$$\frac{16 \quad ^2 h_t^2 h_r^2 d_0^2 \quad P_t G_t G_r \quad ^2}{^2 d^4 \qquad 4 \quad ^2 d_0^2} \qquad P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

Power falls off proportional to distance rose to the fourth powers.

Exercise 3.1

It is given that a mobile is located 5km away from a base station and makes use of a vertical λ/4 monopole with a gain of 2.55dB to receive cellular radio signal. The E-field at the transmitter is measured to be 10^{-3}V/m. The carrier frequency used for this system is 900MHz.

a. Find the length and the effective aperture of the receiving Rx antenna.

b. Compute the receiver power at the mobile using the 2-ray ground reflection model assuming the height of the transmitting antenna is 50m and the receiving antenna is 1.5m above ground.

Solution:

Given that T-R separation distance = 5km, E-field at a distance of 1km = 10^{-3} V/m Frequency of operation, f = 900MHz

Now, $$\frac{c}{f} \quad \frac{3 \quad 10^{8}}{900 \quad 10^{6}} \quad 0.333m$$

(a) Antenna length: L = λ/4 = 0.333/4 = 0.833m = 8.33cm
Also, effective aperture of /4 monopole antenna can be obtained as under:

$$\text{Gain : G} \quad \frac{4 \ \text{A}}{2} \quad 2.55dB \quad 1.8$$

$$\text{A}_{e} \quad \frac{2}{4}\text{G} \quad \frac{0.333^{2}}{4 \ \ 3.1428} \quad 1.8 \quad 0.0158 \ \text{m}^{2}$$

b. Now, since $d \quad \sqrt{h_t h_r}$, the electric field will be given by

$$E_R(d) \quad \frac{2E_0 d_0}{d} \frac{2 \ \ h_t h_r}{d} \quad \frac{k}{d^{2}} V/m$$

$$E_r \quad \frac{2 \quad 10^{\ 3} \quad 1 \quad 10^{3}}{5 \quad 10^{3}} \left[\frac{2 \quad (50)(1.5)}{0.333(5 \quad 10^{3})} \right] \quad 113.1 \quad 10^{\ 6} \ V/m$$

Further, we know that the received power at a distance d can be obtained as below

$$P_r(d) \quad \frac{(113.1 \quad 10^{\ 6})^{2}}{377} \left[\frac{1.8(0.333)^{2}}{4} \right]$$

$$P_r(d \quad 5km) \quad 5.4 \quad 10^{\ 13} W$$

$$122.68 \ dBW \qquad 92.68 \ dBm$$

3.1.2 Diffraction-Loss

If the direct line-of-sight is obstructed by a single object (of height h_m), such as a mountain or building, the attenuation caused by diffraction over such an object can be estimated by treating the obstruction as a diffracting knife-edge.

Allow radio signals to propagate around the curved surface of the earth

Huygen’s principle

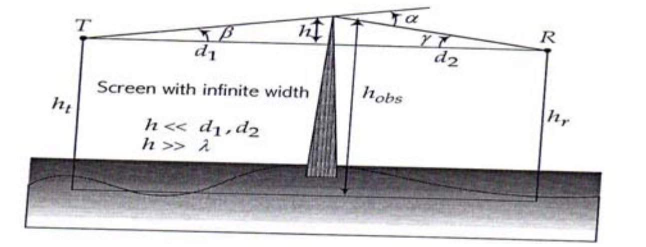


Fig. 3.3 Knife-Edge Geometry

Excess path length ( )= diffraction path length-direct path length

$$\frac{h^2(d_1 \quad d_2)}{2d_1 d_2} \xrightarrow{\text{Phase difference}} \frac{2}{\quad} \qquad \frac{2 \quad h^2 (d_1 \quad d_2)}{2 \quad d_1 d_2}$$

$$\frac{}{2}\left(h\sqrt{\frac{2(d_1 \quad d_2)}{d_1 d_2}} \right)^2 \quad if\ h_t \quad h_r$$

Fresnel Zones:

Illustrate how shadowing is sensitive to the frequency as well as the location of obstructions with relation to the Tx or Rx.

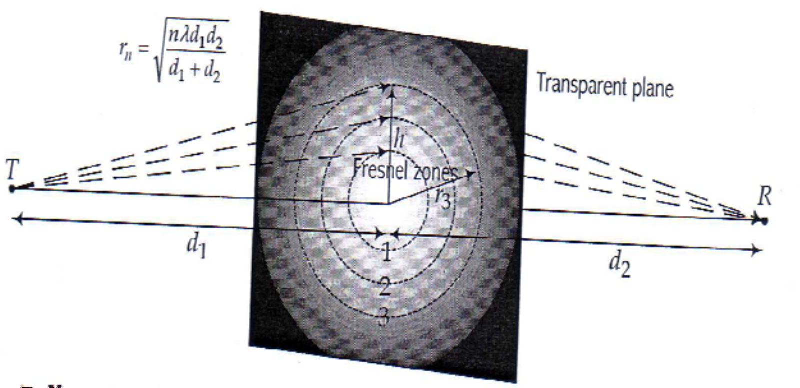


Fig. 3.4 (a) Fresnel Zones

If an obstruction does not block the volume contained within the first Fresnel zone, then the diffraction loss will be minimal, and diffraction effect may be neglected.

For design of LOS microwave links, as long as 55% of the 1st Fresnel zone is kept clear, then further Fresnel zone clearance does not significantly alter the diffraction loss.

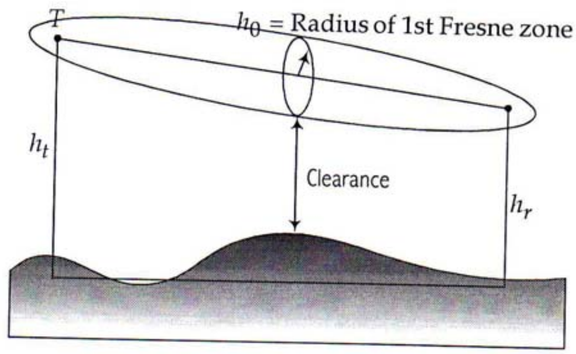


Fig. 3.4 (b) Fresnel Zones

Knife-Edge Diffraction Model

The phenomenon by which an electromagnetic waveform diffracts, or bends, as it strikes the sharp edge of an obstacle transverse to its direction of propagation. The portion of the signal that is not cut off by the knife edge continues to propagate, but the edge of the signal bends into the line-of-sight (LOS) shadow region as if to fill the void left by the portion of the signal cut off. Knife-edge diffraction can be used to advantage in radio communications when line-of-sight (LOS) cannot be achieved due to the presence of an obstacle, such as a mountain top or building, that lies in the path of the transmit and receive antennas.

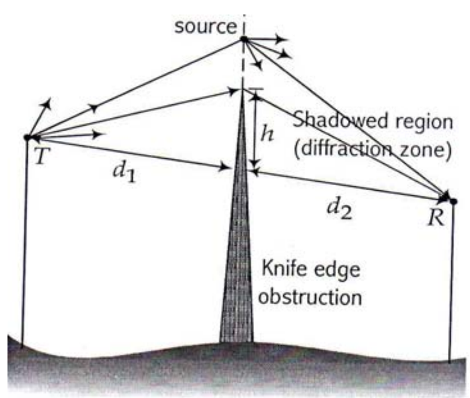


Fig. 3.5 Knife-Edge Diffraction Model

Diffraction gain due to the presence of knife edge

Gd[dB] = 0, 1

Gd[dB] = 20 log(0.5 – 0.62), -1 ≤ ≤0

G_d[dB] = 20 log(0.5exp(-0.95)), -1 ≤ ≤0

$$G_d[\mathrm{dB}] = 20\log(0.4 - \sqrt{0.1184 - (0.38 - 0.1\ \ )^2}, \qquad 1 \qquad 2.4$$

$$G_d[\mathrm{dB}] = 20\log\left(\frac{0.225}{\ }\right), \qquad 2.4$$

$$h\sqrt{\frac{2(d_1 \quad d_2)}{d_1 d_2}} \; : \; \textit{Fresnel} \qquad \textit{Kirchoff diffraction parameter}$$

Exercise 3.2

Find diffraction loss λ = 1/3m, d_1 = 1km, d_2 = 1km.

a. h = 25m

$$h\sqrt{\frac{2(d_1 \quad d_2)}{d_1 d_2}} \quad 25\sqrt{\frac{2(1000 \quad 1000)}{(1/3) \quad 1000 \quad 1000}} \quad 2.74$$

$$Gd\ dB \quad 20\log\left(\frac{0.225}{\ }\right), \qquad 2.4$$

$$G_d\ [dB] \quad 20\log\left(\frac{0.225}{2.74}\right) \qquad 21.7$$

$$\frac{h^2(d_1 \quad d_2)}{2d_1 d_2} \quad \frac{25^2 \ 1000 \quad 1000}{2 \quad 1000 \quad 1000} \quad \frac{1{,}250{,}000}{2000{,}000} \quad 0.625m$$

$$\frac{n}{2} \qquad n \quad \frac{2}{\ } \quad \frac{2 \quad 0.625}{0.333} \quad 3.75$$

The tip of the obstruction completely blocks the first three Fresnel zones

b. h = 0

$$h\sqrt{\frac{2(d_1 \quad d_2)}{d_1 d_2}} \quad 0\sqrt{\frac{2(1000 \quad 1000\ )}{(1/3) \quad 1000 \quad 1000}} \quad 0$$

$$Gd \quad dB \qquad 20\ \log \quad 0.5 \quad 0.62 \quad , when \quad 1 \qquad 0$$

$$G_d[dB\ ] \quad 20\ \log \quad 0.5 \quad 0.62 \quad 0 \qquad 20\ \log\ 0.5 \qquad 6$$

$$0$$

$$n \quad 0$$

The tip of the obstruction lies in the middle of the first Fresnel zone

c. h = -25m

$$h\sqrt{\frac{2(d_1 \quad d_2)}{d_1 d_2}} \quad 25\sqrt{\frac{2(1000 \ \ 1000)}{(1/3) \quad 1000 \ \ 1000}} \quad 2.74 \quad G_d[dB] \quad 0 \quad n \ \ 3.75$$

The diffraction losses are negligible

Multiple Knife-Edge Diffraction

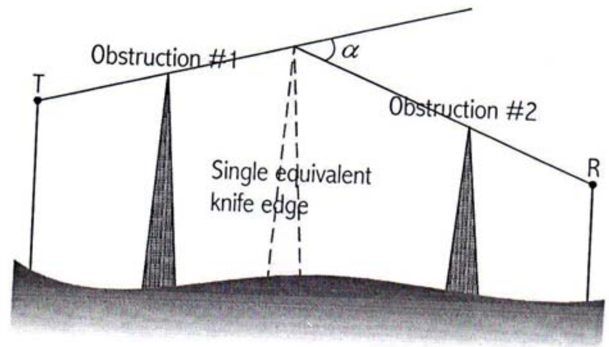


Fig. 3.6 Multiple Knife-Edge Diffraction

3.1.3 Scattering

Objects such as lamp posts and trees tend to scatter energy in all directions, thereby providing additional radio energy at a receiver.

Roughness test: Rayleigh criterion

$$\text{Critical height}: h_c \quad \frac{\quad}{8\sin_{\ i}}, \quad {}_i : \textit{angle of incidence}$$

Smooth surface: Max to min protuberance $h < h_c$

Reflection coefficient for rough surface

$$_{rough} \quad p_s \quad , p_s \quad \exp\left[\quad 8\left(\frac{_h \sin \ _i}{\quad} \right)^2 \right] I_0 \left[8\left(\frac{_h \sin \ _i}{\quad} \right)^2 \right],$$

σ_h : standard deviation of the surface height above the mean surface height.

Radar Cross Section (RCS) Model

For rough surface

$$\text{RCS[m2]} \ \frac{\text{power density of the signal scattered in the direction of receiver}}{\text{power density of the radio wave incident on the scattering object}}$$

Received power due to scattering: the propagation of wave traveling in free space impinges on a distant scattering object, and is then reradiated in the direction of the receiver

Assumption: scattering object is in the far field (Fraunhofer region)

$$P_R[dBm] \quad P \ [dBm] \quad G \ [dBi] \quad 20\log d_R$$

$d_T(d_R)$: the distance from the scattering object to the Tx(Rx)
dBi: dB gain with respect to an isotropic source

RCS for medium and large size building located 5-10km away:
$14.1dB.m^2 \sim 55.7dB.m^2$

3.2 Total Path Loss

The previously presented methods for ground reflection loss and diffraction losses suggest a "Mondriaan" interpretation of the path profile: Obstacles occur at straight vertical lines while horizontal planes cause reflections. That is, the propagation path is seen as a collection of horizontal and vertical elements.

Total loss=Free space loss + Ground reflection loss + Multiple knife-edge diffraction loss

4.0 CONCLUSION

The three basic propagation mechanisms are reflection, diffraction, and scattering.

7.0 SUMMARY

In this unit, you have learnt that:

- Electromagnetic wave consists of electric and magnetic fields.
- Reflection occurs when a propagating electromagnetic wave impinges upon an object which is very large in dimensions when compared to the wavelength of the propagation wave.
- Diffraction occurs when the radio path between the Transmitter (Tx) and Receiver (Rx) are obstructed by a surface that has irregularities (edges).
- Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength, and where the number of obstacles per unit volume is large.

SELF ASSESSMENT EXERCISE

1. What are the mechanisms responsible for electromagnetic wave propagation?
2. Discuss the effect of path loss on the performance of a cellular radio network

6.0 TUTOR-MARKED ASSIGNMENT

Describe Ground Reflection (Two-Ray) Model for mobile radio wave propagation

7.0 REFERENCES/FURTHER READING

Goldsmith, A. (2005). *Wireless Communications*. Cambridge University Press.

Linnartz J. M. G. (1996). *Wireless Communication*. Baitzer Science Publishers.

Molisch, A. F. (2005). *Wireless Communications*. Wiley & Associates.

Rappaport, T. S. (2005). *Wireless Communication: Principles and Practice*. (2nd ed.), India: Prentice Hall.

Sharma, S. (2007). *Wireless and Cellular Communication*. New Delhi: S. K. Kataria & Sons.

UNIT 4 PATH LOSS MODEL

CONTENTS

8.0 INTRODUCTION

In this unit, you are going to learn the various path loss models for predicting radio coverage area when designing a wireless communication system.

9.0 OBJECTIVES

At the end of this unit, you should be able to:

- describe log-distance path model
- list outdoor propagation models
- mention two indoor propagation models.

10.0 MAIN CONTENT

3.1 Empirical Path Loss Model

The primary use of an empirical model such as log-normal shadowing is to predict radio coverage when designing a wireless communication system.

The actual environments are too complex to model accurately. In practice, most simulation studies use empirical models that have been developed based on measurements taken in various real environments.

The commonly used empirical models are: Hata model, Cost 231 Extension to Hata model, COST 231-Walfish-Ikegami Model, Erceg Model etc.

3.1.1 Practical Link Budget Design Using Path Loss Model

What Is Link Budget Calculation?

A link budget is a rough calculation of all known elements of the link to determine if the signal will have the proper strength when it reaches the other end of the link. To make this calculation, various details are required like total length of transmission cable and loss per unit length at the specified frequency as there will always be some loss of signal strength through the cables.

3.1.1.1 Log-Distance Path Loss Model

The log-distance path loss model is a radio propagation model that predicts the path loss a signal encounters inside a building or densely populated areas over distance. In the log-distance path loss model, the path loss is automatically calculated based on the distance between the transmitter and the receiver in the emulator world.

Average large-scale path loss for an arbitrary T_R separation:

$$\overline{PL(d) \quad (d/d^{\;n} \quad PL\ d} \quad PL\ d \qquad n\log\left(\frac{d}{d_0}\right)$$

d_0: the close – in reference distance in the far field of the antenna

Environment	Path Loss exponent, n
Free space	2
Urban area cellular radio	2.7 ~ 3.5
Shadowed urban cellular radio	3 ~ 5
In building line-of –sight	1.6 ~ 1.8
Obstructed in building	4 ~ 6
Obstructed in factories	2 ~ 3

Uses the idea that both theoretical and empirical evidence suggests that average received signal strength decreases logarithmically with distance.

Measure received signal strength near to transmitter and approximate to different distances based on above “reference” observation

3.1.1.2 Log-Normal Shadowing

The path loss PL(d) at a particular location: log-normal distribution

$$PL(d)[dB] \quad \overline{PL(d)} \quad X \quad \overline{PL}(d_0) \quad 10n\log\left(\frac{d}{d_0}\right) \quad X \; ; Normal\,distribution$$

$$P_r(d)[dB] \quad P_t[dBm] \quad PL(d)[dB]$$

$$X \quad \sim N(0, \;\; ^2) : zero \;\; mean\;Gaussian\;distributed\;r.v\;with\;standard\;deviation \;\; [dB]$$

$$due\;to\;environmental\;surrounding$$

$$: 4 \sim 12dB, depending\;on\;the\;severity\;of\;the\;shadowiing$$

$$Log \;\; normal\;rv: \quad e^X, X \sim N(m, \;\; ^2)$$

The probability that the received signal level will exceed a certain value

$$P[P_r(d) \quad][dB] \quad Q\left(\frac{\quad \overline{P_r(d)}}{\quad}\right)$$

$$Q(z) \quad \frac{1}{\sqrt{2}}\int_z \exp\left(\frac{x^2}{2}\right) dx \quad \frac{1}{2}\left[1 \quad erf\left(\frac{z}{\sqrt{2}}\right)\right], erf(x) \quad \frac{2}{\sqrt{\;}}\int_0^x e^{\;t^2}\,dt$$

3.1.1.3 Determination of Percentage of Coverage Area

U(γ) : Percentage of useful service area – Percentage of area with a received signal that is equal or greater than γ

$$U(\;\;) \quad 0.5\left(1 - erf(a) \quad \exp\left(\frac{1-2ab}{b^2}\right)\left[1 \quad erf\left(\frac{1-ab}{b}\right)\right]\right)$$

$$R : the\;radius\;of\;a\;circular\;coverage\;area$$

$$a \quad \frac{\quad P_t \quad \overline{PL}(d_0) \quad 10n\log(R/d_0)}{\sqrt{2}}, \; b \quad \frac{(10n\;\log e)}{\sqrt{2}}$$

$$: standard \;\; deviation$$

Exercise 4.1

A pass loss model: $PL(d)[dB]\,\overline{PL}(d) \quad X \quad \overline{PL}\,d \quad n\log d\,d \quad X \quad d \quad m$

Distance from Tx	Received Power [dBm]
100m / 200m / 1 km /2 km	0 / -20 / -35 / -70

a. Find the minimum mean square error (MMSE) estimate for the path loss exponent n

b. Find the standard deviation

c. Estimate the received power at d = 2km

d. Predict the likelihood that the received signal level at 2km will be greater than -60dBm.

e. Predict the percentage of area within a 2km radius cell that received signals greater than -60dBm.

Solution:

(a) Since

$$PL(d)[dB] \quad \overline{PL}(d_0) \quad 10n\log(d/d_0) \quad \overline{PL}(d_0) - 10n\log(d_i/100m)$$

$$P_r \ (100m) \ \ P_r(100m) - 0 \quad 0,$$

$$P_r \ (200m) \ \ -3n,$$

$$P_r(1km) \quad -10,$$

$$Pr(3km) \quad -14.77n$$

$$J(n) \quad (0-0)^2 \quad (-20-(-3n))^2 \quad (-35-(-10n))^2 \quad (-70-(-14.77n))^2$$

$$6525 - 2887.8n \quad 327.153n^2$$

$$\frac{dJ(n)}{dn} \quad 654.306n \quad 2887.8 \quad 0 \Rightarrow n \quad 4.4$$

(b) standard deviation

$\sigma^2 = J(n) / 4 = 152.36 / 4 = 38.09 \rightarrow \sigma = 6.17dB$

(c) Pr(2km) = 0 – 10 log(2000/100) = -57.24dBm

(d) $$P[P_r(d) \quad -60dBm] \quad Q\left(\frac{-\overline{P_r}(d)}{}\right) \quad Q\left(\frac{60 \quad 57.24}{6.17}\right) \quad 67.4\%$$

(e) 92%

3.1.2 Empirical Model for Outdoor Propagation Models

More sophisticated models take into account factors such as terrain. urban clutter, antenna heights, and diffraction e.g. Longley-Rice, Durkin, Okumura, Hata, COST-231, Walfisch & Bertoni etc.

(a) Longley-Rice Model [1967, 1978]

Applicable to point-to-point communication systems in frequency range from 40MHz ~ 100GHz over different kinds of terrains.

Not considering the effects of buildings and foliage, and the multipath

(b) Durkin's Model [1969]

Adopted by the Joint Radio Committee (JRC) in the U.K for the estimation of effective mobile radio coverage areas

Modeled LOS and diffraction from obstacles
Excludes reflections from other surrounding objects and local scatters

(c) Okumura Model

Most widely used models for signal prediction in urban areas
150 ~ 1920 MHz
Distance: 1km ~ 100km
Base station antenna height: 30m ~ 100m
Wholly based on measured data and does not provide any analytic explanation
The simplest and best in terms of accuracy in path loss prediction for mature cellular and land mobile radio systems in clustered environment
The model is fairly good in urban and suburban areas, but not as good in rural areas
A standard for system planning in modern land mobile radio system in Japan
Common standard derivations between predicted and measured path loss: 10dB ~ 14dB
L50[dB] = LF + Amu(f,d) – G(hte) – G(hre) – GAREA
L50 : the 50th percentile (i.e. median) value of propagation path loss
LF: free space propagation loss

A_{mu} : median attenuation relative to free space

$G(h_{te})$:base station antenna height gain factor
$G(h_{re})$: mobile antenna height gain factor

G_{AREA} : the gain due to the type of environment

$$G(h_{te}) \quad 20\log\left(\frac{h_{te}}{200}\right),\ 1000m \quad h_{te} \quad 30m,$$

$$G(h_{re}) \quad 10\log\left(\frac{h_{re}}{3}\right),\quad h_{re} \quad 3m,$$

$$G(h_{re}) \quad 20\log\left(\frac{h_{re}}{3}\right),\ 10m \quad h_{te} \quad 3m,$$

Exercise 4.2

Find the median path loss and Pr(d) using Okumura's model.
d = 50km, h_{te} = 100m, h_{re} = 10m (suburban environment). Base station's EIRP: 1kW@900MHz, G_r = 0dB.

Solution:

$L_{50}[dB] = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA}$
Free space loss

$$L_F = 10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] = 125.5dB$$

$$A_{mu}(900MHz, 50km) = 43dB, \quad G_{AREA} = 9dB \text{ from the Okumura curves}$$

$$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) = 6dB$$

$$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) = 10.46dB$$

$$L_{50}[dB] = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA}$$
$$= 125.5dB + 43dB - (-6)dB - 10.46dB - 9dB = 155.04dB$$

The medium received power:

Pr(d) = EIRP(dBm) - L50[dB] + Gr(dB) = 60dBm – 155.04dB + 0dB = -95.04dBm

(d) Hata Model [1990]

Empirical formulation of the graphical path loss data provided by Okumura
The model is designed for 150MHz ~ 1500MHz and are applicable to the first generation cellular system
Median path loss in urban areas

L_{50}(urban)[dB] = 69.55 + 26.16logf_c – 13.82log h_{te} -a(h_{re}) + (44.9 –6.55log h_{te})log d d[km] : Tx – Rx distance
f_c = carrier frequency
h_{te} = height of the transmitting (base station) antenna
h_{re} = height of the receiving (mobile) antenna
a(h_{re}) : correction factor for effective mobile antenna height

a(h_{re})= (1.1 logf_c–0.7)h_{re}-(1.56 logf_c-0.8)dB: for a small to medium sized city a(h_{re})= 8.29(log1.54h_{re})^2 – 1.1dB : for a large city, $f_c \leq 300$Hz

$a(h_{re}) = 3.2[\log(11.75h_{re})]^2 - 4.97\text{dB}$: for a large city , $f_c \geq$ 300Hz

Exercise 4.3

Determine the path loss of a 900MHz cellular system operating in a large city from a base station with the height of 100m and mobile station installed in a vehicle with antenna height of 2m. The distance between the mobile and the base station is 4km.

Solution

d[km] : 4km, f_c = 900MHz, h_{te} = 100m, h_{re} = 12m
$a(h_{re}) = 3.2[\log(11.75h_{re})]^2 - 4.97 = 1.045\text{dB}$

$L_{50}(\text{urban})[\text{dB}] = 69.55 + 26.16 \log f_c - 13.82 \log h_{te} - a(h_{re}) + (44.9 - 6.55\log h_{te})\log d$

$= 69.55 + 26.16 \log(900) - 13.82 \log(100) - 1.045 + (44.9 - 6.55\log 100)\log 4 = 137.3\text{dB}$

Path loss in a suburban area

$L_{50}[\text{dB}] = L_{50}(\text{urban}) - 2[\log(f_c / 28)]^2 - 5.4$

Path loss in open rural areas

$L_{50}[\text{dB}] = L_{50}(\text{urban}) - 4.78[\log(f_c)]^2 - 18.33\log f_c - 40.98$

(e) PCS Extension to Hata Model (COST 231 Extension to Hata Model)

Extended Hata model for 2GHz PCS by European Co-operative for Science and Technical Research (EUROCOST)

$L_{50}(\text{urban})[\text{dB}] = 46.3 + 33.9\log(f_c) - 13.82\log(h_{te}) - a(h_{re}) + (44.9 - 6.55\log(h_{te}))\log d + C_M$

$$C_M \quad \begin{matrix} 0dB, & \text{for meium sized city \& suburban areas} \\ 3dB, & \text{for metropolitan centers} \end{matrix}$$

This model is restricted to the following parameters:

Carrier frequency	1.5GHz to 2GHz
Base Antenna Height	30m to 300m
Mobile Antenna Height	1m to 10m
Distance d	1km to 20km

This model is designed for large and small macro-cells, i.e., base station antenna heights above rooftop levels adjacent to base station.

(f) CCIR Model

An empirical formula for the combined effects of free-space path loss and terrain-induced path loss was published by the CCIR (Comité Consultatif International des Radio-Communication, now ITU-R) and is given by

$$L_{CCIR}(dB) = 69.55 + 26.16\log_{10} f_{MHz} - 13.82\log_{10} h_1 - a(h_2) + (44.9 - 6.55\log_{10} h_1)\log_{10} d_{km} - B$$

where h_1 and h_2 are base station and mobile antenna heights in meters, respectively, d_{km} is the link distance in kilometers, f_{MHz} is the center frequency in megahertz, and

$$a(h_2) = (1.1\log_{10} f_{MHz} - 0.7)h_2 - (1.56\log_{10} f_{MHz} - 0.8)$$
$$B = 30 - 25\log_{10}(\%\ of\ area\ covered\ by\ buildings)$$

This formula is the Hata model for medium–small city propagation conditions, supplemented with a correction factor, B.

The term B is such that the correction B = 0 is applied for an urban area, one that is about 15% covered by buildings; for example, if 20% of the area is covered by buildings, then

$$B = 30 - 25\log_{10} 20 \approx 25dB$$

(g) The Hata-Davidson Model

The Telecommunications Industry Association (TIA) recommends in their publication TSB-88A the following modification to the Hata model to cover a broader range of input parameters.
The modification consists of the addition of correction terms to the Hata model:

$$L_{HD} \quad L_{Hata} \quad A\ h_1, d_{km} \quad S_1\ d_{km} \quad S_3\ f_{MHz} \quad S_4\ f_{MHz,}\ d_{km}$$

in which A and S_1 are distance correction factors extending the range to 300 km, S_2 is a base station antenna height correction factor extending the range of h_1 values to 2500 and S_4 are frequency correction factors extending frequency to 1500MHz:

Distance	$A(h_1, d_{km})$	$S_1(d_{km})$
d_{km} <20	0	0
$20 \leq d_{km} <$ 64.38	$0.62137(d_{km} - 20)[0.5+0.15\log_{10}(h_1/121.92]$	0
$64.38 \leq d_{km} <$ 300	$0.62137(d_{km} - 20)[0.5+0.15\log_{10}(h_1/121.92]$	$0.174(d_{km} - 64.38)$

$$S_2\ h_1, d_{km} \quad 0.00784 |\log_{10}\ 9.98/d_{km}\ |\ h_1 \quad 300 \quad for\ h_1 \quad 300$$

$$S_3\ f_{MHz} \quad f_{MHz}/250\log_{10}\ 1500/f_{MHz}$$

$$S_4\ f_{MHz}, d_{km} \quad [0.112\log_{10}\ 1500/f_{MHz}\ ]\ d_{km} \quad 64.38 \quad for\ d_{km} \quad 64.38$$

3.1.3 Indoor Propagation Models

There are several causes of signal corruption in an indoor wireless channel. The primary causes are signal attenuation due to distance, penetration losses through walls and floors and multipath propagation.

The indoor signal propagation differs from an outdoor case particularly in distances and in variability of the environment, so these models are site specific and they have to take account of partition losses and surrounding objects which cause multipath propagation.

Difference from the mobile radio channel

The distances covered are much smaller.

The variability of the environment is very high even for small T-R separations e.g. doors closed vs. opens, ceiling vs. desk mounted antennas walls, floors, furniture, people moving around.

Physical Effects:

Signal decays much faster

Coverage contained by walls, etc.

Walls, floors, furniture attenuate/ scatter radio signals

Path loss formula:

Path Loss = Unit Loss + 10 n log(d) = k F + l W
where:

Unit loss = power loss (dB) at 1m distance (30 dB)
n = power-delay index
d = distance between transmitter and receiver
k = number of floors the signal traverses
F = loss per floor
I = number of walls the signal traverses
W = loss per wall

Building	**Freq (MHz)**	**n**	**dB**
Retail Stores	914	2.2	8.7
Grocery Stores	914	1.8	5.2
Office, Hard Partitions	1500	3.0	7.0
Office, Soft Partitions	900	2.4	9.6
Office, Soft Partitions	1900	2.6	14.1
Factory LOS			
Textile/Chemical	1300	2.0	3.0
Textile/Chemical	4000	2.1	7.0
Paper/Cereals	1300	1.8	6.0
Metalworking	1300	1.6	5.8
Suburban home			
Indoor to street	900	3.0	7.0
Factory OBS			
Textile/Chemical	4000	2.1	9.7
Metalworking	1300	3.3	6.8

Table 4.1: Measure of accuracy of simple model; the larger the σ, the less accurate the model

Source: Prof. Randy H. Katz (Radio Propagation Lecture)

Other Effecting Factors

People moving around: Additional multipath induced attenuation of 10 dB.
Buildings with few metal and hard partitions: RMS delay spread of 30 to 60 ns (several mbps w/o equalization).

Buildings with metal/open aisles: RMS delay spread of up to 300 ns (100s kbps w/o equalisation)

Between floors:

Concrete/steel flooring yields less attenuation than steel plate flooring
Metallic tinted windows yield greater attenuation
15 dB for first floor separation, 6 - 10 dB for next four floors, 1 - 2 dB for each additional floor of separation
Received signal strength depends on open plan offices, construction materials, density of personnel, furniture, etc.

Path loss exponents:

Narrowband (max delay spread < bit period)
Vary between 2 and 6, 2.5 to 4 most common
Wall losses: 10 dB to 15 dB
Floor losses: 12 dB to 27 dB
Wideband (max delay spread > bit period)
Delay spread varies between 15 ns and 100 ns
Can vary up to 250 ns
Requires sophisticated equalisation techniques to achieve acceptable bit error rates.

Example 1: Indoor RF propagation at 2.4GHz (U.C. Berkeley). RF propagation obstacles can be termed hard partitions if they are part of the physical / structural components of a building. On the other hand, obstacles formed by the office furniture and fixed or movable / portable structures that do not extend to a buildings ceiling are considered soft partitions. Radio signals effectively penetrate both kinds of obstacles or partitions in ways that are very hard to predict.

Example 2: Indoor RF propagation at 60GHz. The 60 GHz band can be a good candidate for indoor wireless office communication, once RF components and modules become more widely available. Indoor rms delay spreads presumably are on the order of 15 to 50 nsec.

Typical delay profiles show

a dominant line-of-sight
a collection of early reflections with a constant delay profile between 0 and some instant t.-
an exponential decay beyond t.

For 60 GHz in-office propagation, t is about 50 nanoseconds. Oxygen attenuation is not noticeable for such short-range transmission. With highly directional antennas, the delay spread can be reduced to 5 to 8 nanoseconds. Severe attenuation occurs when signals have to penetrate through glass or wood. This helps to confine cell areas.
Double-glazed windows: 3 - 7 dB, concrete wall: 20-30 dB.

11.0 CONCLUSION

In this unit, you have learned the empirical path loss, practical link budget design using path loss models, the outdoor and indoor propagation models.

12.0 SUMMARY

The main points in this unit include the following:

- The primary use of an empirical model such as log-normal shadowing is to predict radio coverage when designing a wireless communication system.
- A link budget is a rough calculation of all known elements of the link to determine if the signal will have the proper strength when it reaches the other end of the link.
- The log-distance path loss model is a radio propagation model that predicts the path loss as a signal encounters inside a building or densely populated areas over distance.
- The actual environments are too complex to model accurately, so most simulation studies use empirical models such as Hata model, Cost 231 Extension to Hata model, COST 231-Walfish-Ikegami Model, Erceg Model etc.
- The primary causes of indoor wireless channels are signal attenuation due to distance, penetration losses through walls and floors and multipath propagation.

SELF ASSESSMENT EXERCISE

List three outdoor propagation models

13.0 TUTOR-MARKED ASSIGNMENT

1. Describe log-distance path model.
2. What are the causes of signal corruption in an indoor wireless channel?

14.0 REFERENCES/FURTHER READING

Garg, V. K. & Wilkes J. E. (1996). *Wireless and Personal Communications Systems.* Prentice Hall.

Goldsmith, A. (2005). *Wireless Communications*. Cambridge University Press.

Linnartz, J. M. G. (1996). *Wireless Communication*. Baitzer Science Publishers.

Molisch, A. F. (2005). *Wireless Communications*. Wiley & Associates

Rappaport, T. S. (2005). *Wireless Communication: Principles and Practice.* (2nd ed.), India: Prentice Hall.

Saunders, S.R. (1999). *Antennas and Propagation for Wireless Communication Systems*. Wiley & Associates.

Sharma, S. (2007). *Wireless and Cellular Communication*. New Delhi: S. K. Kataria & Sons.

UNIT 5 SHADOWING

CONTENTS

8.0 INTRODUCTION

Shadowing is the effect that the received signal power fluctuates due to objects obstructing the propagation path between transmitter and receiver. These fluctuations are experienced on a local-means power, which is short term averages to remove fluctuations due to multipath fading.

9.0 OBJECTIVES

At the end of this unit, you should be able to:

define a shadowing model
illustrate with a diagram a shadowing model.

10.0 MAIN CONTENT

3.1 Shadowing Concept

If there are any objects (such buildings or trees) along the path of the signal, some part of the transmitted signal is lost through absorption, reflection, scattering, and diffraction. This effect is called shadowing. As shown below, if the base antenna were a light source, the middle building would cast a shadow on the subscriber antenna; hence the name, shadowing.

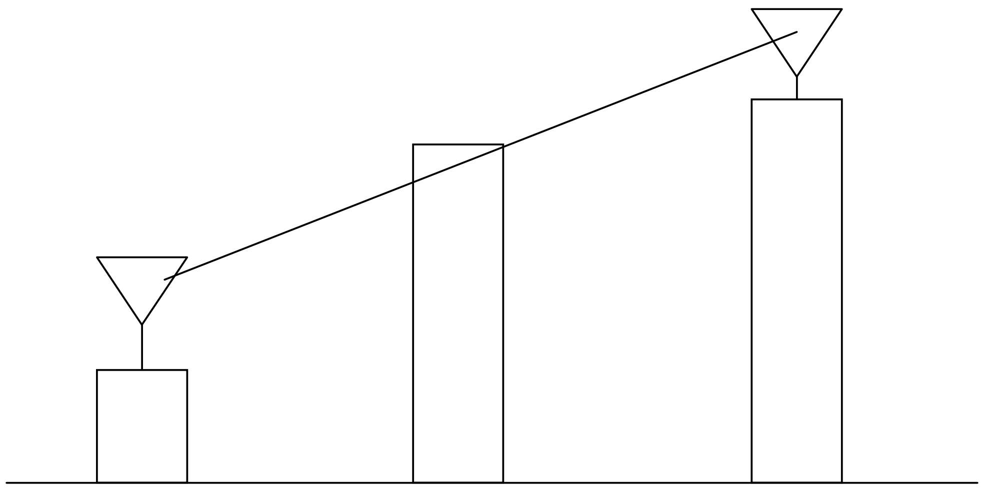


Fig. 5.1 Shadowing

Experiments reported by Egli in 1957 showed that, for paths longer than a few hundred meters, the received (local-mean) power fluctuates with a ‘log-normal’ distribution about the area- mean power.

“Log-normal” means that the local-mean power expressed in logarithmic values i.e, $\bar{P}_{\log}$ $\ln\left(\frac{\bar{P}}{\bar{\bar{P}}}\right)$ dB or neper has a normal *i.e.*, Gaussian distribution.

local means is the average over about 40l, to remove multipath fading denoted by a single overline
area means is the average over tens or hundreds of meters, to remove multipath fading and shadowing denoted by a double overbar.

The probability density function (pdf) of the local-mean power is thus of the form

$$f_{\bar{p}_{\log}}\ \bar{P}_{\log} \quad \frac{1}{\sqrt{2}\ \ _s} \exp\left[\ \frac{1}{2\ \ _s^2}\ \bar{P}_{\log}\ ^2\right]$$

where Ω_s is the logarithmic standard deviation of the shadowing, expressed in natural units. The standard deviation in dB is found from s = 4.34 s. For instance s = 6 dB shadowing is equivalent to s = 1.36. If we convert 'nepers' to 'watts', the log-normal distribution of received (local-mean) power is found

$$f_{\bar{p}_{\log}}\ \bar{P}_{\log} \quad \frac{1}{\sqrt{2}\ \ _s} \exp\left[\ \frac{1}{2\ \ _s^2} \ln^2\left(\frac{\bar{P}}{\bar{\bar{P}}}\right)\right]$$

Here the factor "1/local-mean power" occurs due to the conversion of the pdf of P_{Log} to local-mean power.

3.1.1 Depth of Shadowing

For average terrain, Egli reported a logarithmic standard deviation of about 8.3 dB and 12 dB for VHF and UHF frequencies, respectively. Such large fluctuations are caused not only by local shadow attenuation by obstacles in the vicinity of the antenna, but also by large-scale effects leading to a coarse estimate of the area-mean power.

3.1.2 Implications for Cell Planning

Shadowing makes practical cell planning complicated. To fully predict local shadow attenuation, up-to-date and highly detailed terrain data bases are needed. If one extends the distinction between large-area and small-area shadowing, the definition of shadowing covers any statistical fluctuation of the received local-mean power about a certain area-mean power, with the latter determined by (predictable) large-scale mechanisms. Multipath propagation is separated from shadow fluctuations by considering the local-mean powers. That is, the standard deviation of the shadowing will depend on the geographical resolution of the estimate of the area-mean power. A propagation model which ignores specific terrain data produces about 12 dB of shadowing. On the other hand, prediction methods using topographical data bases with unlimited resolution can, at least in theory, achieve a standard deviation of 0 dB. Thus, the standard deviation is a measure of the impreciseness of the terrain description. If, for generic system studies, the (large-scale) path loss is taking a simple form depending only on distance but not on details of the path profile, the standard deviation will necessarily be large. On the other hand, for the planning of a practical network in a certain (known) environment, the accuracy of the large-scale propagation model may be refined. This may allow a spectrally more efficient planning if the cellular layout is optimized for the propagation environment.

11.0 CONCLUSION

Shadowing is attenuation from natural and man-made object (fast). Signals are blocked by obstructing structures.

12.0 SUMMARY

In this unit, you have learnt that:

Shadowing is the effect that the received signal power fluctuates due to objects obstructing the propagation path between transmitter and receiver.

Log-normal" means that the local-mean power expressed in logarithmic values i.e, $\bar{P}_{\log} \quad \ln\left(\frac{\bar{P}}{\bar{P}}\right)$ dB or neper has a normal

Shadowing covers any statistical fluctuation of the received local-mean power about a certain area-mean power, with the latter determined by (predictable) large-scale mechanisms.

SELF ASSESSMENT EXERCISE

What is meant by shadowing?

13.0 TUTOR-MARKED ASSIGNMENT

Illustrate with a diagram what a shadowing model is.

14.0 REFERENCES/FURTHER READING

Garg, V. K. & Wilkes, J. E. (1996). *Wireless and Personal Communications Systems.* Prentice Hall

Goldsmith, A. (2005). *Wireless Communications.* Cambridge University Press.

Linnartz, J. M. G. (1996). *Wireless Communication*. Baitzer Science Publishers.

Molisch, A. F. (2005). *Wireless Communications*. Wiley & Associates.

Rappaport, T. S. (2005). *Wireless Communication: Principles and Practice.* (2nd ed.). India: Prentice Hall.

MODULE 3 MOBILE RADIO PROPAGATION

UNIT 1 SMALL SCALE FADING AND MULTI-PATH

CONTENTS

1.0 INTRODUCTION

Small scale fading or in simple word fading is used to describe the rapid fluctuations in amplitudes, phases, or muti-path delays of a radio signal over a small period of time or travel distance, so that large scale path loss effects may be ignored. In wireless communications, fading is deviation or the attenuation that a carrier-modulated telecommunication signal experiences over certain propagation media. The fading may vary with time, geographical position and/or radio frequency, and is often modelled as a random process. A fading channel is a communication channel that experiences fading. In wireless systems, fading may be due to multipath propagation, referred to as multipath induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading.

2.0 OBJECTIVES

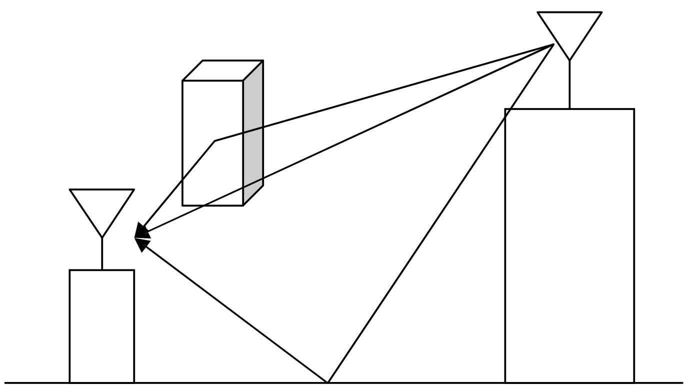
At the end of this unit, you should be able to:

- write concisely on the concept of small scale propagation
- identify the effects of multipath in the radio channel
- discuss the factors affecting small scale fading
- explain doppler shift.

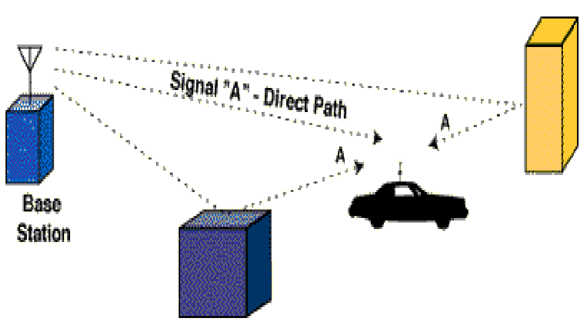
3.0 MAIN CONTENT

3.1 Small Scale Multi-Path Propagation

The objects located around the path of the wireless signal reflect the signal. Some of these reflected waves are also received at the receiver. Since each of these reflected signals takes a different path, it has a different amplitude and phase.



(a)



(b)

Fig. 1.1(a &b) Example of Multi-Path

As a matter of fact, multi-path in the radio channel produces small-scale fading effects. The three important effects are:

i. Rapid changes in signal strength over a small travel distance or time interval
ii. Random frequency modulation due to varying Doppler shifts on different multipath signals
iii. Time dispersion (echoes) caused by multi-path propagation delays.

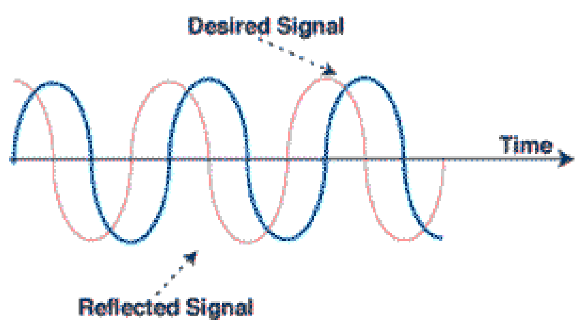


Fig. 1.2 Phase Difference between Original and Reflected Wave

In built-up urban areas, fading occurs since the height of the mobile antennas are well below the height of surrounding structures, hence there is no single line-of-sight path to the base station. Even when a line-of-sight exists, multipath still occurs due to reflections from the ground and surrounding structures. The incoming radio waves arrive from different directions with different propagation delays. The signal received by the mobile at any point in space may consist of a large number of plane waves having randomly distributed amplitudes, phases and angles of arrival. These multipath components combine in a vectorial manner at the receiver antenna and can cause the signal received by the mobile to distort or fade. Even when a mobile receiver is stationary, the received signal may fade because of movement of surrounding objects in the radio channel. If objects are static in the radio channel, and motion is considered to be due to mobile, then fading is purely a spatial phenomenon.

3.1.1 Factors Affecting Small Scale Fading

The physical factors in the radio propagation channel influencing small scale fading are:

i. **Multi-Path Propagation**: The presence of reflecting objects and scattering in the channel creates a constantly changing environment that dissipates the signal energy in amplitude, phase and time. The random phase and amplitudes of different multipath components cause fluctuations in signal strength, thereby inducing small scale fading, signal distortion or both. Multipath propagation often lengthens the time required for the baseband portion of the signal to reach the receiver which can cause signal smearing due to inter-symbol interference.

ii. **Speed of the Mobile:** The relative motion between the base station and the mobile results in random frequency modulation due to different Doppler shifts on each of the multipath component. Doppler shift will be positive or negative depending on whether the mobile receiver is moving toward or away from the base station.

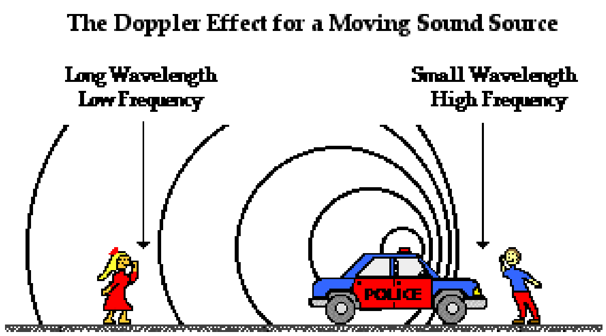


Fig. 1.3 The Doppler Effect for a Moving Sound

Source: Spring 07- CS 527 – Lecture 3

iii. **Speed of Surrounding Objects:** If objects in the radio channel are in motion, they induce a time varying Doppler shift on multipath components. If the surrounding object moves at a greater rate than the mobile, then this effect dominates the small scale fading. Otherwise, motion of surrounding objects may be ignored, and only the speed of the mobile need be considered.

iv. **The Transmission Bandwidth of the Signal:** If the transmitted radio signal bandwidth is greater than the "bandwidth" of the multipath channel, the received signal will be distorted, but the received signal strength will not fade much over a local area (i.e. the small scale fading will not be significant). If the transmitted signal has a narrow bandwidth as compared with the channel, the amplitude of the signal will change rapidly, but the signal will not be distorted in time. Thus, the statistics of small-scale signal strength and the likelihood of signal smearing over small-scale distance are much related to the specific amplitudes and delays of the multipath channel, as well as the bandwidth of the transmitted signal.

3.1.2 Multi-Path Fading Channel Models

The received signal

$$r\ t \quad \sum_{n\ 1}^{N\ t} \ {}_n\ t\ e^{\ j2\ fc\ n\ t}\ x\ t \quad {}_n\ t$$

${}_n\ t$ represents the amplitude fluctuation introduced to the transmitted signal by the nth scatterer at time t

f_c is the carrier frequency

${}_n\ t$ is the associated propagation delay

t denotes the Dirac delta function

$N\ t$ denotes the number of scatterers at time t

The channel output $r\ t$ (Time variant Channel)

$$r\ t \quad c\ t \quad x\ t \quad \int c\ \ ,t\ x\ t \quad d$$

Impulse response of a multi-path model

$$c\ \ ,t \quad \sum_{n\ 1}^{N\ t} \ {}_n\ t\ e^{\ j2\ fc\ n\ t} \qquad {}_n\ t$$

Source: NUS- Statistical Modeling and characterization of Fading Channel

3.1.3 Concept of Doppler

Just as a train whistles or car horn appears to have a different pitch, depending on whether it is moving toward or away from one's location, radio waves demonstrate the same phenomenon. If a receiver is moving toward the source, then the zero crossings of the signal appear faster, and consequently, the received frequency is higher. The opposite effect occurs if the receiver is moving away from the source. The resulting change in frequency is known as the Doppler shift.

Let the *n*-th reflected wave with amplitude c_n and phase ϕ_n arrive from an angle α_n relative to the direction of the motion of the antenna.

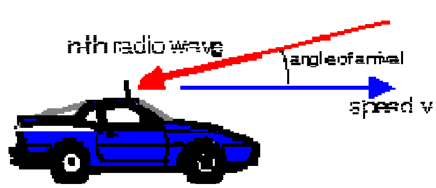


Fig. 1.4 Doppler Shift

The Doppler shift of this wave is

$$f_n \quad f_D \quad \frac{f_0}{c} v\cos$$

where f_0 is the carrier transmission frequency, v is the speed of the antenna

Exercise 1.1

An aircraft is headed toward an airport control tower with a speed of 500km/h at an elevation of 20^0. Safety communications between the aircraft tower and the plane occur at frequency of approximately 128MHz. What is the expected Doppler shift of the received signal?

Solution:

The velocity of the aircraft in the direction away from the tower is

v = -500km/hr x cos 200 = -130m/s

Speed of light = 3 x 10^8

The corresponding Doppler shift is

$$f_D \quad \frac{f_0}{c} v\cos \quad \frac{128 \quad 10^6}{3 \quad 10^8} \quad 130 \quad 55Hz$$

If the plane banks suddenly and heads in the other direction, the Doppler shift will change from 55Hz to -55Hz. This rapid change in frequency, df_D/dt, is sometimes referred to as frequency slewing. A good mobile receiver must be capable of tracking the frequency slew rates that can be generated by the receiving motion.

Exercise 1.2

Given a transmitter which radiates a sinusoidal carrier frequency of 1850 MHz. For a vehicle moving at 60mph, calculate the received carrier frequency if the mobile is moving (i) directly toward the transmitter, (ii) directly away from the transmitter, and (iii) in a direction which is perpendicular to the direction of arrival of the transmitted signal.

Solution:

Given that Carrier frequency f_c = 1850MHz

Hence, wavelength $\frac{c}{f_c} \quad \frac{3 \quad 10^8}{1850 \quad 10^6} \quad 0.162m$

Vehicle speed v =60mph = 26.82m/s

i. The vehicle is moving directly towards the transmitter.
The Doppler shift in this case will be positive and the received frequency will be given by

$$f \quad f_c \quad f_d \quad 1850 \quad 10^6 \quad \frac{3 \quad 10^8}{1850 \quad 10^6}$$

$$f \quad 1850.00016 MHz$$

ii. The vehicle is moving directly away from the transmitter.
The Doppler shift in this case will be negative and therefore, the received frequency will be given by

$$f \quad f_c \quad f_d \quad 1850 \quad 10^6 \quad \frac{3 \quad 10^8}{1850 \quad 10^6}$$

$$f \quad 1849.999834 MHz$$

iii. The vehicle is moving perpendicular to the angle of arrival of the transmitted signal. In this case, $\quad 90^0$, cos $\quad = 0$, and hence, there is no Doppler shift. Thus, in this case, the received signal frequency will remain same as the transmitted frequency of 1850MHz.

4.0 CONCLUSION

In wireless communications, fading is deviation or the attenuation that a carrier-modulated telecommunication signal experiences over certain propagation media. The fading may vary with time, geographical position and/or radio frequency, and is often modeled as a random process. Fading may be due to multipath propagation, referred to as multipath induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading.

5.0 SUMMARY

The main points in this unit are:

Multipath in the radio channel produces three important fading effects which are:

(i) Rapid changes in signal strength over a small travel distance or time interva (ii) Random frequency modulation due to varying Doppler shifts on different multipath signals (iii) Time dispersion (echoes) caused by multipath propagation delays.
Even when mobile is stationary, the received signals may fade due to movement of surrounding objects.

The physical factors in the radio propagation channel influencing small-scale fading are: Multipath propagation, speed of the mobile, speed of surrounding objects, the transmission bandwidth of the signal.

The Doppler shift can be expressed as

$$f_n \qquad f_D \qquad \frac{f_0}{c} v \cos$$

where f_0 is the carrier transmission frequency, v is the speed of the antenna.

SELF ASSESSMENT EXERCISE

Explain four factors affecting small-scale fading

6.0 TUTOR-MARKED ASSIGNMENT

1. What is Doppler effect? Explain
2. What do you understand by small scale fading
3. Identify the three important effects of multipath in the radio channel

7.0 REFERENCES/FURTHER READING

Linnartz, J. M. G. (1996). *Wireless Communication*. Baitzer Science Publishers.

Molisch, A. F. (2005): *Wireless Communications*. Wiley & Associates.

Rappaport, T. S. (2005). *Wireless Communication: Principles and Practice*. (2nd ed.). India: Prentice Hall.

Sharma, S. (2007). *Wireless and Cellular Communication*. New Delhi: S. K. Kataria & Sons.

UNIT 2 TYPES OF SMALL SCALE FADING

CONTENTS

1.0 INTRODUCTION

The presence of reflectors in the environment surrounding a transmitter and receiver create multiple paths that a transmitted signal can traverse.

As a result, the receiver sees the superposition of multiple copies of the transmitted signal, each traversing a different path. Each signal copy will experience differences in attenuation, delay and phase shift while traveling from the source to the receiver. This can result in either constructive or destructive interference, amplifying or attenuating the signal power seen at the receiver. Strong destructive interference is frequently referred to as a deep fade and may result in temporary failure of communication due to a severe drop in the channel signal-to-noise ratio.

A common example of multipath fading is the experience of stopping at a traffic light and hearing an FM broadcast degenerate into static, while the signal is re-acquired if the vehicle moves only a fraction of a meter.

The loss of the broadcast is caused by the vehicle stopping at a point where the signal experienced severe destructive interference. Cellular phones can also exhibit similar momentary fades.

Fading channel models are often used to model the effects of electromagnetic transmission of information over the air in cellular networks and broadcast communication. Fading channel models are also used in underwater acoustic communications to model the distortion caused by the water. Mathematically, fading is usually modeled as a time-varying random change in the amplitude and phase of the transmitted signal.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- mention two types of small scale fading
- explain fading effects due to Doppler spread
- discuss fading effect due to multipath time delay spread.

3.0 MAIN CONTENT

3.1 Types of Small Scale Fading

The type of fading experienced by signal propagating through a mobile radio channel depends upon the nature of the transmitted signal with respect to the characteristics of the channel. Depending on the relation between the signal parameters and the channel parameters, different transmitted signals will undergo different types of fading.

- Fading Effects due to Multipath Time Delay Spread
- Fading Effects due to Doppler Spread

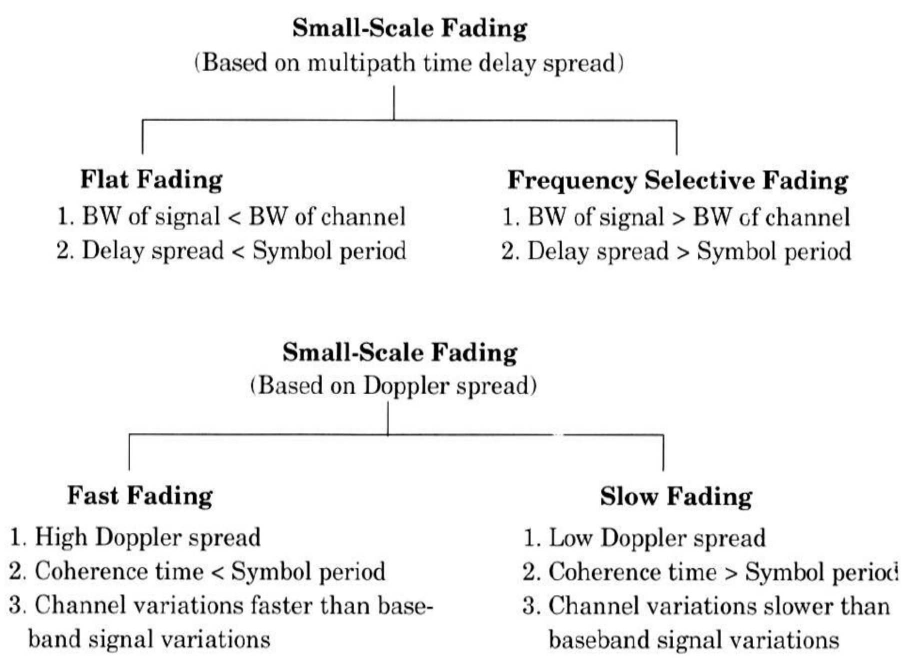


Fig. 2.1 Illustration of Types of Small Scale Fading

3.1.1 Fading Effects Due to Multi-Path Time Delay Spread

As the carrier frequency of a signal is varied, the magnitude of the change in amplitude will vary. The coherence bandwidth measures the separation in frequency after which two signals will experience uncorrelated fading. Because of time dispersion, multipath caused the transmitted signal to experience either flat or frequency selective fading

i. Flat Fading

In flat fading, the coherence bandwidth of the channel is larger than the bandwidth of the signal. Therefore, all frequency components of the signal will experience the same magnitude of fading. That is if the mobile radio channel exhibits a constant gain and linear phase response over a bandwidth which is greater than the bandwidth of the transmitted signal, then the received signal will experience flat fading. In flat fading, the multipath structure of the channel is such that the spectral characteristics of the transmitted signal are preserved at the receiver. However, the strength of the signal changes with time, because of fluctuations in the gain of the channel created by multipath. Flat fading channels are also referred to as amplitude varying channel or narrowband channel.

ii. Frequency Selective Fading

In frequency-selective fading, the coherence bandwidth of the channel is smaller than the bandwidth of the signal. Different frequency components of the signal therefore experience decorrelated fading. That is if the channel possesses a constant-gain and linear phase response over a bandwidth that is smaller than the bandwidth of transmitted signal, then the channel creates frequency selective fading on the received signal. Under such conditions, the channel impulse response has a multipath delay spread which is greater than the reciprocal bandwidth of the transmitted message waveform. When this occurs, the received signal includes multiple versions of the transmitted waveform which are attenuated (faded) and delayed in time, and hence the received signal is distorted. Frequency selective fading is due to time dispersion of the transmitted symbols within the channel.

Since different frequency components of the signal are affected independently, it is highly unlikely that all parts of the signal will be simultaneously affected by a deep fade. Certain modulation schemes such as OFDM and CDMA are well-suited to employing frequency diversity to provide robustness to fading. OFDM divides the wideband signal into many slowly modulated narrowband subcarriers, each exposed to flat fading rather than frequency selective fading. This can be combated by means of error coding, simple equalization or adaptive bit loading. Inter-symbol interference is avoided by introducing a guard interval between the symbols. CDMA uses the Rake receiver to deal with each echo separately.

Frequency-selective fading channels are also *dispersive*, in that the signal energy associated with each symbol is spread out in time. This causes transmitted symbols that are adjacent in time to interfere with each other. Equalisers are often deployed in such channels to compensate for the effects of the intersymbol interference.

The echoes may also be exposed to Doppler shift, resulting in a time varying channel model.

3.1.2 Fading Effects Due to Doppler Spread

Depending on how rapidly the transmitted baseband signal changes as compared to the rate of change of the channel, a channel may be classified either as a fast fading or slow fading channel. The terms slow and fast fading refer to the rate at which the magnitude and phase change imposed by the channel on the signal changes. The coherence time is a measure of the minimum time required for the magnitude change of the channel to become decorrelated from its previous value.

> **Slow Fading:** In Slow fading channel, the impulse response changes at a rate much slower than the transmitted baseband signal. In this case, the channel may be assumed to be static over one or several reciprocal bandwidth interval. In frequency domain, this implies that the Doppler spread of the channel is much less than the bandwidth of the baseband signals.

Slow fading arises when the coherence time of the channel is large relative to the delay constraint of the channel. In this regime, the amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver. The amplitude change caused by shadowing is often modeled using a log-normal distribution with a standard deviation according to the log-distance path loss model.

> **Fast Fading:** In fast fading channel, the channel response changes rapidly within the symbol duration. That is the coherence time of the channel is smaller than the symbol period of the transmitted signal. This causes frequency dispersion (also called time selective fading) due to Doppler spreading, which leads to

signal distortion. When viewed in the frequency domain, signal distortion due to fast fading increases with increasing Doppler spread relative to the bandwidth of transmitted signal.

In a fast-fading channel, the transmitter may take advantage of the variations in the channel conditions using time diversity to help increase robustness of the communication to a temporary deep fade. Although a deep fade may temporarily erase some of the information transmitted, use of an error-correcting code coupled with successfully transmitted bits during other time instances (interleaving) can allow for the erased bits to be recovered. In a slow-fading channel, it is not possible to use time diversity because the transmitter sees only a single realisation of the channel within its delay constraint. A deep fade therefore lasts the entire duration of transmission and cannot be mitigated using coding.

The coherence time of the channel is related to a quantity known as the Doppler spread of the channel. When a user (or reflectors in its environment) is moving, the user's velocity causes a shift in the frequency of the signal transmitted along each signal path. This phenomenon is known as the Doppler shift. Signals traveling along different paths can have different Doppler shifts, corresponding to different rates of change in phase. The difference in Doppler shifts between different signal components contributing to a single fading channel tap is known as the Doppler spread. Channels with a large Doppler spread have signal components that are each changing independently in phase over time. Since fading depends on whether signal components add constructively or destructively, such channels have a very short coherence time.

In general, coherence time is inversely related to Doppler spread, typically expressed as:

$$T_c \quad \frac{k}{D_s}$$

where T_c is the coherence time, D_s is the Doppler spread, and k is a constant taking on values in the range of 0.25 to 0.5.

3.2 Mitigation

Fading can cause poor performance in a communication system because it can result in a loss of signal power without reducing the power of the noise. This signal loss can be over some or all of the signal bandwidth.

Fading can also be a problem as it changes over time: communication systems are often designed to adapt to such impairments, but the fading can change faster than when adaptations are made. In such cases, the probability of experiencing a fade (and associated bit errors as the signal-to-noise ratio drops) on the channel becomes the limiting factor in the link's performance.

RF multipath problems can be mitigated in a number of ways:

(i) Radio system design: redundant paths for each receiver, if at all possible.
(ii) Antenna system design: dual diversity antennas used at each receiver, as a minimum.
(iii) Signal/waveform design: spread spectrum radio design with the highest feasible chip rate.
iv) Building/environment design: not much can be done in this area, unless new "RF Friendly" buildings are constructed.

The effects of fading can be combated by using diversity to transmit the signal over multiple channels that experience independent fading and coherently combining them at the receiver. The probability of experiencing a fade in this composite channel is then proportional to the probability that all the component channels simultaneously experience a fade, a much more unlikely event.

Diversity can be achieved in time, frequency, or space. Common techniques used to overcome signal fading include:

Diversity reception and transmission
OFDM (orthogonal frequency division multiplexing)
Rake receivers
Space–time codes
MIMO (multiple-input multiple-output)

4.0 CONCLUSION

In this unit we have discussed the two types of small scale fading which are fading effects due to multipath time delay spread and fading effects due to Doppler spread.

9.0 SUMMARY

In this unit, you have learnt that:

- Fading channel models are often used to model the effects of electromagnetic transmission of information over the air in cellular networks and broadcast communication.
- The two types of small scale fading are fading effect due to multipath time delay spread and fading effect due to Doppler spread
- Fading effect due to multipath time delay spread causes the signal to experience either flat or frequency selective fading
- In flat fading, the coherence bandwidth of the channel is larger than the bandwidth of the signal.
- In frequency-selective fading, the coherence bandwidth of the channel is smaller than the bandwidth of the signal.
- Fading effect due to Doppler spread may be classified either as a fast fading or slow fading channel
- In Slow fading channel, the impulse response changes at a rate much slower than the transmitted baseband signal.
- In fast fading channel, the channel response changes rapidly within the symbol duration.

SELF ASSESSMENT EXERCISE

Mention two types of small scale fading

10.0 TUTOR-MARKED ASSIGNMENT

1. Explain briefly slow and fast fading
2. Write short note on fading effects due to multipath time delay spread.

7.0 REFERENCES/FURTHER READING

Molisch, A. F. (2005). *Wireless Communications*. Wiley & Associates.

Rappaport, T. S. (2005). *Wireless Communication :Principles and Practice.* (2nd ed.). India: Prentice Hall.

Sharma, S. (2007). *Wireless and Cellular Communication*. New Delhi: S. K. Kataria & Sons.

UNIT 3 SMALL SCALE FADING: RICIAN, RAYLEIGH AND NAKAGAMI

CONTENTS

1.0 INTRODUCTION

Small Scale fading results from the fact that the propagation channel consists of several obstacles and reflectors.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- discuss on the small scale fading models
- list examples of fading models
- differentiate between the fading models.

3.0 MAIN CONTENT

3.1 Fading Models/Local Propagation Effects with Mobile Radio

Most mobile communication systems are used in and around centers of population. The major difficulties are caused by the fact that the mobile antenna is well below the surrounding buildings. Thus, most communication is via scattering of electromagnetic waves from surfaces or diffraction over and around buildings. These multiple propagation paths or multipaths have both slow and fast aspects:

i. Slow-fading arises from the fact that most of the large reflectors and diffracting objects along the transmission path are distant from the terminal. The motion of the terminal relative to these distant objects is small. Consequently, the corresponding propagation changes are slow. These factors contribute to the median path losses between a fixed transmitter and a fixed receiver. The slow fading also referred to as shadowing or log-normal fading.

ii. Fast fading is the rapid variation of signal levels when the user terminal moves short distances. Fast fading is due to reflection of local objects and the motion of terminal relative to those objects. That is, the received signal is the sum of a number of signals reflected from local surfaces, and these signals sum in a signals constructive and destructive manner depending on their relative phase relationships.

Examples of fading models for the distribution of the attenuation are:

Rician fading
Rayleigh fading
Nakagami fading
Log-normal shadow fading
Weibull fading: is a simple statistical model of fading used in wireless communications and based on the Weibull distribution. It is an effective model in both indoor and outdoor environments
Dispersive fading models, with several echoes, each exposed to different delay, gain and phase shift, often constant. This results in frequency selective fading and inter-symbol interference. The gains may be Rayleigh or Rician distributed. The echoes may also be exposed to Doppler shift, resulting in a time varying channel model.

3.1.1 Rician Fading

Rician fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself , the signal arrives at the receiver by two different paths and at least one of the paths is changing (lengthening or shortening). Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution.

The model behind Rician fading is similar to that of Rayleigh fading, except that in Rician fading a strong dominant component is present.

This dominant component can for instance be the line-of-sight wave. Refined Rician models also consider that:

the dominant wave can be a phasor sum of two or more dominant signals, e.g. the line-of-sight, plus a ground reflection. This combined signal is then mostly treated as a deterministic (fully predictable) process, and that

the dominant wave can also be subject to shadow attenuation. This is a popular assumption in the modeling of satellite channels.

Besides the dominant component, the mobile antenna receives a large number of reflected and scattered waves.

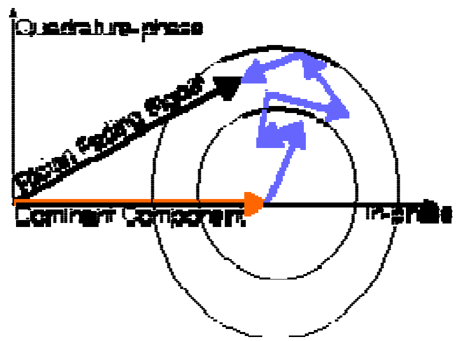


Fig. 3.1 Phasor Diagram of Rician Fading

Rician fading happens when

there is a dominant signal component such as LOS.

random components arriving at different angles are superimposed on a stationary signal i.e. a component is essentially added to the multipath.

Signal Model

A narrowband propagation channel can be model by considering a sinusoidal transmitted carrier: $s(t) = \cos w_c t$

This signal received over a Rician multipath channel can be expressed as $v(t) = C \cos w_t t + \sum_{n=1}^{N} r_n \cos(w_c t + f_n)$

where

C is the amplitude of the line-of-sight component

rn is the amplitude of the n-th reflected wave

fn is the phase of the n-th reflected wave

$n = 1$ .. N identify the reflected, scattered waves.

Rayleigh fading is recovered for $C = 0$
The Rician K-factor is defined as the ratio of signal power in dominant component over the (local-mean) scattered power.

$$K \quad \frac{C^2/2}{{}^2} \quad \frac{\textit{direct power}}{\textit{scattered power}}$$

In the expression for the received signal, the power in the line-of-sight equals $C^2/2$. In indoor channels with an unobstructed line-of-sight between transmitting and receiving antennas the K-factor is between, say, 4 and 12 dB. Rayleigh fading is recovered for $K = 0$ (-infinity dB).

Rician Channels

Examples of Rician fading are found in

Microcellular channels
Vehicle to Vehicle communication, e.g., for AVCS
Indoor propagation
Satellite channels

3.1.2 Rayleigh Fading

Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal. It is a specialised model for stochastic fading when there is no line of sight signal, and is sometimes considered as a special case of the more generalised concept of Rician fading. In Rayleigh fading, the amplitude gain is characterised by a Rayleigh distribution. Rayleigh fading models assume that the magnitude of a signal that passed through a communications channel will vary randomly, or fade, according to a Rayleigh distribution (i.e. the radial component of the sum of two uncorrelated Gaussian random variables).

Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. If there is a dominant line of sight, Rician fading may be more applicable.

Rayleigh fading is caused by multipath reception. The mobile antenna receives a large number, say N, reflected and scattered waves. As a result of wave cancellation effects, the instantaneous received power seen by a moving antenna becomes a random variable, dependent on the location of the antenna.

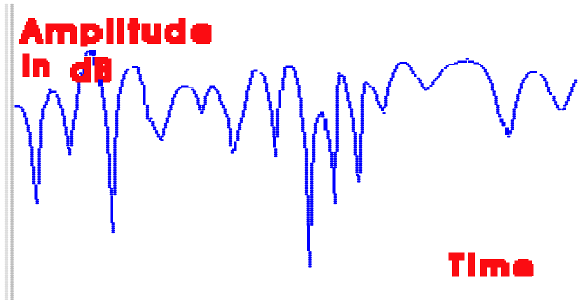


Fig. 3.2 A Sample of a Rayleigh Fading Signal

Signal amplitude (in dB) versus time for an antenna moving at constant velocity.

Deep fades occur occasionally but it have the tendency to occur approximately every half a wavelength of motion. Also, if the antenna speed is set to zero, channel fluctuations will no longer occur. Fading is due to motion of the antenna but an exception occurs if reflecting objects move. In a vehicular cellular phone system, the user is likely to move out of a fade, but in a Wireless LAN, a terminal may by accident be placed permanently in a fade where no reliable coverage is available.

Rayleigh fading happens when:

- flat fading or narrowband mobile radio channel bandwidth of applied signal is narrow compared to channel bandwidth.
- either transmitter or receiver is immersed in cluttered surrounding so that there is no LOS component.

The Model

Rayleigh fading is a reasonable model when there are many objects in the environment that scatter the radio signal before it arrives at the receiver. The central limit theorem holds that, if there is sufficiently much scatter, the channel impulse response will be well-modeled as a Gaussian process irrespective of the distribution of the individual components. If there is no dominant component to the scatter, then such a process will have zero mean and phase evenly distributed between 0 and 2π radians. The envelope of the channel response will therefore be Rayleigh distributed.

It is called random variable R; it will have a probability density function:

$$P_R(r) = \frac{2r}{\Omega} e^{-r^2/\Omega}, \quad r \geq 0$$

where $\Omega = E(R^2)$.

3.1.2.1 Rayleigh Fading Simulator

Narrowband Rayleigh fading is modeled often as a random process that multiplies the radio signal by a complex-valued Gaussian random function. The spectrum of this random function is determined by the Doppler spread of the channel. Thus one can generate two appropriately filtered Gaussian noise signals and use these to modulate the signal and a 90 degree phase shifted version of the signal.

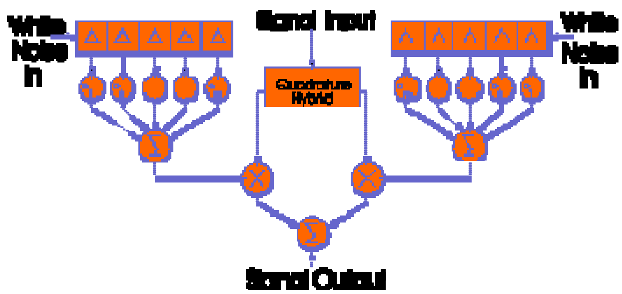


Fig. 3.4 Block Diagram of a Narrowband Rayleigh Fading Simulator (in baseband)

Source: Linnartz J. (2009)

3.1.2.2 Jakes' Simulator

It is common practice to generate two filtered noise components by adding a set of six or more sinusoidal signals. Their frequencies are chosen as to approximate the typical U-shaped Doppler spectrum.

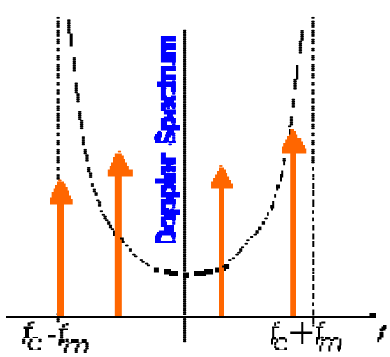


Fig. 3.5 Crude Approximation (Orange) of the Theoretical Doppler Spectr1m (Black) Used in Animation Taking Only 4 Components (*N*=3)

Source: Linnartz J. (2009)

N frequency components are taken as

$$f_i \quad f_m \cos\frac{2}{2\;2N \quad 1} \quad \textit{with } i \quad 1,2,\ldots,N$$

This specific set of frequencies is chosen to approximate the U-shaped Doppler spectrum. All amplitudes are taken equal to unity. One component at the maximum Doppler shift is also added, but at amplitude of $1/\sqrt{2}$,i.e., at about 0.707 . Jakes suggests using 8 sinusoidal signals.

3.1.2.3 Frequency Domain Simulator

Many channel simulation models follow the narrowband model. Wideband channels are often simulated by extending the model assuming multiple time-delayed resolvable paths. This allows the simulation of the channel impulse response, including its stochastic behavior. To determine the performance of a multicarrier, OFDM or MC-CDMA system, another approach can be to model a set of fading subchannels. Considering a single subcarrier, the channel may be modeled as a narrowband fading channel, for instance with Rician or Rayleigh amplitude distributions. The collection of multiple subcarriers can be modeled as a set of mutually dependent fading channels.

3.1.3 Nakagami Fading

Besides Rayleigh and Rician fading, refined models for the probability density function (pdf) of signal amplitude exposed to mobile fading is Nakagami fading.

Nakagami Math

The distribution of the amplitude and signal power can be used to find probabilities on signal outages.

- If the envelope is Nakagami distributed, the corresponding instantaneous power is gamma distributed.
- The parameter m is called the 'shape factor' of the Nakagami or the gamma distribution.
- In the special case m = 1, Rayleigh fading is recovered, with an exponentially distributed instantaneous power
- For m > 1, the fluctuations of the signal strength reduce compared to Rayleigh fading.

The Nakagami fading model was initially proposed because it matched empirical results for short wave ionospheric propagation. In current wireless communication, the main role of the Nakagami model can be summarised as follows

When does Nakagami Fading occur?

- It describes the amplitude of received signal after maximum ratio diversity combining. After k-branch maximum ratio combining (MRC) with Rayleigh-fading signals, the resulting signal is Nakagami with $m = k$. MRC combining of m-Nakagami fading signals in k branches gives a Nakagami signal with shape factor mk.
- The sum of multiple independent and identically distributed (i.i.d.) Rayleigh-fading signals have a Nakagami distributed signal amplitude. This is particularly relevant to model interference from multiple sources in a cellular system.
- The Nakagami distribution matches some empirical data better than other models
- Nakagami fading occurs for multipath scattering with relatively large delay-time spreads, with different clusters of reflected waves.
- The Rician and the Nakagami model behave approximately equivalently near their mean value.

4.0 CONCLUSION

In this unit, we have discussed on the Rician fading, Rayleigh fading and Nakagami fading.

8.0 SUMMARY

In this unit, you have learnt that:

- Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others
- The model behind Rician fading is similar to that of Rayleigh fading, except that in Rician fading a strong dominant component is present. This dominant component can for instance be the line - of-sight wave.
- Rayleigh fading is caused by multipath reception.
- Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver
- Nakagami fading occurs for multipath scattering with relatively large delay-time spreads, with different clusters of reflected waves.

SELF ASSESSMENT EXERCISE

Discuss briefly Rician and Rayleigh fadings

9.0 TUTOR-MARKED ASSIGNMENT

1. Mention five examples of fading models.
2. Differentiate between Rician and Nakagami fading.
3. When does Rician fading occur?

7.0 REFERENCES/FURTHER READING

Awad, M., Wong, K. T. & Li, Z. (2008). An Integrative Overview of the Open Literature's Empirical Data on the Indoor Radiowave Channel's Temporal Properties, IEEE Transactions on Antennas & Propagation, 56, 5,1451-1468.

Linnartz, J. M. G. (1996). *Wireless Communication*, Baitzer Science Publishers.

Rappaport, T. S., *Wireless Communications: Principles and Practice*. (2nd ed.). Prentice Hall.

Tse, D. & Viswanath, P. (2005). *Fundamentals of Wireless Communication*. Cambridge University Press.

UNIT 4 SMALL SCALE FADING: THRESHOLD CROSSING FADE DURATION AND SCATTER FUNCTION

CONTENTS

15.0 INTRODUCTION

In this unit, you will learn what threshold crossing rate, fade duration, average fade duration and scatter function are.

16.0 OBJECTIVES

At the end of this unit, you should be able to:

- explain the concept threshold crossing rate
- discuss briefly on average fade duration
- write concisely on scatter function.

17.0 MAIN CONTENT

3.1 Fading

3.1.1 Threshold Crossing Rate

The average number of times per second that a fading signal crosses a certain threshold is called the threshold crossing rate. Let’s enlarge the following (orange) signal path, at the (yellow) instant when it crosses the (purple) threshold.

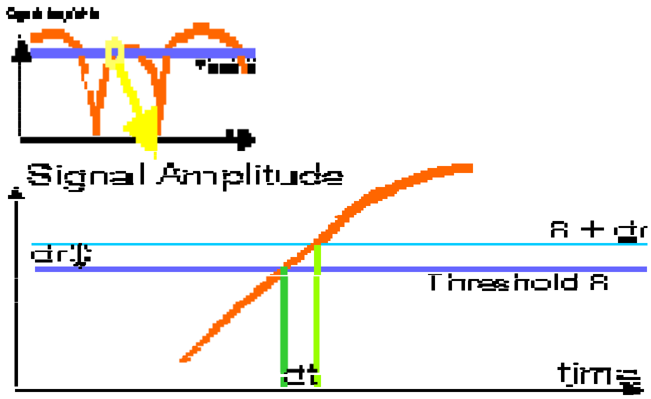


Fig. 4.1 Threshold Crossing: Threshold *R* is Crossed with Derivative *dr/dt*.

The above crossing of the threshold R with width *dr* lasts for *dt* seconds. The derivative of the signal amplitude, with respect to time, is *dr/dt*.

If the signal always crosses the threshold with the same derivative, then:

Average number of crossings per second * *dt* = Probability that the amplitude is in the interval [*R, R* + *dr*].

The probability that the signal amplitude is within the window [R, R + dr] is known from the probability density of the signal amplitude, which can for instance be Rayleigh, Rician or Nakagami. Moreover, the joint pdf of signal amplitude and its derivative can be found. For a Rayleigh-fading signal.

> The amplitude is Rayleigh, with mean equal to the local-mean power
> The derivative is zero-mean Gaussian with variance
> var = 2 * ($\;$)^2 * (Doppler spread)^2 * local-mean power

The expected number of crossings per second is found by integrating over all possible derivatives.

$$TRC \quad \frac{\sqrt{2\quad} f_D}{\sqrt{M}} \exp \quad ^{1/M}$$

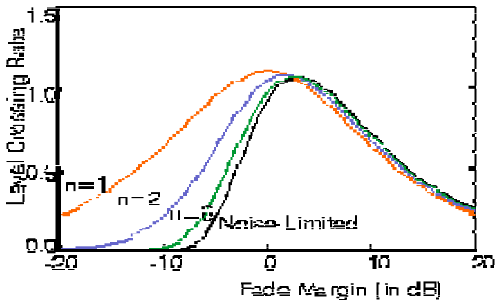


Fig. 4.2 Threshold Crossing Rate in Rayleigh Fading Channel versus Fade Duration for *n* = 1, 2, and 6 Rayleigh Fading Interfering Signals and for a Constant Noise Floor. Normalized to the Doppler Spread

Source Linnartz, J. (1996)

The TCR curve has a maximum if the local-mean-power is about as large as the threshold noise or interference power. If the signal is on average much stronger than the threshold, the number of threshold crossings (i.e., deep fades) is relatively small. Also, if the signal is much weaker than the threshold, the number of crossings is small because signals "up-fades" are unlikely.

3.1.2 Fade Duration

The mobile Rayleigh or Rician radio channel is characterized by rapidly changing channel characteristics. As the amplitude of a signal received over such a channel also fluctuates, the receiver will experience periods during which the signal cannot be recovered reliably. If a certain minimum (threshold) signal level is needed for acceptable communication performance, the received signal will experience periods of

sufficient signal strength or "non-fade intervals"", during which the receiver can work reliably and at low bit error rate
insufficient signal strength or ""fades", during which the bit error rate inevitably is close to one half (randomly guessing ones and zeros) and the receiver may even fall out of lock.

This two-state simplification of the wireless channel behavior is called a Gilbert-Elliot model.

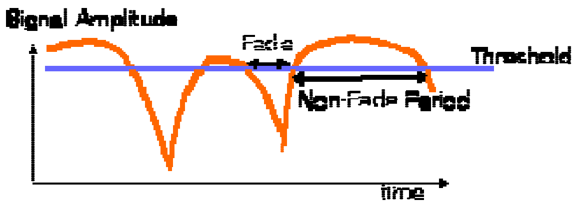


Fig. 4.3 Fade and Non-Fade Periods for a Sample of a Fading Signal

It is of critical importance to the performance of digital mobile networks that the block length or packet duration is chosen taking into account the expected duration of fades and non-fade intervals. One of two approaches can make:

the block length at least an order of magnitude longer than the average fade / non-fade period, and rely on error correction to cope with burst errors. This approach can be used for mobile reception of digital broadcast signals (e.g. DAB), particularly if the effect of fading is mitigated through using a wide transmission bandwidth and appropriate signal processing. This approach would be impractical in indoor office communication (wireless LANs) with high bit rates and extremely small Doppler spreads, i.e., with very long fade / non-fade periods.

the block length shorter than the average fade / non-fade period and retransmit lost data. This approach works best in full duplex mobile data systems and random access data systems. The effective throughput depends on two aspects: (1) the probability that a block runs into a fade and (2) the overhead bits required in block headers.

If the data block length is larger than the average non-fade period, almost all blocks will experience a signal fade and a corresponding burst of bit errors. This may result in an excessive packet dropping rate, unless powerful error correction codes are used. If the system supports a feedback signal with acknowledgments of received blocks, it is mostly advantageous to use only limited error correction coding, but to rely on retransmission of lost blocks. To minimise the number of retransmissions, one should choose the block length shorter than the average fade and non-fade period.

3.1.2.1 Average Fade Duration

The average fade duration quantifies how long the signal spends below the threshold.

Outage Probability = Average number of fades per second * Average fade duration where the average number of fades per second is called the threshold crossing rate.

Expressions for Average Non- Fade Duration

In a Rayleigh fading channel with fade margin *M*, the average non-fade duration (ANFD) is

$$ANFD \quad \frac{\sqrt{M}}{\sqrt{2}\; f_D}$$

where f_D is the Doppler spread, *M* is the ratio of the local-mean signal power and the minimum (threshold) power needed for reliable communication.

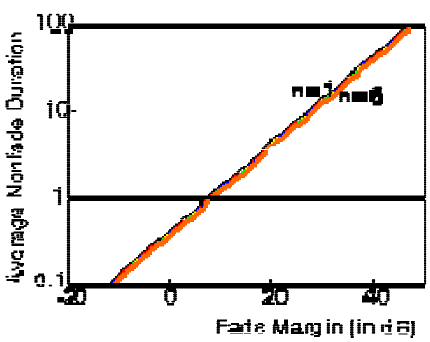


Fig. 4.4 Average Non-Fade Duration in Rayleigh Fading Channel versus Fade Margin for *n* = 1, 2, 3, 4, 5 and 6 Rayleigh Fading Interfering Signals. Normalized by Dividing by the Doppler Spread

Source Linnartz, J. (1996)

The curve for *n* = 6 closely resembles the curve of ANFD in an interference-free but noise-limited channel.

Thus,

> The ANFD is inversely proportional to the speed of the mobile user. Channel fading occurs mainly because the user moves. If the user is stationary almost no time variations of the channel occur (except if reflecting elements in the environment move)
> The ANFD increases proportional with the square root of the fade margin.
> The non-fade duration is not so sensitive to whether the signal experiences fades below a constant noise-floor or a fading interfering signal.

Calculation of the distribution of non-fade periods is tedious, but has been elaborated by Rice. Because of the shape of the Doppler spectrum, fade durations that coincide with a motion of about half a wavelength are relatively frequent.
The average fade duration (AFD) is

$$AFD \quad \frac{\sqrt{M}}{\sqrt{2}\; f_D} \exp^{1/M} \quad 1$$

Thus

> The AFD is inversely proportional to the speed of the mobile user.
> The fade durations rapidly reduce with increasing fade margin, but the time between fades increases much slower.

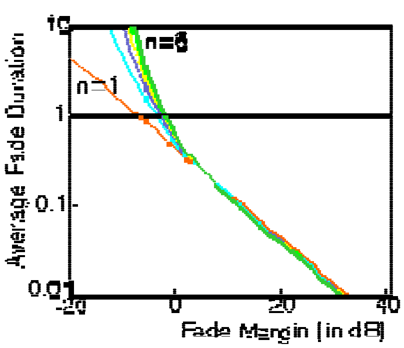


Fig. 4.5 Average Fade Duration in Rayleigh Fading Channel versus Fade Margin for *n* = 1, 2, 3, 4, 5 and 6 Rayleigh Fading Interfering Signals. Normalised by Dividing by the Doppler Spread

Source Linnartz, J. (1996)

Experiments revealed that at large fade margins, the fade durations are approximately exponentially distributed around their mean value.

For deep fades, Rice showed that for Rayleigh fading, the probability that a fade duration lasts longer than T seconds tends to

$$P \quad T \quad 2\frac{AFD}{T} I_1\left[\frac{2AFD^2}{T^2}\right]\exp\left[\frac{2AFD^2}{T^2}\right]$$

where I_1 is the modified Bessel function of the first kind. For small z, $I_1(z)$ approximates $z/2$.

3.1.3 Scatter Function

Multipath fading and user mobility lead to a time and frequency dependent channel. The Transfer function of a particular sample channel does not necessarily provide enough details about the stochastic behavior of the radio channel. Such stochastic properties are captured in the scatter function. The scatter function combines information about

Doppler spread (which relates to angles of arrival) and
Path delays.

The scatter function provides a statistical model for the channel.

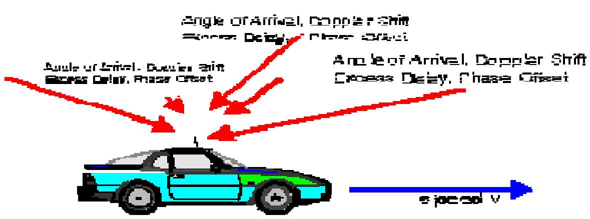


Fig. 4.6 The Basic Idea behind the Scatter Function is that it Plots the Expected Power per Doppler Shift and per Excess Delay Bin. Sometimes, Angle of Incidence (bearing) is Plotted Instead of the Doppler Shift.

Each path can be described by its

Angle of arrival or Doppler shift
Excess delay

A Practical Example

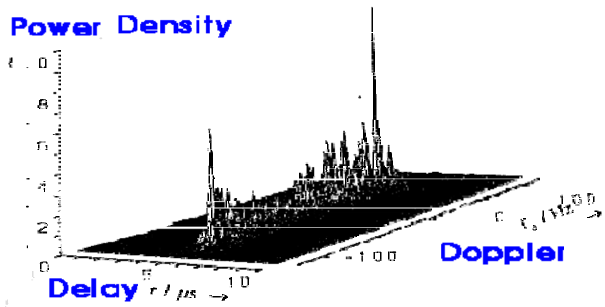


Fig. 4.7 Measured Scatter Plot for DCS 1800 MHz System

Doppler spread = 60.3 Hz; Coherence time = 5.9 msec.
Delay Spread = 1.2 msec; coherence BW = 1.3 MHz

Source Research group of Prof. Paul Walter Baier, U. of Kaiserslautern, Germany.

Theoretical Example

Let's consider a

> U-shaped Doppler spectrum, as it occurs with uniformly distributed angles of arrival of reflected waves. The maximum shift is f_m.
> an exponential delay spread with mean T_{rms}

Moreover, we assume that the delay spread and Doppler spread are separable. Then the amount of scatter power per frequency and time bin can be expressed as

$$P(f,t) = \frac{P_{local\ mean}}{4 \pi f_m} \frac{1}{\sqrt{\left(1 - \frac{(f - f_c)^2}{f_m^2}\right)}} \frac{1}{T_{rms}} \exp\left(-\frac{t}{T_{rms}}\right)$$

The integral over *p(f,t)* gives total received <u>local mean</u> power $P_{\text{local-mean}}$.

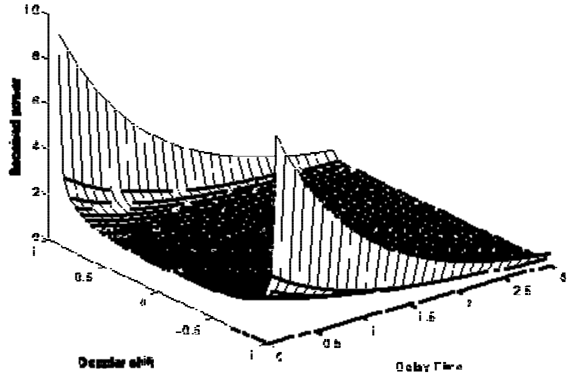


Fig. 4.8(a) **Scatter Function. Received Power per Unit of Frequency Shift and per Unit of Excess Time Delay. Frequency Shift Normalized to the Maximum Doppler Shift.**
Delay Time Normalized to the Delay Spread

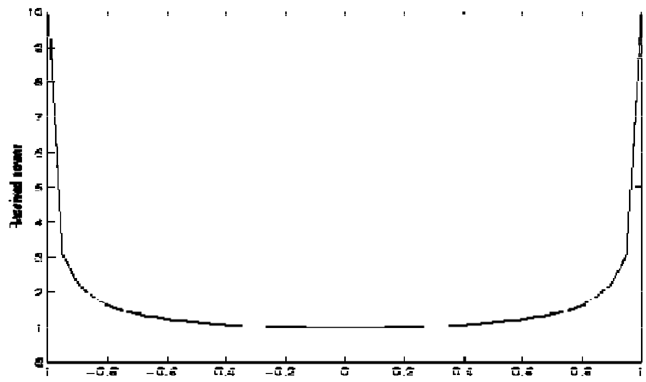


Fig. 4.8(b) **Scatter Function Projected to Frequency Axis. This Gives the Doppler Spread. Received Power per Unit of Frequency Shift. Frequency Shift Normalised to the Maximum Doppler Shift**

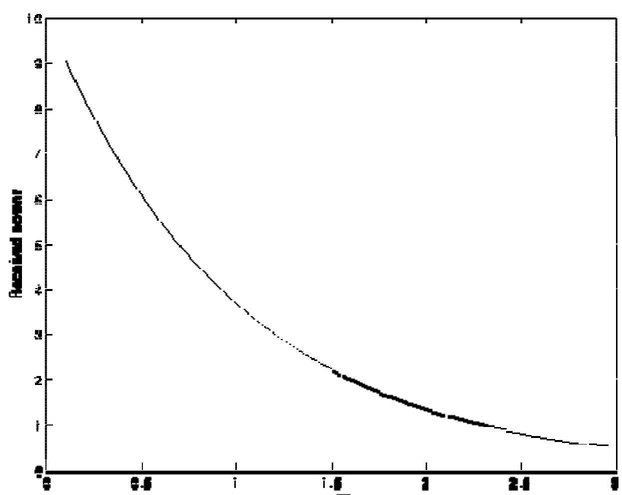


Fig. 4.8(c) Scatter Function Project to Delay Time Axis: This Gives the Delay Profile. Received Power per Unit of Excess Time Delay. Delay Time Normalised to the Delay Spread.

Source Channel simulations based on this theoretical model have been contributed by Ralph Haas (2009).

18.0 CONCLUSION

Here you learnt the concept of threshold crossing rate, average fade duration and scatter function.

19.0 SUMMARY

In this unit, you have learnt that:

Threshold crossing rate is average number of times per second that a fading signal crosses a certain threshold.

The expected number of crossings per second is found by integrating over all possible derivatives

$$TRC \quad \frac{\sqrt{2}\quad f_D}{\sqrt{M}} \exp \quad {}^{1/M}$$

The average fade duration quantifies how long the signal spends below the threshold.

The average fade duration is inversely proportional to the speed of the mobile user.

The average fade duration (AFD) is

$$AFD \quad \frac{\sqrt{M}}{\sqrt{2}\quad f_D} \exp^{1/M} \quad 1$$

The average nonfade duration (ANFD) can be expressed as

$$ANFD \quad \frac{\sqrt{M}}{\sqrt{2}\quad f_D}$$

where f_D is the Doppler spread, M is the ratio of the local-mean signal power and the minimum (threshold) power needed for reliable communication

The scatter function combines information about the Doppler spread (which relates to angles of arrival) and Path delays.

SELF ASSESSMENT EXERCISE

Write short note on threshold crossing rate

20.0 TUTOR-MARKED ASSIGNMENT

What is meant by Average fade duration and scatter function.

21.0 REFERENCE/FURTHER READING

Linnartz, J. M. G. (1996). *Wireless Communication*. Baitzer Science Publishers

UNIT 5 CHANNEL CLASSIFICATION

CONTENTS

15.0 INTRODUCTION

In previous units, we investigated the effect that various propagation phenomena have on the received electric field. From observations we can categorised these as large scale propagation effects and small scale propagation effects.

Large scale effects are due to the general terrain and the density and height of buildings and vegetation. Large-scale effects are important for predicting the coverage and availability of a particular service.

Small scale effects are due to the local environment, nearby trees, buildings etc. and the movement of the radio terminal through that environment. Small-scale effects are important for the design of the modulation format and for general transmitter and receiver design.

16.0 OBJECTIVES

At the end of this unit, you should be able to:

- define a channel
- explain different classifications of channel.

17.0 MAIN CONTENT

3.1 Channel Classification

Channel, in communications (sometimes called communications channel), refers to the medium used to convey information from a sender (or transmitter) to a receiver. Channel can be classified as follows: time-selective channels, frequency selective channels, general channels, WSSUS channels, coherence time channels, power-delay profile channels, coherence bandwidth channels, stationary and non-stationary channels.

3.1.1 Time Selective Channels

A channel is said to be Time selective, if the channel is better at selected times than at other times.

Time variations of the channel due to a relative motion between transmitter and receiver lead to a broadening of the signal spectrum.

This frequency dispersion can be characterized by the U-shaped power spectrum of isotropic scattering.

$$S_C(f) = \begin{cases} \frac{2}{\pi B_D} \frac{1}{\sqrt{1-4\frac{f^2}{B_D^2}}} & |f| < \frac{B_D}{2} \\ 0 & |f| \geq \frac{B_D}{2} \end{cases}$$

The spectral line of a pure sine wave will have a power spectrum as shown in figure 5.1 after transmission over the channel. The frequency range, where the power spectrum is nonzero defines the Doppler spread B_D. The reciprocal of B_D approximates the coherence time T_c of the channel. If we represent the channel influence as an attenuation of the signal amplitude, T_c denotes the minimum time interval between two decorrelated attenuation factors.

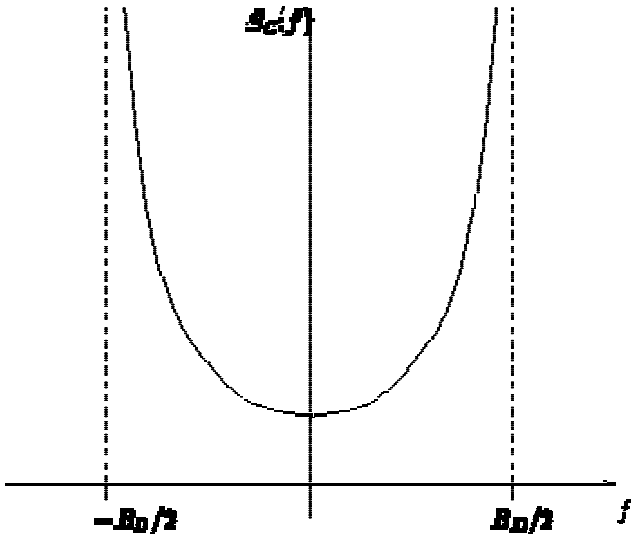


Fig. 5.1 Power Density Spectrum of a Sine Wave Suffering from a Doppler Spread

3.1.2 Frequency Selective Channels

With large-scale effects, the signal may arrive at the reeceiver via paths with different path lengths. As a result, in complex phasor notation, a model for this large-scale effect is

$$\tilde{x}\;t \qquad \sum_{i\;1}^{L} \tilde{\ }_l\,\tilde{s}\;t \qquad _l$$

where $_l$ relative delay associated with the 1[th] path and, for the moment, the complex gains $\tilde{\ }_l$ are assumed constant (due to the transmitter and receiver being physically stationary). With this channel impulse response can be represented as

$$\tilde{h}\;t, \qquad \sum_{i\;1}^{L} \tilde{\ }_l \qquad _l$$

This channel is time-invariant but it does show a frequency-dependent response.

The multipath delay spread T_m represents the time interval for which the impulse response of the channel is considerably greater than zero.

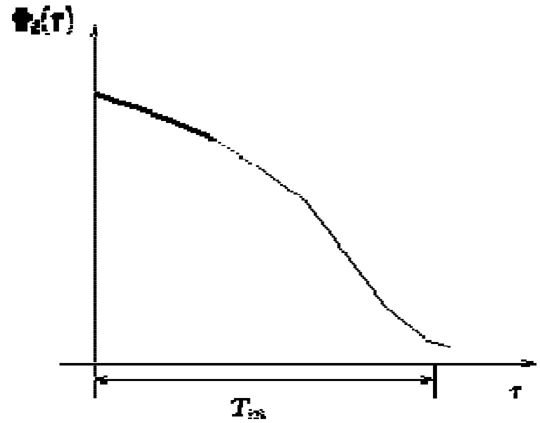


Fig. 5.2 Delay Profile Expected Received Power as a Function of Excess Delay Time

The coherence bandwidth B_c of the channel is proportional to the reciprocal of T_m. B_c denotes the maximum frequency separation of two sinusoidal signals, for which the channel affects these waves still in a highly correlated manner. This implies that a signal with a bandwidth larger than B_c will suffer from intersymbol interference. If its bandwidth is considerably smaller than B_c the channel can be considered as frequency-nonselective or "flat" fading.

3.1.3 General Channels

In a situation where the channel is neither time varying nor frequency varying such a channel is referred to as flat-flat, since the response is flat in both the time and frequency domains

3.1.4 WSSUS Channels

The mobile channel introduces delay spread into the received signal.

That is, the received signal has a longer duration than that of the transmitted signal, due to the different delays of the signal paths. This is referred to as *Time Dispersion.*

The mobile channel introduces Doppler spread into the received signal.

That is, the received signal has a larger bandwidth than that of the transmitted signal, due to the different Doppler shifts introduced by the components of the multipath. This is referred to as *Frequency Dispersion.*

Both time dispersion and frequency dispersion introduce distortion into the received signal. The amount of degradation caused by this distortion depends on how the signal is designed. Doppler spreading or frequency dispersion causes variations of the received signal in the time domain.

Of interest for the design of data transmission systems is the maximum duration for which the channel can be assumed to be approximately constant. A transmitted data symbol that has duration less than this time should suffer little distortion from the effects of frequency dispersion.

However, it will still suffer the effects of reduced signal levels.

Just as fading does in the time domain, time dispersion causes slow variations in the received signal in the frequency domain. Of interest in the design of digital transmissions systems is the maximum transmission bandwidth over which there is little variation. A signal contained within that bandwidth should suffer little distortion from the effects of time dispersion.

A random process is wide-sense stationary if it has a mean that is time independent and a correlation function. It is also assumed that, in multipath channels, the gain and phase shift at one delay are uncorrelated with the gain and phase shift at another delay. This type of behaviour is referred to as uncorrelated scattering (US). The combination of a wide-sense stationary signal and uncorrelated scattering is referred to as a wide-sense stationary uncorrelated scattering (WSSUS) channel. The wide sense stationary uncorrelated scattering (WSSUS) model is commonly used for multipath fading channels. WSSUS channel assumes that the channel correlation function is invariant over time, and that the scattering with different path delays are uncorrelated

3.1.5 Coherence Time

The coherence time is defined as the period over which there is a strong correlation of the channel time response. It is a measure of the length of time for which the channel can be assumed to be approximately constant in the time domain. Coherence time is the time over which a propagating wave may be considered coherent. In other words, it is the time interval within which its phase is, on average, predictable. In long-distance transmission systems, the coherence time may be reduced by propagation factors such as dispersion, scattering, and diffraction.

Coherence Time can be expressed as $T_{coherence} \quad \frac{1}{2 f_D}$

That is, coherence time of the channel is approximately the inverse of the Doppler spread of the channel

3.1.6 Power Delay Profile

The power delay profile (PDP) gives the intensity of a signal received through a multipath channel as a function of time delay. The time delay is the difference in travel time between multipath arrivals. The abscissa is in units of time and the ordinate is usually in decibels. It is easily measured empirically and can be used to extract certain channel's parameters such as the delay spread.

3.1.7 Coherence Bandwidth

Coherence bandwidth is a statistical measurement of the range of frequencies over which the channel can be considered “flat”, or in other words the approximate maximum bandwidth or frequency interval over which two frequencies of a signal are likely to experience comparable or correlated amplitude fading. Coherence bandwidth is a measure of the approximate bandwidth within which the channel can be assumed to be nearly constant. Coherence bandwidth of a channel is related to the autocorrelation function of the time-varying frequency response. As a result of the inverse relationship between the time and frequency domains, we have the relationship

$$BW_{coh} \quad \frac{1}{T_M}$$

That is, the coherence bandwidth is inversely proportional to the multipath spread of the channel. The coherence bandwidth of the channel is the bandwidth over which the frequency response is strongly correlated, that is, relatively flat. If the coherence bandwidth is small with respect to the bandwidth of the transmitted signal, then the channel is said to be frequency selective. When the coherence bandwidth is large with respect to the bandwidth of the transmitted signal, then the channel is said to be frequency non selective or frequency-flat.

3.1.8 Stationary and Non-Stationary Channels

The key feature of wide-sense stationary uncorrelated-scattering (WSSUS) channel is that correlation of the channel response depends only on the time difference and not on the absolute time. These stationary models for channel characteristics are convenient for analysis, but often, except for short time intervals, they are not an accurate description of reality. For example, terrestrial mobile channels are usually highly non-stationary, for the following reasons, among others:

i. The propagation “often consists of several discontinuities, such as buildings, that can cause significant changes in the propagation characteristics.
ii. The environment itself is physically non-stationary. There may be moving trucks, moving people, or other elements of the environment that can significantly affect propagation.
iii. The interference caused by other users sharing the same frequency channel will vary dynamically as these other users come onto and leave the system. All of these factors contribute to the non-stationary of the link

18.0 CONCLUSION

In this unit, you have learned about channel and classifications of wireless channel. A channel is said to be time selective, if the channel is better at selected times than at other times. The coherence time is defined as the period over which there is a strong correlation of the channel time response.

19.0 SUMMARY

In this unit, you have learnt that:

Channel refers to the medium used to convey information from a sender (or transmitter) to a receiver.

Channels are classified on the basic of the properties of the time-varying impulse response. The effects of noise are not considered in classifying channels.

Channel can be classified as follows: time-selective channels, frequency selective channels, general channels, WSSUS channels, coherence time channels, power-delay profile channels, coherence bandwidth channels, stationary and non-stationary channels.

SELF ASSESSMENT EXERCISE

What is meant by a channel?

20.0 TUTOR-MARKED ASSIGNMENT

Briefly explain any five classes of channels.

21.0 REFERENCE/FURTHER READING

Sharma, S. (2006). *Wireless and Cellular Communication.* New Delhi: S. K. Kataria & Sons.

MODULE 4 MODULATION, DIVERSITY AND MULTIPLE ACCESS TECHNIQUES

UNIT 1 INTRODUCTION TO MODULATION

CONTENTS

1.0 INTRODUCTION

The simple transmission scheme outlined in the previous units cannot be used for commercial broadcasting. If a dozen of stations all transmitted sounds by the mechanism described in the previous units, a receiving station would pick up a garbled combination of all transmissions. To prevent interference from a number of transmitting stations, all broadcast radio waves are first modulated.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define a modulation
- state the reason for modulation
- explain how a sound wave is modulated
- list clearly the four types of modulation techniques.

3.0 MAIN CONTENT

3.1 Definition of Modulation

Modulation is the process of encoding information from a message source into manner suitable for transmission. It generally involves translating a baseband message signal (called the source) to a bandpass signal at frequencies that are very high when compared to the baseband frequency. The *bandpass* signal is called the modulated signal and the *baseband* signal is called the modulating signal. Modulation may be done by varying the amplitude, phase or frequency of a high frequency carrier in accordance with the amplitude of the message signal.

Modulation may be defined as a process by which some characteristic of a signal known as carrier is varied according to the instantaneous value of another signal known as modulating signal. The signals containing intelligence or information to be transmitted are called modulating signals. These modulating signals containing information are also called baseband signals. Also the carrier frequency is greater than the modulating frequencies and the signal which results from the process of modulation is known as modulated signal.

Demodulation is the process of extracting the baseband message from the carrier so that it may be processed and interpreted by the intended receiver (also called sink). It is the process of extracting a modulating or baseband signal from the modulated signal. In other word, demodulation is the process by which the message is recovered from the modulated signal at the receiver.

A device that performs modulation is known as a modulator and a device that performs the inverse operation of modulation is known as a demodulator (sometimes detector *or* demod*). A* device that can do both operations is a modem (short for "Modulator-Demodulator").

3.1.1 Why Modulate?

For allowing multiple signals to share a single physical channel by Frequency Division Multiplexing

Necessary for wireless communication where the antenna diameter must be at least equal to the wavelength of the carrier signal.

This means, for a 3000 Hz signal through space, the antenna diameter must be at least 60 miles

3.1.2 Modulation Choices

The *simplest modulation* method is also the first used to transmit messages. The signal is turned on and off to transmit the characters of an agreed code. Text messages can be carried by the signal modulated in this way. Unique patterns stand for letters of the alphabet, numerals, and punctuation marks.

Amplitude modulation is the least complicated modulation method capable of transmitting speech or music by varying the carrier signal's instantaneous power. It means that the amplitude (or size) of the wave of the original sound wave has been changed by adding it to the carrier wave.

Sound waves can be modulated in such a way that their frequency is altered. For example, a sound wave can be added to a carrier signal to produce a signal with the same amplitude, but a different frequency. The sound wave has, in this case, undergone *frequency modulation (FM).*

Sound can be converted to digital data, transmitted, then used to reconstruct the original waveform in the receiver. This sound wave is a form of *digital modulation.*

3.1.3 Modulating a Sound Wave

After the sound wave has been modulated at the transmitting station, both AM and FM signals must be decoded at the receiving station. In either case, the carrier wave is electronically subtracted from the radio wave that is picked up by the receiving antenna. What remains after this process is the original sound wave, encoded, of course, as an electrical signal.

All broadcasting stations are assigned characteristic carrier frequencies by the Federal Communications Commission (FCC). This system allows a number of stations to operate in the same area without overlapping.

Thus, two stations a few kilometers apart could both be sending out exactly the same program, but they would sound different (and have different electric signals) because each had been overlaid on a different carrier signal.

Receiving stations can detect the difference between these two transmissions because they can tune their equipment to pick up only one or the other carrier frequency. When you turn the tuning knob on your own radio, for example, you are adjusting the receiver to pick up carrier waves from station A, station B, or some other station. Your radio then decodes the signal it has received by subtracting the carrier wave and converting the remaining electric signal to a sound wave.

The identifying characteristics by which you recognise a radio station reflect its two important transmitting features. The frequency, such as 101.5 megahertz (or simply "101.5 on your dial") identifies the carrier wave frequency, as described above. The power rating ("operating with 50,000 watts of power") describes the power available to transmit its signal. The higher the power of the station, the greater the distance at which its signal can be picked up.

3.1.4 Types of Modulation Techniques

Analog modulation: The aim of analog modulation is to transfer an analog baseband (or lowpass) signal, for example an audio signal or TV signal, over an analog passband channel, for example a limited radio frequency band or a cable TV network channel.

BandPass digital modulation: The aim of digital modulation is to transfer a digital bit stream over an analog passband channel, for example over the public switched telephone network (where a bandpass filter limits the frequency range to between 300 and 3400 Hz), or over a limited radio frequency band.

Digital baseband modulation or line coding modulation: The aim of digital baseband modulation methods, also known as line coding, is to transfer a digital bit stream over a baseband channel, typically a non-filtered copper wire such as a serial bus or a wired local area network.

Pulse shaping modulation: The aim of pulse modulation methods is to transfer a narrowband analog signal, for example a phone call over a wideband baseband channel or, in some of the schemes, as a bit stream over another digital transmission system.

4.0 CONCLUSION

In this unit, the term "modulation", the reason for modulation, the choices of modulation, how a sound wave is being modulated and the four modulation techniques were discussed.

5.0 SUMMARY

In this unit, you have learnt that:

Modulation is a fundamental requirement of a communication system.

Modulation may be done by varying the amplitude, phase or frequency of a high frequency carrier in accordance with the amplitude of the message signal

The four types of modulation techniques are analog modulation, digital bandpass modulation, digital baseband modulation and pulse shaping modulation.

SELF ASSESSMENT EXERCISE

What do you understand by the term modulation?

6.0 TUTOR-MARKED ASSIGNMENT

1. Briefly describe how sound wave can be modulated?
2. Mention four types of modulation techniques.
3. State two major reasons for modulation.

7.0 REFERENCES/FURTHER READING

Bloomfield, L. A. (2000). *How Things Work: The Physics of Everyday Life.* (2nd ed.). New York: John Wiley & Sons.

Davidovits, P. (1972). *Communication.* New York: Holt Rinehart & Winston Inc.

Sharma, S. (2006). *Wireless and Cellular Communications*. New Delhi: S. K. Kataria & Sons.

UNIT 2 ANALOG MODULATION TECHNIQUES

CONTENTS

1.0 INTRODUCTION

In analog modulation the carrier waveform is continuous in nature. The two families of continuous wave modulation systems are amplitude modulation and angle modulation.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- differentiate between the two types of analog modulation
- explain the meaning of angle modulation
- state the types of angle modulation
- mention the merit and demerit of FM
- compute the modulation index, frequency, deviation, carrier frequency and power of a signal.

3.0 MAIN CONTENT

3.1 Concept of Analog Modulation Techniques

In analog modulation, the modulation is applied continuously in response to the analog information signal. The aim of *analog modulation* is to transfer an analog baseband (or lowpass) signal, for example an audio signal or TV signal, over an analog passband channel, for example a limited radio frequency band or a cable TV network channel.

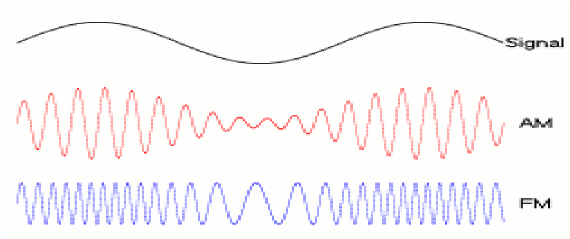


Figure 2.1 Low-Frequency Message Signal (top) May Be Carried by an AM or FM Radio Wave

Common analog modulation techniques are:

Amplitude Modulation and
Angle Modulation

3.1.1 Amplitude Modulation (AM)

AM may be defined as a system in which the maximum amplitude of the carrier wave is made proportional to the instantaneous value (amplitude) of the modulating or baseband signal. *AM* is a technique used in electronic communication, most commonly for transmitting information via a radio carrier wave. *AM* works by varying the strength of the transmitted signal in relation to the information being sent. For example, changes in the signal strength can be used to reflect the sounds to be reproduced by a speaker, or to specify the light intensity of television pixels.

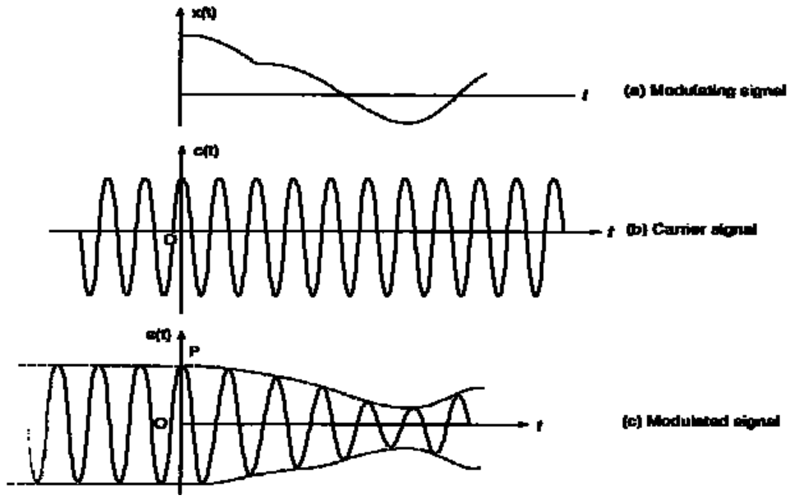


Figure 2.2 Illustration of Amplitude Modulation

Source: Sharma, S. (2006). *Wireless and Cellular Communication.*

Conventional AM

This is how a typical AM system transmitter works:

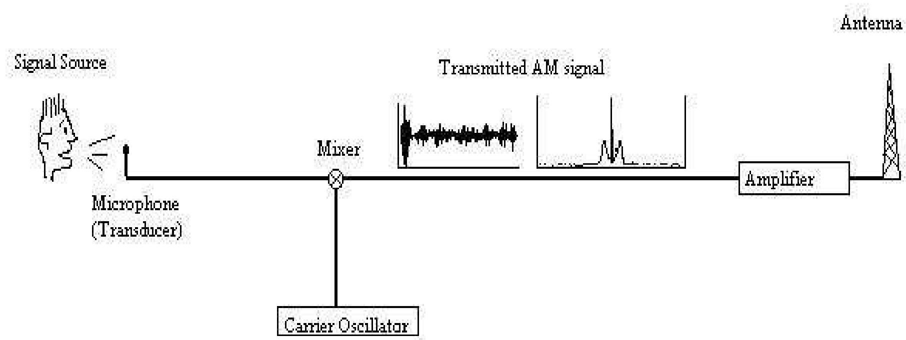


Figure 2.3 Conventional Amplitude Modulation

The information signal is mixed with the carrier signal and produces the full AM signal to be transmitted.

Transmission Efficiency of Amplitude Modulated Signal

The total modulated power of an AM signal is expressed as

$$P_t \quad P_c \quad P_s \quad \frac{1}{2} A^2 \quad \overline{x^2 \ t}$$

Out of this total power P_t, the useful message or baseband power is the power carried by the sidebands, i.e. P_s. The large carrier power P_c is a waste from the transmission point of view because it does not carry any information or message. This large carrier power P_c is transmitted along with the sideband power only for the convenient and cheap detection. Hence, Ps is the only useful message power present in the AM wave.
In AM wave, the amount of useful message power P_s may be expressed by a term known as *transmission efficiency* .

Hence, transmission efficiency of AM wave may be defined as the percentage of total power contributed by the sidebands.

Mathematically,

Transmission Efficiency, $\frac{P_s}{P_t}\ 100$ or

$$\frac{\frac{1}{2}\overline{x^2\ t}}{\frac{1}{2}A^2\quad \overline{x^2\ t}}\ 100 \qquad \frac{100\overline{x^2\ t}}{A^2\quad \overline{x^2\ t}}$$

The maximum transmission efficiency of the AM is only 33.33%. This implies that only one-third of the total power is carried by the sidebands and the rest two-third is wasted.

3.1.1.1 Types of Amplitude Modulation Techniques

(a) **Single-Sideband Modulation** (SSB, or SSB-AM): Is a refinement of amplitude modulation that uses electrical power and bandwidth. It is closely related to vestigial sideband modulation (VSB). Amplitude modulation produces a modulated output signal that has twice the bandwidth of the original baseband signal. Single-sideband modulation avoids this bandwidth doubling, and the power wasted on a carrier, at the cost of somewhat increased device complexity. The SSB Schemes are:

SSB with carrier (SSB-WC)
SSB suppressed carrier modulation (SSB-SC): is a modulation which provides a single sideband with suppressed carrier. In SSB-SC the carrier power level is suppressed to the point where it is insufficient to demodulate the signal. The information represented by the modulating signal is contained in both the upper and the lower sidebands. Since each modulating frequency f_c produces corresponding upper and lower side-frequencies

$$f_c + f_i \quad \text{and} \quad f_c - f_i$$

it is not necessary to transmit both side-bands. Either one can be suppressed at the transmitter without any loss of information.

Advantages of SSB-WC

Less transmitter power.
Less bandwidth, one-half that of Double-Sideband (DSB).
Less noise at the receiver.
Size, weight and peak antenna voltage of a single-sideband (SSB) transmitters is significantly less than that of a standard AM transmitter

The single side-band (SSB) is very simple: if you do not need two side-bands, you can get rid of one of the band. To do this, you add a band pass filter component to your system that removes the extra side-band.

This is how the SSB transmitter looks like:

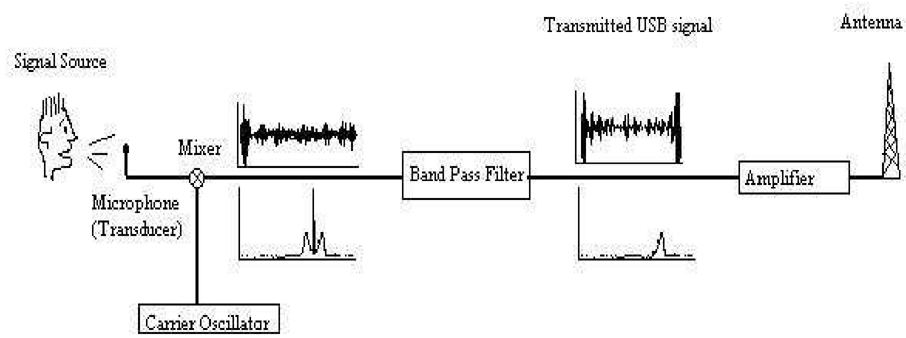


Figure 2.4 SSB Transmitter

Note that the band pass filter has removed the lower side-band (LSB) and the carrier from the spectrum. The remainder is transmitted.

The receiver cannot output the signal as it is, it must first restore the signal to what it should be before demodulation. The receiver in a SSB system has its own carrier signal (from a local oscillator) that is puts back in. The receiver looks like the diagram in figure 2.5 below:

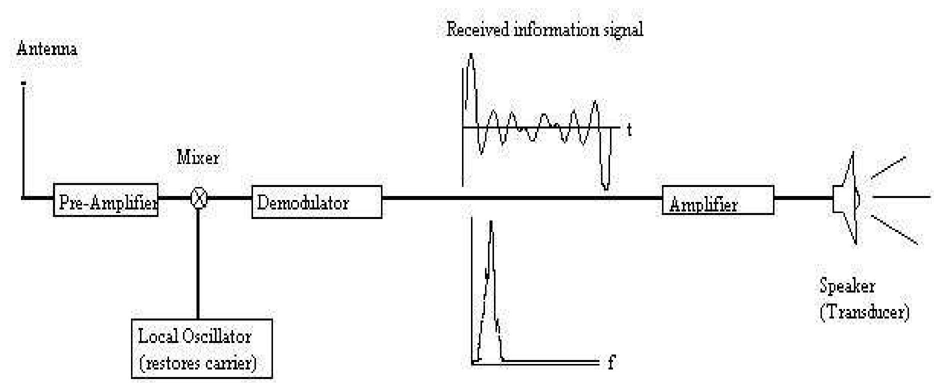


Figure 2.5 SSB Receiver

By having its own carrier signal, the receiver makes the signal back into what would be sent by a conventional AM system. The remaining signal is processed normally.

So, there are two modifications to make it work

The transmitter adds a band pass filter before amplification for transmission and

The receiver adds a local carrier signal back into the signal prior to processing.

Power of SSB-AM Signal

The Total Power of a SSB-AM can be expressed as $P_t \quad P_c\left(1 \quad \frac{m_a^2}{2}\right)$

Example 2.1

A 400 watts carrier is modulated to a depth of 75 percent. Find the total power in the amplitude-modulated wave. Assume the modulating signal to be a sinusoidal one.

Solution: We know that for a sinusoidal modulating signal, the total power is expressed as

$$P_t \quad P_c\left(1 \quad \frac{m_a^2}{2}\right)$$

where

Pt = total power or modulated power

Pc = carrier power or unmodulated power

ma = modulation index

Given that, P_c = 400watts m_a = 75 percent = 0.75

Therefore, $P_t = P_c\left(1 + \frac{m_a^2}{2}\right) = 400\left(1 + \frac{0.75^2}{2}\right) = 512.5 \, watts$

Example 2.2

An AM broadcast radio transfer radiates 10K watts of power, if modulation percentage is 60. Calculate how much of this the carrier power is.

Solution: We known that the total power is expressed as

$$P_t = P_c\left(1 + \frac{m_a^2}{2}\right)$$

where P_t = total power or modulated power

Pc = carrier power or unmodulated power

ma = modulation index

Given that, P_t = 10 K watts m_a =60 percent = 0.6

Therefore $P_c = \dfrac{P_t}{1 + \dfrac{m_a^2}{2}} = \dfrac{10}{1 + \dfrac{0.6^2}{2}}$

or $P_c = \dfrac{10}{1.18} = 8.47 \, KW$

Current Calculation for SSB AM

In AM, it is generally more convenient to measure the AM transmitter current than the power. In this case, the modulation index may be calculated from the values of unmodulated and modulated currents in the AM transmitter. Let I_c be the r.m.s value of the carrier or unmodulated current and I_t be the r.m.s value of the total or modulated current of an AM transmitter. Let R be the antenna resistance through which these currents flow.

We know that for an SSB AM the power relation is expressed as

$$P_t = P_c\left(1 + \frac{m_a^2}{2}\right)$$

where

Pt = total power or modulated power

Pc = carrier power or unmodulated power

ma = modulation index

From the above equation, we may write

$$\frac{P_t}{P_c} = 1 + \frac{m_a^2}{2}$$

or $$\frac{I_t^2 . R}{I_c^2 . R} = 1 + \frac{m_a^2}{2}$$

or $$\frac{I_t}{I_c} = \sqrt{1 + \frac{m_a^2}{2}}$$

or $$I_t = I_c \sqrt{1 + \frac{m_a^2}{2}}$$

Example 2.3

The antenna current of an AM transmitter is 8 A if only the carrier is sent, but it increases to 8.93 A if the carrier is modulated by a single sinusoidal wave. Determine the percentage modulation. Also find the antenna current if the percent of modulation changes to 0.8.

Solution: (i) The current relation for an SSB-AM is expressed as

$$I_t = I_c \sqrt{1 + \frac{m_a^2}{2}}$$

where
I_t = total or modulated current
I_c = carrier or unmodulated current
m_a = modulation index
Using the above equation, we have

$$\frac{I_t}{I_c} = \sqrt{1 + \frac{m_a^2}{2}}$$

or $$\left(\frac{I_t}{I_c}\right)^2 = 1 + \frac{m_a^2}{2}$$

or $$\frac{m_a^2}{2} = \left(\frac{I_t}{I_c}\right)^2 - 1$$

or $$m_a^2 = 2\left[\left(\frac{I_t}{I_c}\right)^2 - 1\right]$$

or $$m_a = \sqrt{2\left[\left(\frac{I_t}{I_c}\right)^2 - 1\right]}$$

Putting all the given values, we have

$$m_a = \sqrt{2\left[\left(\frac{8.93}{8}\right)^2 - 1\right]} = \sqrt{2\left(1.116^2 - 1\right)}$$

$$m_a = \sqrt{2(1.246 - 1)} = \sqrt{0.492} = 0.701 = 70.1\%$$

(ii) Since $I_t = I_c\sqrt{1 + \frac{m_a^2}{2}}$

Here, $I_c = 8A$ and $m_a = 0.8$

Therefore, $I_t = 8\sqrt{1 + \frac{0.8^2}{2}} = 8\sqrt{1 + \frac{0.64}{2}}$

or $I_t = 8\sqrt{1.32} = 8 \times 1.149 = 9.19A$

(b) Double-Sideband Modulation (DSB)

Double-sideband modulation with unsuppressed carrier (DSB-WC): is used on the AM radio broadcasting band.

Double-sideband suppressed-carrier transmission (DSB-SC): is a modulated signal, which contains no carrier but two sidebands. It is a transmission in which (a) frequencies produced by amplitude modulation are symmetrically spaced above and below the carrier frequency and (b) the carrier level is reduced to the lowest practical level, ideally completely suppressed. In the double-sideband suppressed-carrier transmission (DSB-SC) modulation, unlike AM, the wave carrier is not transmitted; thus, a great percentage of power that is dedicated to it is distributed between the sidebands, which imply an increase of the cover in DSB-SC, compared to AM, for the same power used. DSB-SC transmission is a special case of Double-sideband reduced carrier transmission. This is used for RDS (Radio Data System) because it is difficult to decouple.

Double-sideband reduced carrier transmission (DSB-RC): transmission in which (a) the frequencies produced by amplitude modulation are symmetrically spaced above and below the carrier and (b) the carrier level is reduced for transmission at a fixed level below that which is provided to the modulator. In DSB-RC transmission, the carrier is usually transmitted at a level suitable for use as a reference by the receiver, except for the case in which it is reduced to the minimum practical level, i.e. the carrier is suppressed.

(c) **Vestigial Sideband Modulation** (VSB, or VSB-AM) is a sideband that has been only partly cut off or suppressed. In VSB modulation instead of rejecting one sideband completely as in SSB modulation scheme, a gradual cut-off of one sideband is allowed. This gradual cut is compensated by a vestige or portion of the other sideband. Television broadcasts (in analog video formats) use this method if the video is transmitted in AM, due to the large bandwidth used. It may also be used in digital transmission, such as the ATSC standardized 8-VSB.

(d) **Quadrature Amplitude Modulation** (QAM) is also called Quadrature Carrier Multiplexing. This modulation scheme enables two DSC-SC modulated signals to occupy the same transmission bandwidth and therefore it allows for the separation of the two message signals at the receiver output. It is, therefore, known as a bandwidth-conservation scheme.

Problems with Conventional AM

Conventional AM transmission has several problems:

Bandwidth is wasted by having two identical side-bands on either side of the carrier

The efficiency is limited to 33% to prevent distortion in the receiver when demodulating.

The carrier signal is present even if nothing is being transmitted.

3.1.2 Angle Modulation

Angle Modulation is a class of analog modulation. Angle modulation may be defined as the process in which the total phase angle of a carrier wave is varied in accordance with the instantaneous value of the modulating or message signal while keeping the amplitude of the carrier constant. These techniques are based on altering the angle (or *phase*) of a sinusoidal carrier wave to transmit data, as opposed to varying the amplitude, such as in AM transmission. The two main types of angle modulation are: (i) Frequency modulation (FM) and (ii)Phase modulation (PM), with its digital correspondence phase-shift keying (PSK).

3.1.2.1 Types of Angle Modulation

3.1.2.1.1 Frequency Modulation (FM)

Frequency modulation conveys information over a carrier wave by varying its frequency. Here the frequency of the modulated signal is varied. The two types of frequency modulation are Single Tone frequency modulation and Multiple Frequency Modulation.

(a) **Single Tone Frequency Modulation** is a type of frequency modulation (FM) in which the modulating or baseband signal contains a single frequency.

The total variation in frequency from the lowest to the highest point is called carrier swing. Obviously,

$$\text{the Carrier Swing} \quad 2 \text{ x } \text{frequency deviation} \quad 2 \text{ x}$$

For FM, the modulation index is defined as the ratio of frequency deviation to the modulating frequency.

Mathematically,

$$\text{Modulation index, } m_f \quad \frac{\textit{Frequency deviation}}{\textit{Modulaion frequency}}$$

$$or \;\; m_f \quad \frac{}{_m}$$

This modulation index may be greater than unity.

The term “percentage modulation” as it is used in reference to FM refers to the ratio of actual frequency deviation to the maximum allowable frequency deviation. Thus 100% modulation corresponds to 75 kHz for the commercial FM broadcast band and 25 kHz for television.

$$\text{Percent modulation} \quad M \quad \frac{f_{actual}}{f_{\max}}$$

The expression for single-tone FM wave is

$$s(t) \quad A\cos \;_i \quad A\cos \;_c t \quad m_f \sin \;_m t$$

Example 2.4

A single-tone FM is represented by the voltage equation as:

$$v(t) = 12 \cos(6 \text{ x } 10^8 t + 5 \sin 1250 t)$$

Determine the following:

i. carrier frequency
ii. modulating frequency
iii. the modulation index
iv. maximum deviation
v. what power will this FM wave dissipate in 10 resistor

Solution: We know that the standard expression for a single-tone FM wave is given as v(t) = $A\cos \quad {}_c t \quad m_f \sin \quad {}_m t$ ……………………….(i)

The given expression is v(t) = 12 cos(6 x 10^8 t + 5 sin1250 t) …….(ii)

Comparing equation (i) and (ii), we get

i. Carrier frequency

$${}_c \quad 6 \quad 10^8 \text{rad/sec} \qquad \text{or} \qquad f_c \quad \frac{6 \quad 10^8}{2} \quad 95.5MHz$$

ii. modulating frequency

$${}_m \quad 1250\, rad/\sec \quad or \quad f_m \quad \frac{1250}{2} \quad 199Hz$$

iii. $m_f \quad 5$

iv. maximum frequency deviation is given as

$$m_f \quad \frac{\quad}{{}_m} \quad \frac{{}_f}{f_m}$$

or $\quad {}_f \quad m_f \quad f_m \quad 5 \quad 199 \quad 995$

v. the power dissipated is

$$P \quad \frac{V_{rms}^2}{R} \quad \frac{\left(12/\sqrt{2}\right)^2}{10} \quad \frac{72}{10} \quad 7.2watts$$

Example 2.5

What is the modulation index of an FM signal having a carrier swing of 100 kHz when the modulating signal has a frequency of 8 kHz?

Solution: Given that
carrier swing = 100 kHz
modulating frequency f_m = 8 kHz
modulating index is given as

$$m_f \quad \frac{Frequency\ deviation}{Modulaion\ \ frequency} \quad \frac{f}{f_m} \ \ldots\ldots\ldots\ldots(i)$$

but we know that

carrier swing = 2 $\quad _f$

$$_f \quad \frac{carrier\ swing}{2} \quad \frac{100}{2} \quad 50\ kHz$$

using equation (i) we get

$$m_f \quad \frac{50}{8} \quad 6.25$$

Example 2.6

An FM transmission has a frequency deviation of 20 kHz.

i. Determine the percent modulation of this signal if it is broadcasted in the 88 – 08 MHz band
ii. Calculate the percent modulation if this signal is broadcasted as the audio portion of a television broadcast.

Solution: Given that

$$_f \quad 20\ kHz$$

i. Percent modulation for an FM wave is defined as

$$M \quad \frac{f_{actual}}{f_{\max}} \quad 100$$

f_{actual} is given as 20 kHz The maximum frequency deviation

$f_{\max}$ permitted in the FM broadcast band is 75 kHz.

Thus,

$$M \quad \frac{20 \quad 10^3}{75 \quad 10^3} \quad 100 \quad 26.67\%$$

(ii) $$M \quad \frac{f_{actual}}{f_{\max}} \quad 100$$

$$_{f} \quad 20\ kHz$$

The maximum frequency deviation $f_{\max}$ permitted for FM audio portion of a TV broadcast is 25 kHz.

Thus, $$M \quad \frac{20 \quad 10^{3}}{25 \quad 10^{3}} \quad 100 \quad 80\%$$

Types of Frequency Modulation (FM)

Depending on the value of frequency sensitivity k_f, FM may be divided as:

(i) Narrowband FM: In this case, k_f is small and hence the bandwidth of FM is narrow.

(ii) Wideband FM: In this case, k_f is large and hence the FM signal has a wide bandwidth.

Application of FM

Broadcasting: FM is commonly used at VHF radio frequencies for high-fidelity broadcasts of music and speech and also for broadcasting Normal (analog) TV sound. A narrow band form is used for voice communications in commercial and amateur radio settings. The type of FM used in broadcast is generally called wide-FM, or W-FM. In two-way radio, narrowband narrow-fm (N-FM) is used to conserve bandwidth and also to send signals into space.

Sound: FM is used at audio frequencies to synthesise sound. This technique, known as FM synthesis, was popularised by early digital synthesizers and became a standard feature for several generations of personal computer sound cards

Hardware: FM is used at intermediate frequencies by all analog VCR systems, including VHS, to record both the luminance (black and white) and the chrominance portions of the video signal. FM is the only feasible method of recording video to and retrieving video from magnetic tape without extreme distortion, as video signals have a very large range of frequency components - from a few hertz to several megahertz, too wide for equalizers to work with due to electronic noise below -60 dB. FM also keeps the tape at saturation level, and therefore acts as a form of noise reduction, and a simple limiter can mask variations in the playback output, and the FM capture effect removes print-through and pre-echo.

(b) Multiple Frequency Modulations: is the type of frequency modulation (FM) in which the modulating or baseband signal contains multiple frequency.

3.1.2.1.2 Phase Modulation (PM)

Phase modulation is a form of modulation that represents information as variations in the instantaneous phase of a carrier wave. In phase modulation, the phase shift of the modulated signal is varied.

3.1.3 Comparison of Angle Modulated Wave and Amplitude Modulated Wave

Figure 2.3 shows a single tone modulating signal, a carrier signal, amplitude-modulated (AM) wave and angle-modulated (i.e. FM and PM) waves.

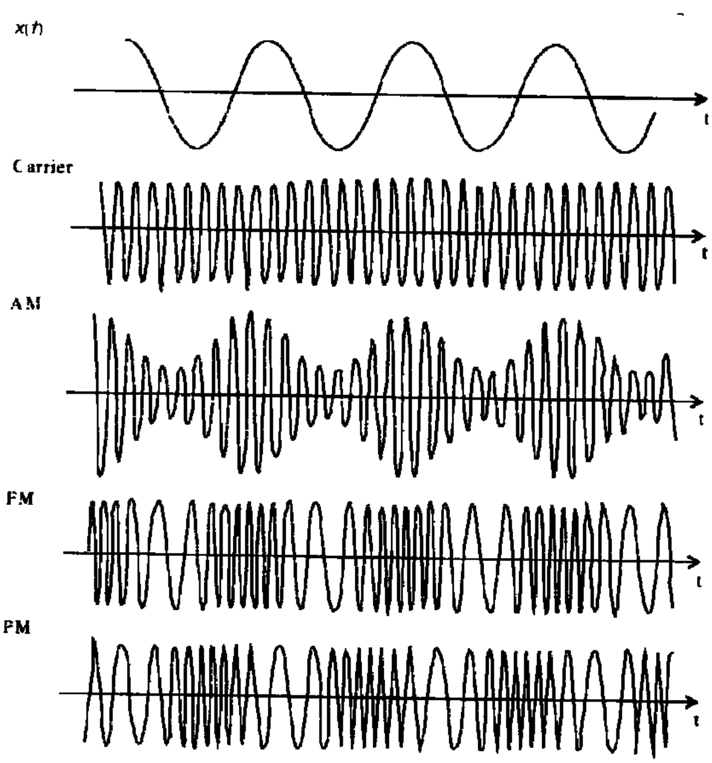


Figure 2.6 AM, FM, and PM Waveforms

Source: Sharma, S.(2006). *Wireless and Cellular Communication*

On comparison, the following differences between the two techniques are:

The envelope of FM wave or PM wave is constant and is equal to the unmodulated carrier amplitude. On the other hand, the envelope of AM wave is dependent on the modulating signal x(t). The zero crossings (i.e. the instants of time at which the waveform changes from negative to a positive value or vice-versa) of a FM wave or a PM wave no longer exhibit a perfect regularity in their spacing like AM wave. Thus this makes the instantaneous frequency of the angle modulated wave depend upon time.

3.1.4 Comparison of Frequency Modulation and Amplitude Modulation

(a) Advantages of FM over AM

FM receivers may be fitted with amplitude limiters to remove the amplitude variations caused by noise. This makes FM reception a good deal more immune to noise than AM reception.
It is possible to reduce noise still further by increasing the frequency-deviation. This is a feature which AM does not have because it is not possible to exceed 100 percent modulation without causing severe distortion.
Standard Frequency Allocations provide a guard band between commercial FM stations. Due to this, there is less adjacent-channel interference than in AM.
FM broadcast operates in the upper VHF and UHF frequency ranges at which there happens to be less noise than in the MF and HF ranges occupied by AM broadcasts.
The amplitude of the FM wave is constant. It is thus independent of the modulation depth, whereas in AM, modulation depth governs the transmitted power.

(b) Disadvantages of FM over AM

A much wider channel typically 200 KHz is required in FM as against only 10 KHz in AM broadcast. This forms serious limitation of FM.
FM transmitting and receiving equipment particularly used for modulation and demodulation tend to be more complex and hence more costly.

4.0 CONCLUSION

You have been taken through the analog modulation concepts and its various techniques, the comparison between angle modulated wave and amplitude modulated wave as well as the comparison between FM and AM.

11.0 SUMMARY

In this unit, you have learnt that:

In analog modulation, the modulation is applied continuously in response to the analog information signal.

The aim of *analog modulation* is to transfer an analog baseband signal over an analog passband channel.

The two types of analog techniques are amplitude modulation and angle modulation.

Amplitude modulation is a system in which the maximum amplitude of the carrier wave is made proportional to the instantaneous value (amplitude) of the modulating or baseband signal.

The amplitude modulation schemes are single sideband modulation (SSB), double-side band modulation (DSB), vestigial sideband modulation (VSB), and quadrature amplitude modulation (QAM)

Angle modulation is based on altering the angle (or *phase*) of a sinusoidal carrier wave to transmit data, as opposed to varying the amplitude, such as in AM transmission.

Angle modulation schemes are frequency modulation and phase modulation.

SELF ASSESSMENT EXERCISE

1. What is angle modulation?
2. What are the types of angle modulation?

12.0 TUTOR-MARKED ASSIGNMENT

1. Differentiate between the two types of analog modulation.
2. Mention the application areas of Frequency Modulation
3. A single-tone FM signal is given by $v(t) \quad 10\sin \; 16 \quad 10^{6} t \quad 20\sin 2 \quad 10^{3t} \; volts$. Determine the modulation index, modulating frequency, frequency deviation, carrier frequency and the power of the FM signal
4. What are the principal merits and limitations of FM?

7.0 REFERENCES/FURTHER READING

Carlson, B. (1981). *Communication Systems*. (2nd ed.). McGraw-Hill Inc.

David, N. & Rick, K. (2004). "Mixers, Modulators and Demodulators". *In*: D. G. Reed (Ed.). The ARRL Handbook for Radio Communications (81st ed.), Newington: ARRL.

Leon, W. C. (2001). *Digital and Analog Communication Systems*, (6th ed.). Prentice-Hall Inc.

Sharma, S. (2006). *Wireless and Cellular Communications.* New Delhi: S. K. Kataria & Sons.

UNIT 3 DIGITAL (BANDPASS) MODULATION TECHNIQUES

CONTENTS

1.0 INTRODUCTION

Modern mobile communication systems use digital modulation techniques. Advancements in very large-scale integration (VLSI) and digital signal processing (DSP) technology have made digital modulation more cost effective than analog transmission systems.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- state the factors that govern the choice of digital modulation
- explain the digital modulation techniques.

3.0 MAIN CONTENT

3.1 An Overview of Digital Modulation Techniques

In digital modulation, an analog carrier signal is modulated by a digital bit stream. Digital modulation methods can be considered as digital-to-analog conversion, and the corresponding demodulation or detection as analog-to-digital conversion. The changes in the carrier signal are chosen from a finite number of M alternative symbols (the modulation alphabet).

The aim of digital modulation is to transfer a digital bit stream over an analog passband channel, for example over the public switched telephone network (where a bandpass filter limits the frequency range to between 300 and 3400 Hz), or over a limited radio frequency band.

For example, a telephone line is designed for transferring audible sounds, for example tones, and not digital bits (zeros and ones).

Computers may however communicate over a telephone line by means of modems, which are representing the digital bits by tones, called symbols. If there are four alternative symbols (corresponding to a musical instrument that can generate four different tones, one at a time), the first symbol may represent the bit sequence 00, the second 01, the third 10 and the fourth 11. If the modem plays a melody consisting of 1000 tones per second, the symbol rate is 1000 symbols/second, or baud.

Since each tone represents a message consisting of two digital bits in this example, the bit rate is twice the symbol rate, i.e. 2000 bit per second.

3.2 Factors that Influence the Choice of Digital Modulation

The performance of a modulation scheme is often measured in terms of its power efficiency and bandwidth efficiency.

- **Power efficiency** describes the ability of a modulation technique to preserve the fidelity of the digital message at low power levels. In a digital communication system, in order to increase noise immunity, it is necessary to increase the signal power. However, the amount by which the signal power should be increased to obtain a certain level of fidelity (i.e., an acceptable bit error probability) depends on the particular type of modulation employed.

Bandwidth efficiency describes the ability of a modulation scheme to accommodate data within a limited bandwidth. In general, increasing the data rate implies decreasing the pulse width of a digital symbol, which increases the bandwidth of the signal. If R is the data rate in bits per second, and B is the bandwidth occupied by the modulated RF signal, then bandwidth efficiency $_B$ is expressed as

$$_B \quad \frac{R}{B} pss / Hz$$

Shannon's channel coding theorem states that for an arbitrarily small probability error, the maximum possible bandwidth efficiency is limited by the noise in the channel, and is given by the channel capacity formula. Note that Shannon's bound applies for AWGN non-fading channels.

$$_B \quad \frac{C}{B} \quad \log_2\left(1 \quad \frac{S}{N}\right)$$

where C is the channel capacity (in bps), B is the RF bandwidth and

$\frac{S}{N}$ is the signal-to-noise ratio.

Exercise 3.1

If the SNR of a wireless communication link is 20 dB and the RF bandwidth is 30 kHz. Calculate the maximum theoretical data rate which may be transmitted. Compare this rate to the US Digital Cellular Standard.

Solution

Given that $\frac{S}{N}$ = 20 dB = 100

RF Bandwidth B = 30000 Hz

Making use of Shannon's channel capacity expression the maximum possible data rate will be given by

$$C \quad B\log_2\left(1 \quad \frac{S}{N}\right) \quad 30000\log_2 1 \quad 100 \quad 199.75\,kbps$$

The USDC data rate is 48.6 kbps, which is only about the one-fourth the theoretical limit under 20 dB SNR conditions.

Exercise 3.2

What is the theoretical maximum data rate which can be supported in a 200 kHz channel for SNR = 10 dB, 30 dB. How can this be compared with the GSM standard.

Solution

For SNR = 10 dB = 10, B = 200 kHz.

Making use of Shannon's channel capacity theorem, the maximum possible data rate, will be given by

$$C \quad B\log_2\left(1 \quad \frac{S}{N}\right) \quad 200000\log_2 1 \quad 10 \quad 691.886\,kbps$$

The GSM data rate is 270.833 kbps, which is only about 40% of the theoretical limit for 10 dB SNR conditions.

For SNR = 30 dB = 1000,B = 200 kHz
The maximum possible data rate will be

$$C \quad B\log_2\left(1 \quad \frac{S}{N}\right) \quad 200000\log_2 1 \quad 1000 \quad 1.99\,Mbps$$

3.3 List of Common Digital Modulation Techniques

Any digital modulation scheme uses a finite number of distinct signals to represent digital data. The most common digital modulation techniques are:

- Phase Shift Keying
- Frequency shift Keying
- Amplitude Shift Keying
- On-Off Keying
- Quadrature Amplitude Modulation
- Continuous Phase Modulation
- Spread-Spectrum Techniques

3.3.1 Phase-Shift Keying (PSK)

PSK is a digital modulation scheme that conveys data by changing, or modulating, the phase of a reference signal (the carrier wave). PSK uses a finite number of phases; each assigned a unique pattern of binary bits.

3.3.1.1 Binary Phase Shift Keying (BPSK), Using M=2 Symbols

In Binary phase shift keying, the binary symbols '1' and '0'modulate the phase of the carrier. With Binary Phase Shift Keying (BPSK), the binary digits 1 and 0 may be represented by the analog levels $+\sqrt{E_b}$ and $-\sqrt{E_b}$ respectively. The system model is as shown in the Figure below.

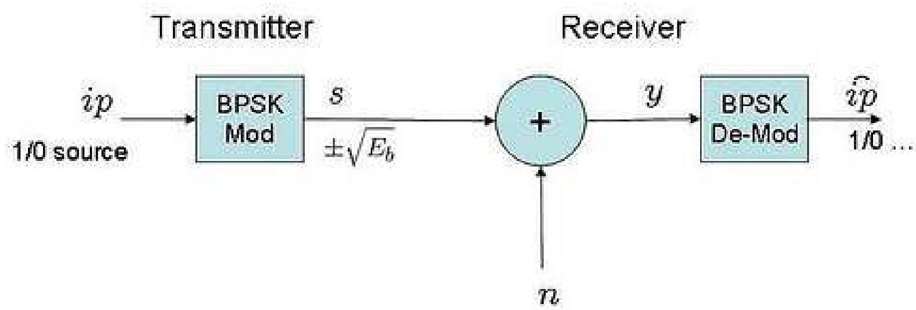


Figure 3.1 Simplified Block Diagram with BPSK Transmitter-Receiver

The Bandwidth of BPSK signal will be,
BW = Highest frequency – Lowest frequency
BW = $f_c \quad f_b \quad f_c \quad f_b$
or $BW \quad 2f_b$

Hence the minimum bandwidth of BPSK signal is equal to twice of the highest frequency contained in baseband signal.

Probability of Bit Error Rate (BER) for BPSK modulation

The received signal, $y \quad s_1 \quad n$ when bit 1 is transmitted and $y \quad s_0 \quad n$ when bit 0 is transmitted.

The conditional probability distribution function (PDF) of y for the two cases are:

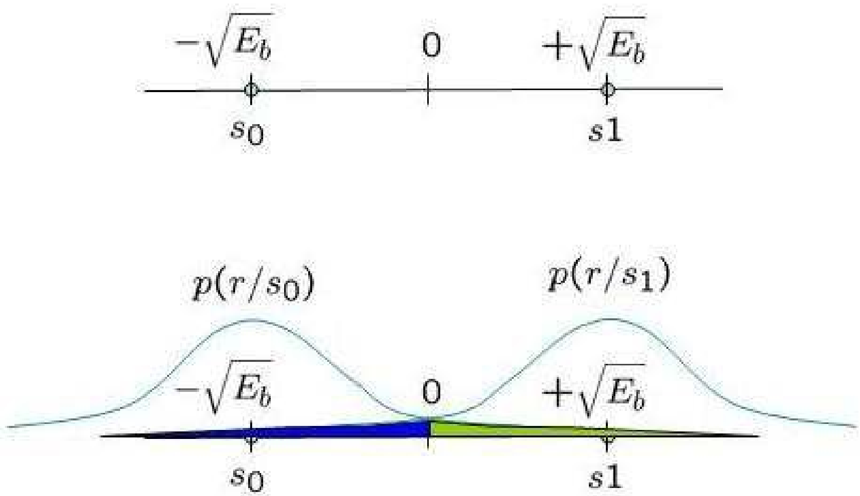


Figure 3.2 Conditional Probability Density Function with BPSK Modulation

Source Krishna Sankar (2007)

Probability of error given s_1 was transmitted

With this threshold, the probability of error given that s_1 was transmitted is (the area in blue region):

$$p(e|s_1) = \frac{1}{\sqrt{\pi N_0}} \int_{-\infty}^{0} e^{-\frac{(y-\sqrt{E_b})^2}{N_0}} dy = \frac{1}{\sqrt{\pi}} \int_{\sqrt{\frac{E_b}{N_0}}}^{\infty} e^{-z^2} dz = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right),$$

where,

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_{x}^{\infty} e^{-x^2} dx$$ is the complementary error function.

Probability of error given s_0 was transmitted

Similarly the probability of error given that s_0 was transmitted is (the area in green region):

$$p(e|s_0) = \frac{1}{\sqrt{\pi N_0}} \int_{0}^{\infty} e^{-\frac{(y+\sqrt{E_b})^2}{N_0}} dy = \frac{1}{\sqrt{\pi}} \int_{\sqrt{\frac{E_b}{N_0}}}^{\infty} e^{-z^2} dz = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right)$$

Total probability of bit error

$$P_e = p(s_1)\, p(e|s1) + p(s_0)\, p(e|s_0)$$

Given that we assumed that s_1 and s_0 are equally probable i.e. $p\ s_1$ = $p\ s_0$ = $^1/_2$, the bit error probability is,

$$P\ e \quad \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right)$$

The error probability of BPSK reception using coherent/matched filter detection can be expressed as

$$P(e) \quad \frac{1}{2} erfc\sqrt{\frac{E_b}{N_0}}$$

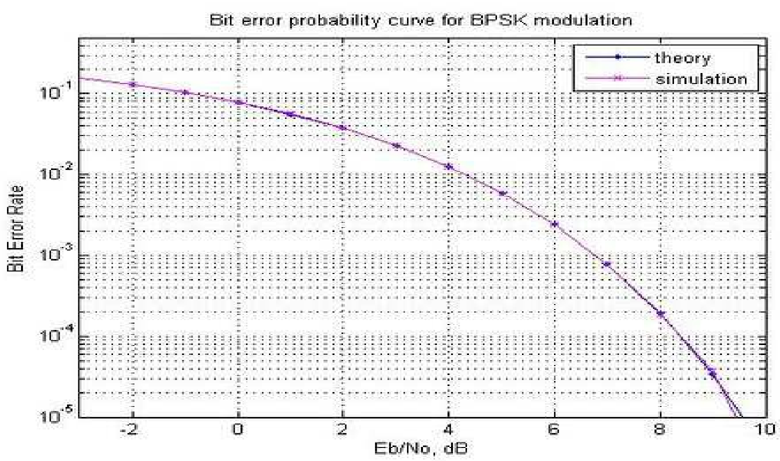


Figure 3.3 Bit Error Rate (BER) Curve for BPSK Modulation Theory, Simulation

Source Krishna Sankar.(2007)

3.3.1.2 Quadrature Phase Shift Keying (QPSK), Using M=4 symbols

In communication systems, there are two main resources which are transmission power and the channel bandwidth. The channel bandwidth depends on the bit rate or signaling rate f_b. In digital bandpass transmission, carrier is used for transmission. This carrier is transmitted over a channel. If two or more bits are combined in some symbols, then the signaling rate will be reduced. Thus, the frequency of the carrier needed is also reduced. This reduces the transmission channel bandwidth. Hence, because of grouping of bits in symbols, the transmission channel bandwidth can be reduced. In quadrature phase shift keying (QPSK), two successive bits in the data sequence are grouped together. This reduces the bits rate or signaling rate (i.e. f_b) and thus reduces the bandwidth of the channel.

The bandwidth of QPSK signal will be $BW \quad 2 \quad \frac{1}{2T_b} \quad f_b$ and the probability of error is

$$P_1^{'}(e) \quad P_2^{'}(e) \quad \frac{1}{2} erfc\sqrt{\frac{2E_b}{2N_0}} \quad \frac{1}{2} erfc\sqrt{\frac{E_b}{N_0}}$$

Thus, bit error probability of QPSK and BPSK are the same.

3.3.1.3 Differential Phase Shift Keying (DPSK)

DPSK does not need a synchronous (coherent) carrier at the demodulator. The input sequence of binary bits is modified such that the next bit depends upon the previous bit.

The Bandwidth is expressed as $BW \quad \frac{2}{T} \quad \frac{1}{T_b} \quad f_b$

and the average probability of error or bit error rate (BER) of DPSK can be expressed as $P(e) \quad \frac{1}{2} e^{\; E_b / N_0}$

3.3.2 Frequency-Shift Keying (FSK)

FSK is a frequency modulation scheme in which digital information is transmitted through discrete frequency changes of a carrier wave. The simplest FSK is binary FSK (BFSK). BFSK literally implies using a couple of discrete frequencies to transmit binary (0s and 1s) information.

In BFSK, the frequency of the carrier is shifted according to the binary symbol. However, the phase of the carrier is unaffected. This means that we have two different frequency signals according to binary symbols.

With this scheme, the "1" is called the mark frequency and the "0" is called the space frequency. In the case of FSK, a finite number of frequencies are used.

The bandwidth of BFSK $\quad 2 f_b \quad 2 f_b$

or BW = $4 f_b$

Now, if we compare this bandwidth with that of BPSK, we note that
BW (BFSK) = 2 x BW(BPSK)

The probability of error, of BFSK signal can be expressed as

$$P_e = \frac{1}{2} erfc\left(\frac{\sqrt{2E_b}}{2\sqrt{N_0}}\right) \quad \text{or} \quad P_e = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{2N_0}}\right)$$

This equation shows that error probability of BFSK is higher compared to that of BPSK

The various frequency-shift keying scheme are

3.3.2.1 Audio Frequency-Shift Keying (AFSK)

AFSK is a modulation technique by which digital data is represented by changes in the frequency (pitch) of an audio tone, yielding an encoded signal suitable for transmission via radio or telephone. Normally, the transmitted audio alternates between two tones: one, the “mark”, represents a binary one; the other, the “space”, represents a binary zero.

AFSK differs from regular frequency-shift keying in performing the modulation at baseband frequencies. In radio applications, the AFSK-modulated signal normally is being used to modulate an RF carrier (using a conventional technique, such as AM or FM) for transmission.

AFSK is not always used for high-speed data communications, since it is far less efficient in both power and bandwidth than the other modulation modes. In addition to its simplicity, however, AFSK has the advantage that encoded signals will pass through AC-coupled links, including most equipment originally designed to carry music or speech.

3.3.2.2 Continuous-Phase Frequency-Shift Keying (CPFSK)

CPFSK is a commonly-used variation of frequency-shift keying (FSK), which is itself a special case of analog frequency modulation. FSK is a method of modulating digital data onto a sinusoidal carrier wave, encoding the information present in the data to variations in the carrier's instantaneous frequency between one of two frequencies (referred to as the space frequency and mark frequency). In general, a standard FSK signal does not have continuous phase, as the modulated waveform switches instantaneously between two sinusoids with different frequencies.

As the name suggests, the phase of a CPFSK is in fact continuous; this attribute is desirable for signals that are to be transmitted over a band limited channel, as discontinuities in a signal introduce wideband frequency components. In addition, some classes of amplifiers exhibit nonlinear behavior when driven with nearly-discontinuous signals; this could have undesired effects on the shape of the transmitted signal.

3.3.2.3 Multi-Frequency Shift Keying (M-ary FSK or MFSK)

MFSK is a variation of frequency-shift keying (FSK) that uses more than two frequencies. MFSK is a form of M-ary orthogonal modulation, where each symbol consists of one element from an alphabet of orthogonal waveforms. M, the size of the alphabet, is usually a power of two so that each symbol represents $\log_2 M$ bits. M is usually between 2 and 64

3.3.2.4 Dual-Tone Multi-Frequency (DTMF)

DTMF signaling is used for telecommunication signaling over analog telephone lines in the voice-frequency band between telephone handsets and other communications devices and the switching center. As a method of in-band signaling, DTMF tones were also used by cable television broadcasters to indicate the start and stop times of local commercial insertion points during station breaks for the benefit of cable companies.

3.3.3 Amplitude-Shift Keying (ASK)

ASK is a form of modulation that represents digital data as variations in the amplitude of a carrier wave. The amplitude of an analog carrier signal varies in accordance with the bit stream (modulating signal), keeping frequency and phase constant. In the case of ASK, a finite number of amplitudes are used.

3.3.4 On-Off Keying (OOK)

OOK is the simplest form of amplitude-shift keying (ASK) modulation that represents digital data as the presence or absence of a carrier wave. In its simplest form, the presence of a carrier for a specific duration represents a binary one, while its absence for the same duration represents a binary zero. Some more sophisticated schemes vary these durations to convey additional information. It is analogous to unipolar encoding line code.

M-ary vestigial sideband modulation, for example 8VSB: A vestigial sideband (in radio communication) is a sideband that has been only partly cut off or suppressed.

3.3.5 Quadrature Amplitude Modulation (QAM)

QAM is a combination of PSK and ASK. QAM is both an analog and a digital modulation scheme. It conveys two analog message signals, or two digital bit streams, by changing (modulating) the amplitudes of two carrier waves, using the amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme. These two waves, usually sinusoids, are out of phase with each other by 90° and are thus called quadrature carriers or quadrature components — hence the name of the scheme. The modulated waves are summed, and the resulting waveform is a combination of both phase-shift keying (PSK) and amplitude-shift keying, or in the analog case of phase modulation (PM) and amplitude modulation. In the digital QAM case, a finite number of at least two phases and at least two amplitudes are used.

Polar modulation like QAM is a combination of PSK and ASK: It makes use of polar coordinates, *r* (amplitude) and Θ (phase).

3.3.6 Continuous Phase Modulation (CPM) Method

CPM is a method for modulation of data commonly used in wireless modems. In contrast to other coherent digital phase modulation techniques where the carrier phase abruptly resets to zero at the start of every symbol (e.g. M-PSK), with CPM the carrier phase is modulated in a continuous manner.

(i) **Minimum-Shift Keying (MSK):** In MSK, the output waveform is continuous in phase hence there are no abrupt changes in amplitude. The sidelobes of MSK are very small hence bandpass filtering is not required to avoid interchannel interference. The Bandwidth of MSK is $BW = 1.5\ f_b$

(ii) **Gaussian Minimum-Shift Keying (GMSK):** It is similar to standard minimum-shift keying (MSK); however the digital data stream is first shaped with a Gaussian filter before being applied to a frequency modulator. This has the advantage of reducing sideband power, which in turn reduces out-of-band interference between signal carriers in adjacent frequency channels. However, the Gaussian filter increases the modulation memory in the system and causes intersymbol interference, making it more difficult to discriminate between different transmitted data values and requiring more complex channel equalization algorithms such as an adaptive equalizer at the receiver. GMSK is most notably used in the Global System for Mobile Communications (GSM).

3.3.7 Orthogonal Frequency Division Multiplexing (OFDM) Modulation

OFDM is essentially identical to Coded OFDM (COFDM) and Discrete Multi-Tone modulation (DMT). It is a frequency-division multiplexing (FDM) scheme utilised as a digital multi-carrier modulation method. A large number of closely-spaced orthogonal sub-carriers are used to carry data. The data is divided into several parallel data streams or channels, one for each sub-carrier. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions — for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath — without complex equalization filters.

3.3.8 Wavelet Modulation

Wavelet modulation also known as fractal modulation is a modulation technique that makes use of wavelet transformations to represent the data being transmitted. One of the objectives of this type of modulation is to send data at multiple rates over a channel that is unknown. If the channel is not clear for one specific bit rate, meaning that the signal will not be received, the signal can be sent at a different bit where the signal to noise ratio is higher.

3.3.9 Trellis Coded Modulation (TCM)

Trellis coded modulation also known as trellis modulation is a modulation scheme which allows highly efficient transmission of information over band-limited channels such as telephone lines.

3.3.10 Spread-Spectrum Techniques

Spread-spectrum techniques are methods by which electromagnetic energy generated in a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth. These techniques are used for a variety of reasons, including the establishment of secure communications, increasing resistance to natural interference and jamming, to prevent detection, and to limit the power flux density on satellite downlinks.

i. **Direct-sequence spread spectrum (DSSS):** As with other spread spectrum technologies, the transmitted signal takes up more bandwidth than the information signal that is being modulated. The name 'spread spectrum' comes from the fact that the carrier signals occur over the full bandwidth (spectrum) of a device's transmitting frequency.
ii. **Chirp spread spectrum (CSS):** uses pseudo-stochastic coding. It is a spread spectrum technique that uses wideband linear frequency modulated chirp pulses to encode information. A chirp is a sinusoidal signal whose frequency increases or decreases over a certain amount of time.
iii. **Frequency-hopping spread spectrum (FHSS)** applies a special scheme for channel release. It is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both transmitter and receiver. It is utilized as a multiple access method in the frequency-hopping code division multiple access (FH-CDMA) scheme.

3.4 Modulator and Detector Principles of Operation

PSK and ASK, and sometimes also FSK, are often generated and detected using the principle of QAM. The I and Q signals can be combined into a complex-valued signal I+jQ (where j is the imaginary unit). The resulting so called equivalent lowpass signal or equivalent baseband signal is a complex-valued representation of the real-valued modulated physical signal (the so called passband signal or RF signal).

These are the general steps used by the modulator to transmit data:

i. Group the incoming data bits into codewords, one for each symbol that will be transmitted.
ii. Map the codewords to attributes, for example amplitudes of the I and Q signals (the equivalent low pass signal), or frequency or phase values.
iii. Adapt pulse shaping or some other filtering to limit the bandwidth and form the spectrum of the equivalent low pass signal, typically using digital signal processing.
iv. Perform digital-to-analog conversion (DAC) of the I and Q signals (since today all of the above is normally achieved using digital signal processing, DSP).
v. Generate a high-frequency sine wave carrier waveform, and perhaps also a cosine quadrature component. Carry out the

modulation, for example by multiplying the sine and cosine wave form with the I and Q signals, resulting in that the equivalent low pass signal is frequency shifted into a modulated passband signal or RF signal. Sometimes this is achieved using DSP technology, for example direct digital synthesis using a waveform table, instead of analog signal processing. In that case the above DAC step should be done after this step.

vi. Amplification and analog bandpass filtering to avoid harmonic distortion and periodic spectrum.

At the receiver side, the demodulator typically performs:

i. Bandpass filtering.
ii. Automatic gain control, AGC (to compensate for attenuation, for example fading).
iii. Frequency shifting of the RF signal to the equivalent baseband I and Q signals, or to an intermediate frequency (IF) signal, by multiplying the RF signal with a local oscillator sinewave and cosine wave frequency (see the superheterodyne receiver principle).
iv. Sampling and analog-to-digital conversion (ADC) (Sometimes before or instead of the above point, for example by means of undersampling).
v. Equalization filtering, for example a matched filter, compensation for multipath propagation, time spreading, phase distortion and frequency selective fading, to avoid intersymbol interference and symbol distortion.
vi. Detection of the amplitudes of the I and Q signals, or the frequency or phase of the IF signal.
vii. Quantization of the amplitudes, frequencies or phases to the nearest allowed symbol values.
viii. Mapping of the quantized amplitudes, frequencies or phases to codewords (bit groups).
ix. Parallel-to-serial conversion of the codewords into a bit stream.
x. Pass the resultant bit stream on for further processing such as removal of any error-correcting codes.

As it is common to all digital communication systems, the design of both the modulator and demodulator must be done simultaneously.

Digital modulation schemes are possible because the transmitter-receiver pair have prior knowledge of how data is encoded and represented in the communications system. In all digital communication systems, both the modulator at the transmitter and the demodulator at the receiver are structured so that they perform inverse operations.

Non-coherent modulation methods do not require a receiver reference clock signal that is phase synchronized with the sender carrier wave. In this case, modulation symbols (rather than bits, characters, or data packets) are asynchronously transferred. The opposite is coherent modulation.

4.0 CONCLUSION

In this unit, the concept of digital bandpass modulation and its various techniques as well as the factors that govern the choice of digital modulation were discussed.

10.0 SUMMARY

In this unit, you have learnt that:

- The aim of digital modulation is to transfer a digital bit stream over an analog passband channel.
- In digital modulations, instead of transmitting one bit at a time, two or more bits are transmitted simultaneously.
- The factors that influence the choice of digital (bandpass) modulation are power efficiency and bandwidth efficiency.
- Power efficiency describes the ability of a modulation technique to preserve the fidelity of the digital message at low power levels
- Bandwidth efficiency describes the ability of a modulation scheme to accommodate data within a limited bandwidth.
- The common digital modulation techniques are PSK, FSK, ASK, OOK,QAM,CPM,OFDM, Wavelet modulation, TCM and spread-spectrum techniques.
- The most fundamental digital modulation techniques are PSK, FSK, ASK and QAM.

SELF ASSESSMENT EXERCISE

What factors govern the choice of digital modulation?

6.0 TUTOR-MARKED ASSIGNMENT

Explain briefly four major digital modulation techniques**.**

7.0 REFERENCES/FURTHER READING

Leon, W. C. (2001). *Digital and Analog Communication Systems,* (6th ed.). Prentice-Hall. Inc.

Sharma, S. (2006). *Wireless and Cellular Communications*. New Delhi: S. K. Kataria & Sons.

UNIT 4 DIGITAL BASEBAND AND PULSE SHAPING MODULATION TECHNIQUES

CONTENTS

22.0 INTRODUCTION

In this unit, you will learn baseband and pulse shaping modulation techniques. Baseband modulation aims at transferring a digital bit stream over a baseband channel, as an alternative to carrier-modulated approaches. The term digital baseband modulation (or digital baseband transmission) is synonymous to line codes. Line codes are codes chosen for use within a communications system for baseband transmission purposes.

23.0 OBJECTIVES

At the end of this unit, you should be able to:

- discuss digital baseband modulation
- write concisely on pulse modulation
- explain briefly the types of pulse modulation.

24.0 MAIN CONTENT

3.1 Digital Baseband and Pulse Shaping Modulation

3.1.1 Digital Baseband Modulation or Line Coding Techniques

Line coding is a method which transfer a digital bit stream over an analog baseband channel (lowpass channel) using a pulse train, i.e. a discrete number of signal levels, by directly modulating the voltage or current on a cable such as fiber optical cables and short-range copper cables, for example serial cables and LAN networks.

Baseband signal is used to modulate a higher frequency carrier wave so that it may be transmitted via radio. Shifting the signal to higher frequencies (radio frequencies, or RF) than it originally spanned result in modulation. The key consequence of the usual double-sideband amplitude modulation (AM) is that, the range of frequencies of the signal span (its spectral bandwidth) is doubled. Thus, the RF bandwidth of a signal (measured from the lowest frequency as opposed to 0 Hz) is usually twice its baseband bandwidth. Steps may be taken to reduce this effect, such as single-sideband modulation; the highest frequency of such signals greatly exceeds the baseband bandwidth.

Some signals can be treated as baseband or not, depending on the situation. For example, a switched analog connection in the telephone network has energy below 300 Hz and above 3400 Hz removed by bandpass filtering; since the signal has no energy very close to zero frequency, it may not be considered a baseband signal, but in the telephone systems frequency-division multiplexing hierarchy, it is usually treated as a baseband signal, by comparison with the modulated signals used for long-distance transmission. The 300 Hz lower band edge in this case is treated as “near zero”, being a small fraction of the upper band edge.

Figure 4.1 below depicts what happens with AM modulation:

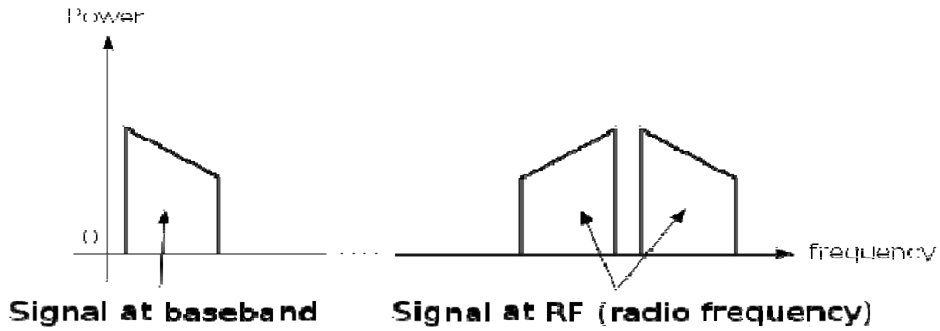


Figure 4.1 Comparing Baseband Version of a Signal and its Equivalent AM-Modulated (double-sideband) RF Version, Showing the Typical Doubling of the Occupied Bandwidth

Source Wikipedia (2009)

The composite video signal created by devices such as the new VCRs, game consoles and DVD players are commonly used baseband signal.

3.1.2 Pulse Shaping Modulation Techniques

In digital telecommunication, pulse shaping is the process of changing the waveform of transmitted pulses. Its purpose is to make the transmitted signal suit better to the communication channel by limiting the effective bandwidth of the transmission. By filtering the transmitted pulses this way, the intersymbol interference caused by the channel can be kept in control. In RF communication pulse shaping is essential for making the signal fit in its frequency band.

These methods are used to transfer a digital bit stream over an analog baseband channel (lowpass channel) using a pulse train. Some pulse modulation schemes also allow the narrowband analog signal to be transferred as a digital signal (i.e. as a quantized discrete-time signal) with a fixed bit rate, which can be transferred over an underlying digital transmission system, for example some line code. These are not modulation schemes in the conventional sense since they are not channel coding schemes, but should be considered as source coding schemes, and in some cases analog-to-digital conversion techniques.

3.1.2.1 Analog-Over-Analog Methods

(i) **Pulse-Amplitude Modulation (PAM)** is a form of signal modulation where the message information is encoded in the amplitude of a series of signal pulses. For example, a two bit modulator (PAM-4) will take two bits at a time and will map the signal amplitude to one of four possible levels, for example −3 volts, −1 volt, 1 volt, and 3 volts.

(ii) **Pulse-Width Modulation (PWM)** is a very efficient way of providing intermediate amounts of electrical power between fully on and fully off. A simple power switch with a typical power source provides full power only, when switched on. PWM is a comparatively-recent technique, made practical by modern electronic power switches.

(iii) **Pulse-Position Modulation (PPM)** is a form of signal modulation in which M message bits are encoded by transmitting a single pulse in one of 2^M possible time-shifts. This is repeated every T seconds, such that the transmitted bit rate is M/T bits per second. It is primarily useful for optical communications systems, where there tends to be little or no multipath interference.

3.1.2.2 Analog-Over-Digital Methods

(i) **Pulse-Code Modulation (PCM)** is a digital representation of an analog signal where the magnitude of the signal is sampled regularly at uniform intervals, then quantized to a series of symbols in a numeric (usually binary) code. PCM has been used in digital telephone systems, 1980s-era electronic musical keyboards, digital audio in computers, digital video and the compact disc “red book” format.

Differential pulse-code modulation (DPCM) is a signal encoder that uses the baseline of PCM but adds some functionality based on the prediction of the samples of the signal. The input can be an analog signal or a digital signal. If the input is a continuous-time analog signal, it needs to be sampled first so that a discrete-time signal is the input to the DPCM encoder.
Adaptive DPCM (ADPCM) is a variant of DPCM (differential pulse-code modulation) that varies the size of the quantization step, to allow further reduction of the required bandwidth for a given signal-to-noise ratio.

(ii) **Delta modulation (DM or Δ-modulation)** is an analog-to-digital and digital-to-analog signal conversion technique used for transmission of voice information where quality is not of primary importance. DM is the simplest form of differential pulse-code modulation (DPCM) where the difference between successive samples is encoded into n-bit data streams. In delta modulation, the transmitted data is reduced to a 1-bit data stream.

Its main features are:

the analog signal is approximated with a series of segments.
each segment of the approximated signal is compared to the original analog wave to determine the increase or decrease in relative amplitude.
the decision process for establishing the state of successive bits is determined by this comparison.
only the change of information is sent, that is, only an increase or decrease of the signal amplitude from the previous sample is sent whereas a no-change condition causes the modulated signal to remain at the same 0 or 1 state of the previous sample.

(iii) **Delta-Sigma (ΔΣ) or sigma-delta (ΣΔ) modulation** is a method for encoding high resolution signals into lower resolution signals using pulse-density modulation. This technique has found increasing use in a range of modern electronic components, such as analog-to-digital and digital-to-analog converters, frequency synthesizers, switched-mode power supplies and motor controls. One of the earliest and most widespread uses of delta-sigma modulation is in data conversion.

(iv) **Continuously variable slope delta modulation (CVSDM)** also called Adaptive-delta modulation (ADM) is a voice coding method. It is a delta modulation with variable step size (i.e. special case of adaptive delta modulation).CVSD encodes at 1 bit per sample, so that audio sampled at 16 kHz is encoded at 16 kbit/s.

(v) **Pulse-density modulation (PDM)** is a form of modulation used to represent an analog signal in the digital domain. In a PDM signal, specific amplitude values are not encoded into pulses as they would be in PCM. Instead, it is the relative density of the pulses that corresponds to the analog signal's amplitude. Pulse-width modulation (PWM) is the special case of PDM where all the pulses corresponding to one sample are contiguous in the digital signal.

25.0 CONCLUSION

Digital baseband modulations and pulse modulation were discussed in this unit.

26.0 SUMMARY

In this unit, you have learnt that:

- Baseband modulation aims at transferring a digital bit stream over a baseband channel, as an alternative to carrier-modulated approaches.
- Pulse shaping is the process of changing the waveform of transmitted pulses.
- Some pulse shaping modulation schemes also allow the narrowband analog signal to be transferred as a digital signal (i.e. as a quantized discrete-time signal) with a fixed bit rate, which can be transferred over an underlying digital transmission system.

SELF ASSESSMENT EXERCISE

What is digital baseband modulation?

27.0 TUTOR-MARKED ASSIGNMENT

Explain briefly two types of pulse modulation

28.0 REFERENCES/FURTHER READING

Jayant, N. S. & Noll, P. (1984). *Digital Coding of Waveforms: Principles and Applications to Speech and Video*. Englewood Cliffs: Prentice-Hall.

Schreier, R. & Temes, G. (2005). *Understanding Delta-Sigma Data Converters*.

UNIT 5 DIVERSITY TECHNIQUES FOR FADING CHANNEL

CONTENTS

22.0 INTRODUCTION

Diversity is a powerful communication receiver technique that provides wireless link improvement at relatively low cost. Diversity exploits the random nature of radio propagation by finding independent or at least highly uncorrected signal paths for communication.

23.0 OBJECTIVES

At the end of this unit, you should be able to:

explain diversity concept
discuss the types of diversity techniques
outline space diversity scheme
state the application of space diversity technique.

24.0 MAIN CONTENT

3.1 Concept of Diversity

A signal transmitted at a particular carrier frequency and at a particular instant of time may be received in a multipath null. Diversity reception reduces the probability of occurrence of communication failures (outages) caused by fades by combining several copies of the same message received over different channels.

In telecommunications, diversity scheme is referred to as a method for improving the reliability of a message signal by using two or more communication channels with different characteristics. Diversity plays an important role in combating fading and co-channel interference and avoiding error bursts. It is based on the fact that individual channels experience different levels of fading and interference. Multiple versions of the same signal may be transmitted and/or received and combined in the receiver. Alternatively, a redundant forward error correction code may be added and different parts of the message transmitted over different channels. Diversity techniques may exploit the multipath propagation, resulting in a diversity gain, often measured in decibels. In general, the efficiency of the diversity techniques reduces if the signal fading is correlated at different branches.

Diversity is a commonly used technique in wireless systems to combat channel fading, due to the following facts:

(i) The degradation of transmission quality due to channel fading cannot be simply overcome by increasing the transmitted signal power. This is because, even with high transmitted power, when the channel is in deep fading, the instantaneously received SNR can still be very low, resulting in a high probability of transmission error during the deep fading period.

(ii) In wireless communications, the power available on the reverse link is severely limited by the battery capacity in hand-held subscriber units. With diversity, the required transmitted power can be greatly reduced.

(iii) Cellular communications systems are mostly limited by interference. Also, mitigation of channel fading by diversity reception can translate into improved interference tolerance which, in turn, means greater ability to support additional users and therefore higher system capacity.

3.1.1 Diversity Techniques

The following classes of diversity schemes can be identified:

(a) **Time diversity**: Multiple versions of the same signal are transmitted at different time instants. Alternatively, a redundant forward error correction code is added and the message is spread in time by means of bit-interleaving before it is transmitted. Thus, error bursts are avoided, which simplifies the error correction. In time diversity, the time difference between two transmissions should be large compared to the time it takes the mobile antenna to move half a wavelength. In systems with stationary antennas, such as indoor wireless communication, time diversity will be less effective as the channel characteristics do not change very much with time. However, time diversity may be helpful if uncorrected interference signals are experienced during successive attempts.

(b) **Frequency diversity**: In frequency diversity, the same message is transmitted more than once, respectively at different carrier frequencies. The difference in carrier frequency should be more than the coherence bandwidth to achieve effective diversity. Digital cellular system can use slow frequency hopping (SFH) for diversity reason: each block of bits is transmitted at a different carrier.

(c) **Angle diversity:** The desired message is received simultaneously by several directed antennas pointing in widely different directions. The received signal consists of scattering wave coming from all directions. It has been observed that the scattered signals associated with the different (non-overlapping) directions are uncorrelated. Angle diversity can be viewed as a special case of space diversity since it also requires multiple antennas.

(d) **Multiuser diversity**: Multiuser diversity is obtained by opportunistic user scheduling at either the transmitter or the receiver. Opportunistic user scheduling is as follows: the transmitter selects the best user among candidate receivers according to the qualities of each channel between the transmitter and each receiver. In Frequency Division Duplex (FDD) systems, a receiver must feedback the channel quality information to the transmitter with the limited level of resolution.

(e) **Co-operative diversity**: Is a co-operative multiple antenna techniques which exploit user diversity by decoding the combined signal of the relayed signal and the direct signal in wireless multihop networks. A conventional single hop system uses direct transmission where a receiver decodes the information only based on the direct signal while regarding the relayed signal as interference, whereas the cooperative diversity considers the other signal as contribution. That is, cooperative diversity decodes the information from the combination of two signals. Hence, it can be seen that cooperative diversity is an antenna diversity that uses distributed antennas belonging to each node in a wireless network. Note that user co-operation is another definition of co-operative diversity. User co-operation considers an additional fact that each user relays the other user's signal while co-operative diversity can also be achieved by multi-hop relay networking systems.

Co-operative diversity achieves antenna diversity gain by using the cooperation of distributed antennas belonging to each node.

Co-operative diversity decodes information from the combination of two signals.

(f) **Space diversity**, also known as **Antenna diversity,** is any one of several wireless diversity schemes that use two or more antennas to improve the quality and reliability of a wireless link. Often, especially in urban and indoor environments, there is no clear line-of-sight (LOS) between transmitter and receiver. Instead the signal is reflected along multiple paths before finally being received. Each of these bounces can introduce phase shifts, time delays, attenuations, and even distortions that can destructively interfere with one another at the aperture of the receiving antenna. Antenna diversity is especially effective at mitigating these multipath situations.

The desired message is transmitted by using multiple transmitting antennas (transmit diversity) and/or receiving antennas (reception diversity). This is because multiple antennas afford a receiver several observations of the same signal. The space separation between adjacent antennas should be large enough to ensure that the signals from different antennas are independently faded; each of the antennas will experience a different interference environment. Thus, if one antenna is experiencing a deep fade, it is likely that another has a sufficient signal. Collectively such a system can provide a robust link.

3.2 Space/Antenna Diversity Scheme

Antenna diversity can be realized in several ways. Depending on the environment and the expected interference, designers can employ one or more of these methods to improve signal quality. In fact multiple methods are frequently used to further increase reliability.

Spatial Diversity – Spatial diversity employs multiple antennas, usually with the same characteristics, that are physically separated from one another. Depending upon the expected incidence of the incoming signal, sometimes a space on the order of a wavelength is sufficient. Other times much larger distances are needed. Cellularization or sectorization, for example, is a spatial diversity scheme that can have antennas or base stations miles apart. This is especially beneficial for the mobile communications industry since it allows multiple users to share a limited communication spectrum and avoid co-channel interference.

Pattern Diversity – Pattern diversity consists of two or more co-located antennas with different radiation patterns. This type of diversity makes use of directive antennas that are usually physically separated by some (often short) distance. Collectively they are capable of discriminating a large portion of angle space and can provide a higher gain versus a single omnidirectional radiator.

Polarisation Diversity – Polarisation diversity combines pairs of antennas with orthogonal polarisations (i.e. horizontal/vertical, ± slant 45°, Left-hand/Right-hand CP etc). Reflected signals can undergo polarization changes depending on the media. By pairing two complementary polarisations, this scheme can immunise a system from polarisation mismatches that would otherwise cause signal fade. Additionally, such diversity has proven valuable at radio and mobile communication base stations since it is less susceptible to the near random orientations of transmitting antennas.

Transmitter/Receiver Diversity–Transmitter/Receiver diversity uses two separate, collocated antennas for transmitting and receiving functions. Such a configuration eliminates the need for a duplexer and can protect sensitive receiver components from the high power used in transmission.

Adaptive Arrays – Adaptive arrays can be a single antenna with active elements or an array of similar antennas with ability to change their combined radiation pattern as different conditions persist. Active electronically scanned arrays (AESAs) manipulate phase shifters and attenuators at the face of each radiating site to provide a near instantaneous scan ability as well as pattern and polarization control. This is especially beneficial for radar applications since it affords a signal antenna the ability to switch among several different modes such as searching, tracking, mapping and jamming countermeasures.

3.2.1 Applications of Space/Antenna diversity Techniques

A well-known practical application of diversity reception is in wireless microphones, and in similar electronic devices such as wireless guitar systems. A wireless microphone with a non-diversity receiver (a receiver having only one antenna) is prone to random drop-outs, fades, noise, or other interference, especially if the transmitter (the wireless microphone) is in motion. A wireless microphone or sound system using diversity reception will switch to the other antenna within microseconds if one antenna experiences noise, providing an improved quality signal with fewer drop-outs and noise. Ideally, no drop-outs or noise will occur in the received signal.

Another common usage is in Wi-Fi networking gear and cordless telephones to compensate for multipath interference. The base station will switch reception to one of two antennas depending on which is currently receiving a stronger signal. For best results, the antennas are usually placed one wavelength apart. For microwave bands, where the wavelengths are under 100 cm, this can often be done with two antennas attached to the same hardware. For lower frequencies and longer wavelengths, the antennas must be multiple meters apart, making it much less reasonable.

Mobile phone towers also often take advantage of diversity - each face of a tower will often have three antennas; one is transmitting, while the other two perform diversity reception.

The uses of multiple antennas at both transmitter and receiver results in a multiple-input multiple-output (MIMO) system. The use of diversity techniques at both ends of the link is termed space–time coding.

25.0 CONCLUSION

In this unit the concept of diversity and different types of diversity techniques were discussed. It was revealed that diversity improves transmission performance by making use of more than one independently faded version of the transmitted signal. If several replicas of the signal, carrying the same information, are received over multiple channels that exhibit independent fading with comparable strengths, the chances that all the independently faded signal components experience deep fading simultaneously are greatly reduced.

26.0 SUMMARY

Diversity is a powerful communication receiver technique that provides wireless link improvement at relatively low cost.

Diversity reception reduces the probability of occurrence of communication failures (outages) caused by fades by combining several copies of the same message received over different channels.

Diversity scheme is refers to as a method for improving the reliability of a message signal by using two or more communication channels with different characteristics.

The classes of diversity schemes are time diversity, frequency diversity, space diversity, angle diversity, multiple diversity and cooperative diversity techniques

SELF ASSESSMENT EXERCISE

What is meant by diversity?

27.0 TUTOR-MARKED ASSIGNMENT

1. Write short note on any four diversity techniques.
2. State the application areas of space diversity techniques.
3. Mention the types of space diversity schemes.

28.0 REFERENCES/FURTHER READING

Dietrich, C. (2000). Adaptive Arrays and Diversity Antenna Configurations for Handheld Wireless Communication Terminals.

Laneman, J. N.; Tse, D. N. C. & Wornell, G. W. (2004). “Cooperative Diversity in Wireless Networks: Efficient Protocols and Outage Behavior,” IEEE Trans. Inform. Theory, 50 (12), 3062-3080.

Moon, J. & Kim, Y. (2003). “Antenna Diversity Strengthens Wireless LANs.” Communication Systems Design.

Sendonaris, A.; Erkip E, & Aazhang, B. (2003). “User Cooperation Diversity Part I and Part II,” IEEE Trans. Communication, 51(11), 1927–48.

Sharma, S. (2006). *Wireless and Cellular Communications*. New Delhi: S.K. Kataria & Sons.

UNIT 6 MULTIPLE ACCESS TECHNIQUES

CONTENTS

1.0 INTRODUCTION

Multiple Access is a signal transmission situation in which two or more users wish to simultaneously communicate with each other using the same propagation channel. This is precisely the uplink transmission situation in a wireless communication. In the uplink or reverse channel, multiple users will want to transmit information simultaneously.

Without proper coordination among the transmitting users, collisions will occur when two or more users transmit simultaneously. Access methods that incur collision are referred to as random access and variants of random access.

Multiple access method allows several terminals connected to the same multi-point transmission medium to transmit over it and to share its capacity.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- explain Multiple Access Concept
- discuss the types of Multiple Access Techniques
- define Carrier Sense Multiple Access
- state the types of Carrier Sense Multiple Access
- describe the attribute of Carrier Sense Multiple Access
- mention the application areas of Multiple Access.

3.0 MAIN CONTENT

3.1 Multiple Access in a Radio Cell

In each radio cell, the transmission from the base station in the downlink can be heard by each and every mobile user in the cell. For this reason, this mode of transmission is referred to as broadcasting. On the other hand, a transmission from the mobile user in the uplink to the base station is many-to-one, and is referred to as multiple access.

Transmission in the uplink mode has the following properties:

- Multiple mobile users want to access the common resource (base station) simultaneously;
- If the transmission from two or more users arrive at the base station at the same time, there will be destructive interference, umless the multiple arriving signals are mutually orthogonal;
- Orthogonality between two signals x_i (t) and x_j (t), $t \in [0,T]$, means that their inner product over the signaling interval vanishes. Mathematically, this means that

$$\int_0^T x_i(t)\, x_j(t)\, dt = 0. \quad for\ i \neq j$$

The key element in multiple access is to make the transmitted signals from the different users orthogonal to each other.

3.1.1 Multiple Access Techniques

Multiple Access method allows several terminals connected to the same multi-point transmission medium to transmit over it and to share its capacity. Examples of shared physical media are wireless networks, bus networks, ring networks, hub networks and half-duplex point-to-point links. Multiple Access technique is based on a multiplex method that allows several data streams or signals to share the same communication channel or physical media.

Multiple Access methods address the problem of how many users can share the same spectrum resources in an efficient manner. We distinguish between:

- Multiple access within one cell, i.e., a fixed assignment of resources in time or bandwidth to specific users
- Random access, i.e., a dynamic assignment of spectrum resources in time or bandwidth to users, according to their needs

Frequency reuse, i.e., assignment of spectrum resources considering the location of users and the attenuation of radio signals that travel over sufficiently large distances.

Multiple access is a signal transmission situation in which two or more users wish to simultaneously communicate with each other using the same propagation channel. Multiple access methods/techniques can be categorized under circuit mode and channelization methods, packet mode methods and duplex methods.

3.1.1.1 Circuit Mode and Channelization Methods

(a) Frequency Division Multiple Access (FDMA)

FDMA is based on frequency-division multiplex (FDM). It gives users an individual allocation of one or several frequency bands, or Channels.

FDMA provides different frequency bands to different users or nodes. In FDMA, the total bandwidth is divided into non-overlapping frequency subband. Each user is allocated a unique frequency subband for the duration of the connection, whether the connection is an active or idle state. Othogonality among transmitted signals from different mobile users is achieved by bandpass filtering in the frequency domain. This type of multiple access support is narrowband, and is not suitable for multimedia communications with various transmission rates. In addition, it incurs a waste of bandwidth when the user is in a dormant state.

An example of FDMA systems were the first-generation (1G) cell-phone systems. A related technique is wave-length division multiple access (WDMA), based on Wavelength division multiplex (WDM), where different users get different colors in fiber-optical communication.

Wavelength division multiple access (WDMA): is a technology which transmit multiple radio carrier signals on a single channel by using different frequency to carry different signals.

Orthogonal Frequency Division Multiple Access (OFDMA), based on Orthogonal frequency-division multiplexing (OFDM). Multiple access is achieved in OFDMA by assigning subsets of subcarriers to individual users.

Single-carrier FDMA (SC-FDMA) can be viewed as linearly-preceded OFDMA (LP-OFDMA), based on single-carrier frequency-domain-equalization (SC-FDE).

(b) Time-Division Multiple Access (TDMA)

TDMA is based on time-division multiplex (TDM). It allows several users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each using his own time slot. This allows multiple stations to share the same transmission medium (e.g. radio frequency channel) while using only a part of its channel capacity.

TDMA provides different time-slots to different transmitters in a cyclically repetitive frame structure. In a TDMA, the channel time is partitioned into frames. The length of a frame is long enough so that every user in service has an opportunity to transmit once per frame. To achieve this, a TDMA frame is further partitioned into time slots. Users have to transmit in their assigned slots from frame to frame. For example, user 1 may use time slot 1, user 2 time slot 2, etc until the last user. Then it starts all over again. TDMA is used in the digital 2G cellular systems such as Global System for Mobile Communications (GSM), IS-136, Personal Digital Cellular (PDC) and in the Digital Enhanced Cordless Telecommunications (DECT) standard for portable phones. It is also used extensively in satellite systems, and combat-net radio systems. Multi-Frequency Time Division Multiple Access (MF-TDMA) is one of the types of TDMA.

(c) Code Division Multiple Access (CDMA), or **Spread Spectrum Multiple Access** (SSMA)

CDMA is a spread spectrum multiple access method. The principle of spread spectrum communications is that the bandwidth of the baseband information-carrying signals from the different users is spread by different signals with a bandwidth much larger than that of the baseband signals. Ideally, the spreading signals used for different users are orthogonal to each other. Thus, at the receiver, the same spreading signal is used as the dispreading signals to coherently extract the baseband signal from the target user, while suppressing the transmissions from any other users. An example of CDMA is the 3G cell phone system.

In Spread Spectrum communication, the bandwidth occupancy of a single transmitted signal is much higher than in systems using conventional modulation methods. This band-spreading is achieved by selecting appropriate transmission waveforms with a wide bandwidth. A very popular method is to multiply the user data signal with a fast code sequence, which mostly is independent of the transmitted data message.

With Code Division Multiple Access (CDMA) multiple users can share the same portion of the radio spectrum but use different codes to distinguish their transmissions.

CDMA Schemes

Various spread-spectrum techniques are:

Direct-Sequence CDMA (DS-CDMA**),** based on Direct-sequence spread spectrum (DSSS): DS-CDMA is a method which shares spectrum among multiple simultaneous users. Moreover, it can exploit frequency diversity, using a RAKE receiver. However, in a dispersive multipath channel, DS-CDMA with a spread factor N can accommodate N simultaneous users only if highly complex interference cancellation techniques are used. In practice this is difficult to implement. MC-CDMA can handle N simultaneous users with good bit error rate (BER), using standard receiver techniques.

Frequency-Hopping CDMA (FH-CDMA), based on Frequency-hopping spread spectrum (FHSS) is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both transmitter and receiver.

Orthogonal frequency-hopping multiple access (OFHMA).

Multi-Carrier Code Division Multiple Access (MC-CDMA): is a multiple access scheme used in OFDM-based telecommunication systems, allowing the system to support multiple users at the same time. Its development aimed at improved performance over multipath links.

Ultra Wide Band (UWB) techniques using very steep pulses at well defined instants. This is sometimes called “Time Hopping”. Time hopping technique is a spread spectrum technique in which the carrier is turned on and off by the pseudorandom code sequence. It is usually used in combination with other methods, in which the transmitted pulse occurs in a manner determined by a pseudorandom code which places the pulse in one of several possible positions per frame.

Attributes of CDMA in Cellular Systems

There are many attributes of CDMA which are of great benefit to the cellular system

Soft-handoff: Since every cell uses the same radio frequency band, the only difference between user channels is the spreading code sequences. Therefore, there is no jump from one frequency to another frequency when a user moves between cells. The mobile terminal receives the same signal in one cell as it does in the next, and thus there is no harsh transition from one receiving mode to another. Two or more neighboring base stations can receive the signal of a particular user, because they all use the same channel. Moreover, two base stations can simultaneously transmit to the same user terminals. The mobile (rake) receiver can resolve the two signals separately and combine them. This feature is called soft handoff.

Soft capacity or graceful degradation: In FDMA and TDMA, N channels can be used virtually without interference from other users in the same cell but potential users $N+1$, $N+2$, ..., are blocked until a channel is released. The capacity of FDMA and TDMA is therefore fixed at N users and the link quality is determined by the frequency reuse pattern. In theory, it does not matter whether the spectrum is divided into frequencies, time slots, or codes, the capacity provided from these three multiple access schemes is the same. However, in CDMA, all the users in all cells share one radio channel and are separated by codes. Therefore, an additional user may be added by sacrificing somewhat the link quality, with the effect that voice quality is just slightly degraded compared to that of the normal N-channel cell. Thus, degradation of performance with an increasing number of simultaneous users is "graceful" in CDMA systems, versus the hard limits placed on FDMA and TDMA systems.

Multipath-tolerance: Spread spectrum techniques are effective in combating the frequency selective fading that takes place in multipath channels. The underlying principle is that when a signal is spread over a wide bandwidth, a frequency selective fade will corrupt only a small portion of the signal's power spectrum, while passing the remaining spectrum unblemished. As a result, upon dispreading there is a better probability that the signal can be recovered correctly. For an unspread signal whose spectral density happens to be misplaced in a deep fade, an unrecoverable signal at the receiver is virtually assured. To optimally combine signals received over various delayed paths, a rake receiver can be used.

No channel equalization needed: When the transmission rate is much higher than 10 kbps in both FDMA and TDMA, an equalizer is needed for reducing the intersymbol interference caused by time delay spread. This is because when the bit period becomes smaller than about ten times the time delay spread, intersymbol interference becomes significant. However, in CDMA a correlation is needed at minimum. To achieve good performance a rake receiver is needed to combat delay spread.

Privacy: An important requirement of spreading signals is that they are "noise-like", or pseudorandom. Dispreading the signal requires knowledge of the user's code, and for a binary code with spreading factor N there exist 2^N possible random sequences. In military systems these codes are kept secret, so it is very difficult for an unauthorised attacker to tap into or transmit on another users channel. Often it is even difficult to detect the presence of a spread-spectrum signal because it is below the noise that is present in the transmit bandwidth.

Note that in cellular systems, the codes are fully described in publicly available standards. In digital systems, security against eavesdropping (confidentiality) is obtained through encryption. This is a highly desirable alternative to the analog FDMA cellular phone system in wide use today, where with an inexpensive scanner one can tune in to the private conversations of unwary neighbours.

Disadvantages of CDMA

There are, of course, a number of disadvantages associated with CDMA; two of the most severe are the problem of "self-interference," and the related problem of the "near-far" effect.

Self-interference arises from the presence of delayed replicas of signal due to multipath. The delays cause the spreading sequences of the different users to lose their orthogonality, as by design they are orthogonal only at zero phase offset. Hence in dispreading a given user's waveform, nonzero contributions to that user's signal arise from the transmissions of the other users in the network. This is distinct from both TDMA and FDMA, wherein for reasonable time or frequency guardbands, respectively, orthogonality of the received signals can be preserved.

The near-far problem arises from the fact that signals closer to the receiver are received with smaller attenuation than signals located further away. Therefore the strong signal from the nearby transmitter will mask the weak signal from the remote transmitter. In TDMA and FDMA, this is not a problem since mutual interference can be filtered. In CDMA, however, the near-far effect combined with imperfect orthogonality between codes (e.g. due to different time sifts), leads to substantial interference. Accurate and fast power control appears essential to ensure reliable operation of multi-user DS-CDMA systems.

Applications of spread spectrum are in:

Military System: This is the oldest known application. It is popular for security reasons.
Positioning Systems: High bandwidth signals allow accurate measurements of propagation delays. This is used to estimate the distance of a transmitter.
Cellular radio: It is mainly used to combat dispersion and to provide multiple access.
Wireless LANs: If conventional modulation would be used, frequency management for many coexisting links can be very difficult. Moreover, narrowband transmission could be impaired by deep local fades.

(a) Space Division Multiple Access (SDMA)

SDMA enables creating parallel spatial pipes next to higher capacity pipes through spatial multiplexing and/or diversity, by which it is able to offer superior performance in radio multiple access communication systems. In traditional mobile cellular network systems, the base station has no information on the position of the mobile units within the cell and radiates the signal in all directions within the cell in order to provide radio coverage. These results in wasting power on transmissions when there are no mobile units to reach, in addition to causing interference for adjacent cells using the same frequency, so called co-channel cells.

Likewise, in reception, the antenna receives signals coming from all directions including noise and interference signals. By using smart antenna technology and by leveraging the spatial location of mobile units within the cell, space-division multiple access techniques offer attractive performance enhancements. The radiation pattern of the base station, both in transmission and reception is adapted to each user to obtain highest gain in the direction of that user. This is often done using phased array techniques.

3.1.1.2 Packet Mode Methods

Packet mode methods are typically also based on time-domain multiplexing, but not in a cyclically repetitive frame structure, and therefore it is not considered as TDM (Time Division Multiplexing) or TDMA (Time Division Multiple Access). Due to its random character it can be categorized as statistical multiplexing methods, making it possible to provide dynamic bandwidth allocation.

(a) Contention based random multiple access methods

In packet mode communication networks, contention is a media access method that is used to share a broadcast medium.

i. **Aloha**: Any terminal is allowed to transmit without considering whether channel is idle or busy. If packet is received correctly, the base station transmits an acknowledgement. If no acknowledgement is received by the mobile, it retransmits the packet after waiting a random time. The mode of random access in which users can transmit at anytime is called pure aloha. In pure aloha system, where the packet length is a fixed constant, the vulnerability period (i.e. the maximum interval over which two packets can overlap and destroy each other) is two slot times i.e. the time interval required to transmit two packets.

ii. **Slotted Aloha:** A version in which users are restricted to transmit only from the instant corresponding to the slot boundary. Any slot is available for utilization without regards to prior usage

iii. **Multiple Access with Collision Avoidance (MACA)** is a slotted media access control protocol used in wireless LAN data transmission to avoid collisions caused by the hidden station problem and to simplify exposed station problem. The basic idea of MACA is that, a wireless network node makes an announcement before it sends the data frame to inform other nodes to keep silent. When a node wants to transmit, it sends a signal called Request-To-Send (RTS) with the length of the data frame to send. If the receiver allows the transmission, it replies the sender with a signal called Clear-To-Send (CTS) with the length of the frame it is about to receive. Meanwhile, a node that hears RTS should remain silent to avoid conflict. with CTS; a node that hears CTS should keep silent until the data transmission is complete.

iv. **Multiple Access with Collision Avoidance for Wireless (MACAW):** If WLAN data transmission collisions occur after data transmission completion in MACA, then the MACA for Wireless (MACAW) is introduced to extend the function of MACA. It requires nodes sending acknowledgements after each successful frame transmission, as well as the additional function of Carrier sense.

v. **Carrier Sense Multiple Access (CSMA)** is a probabilistic Media Access Control (MAC) protocol in which a node verifies the absence of other traffic before transmitting on a shared transmission medium, such as an electrical bus, or a band of the electromagnetic spectrum. In Carrier Sense Multiple Access (CSMA), users listen before transmission and the listening is referred to as sensing the channel. A station wishing to transmit has to first listen to the channel for a predetermined amount of time so as to check for any activity on the channel. If the channel is sensed "idle" then the station is permitted to transmit. If the channel is sensed as "busy" the station has to defer its transmission.

Types of CSMA

1-persistent CSMA: When the sender (station) is ready to transmit data, it checks if the physical medium is busy. If so, it senses the medium continually until it becomes idle, and then it transmits a piece of data (a frame). In case of a collision, the sender waits for a random period of time and attempts to transmit again.

P-persistent CSMA: This protocol is a generalisation of 1-persistent CSMA. When the sender is ready to send data, it checks continually if the medium is busy. If the medium becomes idle, the sender transmits a frame with a probability *p*. In case the transmission did not happen (the probability of this event is *1-p*) the sender waits until the next available time slot and transmits again with the same probability *p*. This process repeats until the frame is sent or some other sender starts transmitting. In the latter case the sender waits a random period of time, checks the channel, and if it is idle, transmits with a probability *p*, and so on.

Non-persistent CSMA: When the sender is ready to send data, it checks if the medium is busy. If so, it waits for a random amount of time and checks again. When the medium becomes idle, the sender starts transmitting. If collision occurs, the sender waits for a random amount of time, and checks the medium, repeating the process.

Carrier Sense Multiple Access with Collision Detection (CSMA/CD) - suitable for wired networks. CSMA/CD is a modification of pure Carrier Sense Multiple Access (CSMA). Collision detection is used to improve CSMA performance by terminating transmission as soon as a collision is detected, and reducing the probability of a second collision on retry.

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) - suitable for wireless networks. In CSMA/CA (Local Talk), once the channel is clear, a station sends a signal telling all other stations not to transmit, and then sends its packet. In Ethernet 802.3, the station continues to wait for a time, and checks to see if the channel is still free. If it is free, the station transmits, and waits for an acknowledgment signal that the packet was received.

Distributed Coordination Function (DCF): requires a station wishing to transmit to listen for the channel status for a DCF Interframe Space (DIFS) interval. If the channel is found busy during the DIFS interval, the station defers its transmission. In a network where a number of stations contend for the multi-access channel, if multiple stations sense the channel busy and defer their access, they will also virtually simultaneously find that the channel is released and then try to seize the channel. As a result, collisions may occur. In order to avoid such collisions, DCF also specifies random backoff, which forces a station to defer its access to the channel for an extra period. DCF also has an optional virtual carrier sense mechanism that exchanges short Request-to-send (RTS) and Clear-to-send (CTS) frames between source and destination stations during the intervals between the data frame transmissions. DCF includes a positive acknowledgement scheme, which means that if a frame is successfully received by the destination it is addressed to, the destination needs to send an ACK frame to notify the source of the successful reception.

Point Coordination Function (PCF): is a Media Access Control (MAC) technique used in wireless networks which relies on a central node, often an Access Point (AP), to communicate with a node listening to see if the airwaves are free (i.e., all other nodes are not communicating). Since most APs have logical bus topologies (they are shared circuits) only one message can be processed at one time (it is a contention based system), and thus a media access control technique is required.

Carrier Sense Multiple Access with Collision Avoidance and Resolution Using Priorities (CSMA/CARP): Instead of detecting network collisions, CSMA/CARP attempts to avoid collisions by using a system of transmission priorities. When a station wants to transmit on a CSMA/CARP network it first listens for network traffic and if the medium is clear instead of immediately transmitting as a station would in CSMA/CD, it waits a predefined amount of time. This waiting period is called the interframe spacing (IFS) and it varies by the type of data being transmitted. High priority data will transmit almost immediately whereas lower priority data such as polling will have a longer IFS. This system allows CSMA/CARP to avoid many collisions that would occur if it was not used. In addition to having different IFS per priority, a station in a CSMA/CARP network will add a "random backoff" to its waiting period, to reduce the collision probability between stations that have to transmit packets in the same priority.

Carrier Sense Multiple Access/Bitwise Arbitration (CSMA/BA) Based on constructive interference (Controller Area Network - bus) .When two nodes on CAN attempt to transmit at the same time, a non-destructive arbitration technique guarantees the messages are sent in order of priority.

a. **Token passing:** Is where a signal called a token is passed around between nodes that authorize the node to communicate. Token passing schemes are technique in which only the system which has the token can communicate. The token is a control mechanism which gives authority to the system to communicate or use the resources of that network. Once the communication is over, the token is passed to the next candidate in a sequential manner. The most well-known examples are *token ring and token bus*.

b. **Token ring:** Token ring local area network (LAN) technology is a local area network protocol which resides at the data link layer (DLL) of the OSI model. It uses a special three-byte frame called a token that travels around the ring. Token ring frames travel completely around the loop.

c. **Token bus:** Is a network implementing the token ring protocol over a "virtual ring" on a coaxial cable. A token is passed around the network nodes and only the node possessing the token may transmit. If a node doesn't have anything to send, the token is passed on to the next node on the virtual ring. Each node must know the address of its neighbour in the ring, so a special protocol is needed to notify the other nodes of connections to, and disconnections from, the ring.

d. **Polling:** Refers to actively sampling the status of an external device by a client program as a synchronous activity. Polling also refers to the situation where a device is repeatedly checked for readiness, and if it is not the computer returns to a different task.

e. **Resource Reservation (scheduled) Packet-Mode Protocols:** Is a transport layer protocol designed to reserve resources across a network for an integrated internet services.

i. **Dynamic Time Division Multiple Access** (Dynamic TDMA): is a scheduling algorithm which dynamically reserves a variable number of time slots in each frame to variable bit-rate data streams, based on the traffic demand of each data stream. Dynamic TDMA is used in HIPERLAN/2 broadband radio access network, IEEE 802.16a WiMax , Bluetooth , etc.

ii. **Packet Reservation Multiple Access (PRMA)** is a packet-based TDMA concept where the users contend for the time slots. In situations where the system is not near capacity, a user can reserve a time slot for future uses.

iii. **Reservation ALOHA (R-ALOHA)** is a multiple access method for wireless transmission which allows uncoordinated users to share a common transmission resource. Reservation ALOHA (and its parent scheme, Slotted ALOHA) is a schema or rule set for the division of transmission resources over fixed time increments also known as slots. If this rule set or schema is properly followed, the bandwidth users are allowed to cooperatively utilize a shared transmission resource (i.e. the allocation of transmission time).

3.1.1.3 Duplex Methods

A **duplex** communication system is a system composed of two connected parties or devices that can communicate with one another in both directions. Duplex systems are employed in many communications networks, either to allow for “two-way street" communication between two connected parties or to provide a "reverse path" for the monitoring and remote adjustment of equipment in the field. Where these methods are used for dividing forward and reverse communication channels, they are known as duplex methods. Examples are:

(i) **Time division duplex (TDD)** is the application of time-division multiplexing to separate outward and return signals. It emulates full-duplex communication over a half-duplex communication link. Time-division duplex has a strong advantage in the case where there is asymmetry of the uplink and downlink data rates. As the amount of uplink data increases, more communication capacity can be dynamically allocated, and as the traffic load becomes lighter, capacity can be taken away. The same applies in the downlink direction.

(ii) **Frequency division duplex (FDD)** means that the transmitter and receiver operate at different carrier frequencies. The term is frequently used in ham radio operation, where an operator is attempting to contact a repeater station. The station must be able to send and receive a transmission at the same time, and does so by slightly altering the frequency at which it sends and receives. This mode of operation is referred to as duplex mode or offset mode.

Uplink and downlink sub-bands are said to be separated by the frequency offset. Frequency- division duplex can be efficient in the case of symmetric traffic.

Frequency-division duplex makes radio planning easier and more efficient, since base stations do not "hear" each other (as they transmit and receive in different sub-bands) and therefore will normally not interfere with each other.

3.1.2 Comparison of Multiple Access Techniques

(i) **Modulation:** TDMA and FDMA depend on the choice of a modulation scheme to maximize spectral efficiency. To achieve a higher throughput in the same bandwidth, a higher order modulation scheme must be used. With CDMA, the simple method of BPSK modulation is required, although, for practical symmetry considerations, QPSK is often used. In fact, the choice of modulation strategy and the use of SDMA are independent.

(ii) **Forward Error-Correction (FEC) Coding**: All multiple-access techniques are affected by the distortions offered by the wireless channel. With FDMA and TDMA, if the same basic throughput is to be maintained, a higher transmission rate and a greater bandwidth is required as a result of the redundancy introduced by FEC coding. This is the classic trade-off between bandwidth and power efficiency. With CDMA, FEC coding can be added without increasing the system bandwidth or harming the processing gain. The inclusion of FEC is transparent to SDMA. If transmit diversity is implemented, then there can be increased bandwidth with SDMA.

(iii) **Source Coding:** The use of source coding improves the bandwidth efficiency of all multiple-access techniques. However, CDMA is in a position to take greater advantage of voice activation than other techniques, since its bandwidth efficiency is determined by average interference.

(iv) **Diversity:** Multiple transmitters or receivers or both are required to obtain diversity with FDMA, which is an added hardware expense. The same is applied to TDMA, except when it is used as part of a TDMA/FDMA hybrid. In that case, frequency-hopped TDMA can provide some diversity advantage. The large bandwidth of CDMA naturally provides some frequency diversity, and this can be used advantageously with a rake receiver (A rake receiver is a radio receiver designed to counter the effects of multipath fading). The implementation cost of a rake receiver is less than the dual-receiver cost of an FDMA system with frequency diversity.

(v) **User Terminal Complexity:** With the progression from FDMA through TDMA to CDMA comes an evolution of terminal complexity. SDM systems introduce a different and additional form of complexity that is related to the antennas which is not present in any of the other systems.

(vi) **Handover:** With their single-receiver terminals, both FDMA and TDMA are somehow handicapped when they must switch between base stations at a cell boundary. With CDMA, since the frequencies are used in adjacent cells, it is easier to implement a "dual receiver" and provide a soft handover capability.

(vii) **System Complexity:** With an FDMA system, users can operate quite independently. With TDMA, the level of cooperation among users must increase to share slots. With CDMA, the system must delegate spreading codes, power control information, and synchronization information.

(viii) **Multiple-Access Interference (MAI):** Because FDMA and TDMA tend to be limited by worst-case interference, interference is often limited in the system planning stage by the fixed assignment of frequency groups to specific cells. With CDMA, the same bandwidth is used everywhere, and performance is limited by average interference levels. However, CDMA relies heavily on accurate power control to eliminate the near-far problem.

(ix) **Fading-Channel Sensitivity:** FDMA systems are typically narrowband and therefore suffer from flat fading. If the fading is not severe, then simple channel estimation and forward error correction can often compensate for its effects. TDMA systems are typically medium-bandwidth solutions. As a result of this, they observe some frequency selectivity. This requires the implementation of an equalizer. In fact, the implementation of a robust tracking equalizer in wireless channels is of utmost importance. CDMA systems face frequency-selective channels because of their large bandwidth, but take advantage of this natural diversity with a RAKE receiver.

(x) **Bandwidth Efficiency:** For single-cell systems, FDMA and TDMA systems are generally more bandwidth efficient than CDMA systems, because they do not have to cope with multiple-access interference (MAI). However, once their frequency plan is made and the modulation selected, the maximum throughput is fixed. CDMA holds an advantage because it can reuse frequencies everywhere, while FDMA and TDMA have much lower frequency reuse rates because they are limited by peak interference levels. CDMA can often add a user at the expense of a small degradation of existing users.

(xi) **Synchronization:** Wireless system using FDMA, TDMA and CDMA show a progression in synchronization resolution and a corresponding progression in complexity. The main concern of FDMA is symbol timing. In fact, TDMA terminals must contend with chip timing.

(xii) **Flexibility:** FDMA is the least flexible of the techniques. Once the service is designed, any change requires a redesign. With TDMA, higher data rates can be provided by assigning more slots per user, usually with very little change to the hardware. With CDMA, different data rates can be provided by trading off the spreading rate (processing gain), making it very flexible. Out of these techniques Space Division Multiple Access (SDMA) is transparent.

(xiii) **Voice and Data Integration:** The comments regarding flexibility also apply to the integration of voice and data over the same terminal. With TDMA, it is possible as well to make use of periods of voice inactivity to transmit data, thus making the system more efficient. CDMA can easily integrate voice and data, but usually it leads to multicode transmissions, which may reduce the efficiency of the user-terminal power amplifier.

(xiv) Evolution: Evolving from a small system to a large system is easiest with the FDMA approach. We can easily start with a single-user system and remain relatively efficient at each step. With TDMA, start-up efficiency is related to the transmission rate; the system can evolve easily through the addition of more TDMA channels using an FDMA overlay. With CDMA, there is a large start-up cost, because a large bandwidth to serve perhaps only a few initial user terminals is needed.

Parameters of comparison	**FDMA**	**TDMA**	**CDMA**	**SDMA**
Modulation	Relies on bandwidth efficient modulation	Relies on bandwidth efficient modulation	Simple modulation	Transparent
Forward error correction	Increases power efficiency at expense of bandwidth efficiency	Increases power efficiency at expense of bandwidth efficiency	Can be implemented without affecting bandwidth efficiency	Transparent
Source coding	Improves efficiency	Improves efficiency	Improves efficiency voice activation advantage	Transparent
Diversity	Requires multiple transmitters or receivers	Requires multiple transmitters or receivers can be frequency hopped	Includes frequency diversity when implemented with a RAKE receiver.	Single antenna reduces space diversity, orthogonal coding improves diversity with multiple transmit antennas
User terminal complexity	Simple	Medium complexity	More complex	Requires smart antennas

Handover	Hard	Hard	Soft	Potentially soft
System complexity	Large number of simple components	Reduced number of channel unit	Large number of complex interacting components	Additional complexity related to antennas
Multiple-access interference	Limited by system planning	Limited by system planning	Dynamic power control	Limited by resolution of antennas
Fading	Flat-fading no diversity simple to track	May need frequency-selective and equalizer	Frequency-selective diversity via RAKE receiver	Reduced multipath
Bandwidth efficiency	Hard limits based on modulation and channel spacing	Hard limits based on modulation and channel spacing	Soft limits	Depends on antenna resolution
Synchronization	Low resolution	Mid-resolution	High resolution	Requires terminal location
Flexibility	Fixed data rate	Data rate variable in discrete steps	Can provide a variety of data rates without affecting signal in space	Transparent
Voice and data integration	Possible, but may require revisions to system	Straight forward using multiple slots	Multicode transmission, which may decrease efficiency of mobile terminal	Transparent
Evolution	Bandwidth to fit application	Requires medium initial	Requires large initial bandwidth	Flexible, can be added as

		bandwidth		far as it does not affect mobile

Table 6.1 Comparison of Different Multiple Access Strategies

Source Sharma S. (2006)

3.1.3 Application Areas of Multiple Access

Local and metropolitan area networks : In local area networks (LANs) and metropolitan area networks (MANs), multiple access methods enable bus networks, ring networks, hubbed networks, wireless networks and half duplex point-to-point communication, but are not required in full duplex point-to-point serial lines between network switches and routers, or in switched networks (logical star topology). The most common multiple access method is CSMA/CD, which is used in Ethernet. Although today's Ethernet installations typically are switched, CSMA/CD is utilised to achieve compatibility with hubs.

Satellite communications: In satellite communications, multiple access is the capability of a communications satellite to function as a portion of a communications link between more than one pair of satellite terminals concurrently. Three types of multiple access presently used with communications satellites are code-division, frequency-division, and time-division multiple access.

Switching centers: In telecommunication switching centers, multiple access is the connection of a user to two or more switching centers by separate access lines using a single message routing indicator or telephone number.

4.0 CONCLUSION

In this unit, different multiple access techniques were discussed under circuit and packet mode, channelization and duplex methods. Also areas where multiple access can be applied and the comparison of multiple access techniques were discussed.

5.0 SUMMARY

In this unit, you have learnt that:

Multiple Access is a signal transmission situation in which two or more users wish to simultaneously communicate with each other using the same propagation channel.

Multiple Access can be categorized under:

- Circuit mode and channelization methods: FDMA, TDMA, CDMA, SDMA.
- Packet mode
- Duplex Method

The basic multiple access techniques are FDMA, TDMA, CDMA, SDMA, and PMMA

FDMA is based on frequency division multiplex. It gives users an individual allocation of one or several frequency bands, or Channels. Each user is allocated a unique frequency subband for the duration of the connection, whether the connection is an active or idle state.

TDMA is based on time-division multiplex (TDM). It allows several users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each using his own time slot.

CDMA is a spread spectrum multiple access method. The principle of spread spectrum communications is that the bandwidth of the baseband information-carrying signals from the different users is spread by different signals with a bandwidth much larger than that of the baseband signals.

SDMA enables creating parallel spatial pipes next to higher capacity pipes through spatial multiplexing and/or diversity, by which it is able to offer superior performance in radio multiple access communication systems.

SELF ASSESSMENT EXERCISE

1. What is multiple access?
2. Define CSMA.
3. Discuss the types of CSMA.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss on any three types of multiple access techniques.
2. Write short note on the following: OFDMA, Dynamic TDMA and Aloha.
3. Discuss the concept of CDMA techniques.
4. Define and explain TDMA systems.

7.0 REFERENCES/FURTHER READING

Linnartz, J. P. G (2001). “Performance Analysis of Sychronous MC-CDMA in Mobile Rayleigh Channels with Both Delay and Doppler Spreads”, IEEE, 50(6), 1375-1387.

Linnartz, J. P. G. (1995). Cellular Telephone Network. (Online) Available at http://wireless.per.nl/reference/about.htm

Sharma, S. (2006). *Wireless and Cellular Communications*. New Delhi: S.K. Kataria & Sons.

Yee, N. & Linnartz J. P.G (1994). “Wiener Filtering for Multi-Carrier CDMA”, IEEE/ICCC Conference on Personal Indoor Mobile Radio Propagation Communications (PIMRC) and Wireless Computer Networks (WCN), 4, 1344-1347

Yee, N., Linnartz, J. P.G & Fettweis, G. (1993). “Multi-Carrier CDMA in Indoor Wireless Radio Network”, IEEE Personal Indoor and Mobile Radio Communications (PIMRC) International Conference, Yokohama, Japan, 109-113