Data Communication CS601

Table of Contents

LECTURE #1

Course Outline

- **The course will consist of :**
  - 45 lectures
  - 10-14 assignments
  - 2exams (1 midterm and 1 final)
  - GMDB
- **Grading Criteria**:
  - One Midterm: 35 %
  - Final Exam: 45%
  - Assignments: 15%
  - GMDB: 5%

Textbook

- **"Data Communications and Networking" 4th Edition by Behrouz A. Forouzan**
- **"Data and Computer Communication" 6th Edition by William Stallings**

INTRODUCTION TO DATA COMMUNICATION

DEFINITION OF DATA COMMUNICATION

"Data Communication is the ***exchange*** of ***Information*** from one ***entity*** to the other using a ***Transmission Medium***".

DEFINITION OF DATA COMMUNICATION (Cont'd)

As you can clearly notice, the definition of Data Communication although Simple leaves many questions unanswered:

- Exchange??????
- Information?????
- Entities???????
- Transmission????
- Medium????

We will try to answer all these Questions in this Course

History of Data Communication

Data communications history represents a blend of histories, including:

- The history of the telecommunications industry
- The history of data communications, and
- The history of the Internet

- **Telegraph 1837 Samuel Morse**

  Modern telecommunication industry began in 1837 with the invention of the telegraph by Samuel Morse

  This led to building a telecommunications infrastructure of poles and wires as well as to the development of communication hardware and protocols

- **Telephone 1876 Alexander Graham Bell**

  Invention of telephone by Alexander Graham Bell in 1876 and the development of wireless communication technology by Guglielmo Marconi in the 1890s set the stage for today's communication industry

- **By 1950's**

  By 1950s, telephone and telegraph companies had developed a network of communication facilities throughout the industrialized world

- **1970'S**

  Although development of databases, languages, operating systems, and hardware was strong from 1950s to 1970s, large-scale data communication systems did not emerge until the 1970s.

  This was stimulated by *3 major developments*:

  - Large-scale integration of circuits reduced cost and size of terminals and communication equipment

- New software systems that facilitated the development of data communication networks
- Competition among providers of transmission facilities reduced the cost of data circuits

TODAY’S EVERGHANGING & BUSY WORLD

- Today’s fast world demands better, secure and most of all FAST ways of communication
- Gone are the days when you had to wait a couple of weeks to get a letter from USA
- Why wait ONE week when you can get the information you require in just a split of a second, using what we know by the name of “**DATA COMMUNICATION”**.

HOW TO ACHIEVE THIS?

- How to achieve this ACCURACY, SECURITY and SPEED for the transfer of this information?
- What HARDWARE and the SOFTWARE is needed?
- And, what should be the MEANS of sending this info?

ARE SOME OF TOPIC WE WILL BE EXPLORING DURING THE COURSE OF OUR STUDY

DATA COMMUNICATION

- When we communicate , we share information
- Information can be LOCAL or REMOTE
- Between Individuals LOCAL communication occurs face to face
- REMOTE communication occurs over a long distance
- When we refer to COMPUTER SYSTEMS, Data is represented in the form of Binary Units (Bits) in the form of Zeros (0’s) and One’s (1’s)
- Also the entities can most of the times be considered to be COMPUTERS

Data Communication Definition (Modified)

Therefore, our earlier definition can easily be modified to:

“Data Communication is the exchange of data (in the form of 0’s and 1’s) between two devices (computers) via some form of the transmission medium.”

LOCAL and REMOTE Data Communication

- **LOCAL**
  Data communication is considered to be local if the communicating devices are present in the same building or a similarly restricted geographical area

- **REMOTE**
  Data Communication is considered remote, if the devices are farther apart.

VAGUE DEFINITIONS
We will clarify

Data Communication System

For Data Communication to occur, the communicating devices must be a part of a communication system made up of some specific kind of hardware and software
This type of a system is known as a

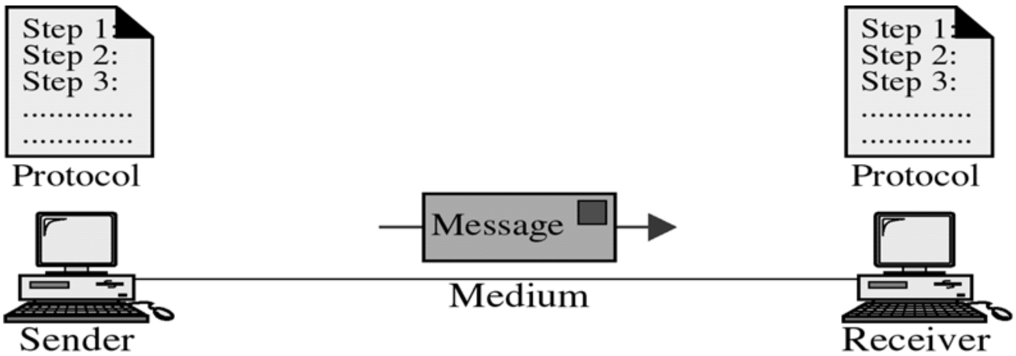
"DATA COMMUNICATION SYSTEM"

Effectiveness of Data Comm. System

Effectiveness depends upon three fundamental characteristics:

- Delivery
- Accuracy
- Timeliness (Better NEVER than LATE)
  - Example of the POSTAL MAIL

Components of Data Comm. Systems



Components of Data Com Systems

Any system is made up of more than one component. Similarly, a data communication system is made up of 5 components as shown in the fig:

- Message
- Sender
- Receiver
- Medium
- Protocol

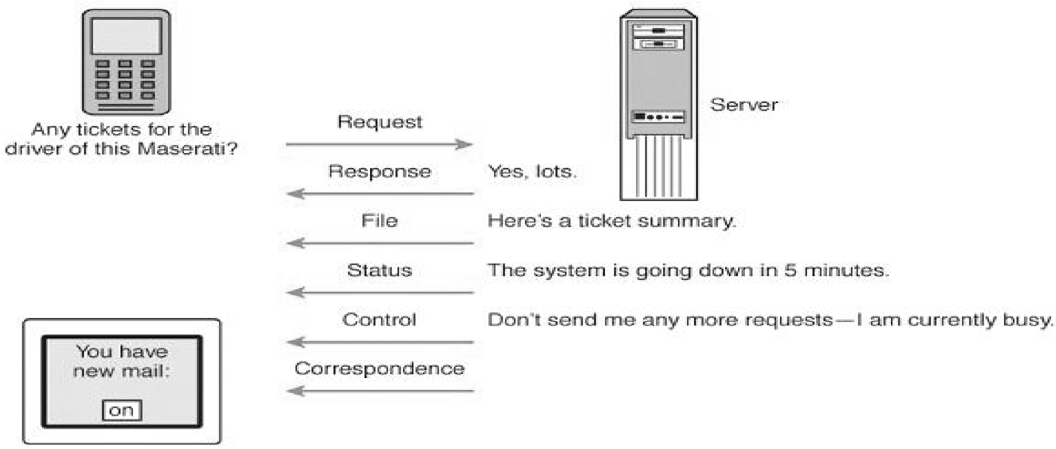
- **MESSAGE**

  - Information or Data to be communicated
  - Can be text, numbers, video or any combination of these
  - In short anything that can be represented using binary bits

Data Communication Messages

- **Files** (meaningful collections of records)
- **Data/information requests** (database queries, Web page requests, etc.)
- **Responses** to requests and commands or error messages
- **Status messages** (about the network's functional status)
- **Control messages** transmitted between network devices to control network traffic
- **Correspondence** among network users

MESSAGE TYPES



- **SENDER**

  - Device that sends the data message
  - Can be a Computer , Workstation, Video camera etc
  - As already discussed, the data from the sender might not be in the appropriate format for the transmission medium and will need to be processed

- **RECEIVER**

  - Device that receives the message
  - Can be a computer, workstation, Television etc
  - At times, the data received from the transmission medium may not be in a proper form to be supplied to the receiver and it must be processed

- **MEDIUM**

  - Physical path that a message uses to travel from the Sender to the Receiver
  - Can be a Copper Cable (Telephone), Coaxial Cable (Cable TV), Fiber Optic Cable, LASERS or Radio Waves (Wireless Medium)
  - We will see that Data needs to be transferred in the form of ELECTROMAGNETIC signals and The Transmission Medium should be capable of carrying these EM Signals
  - Transmission Media

Transmission Media

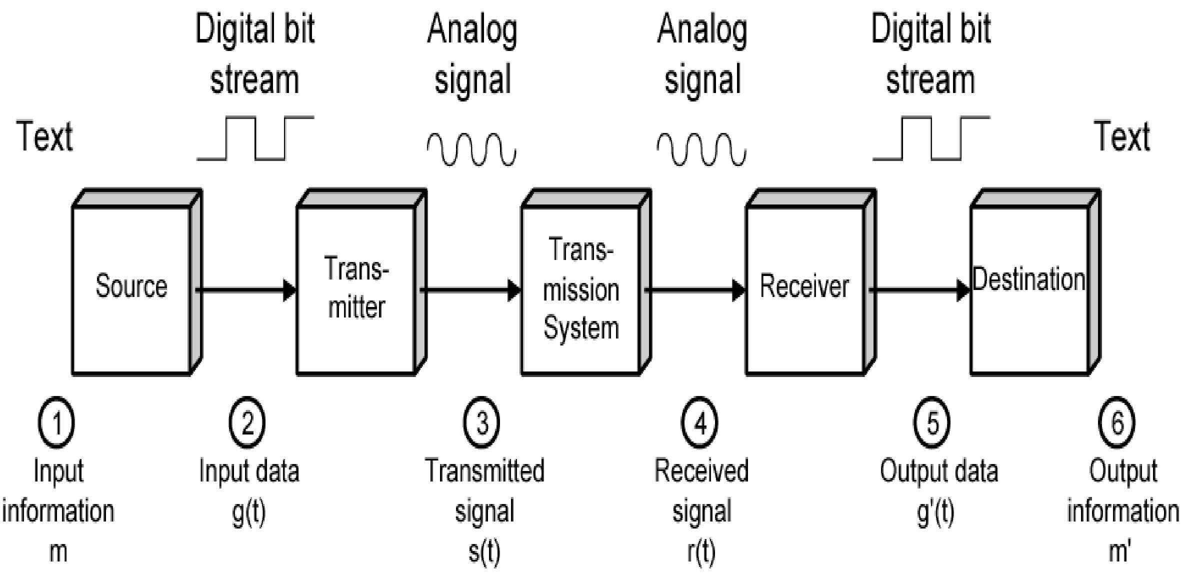
Medium	**Speed**	**Cost**
Twisted Wire	**300bps-10Mbps**	**Low**
Microwave	**256Kbps-100Mbps**	**Low**
Coaxial Cable	**56Kbps-200Mbps**	**Low**
Fiber Optic Cable	**500Kbps-10Gbps**	**High**

- **PROTOCOL**

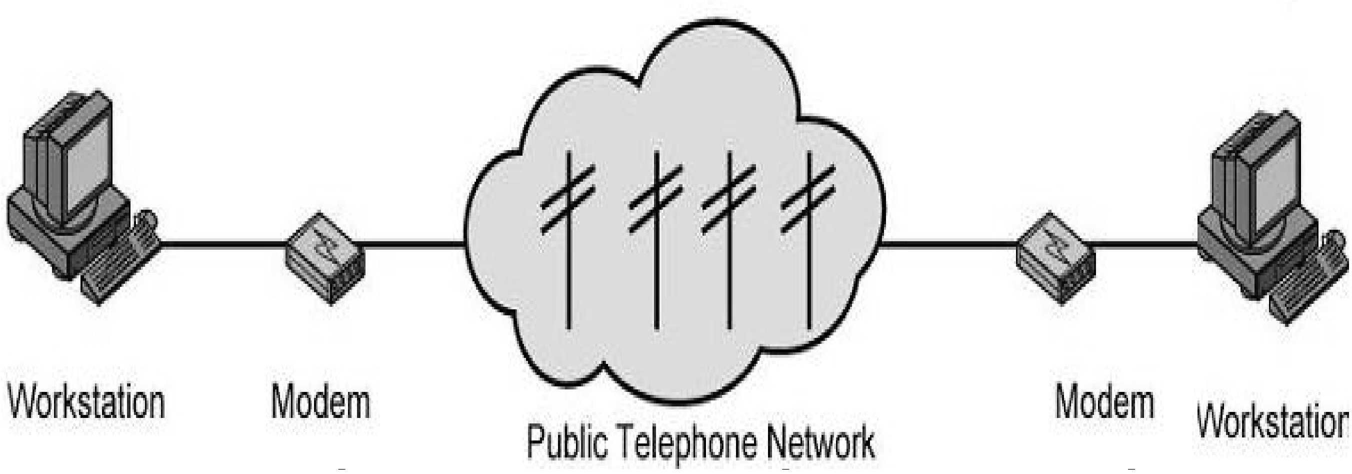
  - Set of Rules Governing Communication
  - Represents an Agreement between communication devices
  - Without Protocol, two devices may be connected but they will not be able to communicate

    - **EXAMPLE**: Consider the communication between two individuals. They can only communicate provided they both speak the same language.

A little more complex Comm. System



EXAMPLE – ELECTRONIC MAIL



- User of a PC wishes to send a message 'm'
- User activates electronic mail package e.g. hotmail
- Enters the message via input device (keyboard)
- Character string is buffered in main memory as a sequence of bits 'g'
- PC is connected to some trans system such as a Telephone Network via an I/O Transmitter like Modem
- Transmitter converts incoming stream 'g' into a signal 's'

- **RECEIVER SIDE**

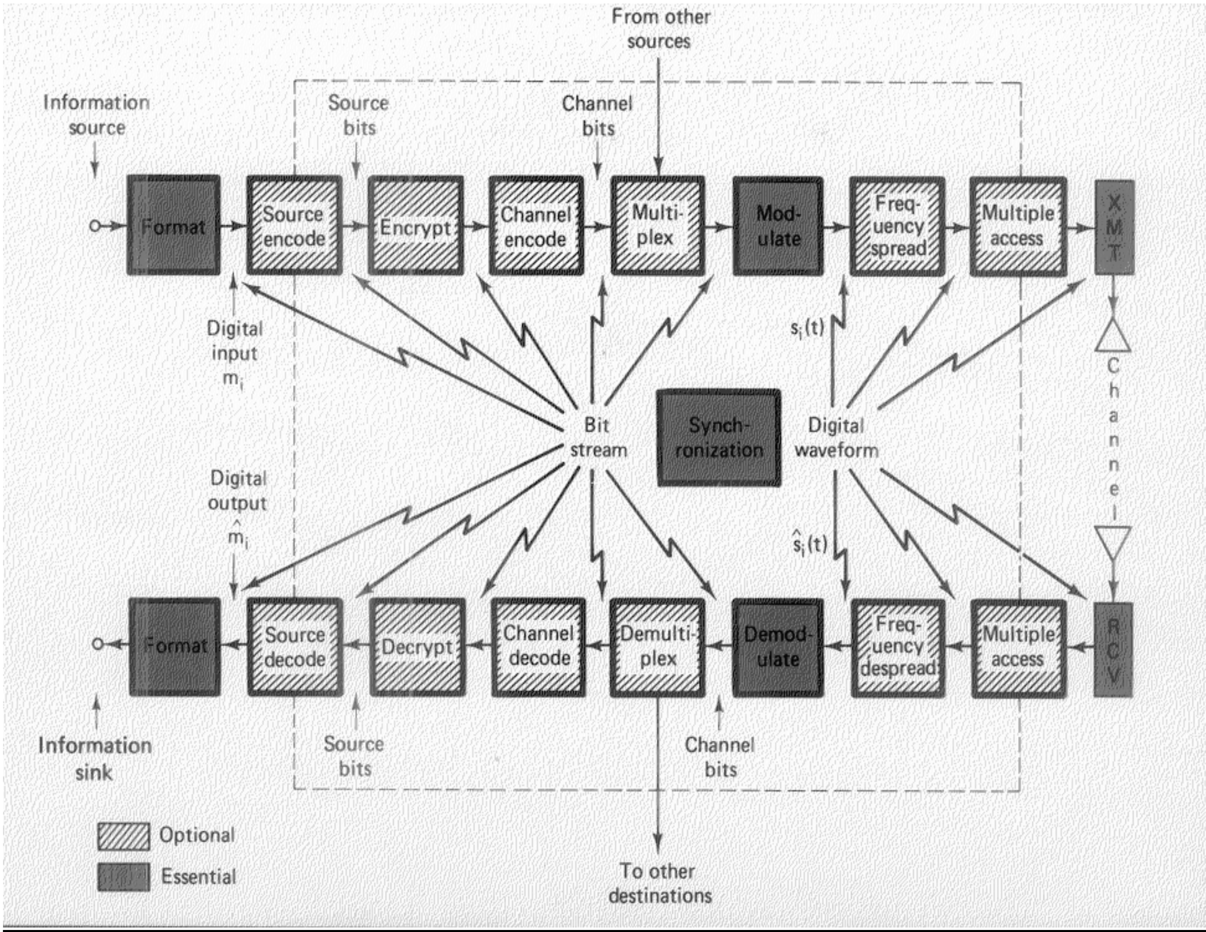
- The transmitted signal 's' is subject to a number of impairments depending upon the medium
- Therefore, received signal 'r' may differ from 's'.
- Receiver attempts to estimate original 's' based on its knowledge of the medium and received signal 'r'
- Receiver produces a bit stream g'(t)
- Briefly buffered in the memory
- Data is presented to the user via an output device like printer, screen etc.

- The data viewed by user m' will usually be an exact copy of the data sent 'm'

EXAMPLE-Telephone System

- Input to the Telephone is a message 'm' in the form of sound waves
- The sound waves are converted by telephone into electric signals of the same frequency
- These signals are transmitted w/o any modification over the telephone line
- Hence g(t) and s(t) are identical
- S(t) will suffer some distortion so that r(t) will not be the same as s(t)
- R(t) is converted back to sound waves with no attempt of correction or improvement of signal quality
- Thus m' is not an exact replica of m

An Actual Digital Data Communication System Key Data Communication Terminology



- **Session**: communication dialog between network users or applications
  Different Types of this session for Info Exchange
- **Network**: interconnected group of computers and communication devices
  We will look into it in a little bit
- **Node**: a network-attached device
  Node can be any device in the network

Summary

- Data Communication
- Brief History of Communication
- Data Communication System
- Key Data Communication Terminology

Reading Sections

- Section 1.2, “Data Communications and Networking” 4th Edition by Behrouz A. Forouzan
- Sections 1.1, 1.2, “Data and Computer Communication” 6th Edition by William Stallings

LECTURE #2

KEY DATA COMMUNICATION TERMINOLOGY

- **Link: connects adjacent nodes**
  Wires, Cables, Any thing that physically connects two nodes

- **Path: end-to-end route within a network**

- **Circuit: the conduit over which data travels**

- **Packetizing: dividing messages into fixed-length packets prior to transmission over a network's communication media**

- **Routing: determining a message's path from sending to receiving nodes**

  ./ **The transmission medium may itself be a network, so route needs to be specified**

Network

"A NETWORK is a set of devices (Nodes) connected by Communication Links"

- **Node**: Can be a Computer, Printer or any other device capable of sending or receiving

  Y The links connecting Nodes are called COMMUNICATION CHANNELS Networks- Why we need them?

Networks- Why we need them?

It is often impractical for devices to be directly connected for two major reasons:

- The devices are very far apart. They are expensive to connect just two devices with one in Lahore and other in Islamabad
- Large set of devices would need impractical number of connections e .g. Telephone Lines in the world and all the computers owned by a single organization

Solution to the Problem=Networks

- Solution is to connect all devices to a central system known as a ***NETWORK*** in which all terminals or computers share the links.

- Two Main Classifications of the Networks

- LANS
- WANS

DISTRIBUTED PROCESSING

- Instead of a single large machine being responsible for all aspects of a process , each separate computer handles a subset of the task
  - Example – Project Given as a part of the Course
  - Example – Office Work

Advantages of Distributed Processing

- **Security**

  A system designer can limit the kind of interaction that a given user can have with the entire system.

  - For example : Bank's ATM

- **Distributed Data bases**

  No one system need to provide storage capacity for the entire database

  - For example WWW gives user access to pages stored anywhere on Internet

- **Faster Problem Solving**

  Multiple computers working on a problem can solve a problem faster than a computer working alone

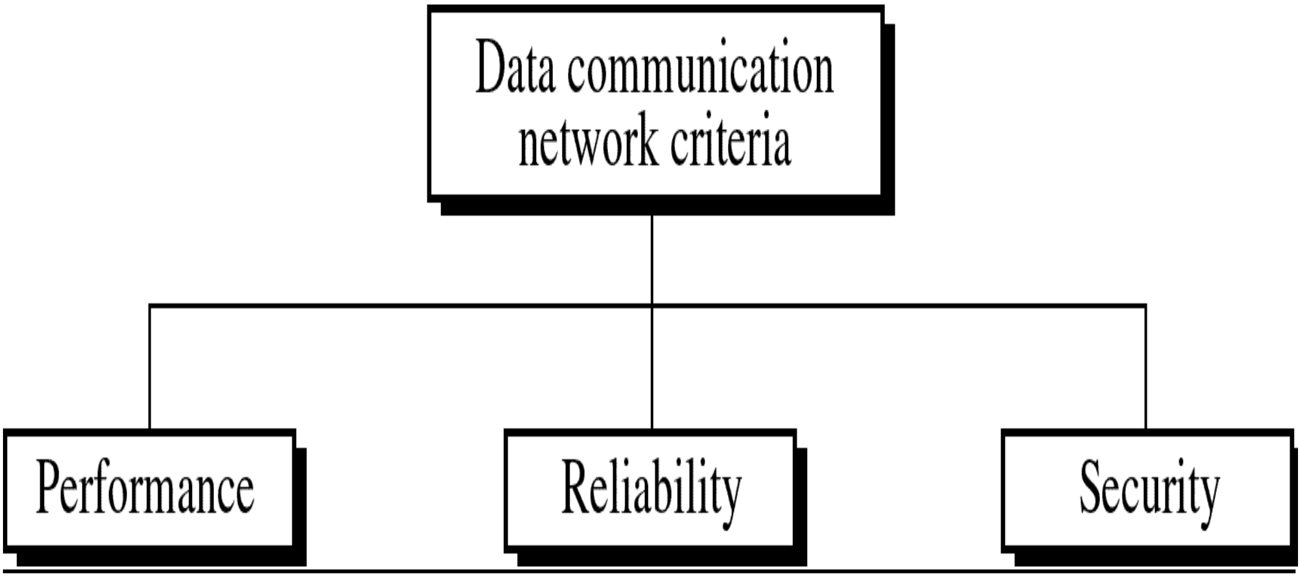
- **Security through Redundancy**

  Multiple computers running the same program provide security through redundancy
  If one computer hardware breaks down then others cover up.

- **Collaborative Processing**

  Both multiple computers and multiple users can interact for a task

Network Criteria



- **<u>Performance</u>**

Can be measured in many ways including ***Transit and Response Time***

- **Depends on a no. of Factors:**

    - Number of USERS
    - Type of Transmission Medium
    - Hardware
    - Software
    - Network Criteria

    - **<u>Number of USERS</u>**
        - Large Number of concurrent users slow network
        - Design of a network
        - Peak Load Periods
        - Network Criteria
    - **<u>Type of Transmission Medium</u>**
        - Medium defines speed at which data can travel
        - Fiber Optic Cable
        - 100Mbps and 10 Mbps
        - Hardware
        - Software
    - **<u>Hardware</u>**
        - Effect speed and the capacity of transmission
        - Fast computer with large storage capacity
        - Software
        - Network Criteria

    - **<u>Software</u>**

- ./ Software processes data at sender , receiver and intermediate nodes
- ./ All communication steps need software:
- ./ Moving message from node to node
- ./Transforming,
- ./ Processing at the sender and receiver
- ./ Error Free Delivery

Well designed software can speed up the process

- **Reliability**
  - Depends on a no. of Factors:
    - Frequency of Failure
    - Recovery Time of a Network after Failure
    - Catastrophe
    - Fire , Earthquake or Theft
- **Security**
  - **Unauthorized Access**
    - Sensitive data
    - Protection at multiple levels:
    - Lower level: Passwords and user ID codes
    - Upper Level: Encryption
  - **Viruses**

Network Applications

- **Marketing and Sales**
  - **Marketing**
    - Collect, exchange and analyze data relating to the customers needs
    - Product development cycles
  - **Sales**
    - Tele shopping,
    - On line reservation systems
- **Financial Services**
  - Online Banking
  - Foreign Exchange Transfers
  - Rates
- **Manufacturing**

  - Computer Aided Design
  - Computer Assisted Manufacturing
  - Network Applications

- **Electronic Messaging**

- **Teleconferencing**

  - Conferences to occur w/o participants at the same place
  - Chat
  - Voice Conferencing
  - Video Conferencing

- **Cable Television**

Summary

- Key Data Communication Terminology
- Networks and why we need them?
- Distributed Processing
- Network Criteria
- Network Applications

Reading Sections

- Section 1.3, "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan
- Sections 1.3, "Data and Computer Communication" 6th Edition by William Stallings

LECTURE #3

Communication Tasks

There are some key tasks that must be performed in a data communication system
Elements can be added, deleted, or merged together

Transmission System utilization	Interfacing
Signal Generation	Synchronization
Exchange Management	Error Detection and Correction
Flow Control	Addressing
Routing	Recovery
Security	Network Management

- **Transmission System Utilization**

  Need to make efficient use of Transmission facilities that are shared among a no. of communicating devices

  For Example:
  - ./ Techniques like **Multiplexing** to allow multiple users to share total capacity of a Transmission Medium
  - ./ **Congestion Control**: TX. System should not be overwhelmed by traffic

- **Interfacing**
  A device must have an Interface with the Transmission System/Transmission Medium

- **Signal Generation**

  Electromagnetic Signals travel over Transmission Medium. Once an interface is established, Signal generation is required

  - Y **Properties of Signals**
    - ./ Capable of being propagated over TX. Medium
    - ./ Interpretable as data at the Receiver

- **Synchronization**
  The transmission and the reception should be properly synchronized. Synchronization means that the receiver must be able to determine, when to

expect a new transmission and when to send acknowledgements. In other words transmitter and receiver should have an agreement on the nature as well as timing of the signals

- **Exchange Management**
  If the data needs to be exchanged in both directions over a period of time, both parties must cooperate as follows

  - Whether both devices must transmit simultaneously or take turns
  - Amount of Data to be sent at one time
  - Format f the Data
  - What to do when an Error Arises

- **Error Detection and Correction**
  In all comm. Systems, there is a potential risk for errors and impairments.
  Tx. Signals are distorted to some extent before reaching their destination. Error Detection & Correction needs to be employed in Data Processing Systems where a change in say the contents of a file cannot be tolerated

- **Flow Control**
  To make sure that source does not overwhelm destination by sending data faster than it can be handled and processed

- **Addressing & Routing**
  If TX facility is shared by two or more devices, source must specify the identity or the address of the destination system and if Tx. System is itself a system, a proper route must be allocated that the data will take in order to reach the desired destination

- **Recovery**
  If a data transmission is interrupted due to a fault somewhere in the system, recovery techniques are needed. The objective is either to resume activity at the point of interruption and to restore the state of the system to what it was prior to the interruption

- **Security**

  Security is very important issue in a Data Communication System. The sender needs to be assured that

  - Only the Intended receiver receives the data
  - Data is delivered unaltered

Introduction to Protocol

In computer Networks, communication occurs between two entities in different systems.

- Entity is anything sending and receiving information
- SYSTEM is a physical object containing more than one entities

Now, two entities in different systems cannot just send data and expect to be understood. For communication to occur, these entities must agree on a PROTOCOL

PROTOCOLS

As discussed earlier**, "Protocol is a set of rules governing communication"**

- Two computers cannot just send bit streams to each other and expect to be understood
- Entities must agree on a PROTOCOL

    - Same Example French and German

Protocol defines:

- What is Communicated?
- How it is Communicated?
- When it is Communicated?

KEY elements of a PROTOCOL

- **Syntax:**

    - Represents the Structure or the format of the Data
    - Meaning the order in which data is presented

    For Example
    - First eight bits to be Sender address
    - Next eight to be Receiver's Address
    - The Rest to be Data

- **Semantics:**

    - Refer to the Meaning of each section of bits
    - How is a particular pattern to be interpreted?
    - What action should be taken based on interpretation?

    For Example
    - Does an address identify the route to be taken or the final destination of the message?

- **Timing**

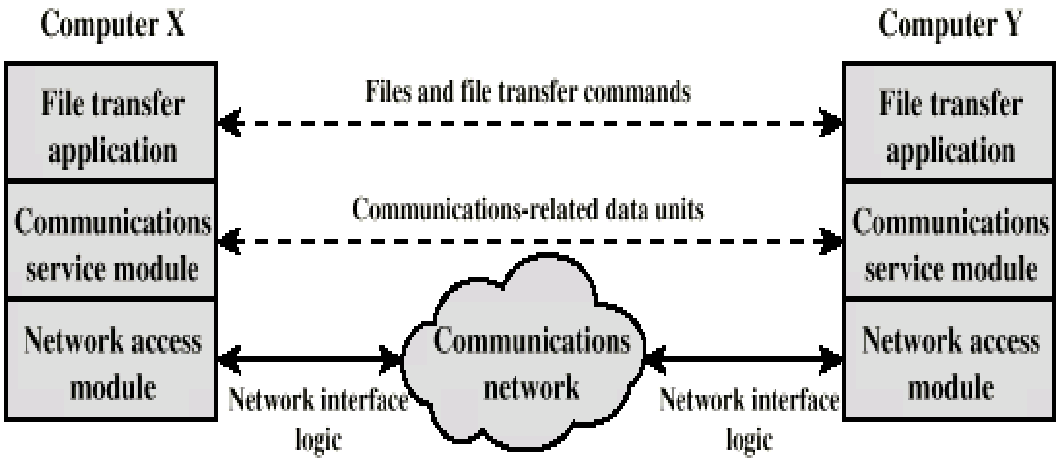
    Refers to 2 characteristics:
    - When data should be sent?
    - How fast it should be sent?

    For Example
    - If sender produces data at 100 Mbps
    - But Receiver can only process data at 1 Mbps
    - The TX. will overload receiver and data will be lost

Protocol Architecture

Instead of having a single Module for performing communication, there is a structured set of modules that implement communications function"
This structure is called Protocol Architecture
Let's explain it by an example of File transfer system.

Simplified File Transfer Architecture



In the above example File transfer could use three modules

- File transfer application
- Communication service module
- Network access module

- **File transfer application**

File Transfer contains all of the logic is unique to the file transfer application such as:

- Transmitting passwords
- File Commands
  - Checking File System on other machine if it is ready
  - Check File System Compatibility
- File records

- **Communication service module**

Instead of allowing File Transfer Module to deal with actual transfer of data and commands, we can have a separate module for this transfer. This module must make sure that the receiver system is ready to receive and look into the reliable exchange of data

- **Network access module**

Nature of the exchange between systems is independent of the network that connects them. That allows us to have a 3rd module that handles the details of the Network interface and interacts with the network. If Network to be used changes, only Network access Module has to change

Characteristics of a Protocol

- Direct or indirect
- Monolithic or structured
- Symmetric or asymmetric
- Standard or nonstandard

- **Direct**
  - Systems share a point to point link or
  - Data can pass without intervening active agent
  - Simple Protocol

- **Indirect**
  - Switched networks or
  - Interne works or internets
  - Data transfer depend on other entities
  - Complex Protocol

- **Monolithic or Structured**
  - Communications is a complex task
  - To complex for single unit
  - Structured design breaks down problem into smaller units
  - Layered structure

- **Symmetric or Asymmetric**

  Symmetric
  - Communication between peer entities

  Asymmetric
  - Client/server

Standard or Nonstandard
- Nonstandard protocols built for specific computers and tasks

Summary

- Communication Tasks
- Protocols
- Protocol Architecture
- Characteristics of a Protocol

Reading Sections

- Section 1.4 “Data Communications and Networking” 4th Edition by Behrouz A. Forouzan
- Sections 1.1,2.1 “Data and Computer Communication” 6th Edition by William Stallings

LECTURE #4

Standards

"A standard provides a model for development that makes it possible for a product to work regardless of the individual manufacturer|"

- A great deal of coordination and cooperation is required by the devices to communicate
- A device prepared by a specific manufacturer may not be compatible with the devices prepared by other manufacturers
- Unavailability of standards creates problems and puts a halt to product growth

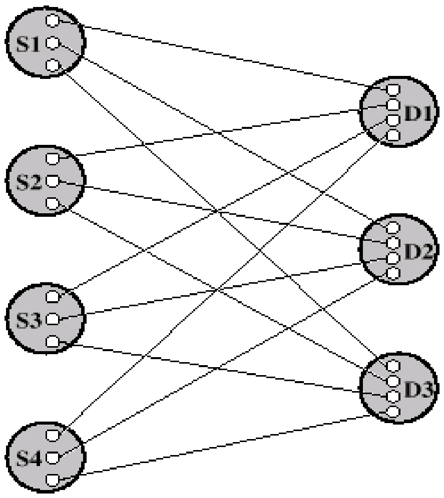
  ./ An example of non-standardized products is AUTOMOBILES

Why Standards are Essential?

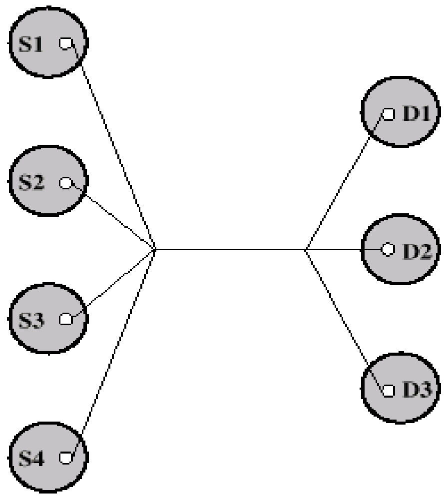
Standards are therefore essential in:

- Creating and Maintaining an Open and competitive Market for Equipment Manufacturers
- Guaranteeing National and International Interoperability of Data and Telecommunications Technology and Equipment

Let us understand this using an EXAMPLE



(a) Without standards: 12 different protocols; 24 protocol implementations

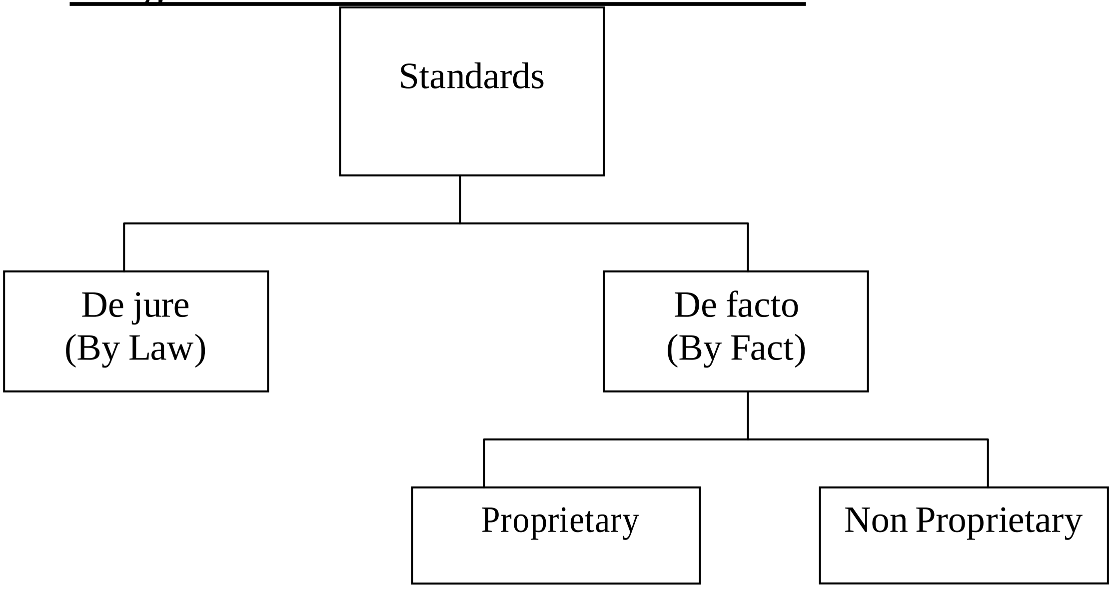


(a) With standards: 1 protocol; 7 implementations

NOTE

- K sources and L receivers leads to K*L protocols and 2*K*L implementations
- If common protocol used, K + L implementations needed

Categories of Data Communication Standards



- **De facto (By fact or By Convention)**

  Standards not approved by an organized body but have been adopted as standards through their widespread use

- **De jure (By Law or By Regulation)**

  Standards that have been legislated by an officially recognized regulation body

Subdivision of De Facto Standards

- **PROPRIETARY** (Closed Standards)

  Standards that are originally invented by a Commercial Organization as a basis for the operation of its products they are wholly owned by that company. They are also called Closed Standards because they close off Communication between systems

- **NON- PROPRIETARY** (Open Standards)

  They are originally developed by groups or committees that have passed them into public domains. They are also called Open Standards because they open Communication between different systems

Standard Organizations

Standards are developed mainly by 3 entities:

- Standard Creation Committees
- Forums
- Regulatory Agencies

- **Standard Creation Committees**

They are Procedural Bodies and they are so slow moving and cannot co-op with the fast growing communication industry.

- **ISO**
  - International Standard's Organization
  - Voluntary Organization
  - Created in 1947
  - Members are from Standard Creation Committees of different countries
  - Includes representatives from 82 countries
  - Open System Interconnection (OSI) Model

- **ITU-T**
  - By 1970s a lot of countries were defining standards but there was no International compatibility
  - United Nations made as a part of their ITU
  - Consultative Committee for International Telegraphy and Telephony (CCITT)
  - IN 1993 , ITU-Telecomm Standards Sector
  - Important ITU-T Standards
  - V Series (V32, V33, V42, Define Data Transmission over phone lines
  - X Series(X.25, 400, 500): Define Transmission over Public Digital Network
  - ISDN: Integrated Services Digital Network

- **The American National Standard Institute (ANSI)**
  - Private-Non Profit Cooperation not affiliated with US Government
  - Members include professional societies, industrial associations, govt. and regulatory bodies
  - Submits proposal to ITU-T and is a voting member for USA in ISO

- **The Institute of Electrical and Electronics Engineers (IEEE)**
  - Largest professional engineering society in the world
  - Also oversees the development of Telecommunication and Wireless International Standards
  - Special committee for LANS out of which emerged Project 802 (802.3, 802.4, 802.5)

- **Forums**

Special Interest Groups with representatives from interested corporations they facilitate and fasten standardization process by working with universities, and users to test, evaluate and standardize new technologies

Each Forum Concentrate on a specific technology and present their conclusions to the standard bodies

- Frame Relay Forum
- ATM Forum
- Internet Society & IETF

- **Regulatory Agencies**

  All communication technology is subject to regulation and laws by government agencies. The purpose is to protect Public Interest by regulating Radio, Television and Cable Communications.

  - FCC

Before we go into the details of how data are transmitted from one device to the other, it is important to understand:

- The relationship between communication devices.
- How the devices connect with each other in a System?
- How do they do the exchange of information?

Five Concepts provide the basis

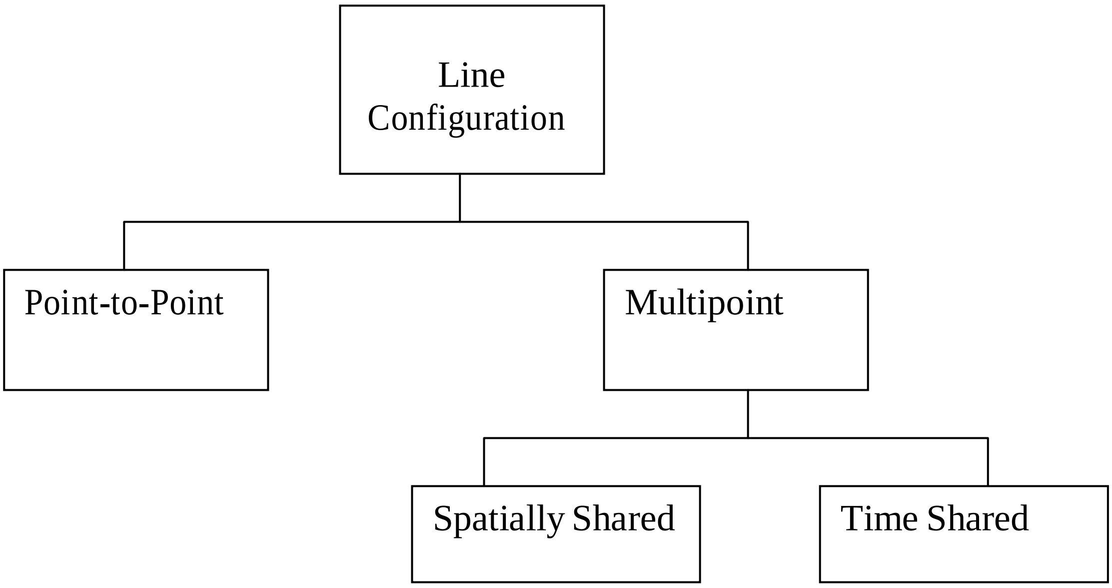
- Line Configuration
- Topology
- Transmission Mode
- Categories of networks
- Internetworks

LINE CONFIGURATION

"Line Configuration refers to the way two or more devices attach to a ***Link***"

A link is the physical communication path that transfers data from one device to the other. Link can be thought of as a Line drawn between two points. For communication to occur, two devices must be connected to each other using a link.

Line Configurations

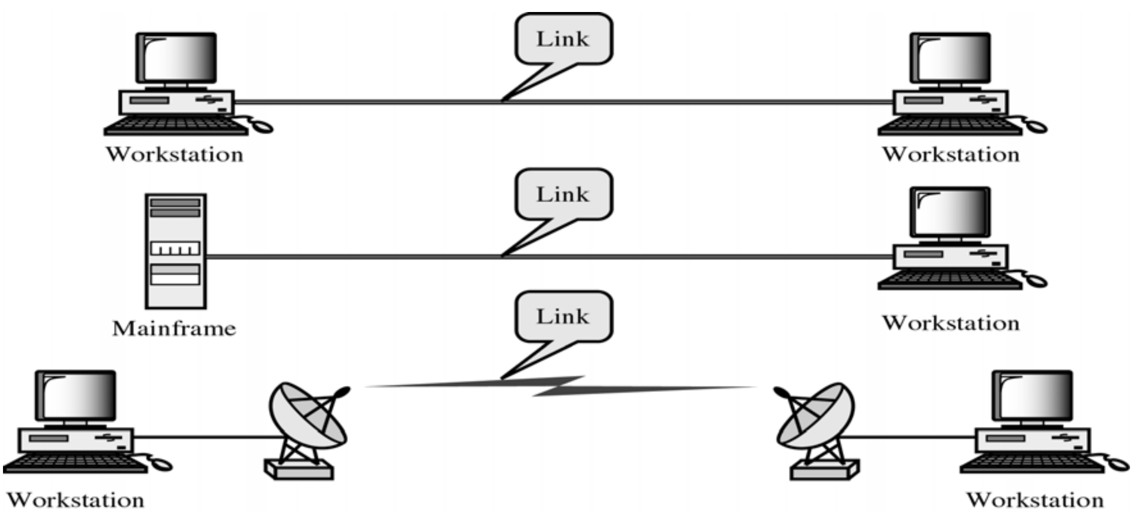


- **Point-to-Point Line Configuration**

  Dedicated Link between two devices. Entire Capacity of the channel is reserved for TX B/w these two devices. Mostly point-to-point connection use wire/cable to connect with each other. But Microwave, Satellite Links can also be used
  Data and Control information pas directly between entities with no intervening agent

  - **Examples**:

    - TV Remote Control and TV Control Systems
    - Mobile Phone (when talking) and Base Station (Antenna)

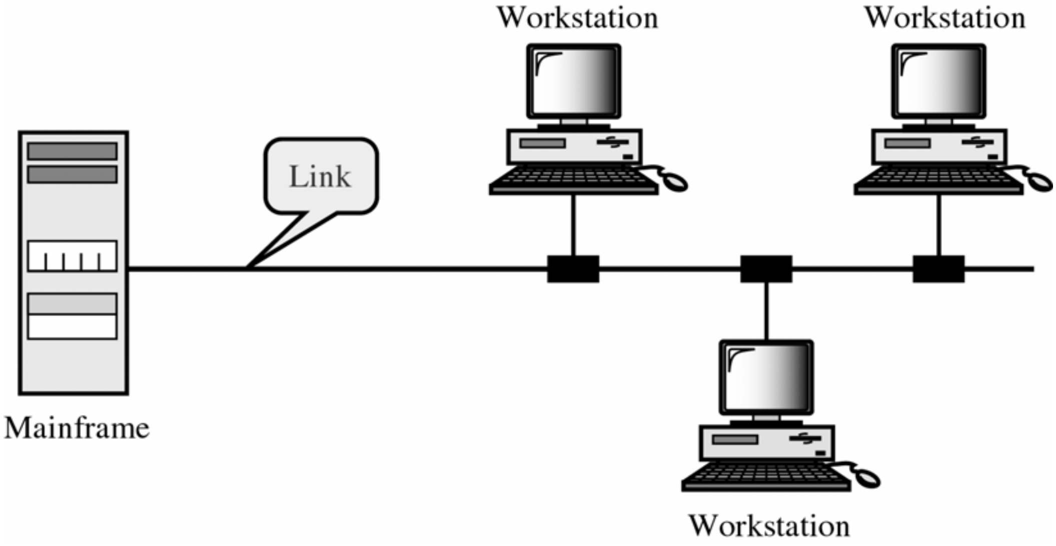


- **Multipoint Line Configuration**

More than two devices share the Link that is the capacity of the channel is SHARED now. With shared capacity, there can be two possibilities in a Multipoint Line Config:

- **Spatial Sharing**: If several devices can share the link simultaneously, its called Spatially shared line configuration

- **Temporal (Time) Sharing**: If users must take turns using the link , then its called Temporally shared or Time Shared Line Configuration



Summary

- Standards
- Standard Organizations
- Line Configuration
- Categories of Line Configuration

Reading Sections

- Section 1.5,2.1 "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

LECTURE #5

TOPOLOGY

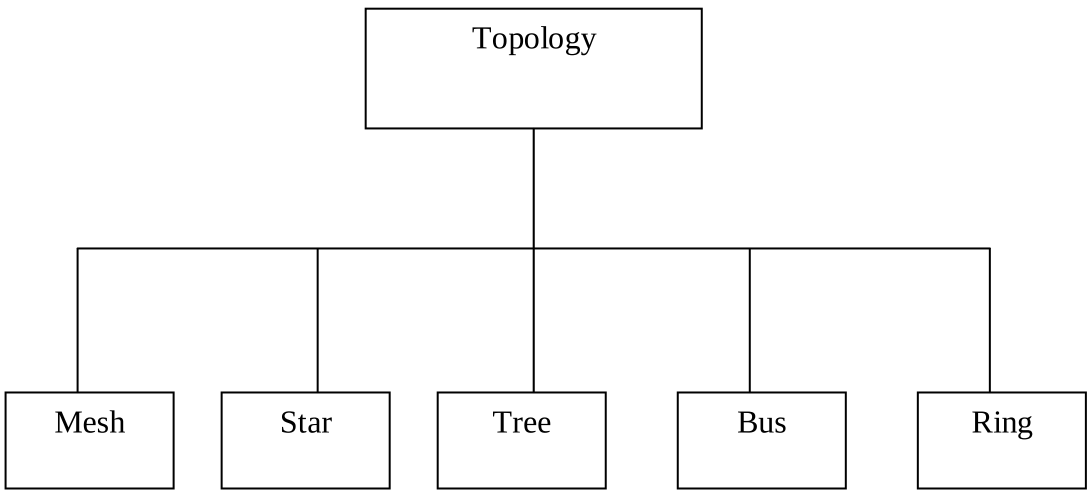
"The Topology is the geometric representation of the relationship of the links and the linking devices (Nodes) in a Network"

Or

"Topology defines the physical or the Logical Agreement of Links in a Network"

Topology of a Network is suggestive of how a network is laid out. It refers to the specific configuration and structure of the connections between the Links and the Nodes. Two or more devices connect to a Link and two or more Links form a Topology

Categories of TOPOLOGY



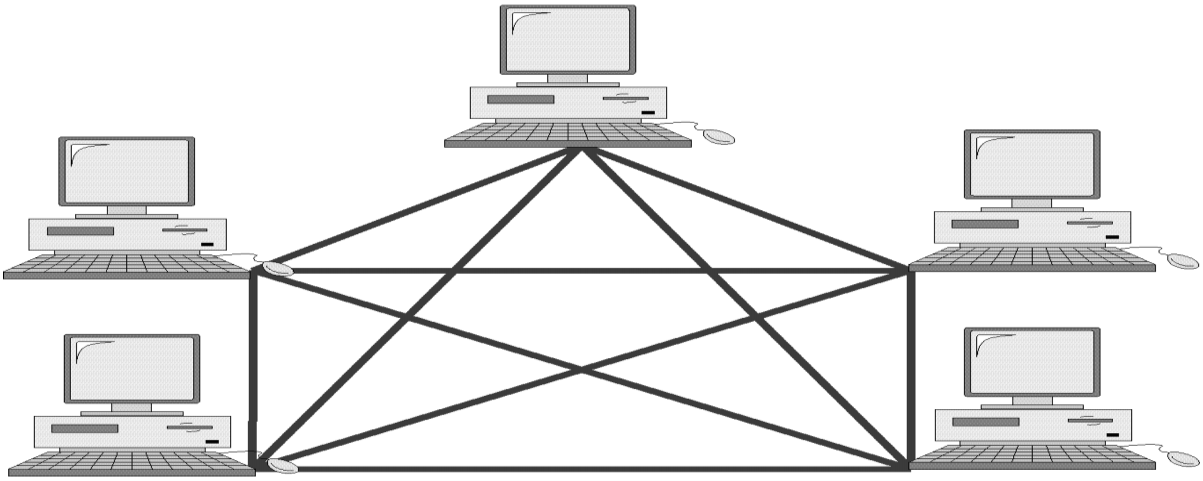
./ Question: What to consider when choosing a Topology????????
./ Answer: Relative status of the devices to be linked.

Two relationships are possible in a network

Y **PEER-TO-PEER**: Devices share the link equally

Y **PRIMARY-SECONDARY**: One device controls traffic and the others must transmit through it

MESH TOPOLOGY



- Every device has ***dedicated*** a point-to-point link to every other device
  - Dedicated: Means that the link carries traffic only between these two devices
- $\frac{n(n-1)}{2}$ Links to connect '*n*' devices
- Each device must have $n-1$ I/O Ports

Example Mesh Topology

In figure above, we have 5 Nodes, therefore:

- No. of Links= 5(5-1)/2 = 10
- No. of I/O Ports= 5-1 = 4

- ***This increase exponentially with increase in No. of Nodes***

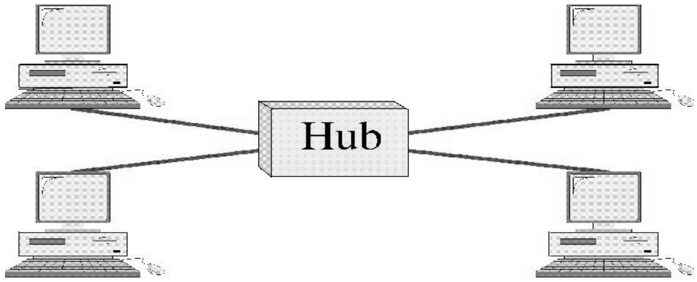
- e.g. for 6 nodes = 15 Links
- 7 Nodes=21 Links

- **Advantages of Mesh Topology**
  - Use of Dedicated links guarantees that each connection can carry its own load. This eliminates Traffic Problems as in case of Shared Link
  - Mesh Topology is robust. If one link fails, it does not effect other links
  - Security & Privacy due to dedicated links
  - Point – to –Point links make Fault Identification easy

- **Disadvantages of Mesh Topology**
  - Amount of Cabling
    - Makes Installation & Reconfiguration difficult
    - Sheer bulk of wiring can be greater than the available space
  - Number of I/O Ports Required
    - Hardware required to connect each link can be prohibitively expensive

Therefore, Mesh topology has limited use

Star Topology



- Each device has a dedicated point-to-point link to a central controller (Hub)
- Devices are not directly connected to each other
- Controller (Hub) acts as an exchange
- If one device wants to send data to the other, it sends the data to the controller , which then relays it to the other connected device

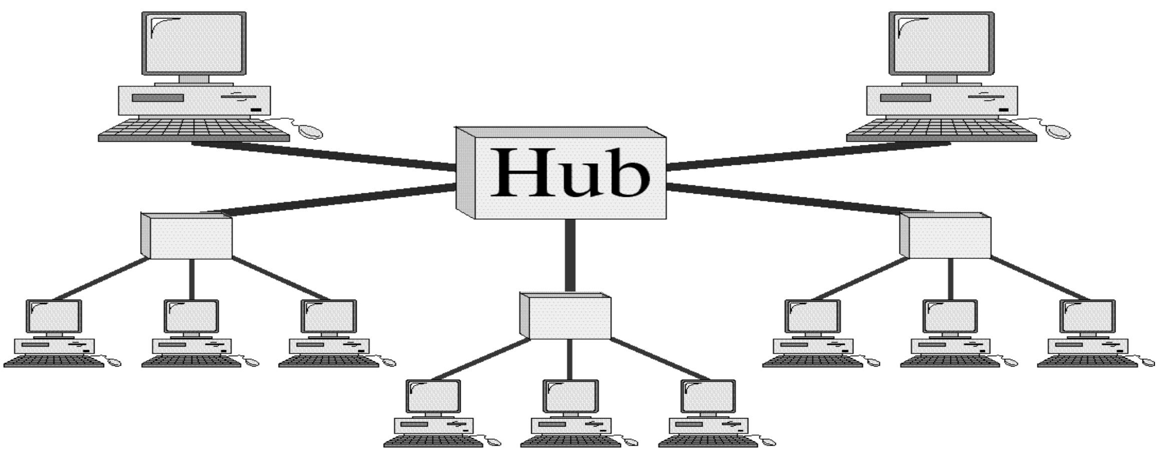
- **Advantages of Star Topology**

  - Less Cabling
  - Less Expensive than Mesh as each device need sonly one link and one I./O Port
  - Easy to Install and Reconfigure
  - Robust, if a link fails , only that link fails
  - Easy Fault Detection

- **Disadvantages of Star Topology**

  - Although Cabling required is far less than Mesh
  - Still each node must be connected to a Hub , so Cabling is still much more than some other Topologies

Tree Topology



- A variation of Star Topology

- Nodes in a Tree are linked to a central hub that controls the traffic to and from network
- Difference b/w star and tree is not all the devices plug directly into the central HUB
- Majority connects to secondary hub that is connected to central hub

- **CENTRAL HUB in Tree Topology**

  - Central Hub in a Tree is an ***ACTIVE HUB***
  - ACTIVE HUB contains a repeater
  - Repeater is a hardware device that regenerates the received bit pattern before sending them out.
  - Repeater strengthens TX. And increases the distance a signal can travel

- **Secondary HUB in Tree Topology**

  - Secondary Hub in a Tree may be ***Active*** or ***Passive HUB***
  - Passive Hub simply provides physical connection between attached devices

- **Advantages of Tree Topology**

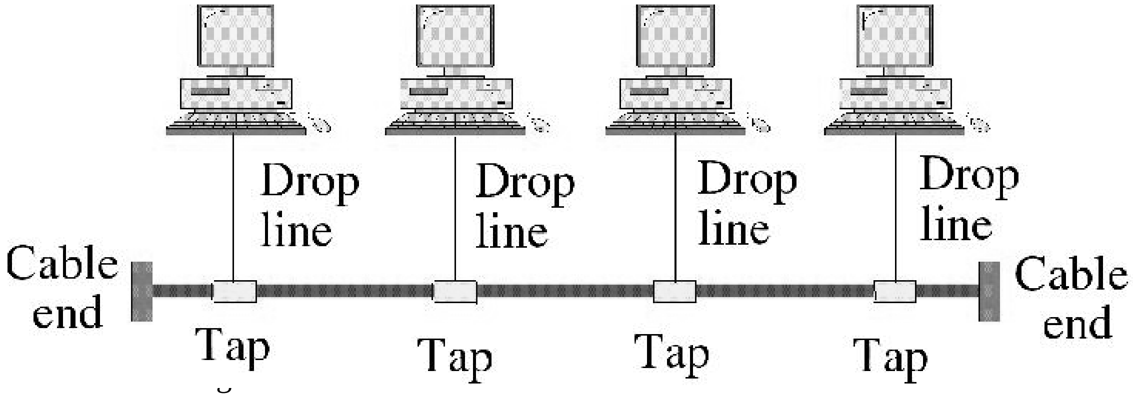
  - Because of Secondary Hub, More devices can be attached to a Central Hub and therefore increase the distance a signal can travel
  - Enables Differentiated Services: Allows to prioritize communication, e.g. computers attached to one secondary hub can be given priority over others
  - Therefore, TIME SENSITIVE data will not have to wait for access to the network
  - Rest of the advantages are almost the same as STAR
    - **Example Tree Topology: Cable TV**

CABLE TV

–Main cable from main office is divided into many branches and each branch is divided into smaller branches and so on

–Hubs are used when cable is divided

BUS TOPOLOGY



- Drop Lines and Taps
- Drop Line is the connection between device and the main cable (Backbone)
  - Tap is a connector that;
    - Splices into the main cable or
    - Punctures the sheathing of a cable to create connection with the metallic core

- Signal degrades as it travels, therefore there is a limit on:
  - The number of Taps a Bus can support and
  - The distance between those Taps

Advantages of BUS TOPOLOGY

- Easy to install
  - Backbone can be laid on the most efficient path and then rest of the nodes can be connected using Drop Lines
- Less cabling than Mesh , Star or Tree
- Difference b/w Star Cabling and Bus Cabling

Disadvantages of BUS Topology

- Difficult Reconfiguration
  - Difficult to add new devices
  - adding new devices may require modification of backbone

- No Fault Isolation
  - A fault or break in backbone can disable communication even on the same side of the problem
  - Damaged area reflects signals back in the direction of origin creating Noise in both directions

Summary

- Topology
- Categories of Topologies

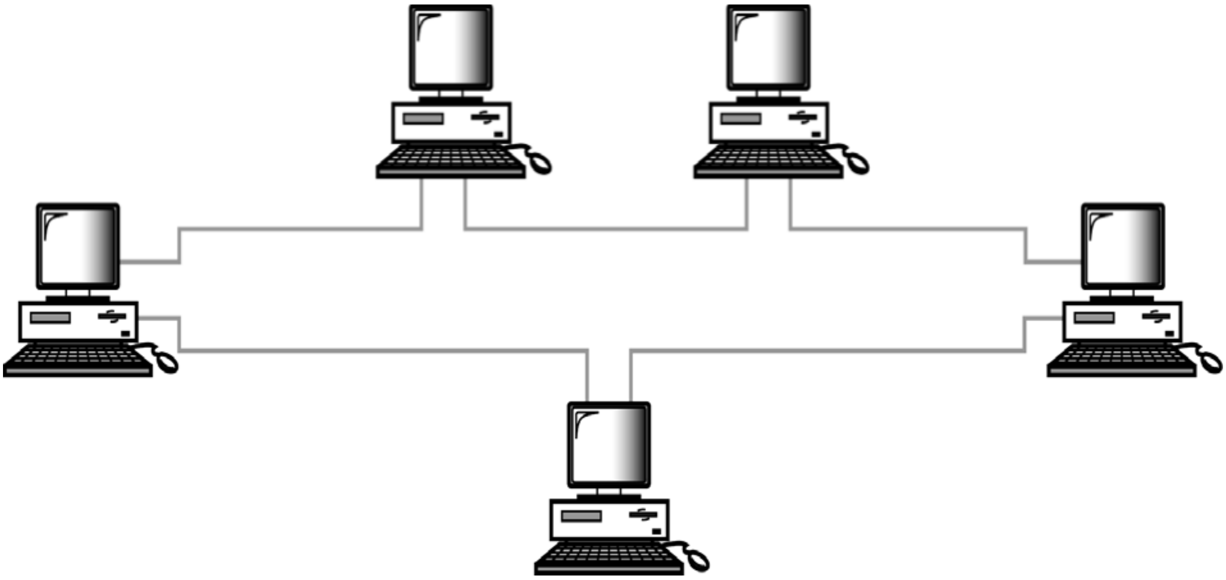
Reading Sections

- Section 2.2 “Data Communications and Networking” 4th Edition by Behrouz A. Forouzan

LECTURE #6

Ring Topology

Ring Topology Diagram



- Each device has point-to-point dedicated link with only two devices on either side
- A signal is passed in the ring in one direction from device to device until it reaches its destination
- Each device has a repeater incorporated
- When a device receives a signal destined for another device, it regenerates the bits and pass them along

Advantages of Ring Topology

- Easy to Install and Reconfigure
  - Only two connections to be moved to add or delete a device
- SIMPLE Fault Isolation
  - Generally a signal is circulating at all times in a ring.
  - If one device does not receive a signal within a specified period, it can issue an alarm to tell network operator about the problem and its location

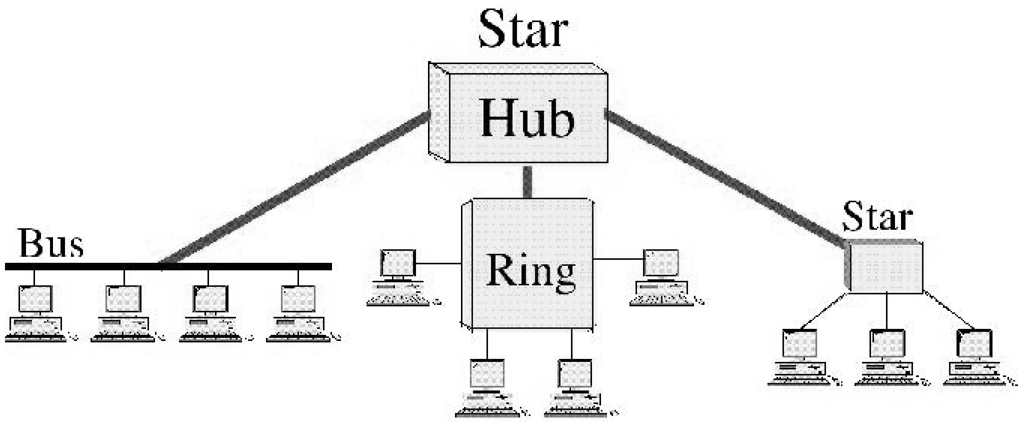
Disadvantages of Ring Topology

- Unidirectional Traffic
  - A break in a ring I.e. a disabled station can disable the entire network
- Can be solved by using:

- ./ Dual Ring or
- ./ A switch capable of closing off the Break

- **Hybrid Topologies**

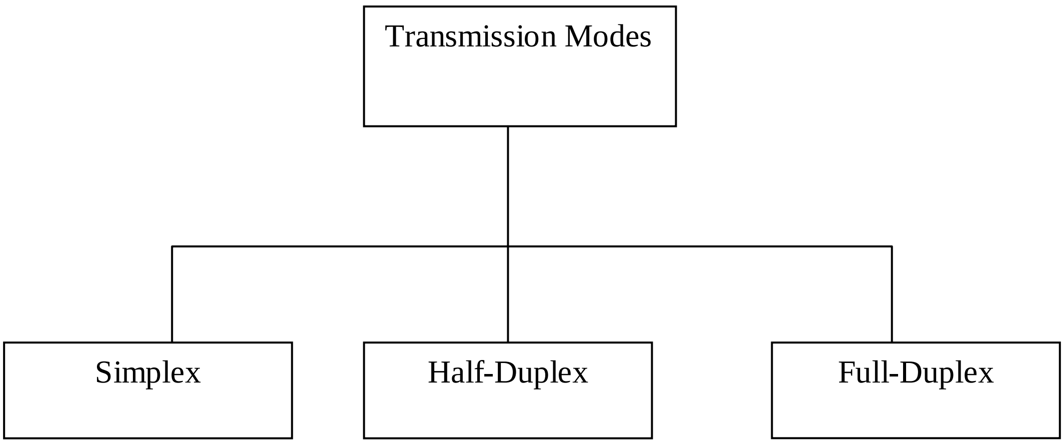
<u>Hybrid Topologies</u>



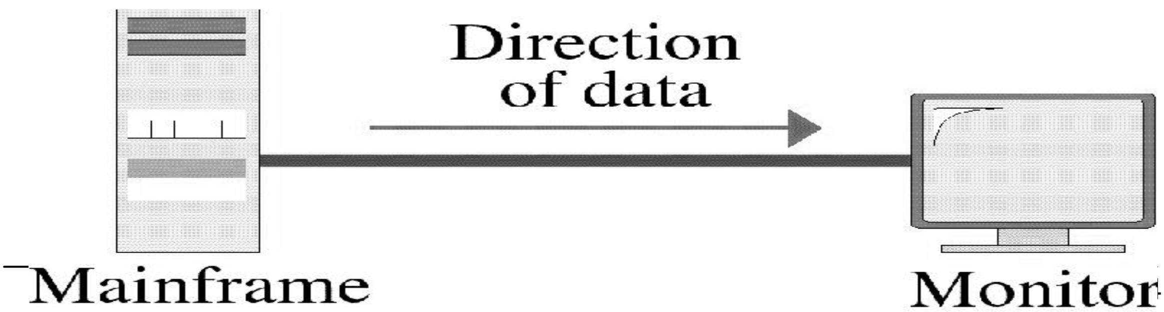
- o Several topologies combined in a larger topology
  - ./ Example: One department of a business may have decided to use a Bus while other has a Ring
- o The two can be connected via a Central Controller in Star Topology

TRANSMISSION MODE

"Transmission Mode is used to define the direction of the signal flow between the linked devices"



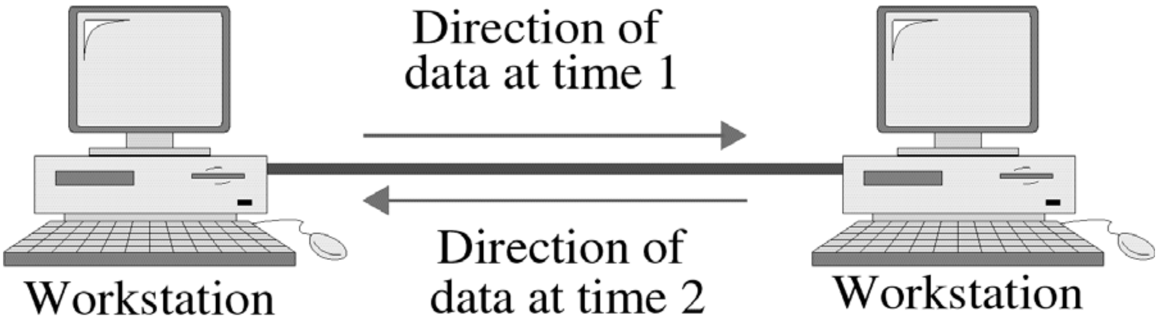
- **SIMPLEX MODE**



- Communication is Unidirectional
- Only one of the two stations can transmit
- Other can only receive

    - Examples: KEYBOARDS (Only Input), Monitors (Only Output)

- **Half – Duplex Mode**



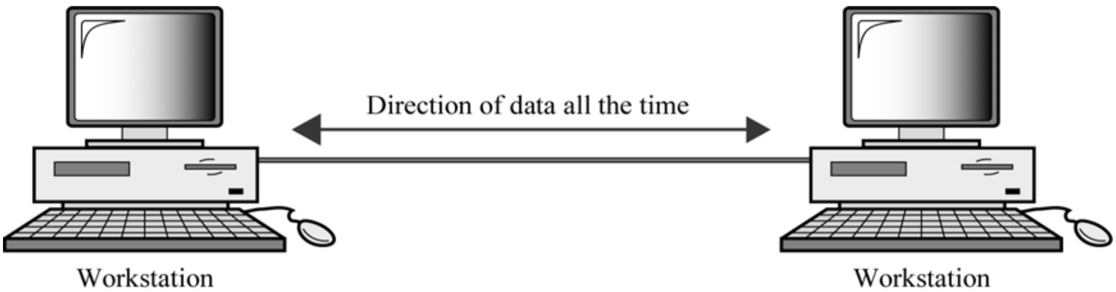
- Each station can both transmit and receive but not at the same time
- When one device is sending the other can only receive and vice versa
- Lets understand the concept by using an example

    - One Lane Road with two directional traffic
    - When cars are traveling in one direction, cars going the other way must wait

- Full Channel capacity is allocated to whatever entity that is transmitting at a specific time

    - Walkie Talkies

- **Full Duplex (Duplex)**



- Both stations can transmit and receive simultaneously
- Two way street with traffic flowing in both directions at the same time
- Signals traveling in either direction share the capacity of the link
- The sharing can take place in two ways:

- Either the link must contain two physically separate transmission paths:
  - ./ One for sending and
  - ./ One for receiving

- Capacity of the channel is divided between signals traveling in opposite directions

  - ./ EXAMPLE

    –Telephone Network

    When two people are communicating via a telephone line, both can talk and listen at the same time

Categories of Networks

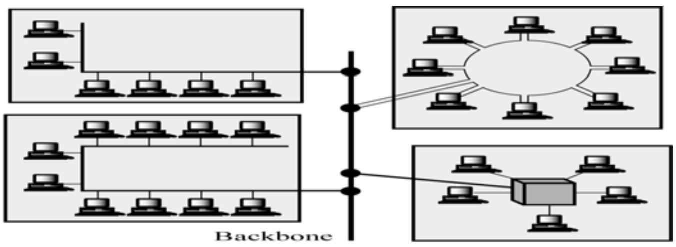
- There are three main categories of Networks:

  - Y LANS
  - Y WANS
  - Y MANS

- Into which category a network falls is determined by its **SIZE, OWNERSHIP, DISTANCE IT COVERS**, and its **PHYSICAL ARCHITECTURE**

• LANS

a. Single building LAN



b. Multiple building LAN

- A LAN is usually Privately owned and Links the devices in a single office, Building or a campus

- **Two Implications**
  - Y Care must be taken in choice of a LAN, because there may be a substantial capital investment for purchase and maintenance.
  - Y Secondly, the network management responsibility falls solely on the user/company

- **Size of a LAN**
  - Y Size of a LAN depends upon the Needs of Organization and the Type of Technology

  - Y LAN can be as simple as two PCs and a printer in someone's home office or it can extend throughout a company and include complex equipment too
  - Y Currently LAN size is limited to a few kilometers

- **Design of a LAN**

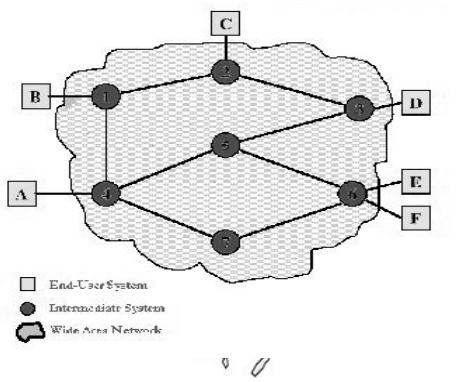
- LANs are designed to allow resources to be shared between personal computers or workstations
- The resources to be shared can include hardware (printer), software (an application program) or data.

  - Example of a LAN
    A common example of a LAN found in many business environments links a work group of task related computers, for example engineering workstations or Accounting PCs. One of the PCs may be given a large capacity disk and becomes a server to others. Software stored on the server and is used by the whole group. In this case size is determined by software licenses

- **Transmission Media & Topology**
  - In addition to size, LANs are distinguished from other types of networks by Transmission media and topology
  - In general a given LAN will use only one type of Transmission medium
  - The most common LAN topology Bus, Star Ring

- **Data Rates in a LAN**
  - Traditionally 4 – 16 Mbps
  - Speeds increased and now 100Mbps and above are also possible
  - Giga Bit LAN technologies

WANs

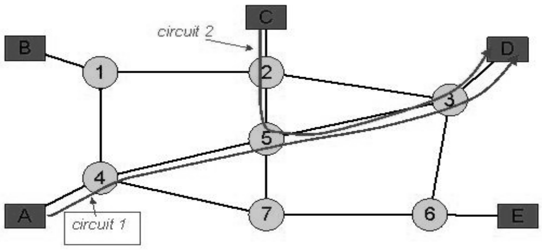


- Generally cover a large geographical area and it usually span an Unlimited number of miles by utilizing Public or Leased networks instead of having their own hardware as in the case of LANs

- **Design of a WAN**
  - Typically , it consists of a large number of Switching Nodes
  - Transmission from any one device is routed through these internal nodes to the specified destination device
  - These nodes are not concerned with the content of the data, rather their purpose is to provide a switching facility that will move the data from node to node until it reaches its destination
- How to Implement a WAN?
  - Traditionally WAN s have been implemented using one of the 2 technologies:
    – Circuit Switching
    – Packet Switching

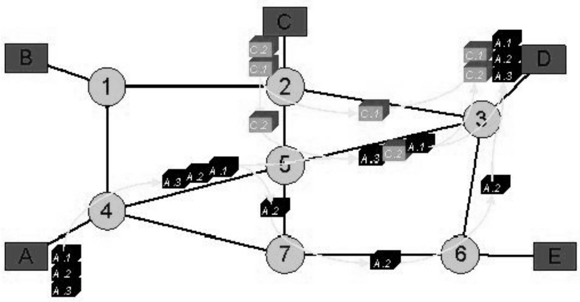
- Frame Relay and ATM Networks play important role nowadays too

Circuit Switching



- o A dedicated communication path is established between two stations through the nodes of the network
- o This path/CAPACITY stays up for the duration of the communication
  Example is **Telephone Network**

Packet Switching



- o No capacity is dedicated along a path through the network
- o Data Is sent out in small chunks called **"Packets"**
- o Each path is passed from node to node
- o At each node, entire packet is received, stored briefly and then transmitted to the next node.
  - ./ Example is : **Computer to Computer Communication**

Frame Relay & ATM

- o Overhead bits for Error Protection are removed
- o 10's of 100's of Mbps and also Gbps is possible

Summary

- The OSI Model
- Layered Architecture
- Encapsulation and Decapsulation
- Physical Layer
- Data Link Layer

Reading Sections

- Section 2.4,2.5, "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan
- Sections 1.3, "Data and Computer Communication" 6th Edition by William Stallings

LECTURE # 7

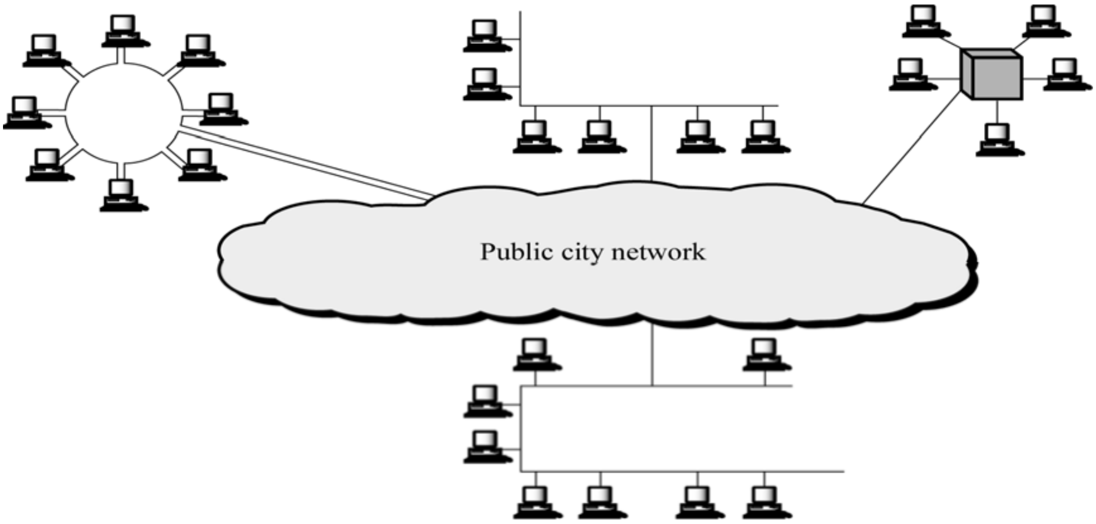
Metropolitan Area Networks

- Designed to extend over an entire city
- It may be a single network e.g. Cable TV Network

Or

- Interconnection of a No. of LANs into a larger network

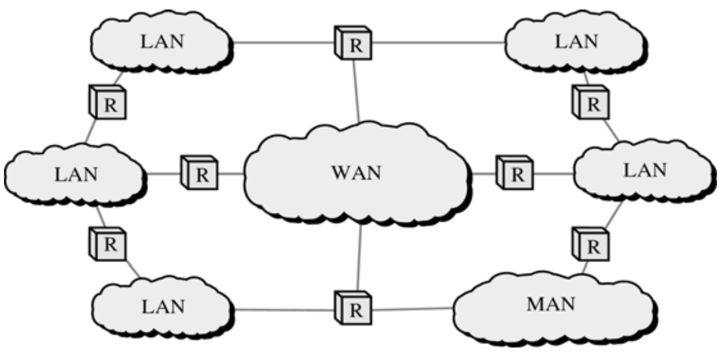
    - Example: A company can use a MAN to connect the LANs in all of its offices throughout a city



Internetworks

- When two or more networks are connected they become an internetwork or internet
- Individual networks are joined together by the use of Internetworking Devices like Routers, Gateways etc.

    - **internet**: Combination of Networks
    - **Internet**: Specific World wide Network



The OSI MODEL

- International Standards Organization (ISO) 1947
- Multinational body dedicated to worldwide agreement on International Standards

- An ISO Standard that covers all aspects of Network Communication is **Open System Interconnection Model (OSI)**
- **Open System:** A model that allows two different systems to communicate regardless of their underlying network
- Vendor –Specific Models close off communication

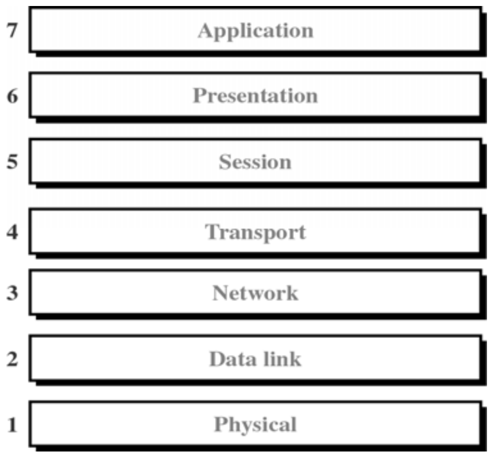
- **Purpose of the OSI MODEL**

  - Open Communication between different systems without requiring changes to the underlying hardware and software.

OSI Model is not a Protocol. It is a model for understanding and designing a network architecture that is flexible, robust and interoperable

- ## Definition of the OSI MODEL

A layered framework for the design of network systems that allows communication across all types of computer systems regardless of their underlying architecture

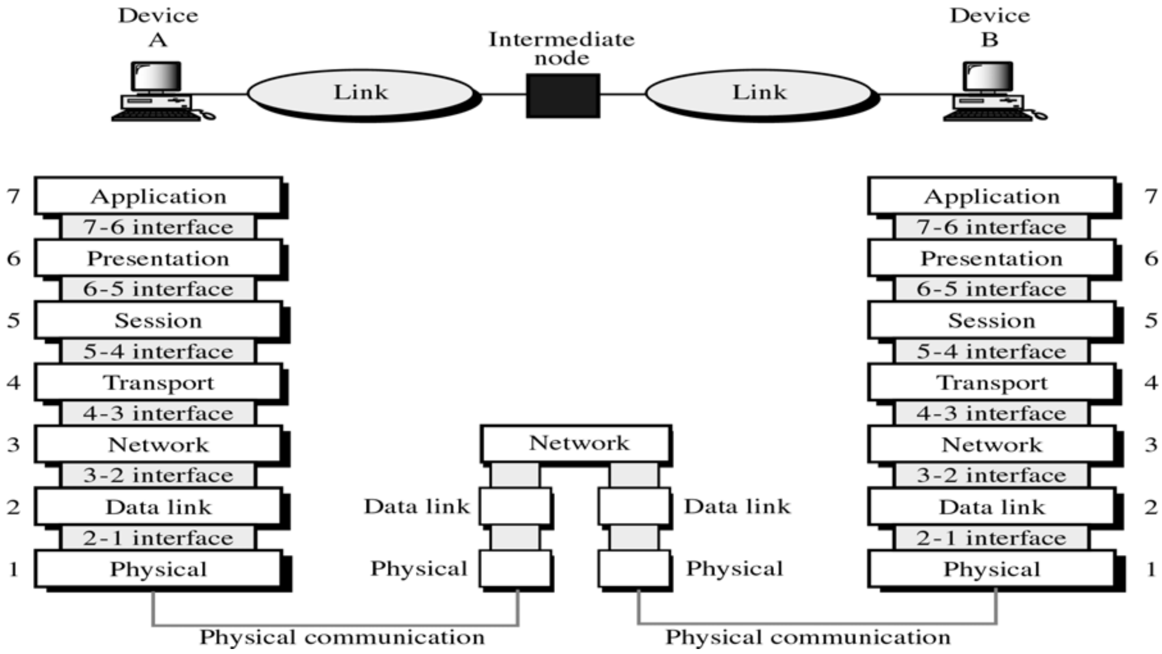


- ## Layers of the OSI Model

1. **Physical (Bits)**
2. **Data Link (Frames)**
3. **Network (Packets)**
4. **Transport (Segment)**
5. **Session (Dialog units)**
6. **Presentation (Raw Data)**
7. **Application (Text, Numbers)**

<u>Please Do not Touch Steve's Pet Alligator</u>

What happen when a message travels from device A to Device B?



- o As the message travels from A to B , it may pas through many intermediate "Nodes"
- o These nodes usually involve only the first three layers of the OSI Model
- o In developing the OSI model, designers identified which networking functions had related uses and collected those functions into discrete groups that became the layers
- o Each layer defines a family of functions distinct from other layers
- o By defining and localizing functionality in this fashion , the designers created an architecture that is both comprehensive and flexible
- o The OSI model allows complete transparency b/w otherwise incompatible systems

Peer-to-Peer Processes

- o Within a single machine, each layer provides services to the layer above it and all upon the services from the layer below it.
- o For example Layer 3
- o Between machines, layer x on one machine communicates with layer x on the other machine.
- o The communication is governed by Protocols
- o The processes on each m/c that communicate at a given layer are called Peer –to peer processes

Headers and trailers

- o Control data added to a data parcel
- o Sender appends header and passes it to the lower layer
- o Receiver removes header and passes it to upper layer

- o Headers are added at layer 6,5,4,3,2. Trailer is added at layer 2

Passing of data and network information down through the layers of sending machine AND Back up through the layers of the receiving machine is made possible by an

INTERFACE

- Each interface defines what information and services a layer must provide for the layer above it
- Interface provides **MODULARITY**
- Each layer works as a separate module
- Any modification or replacements can be made without changes in surrounding layers
- Organization of Layers

Y Network Support Layers
–Deals with the Physical aspect of moving data from one device to another
–Layers 1, 2, 3

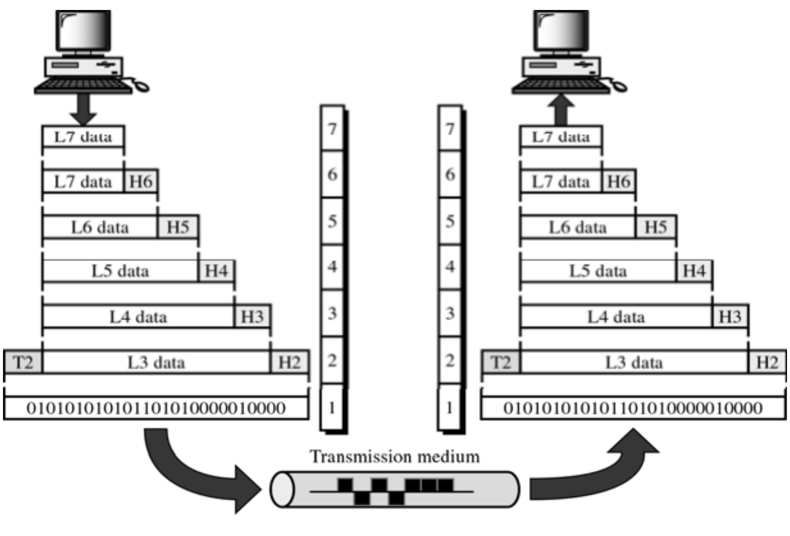
Y User Support Layers
–Allows interoperability among unrelated software systems
–Layers 5, 6, 7

Organization of Layers

- Layer 4
  –Ensures end-to-end reliable transmission

- Upper OSI Layers always implemented in Software
- Lower Layers are a combination of software and hardware
- Physical layer is mostly Hardware

The OSI Model



Summary

- Categories of Networks (MANs)
- Internetworks
- The OSI Model

Reading Sections

- Section 2.5, 3.1, 3.2 “Data Communications and Networking” 4th Edition by Behrouz A. Forouzan

LECTURE # 8

Critique of OSI Model

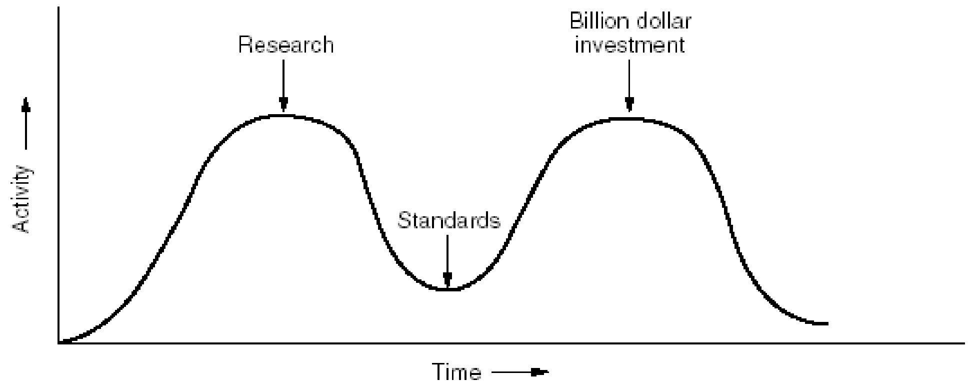
Reasoning for OSI not getting Widespread

- Bad Timing(slide) (**Apocalypse** of Two Elephants)
  - –David Clarke of MIT
  - –If standards are written too early: subject is badly understood and bad standards
  - –If standards are written too late so many companies may have already made investments in doing the same thing with different other ways

- Bad Technology
  - –Flow control, error control, addressing is multiple
  - –Session and Presentation(EMPTY), Network and DL(Full)

- Bad Implementations

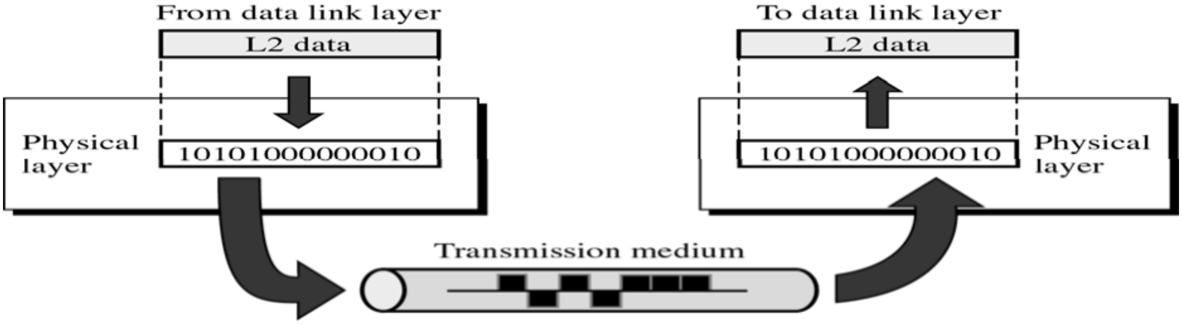
Apocalypse of Two Elephants



- **Physical (Layer 1)**

- Coordinates the functions required to transmit a bit stream over a physical medium
- Deals with mechanical and electrical specifications of Tx. Medium and Interface
- Also defines procedures and functions that physical devices and interfaces need to perform for TX. To occur (Figure)

Figure



- **Functions of Physical Layer**

- Physical Characteristics of Interface & Media
  - Defines characteristics of Interface b/w device and Tx Medium
  - Interface is a plug gable connector that joins one or more signal conductors
  - Also defines the type of transmission medium

- Representation of Bits/Encoding
  - The physical layer data consists of a stream of bits (sequence of 1's and 0's)
  - To be transmitted the bits must be ENCODED into signals: Electrical or Optical
  - Physical layer decides the type of **ENCODING**

- Data Rate / Transmission Rate
  - Date Rate (Bits per second) also decided by the Physical Layer
  - So , Physical layer defines the Duration of a Bit
  - Means how long will a bit last

- Synchronization of Bits
  - Sender and Receiver must be synchronized at the bit level
  - Sender and Receiver clocks must be synchronized
  - It is done by Physical layer

- Line Configuration
  - Physical Layer is also concerned with Line Configuration
  - Line Configuration represents the connection of device with the Medium
  - Point-To-Point or Multipoint

- Physical Topology
  - Mesh, Star, Ring, Bus etc.

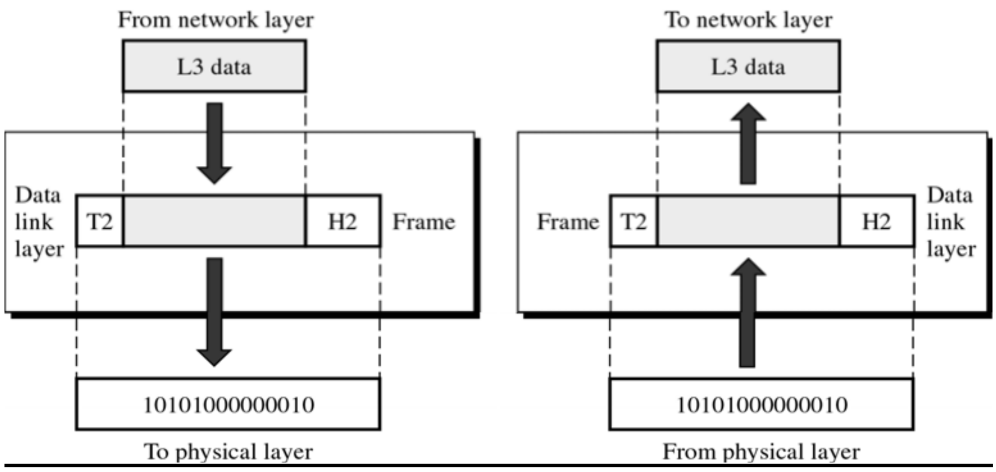
- Transmission Mode

    - Physical Layer also defines the direction of Transmission between the devices
    - Simplex. Half Duplex, Full Duplex

- **Data Link Layer (Layer 2)**

- Transforms physical layer which is raw transmission facility to a reliable link
- Responsible for Node to Node Delivery
- Makes physical layer look error free to the upper layer

Figure



- **Functions of Data Link Layer**

- **Framing**

    - The data link divides the stream of bits from Network layer into manageable data units called "FRAMES". This process is known as Framing.

- **Physical Addressing**

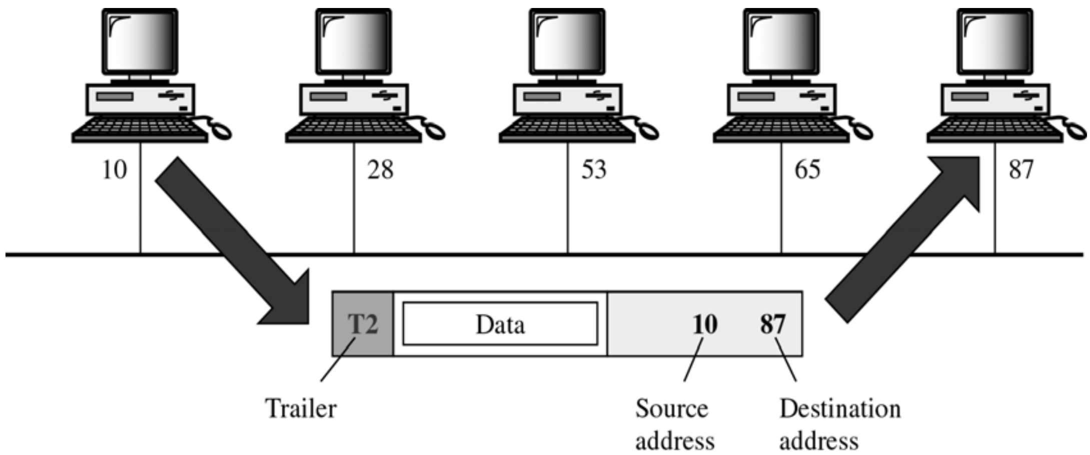
    - Frames need to be transmitted to different systems on a network
    - Data Link layer adds a HEADER to Frame
    - Header defines the physical address of sender(Source address) and/or receiver address (Destination address)
    - If frame is intended for a device outside the network, the receiver address is the address of the device that connects one network to the other

- **Flow Control**
    - Data Link layer imposes Flow Control mechanisms to prevent overwhelming the receiver

- **Error Control**
  - Data link layer adds reliability to physical layer by adding mechanisms to detect and retransmit lost or damaged frames
  - Also uses a mechanism to prevent duplication of frames
  - Error Control bits are added to the form in the TRAILER

- Access Control
  - Two or more devices may be connected to a single link
  - Data link protocols are necessary to determine which device will have the control of the link at a given time

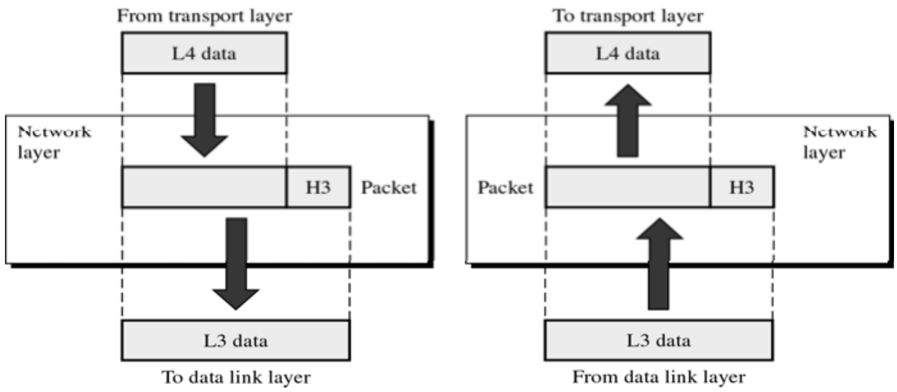
  - **EXAMPLE**
    - Node with physical address 10 sends a frame to a node with physical address 87
    - Two nodes are connected by a link.
    - At the DL level, this frame contains physical address in the Header, This is the only address needed at this level
    - Rest of header contains other info as needed
    - Trailer contains extra bits needed for error detection



- **NETWORK LAYER**

  - Responsible for Source-to-Destination delivery
  - DL Layer oversees the delivery of data between 2 systems on the same network
  - Network Layer ensures that each packet gets from its point of origin to its final destination

  - **Node –to Node vs Source to Destination**
    - If the two systems are connected to the same network, there is no need for Network layer and node –to node delivery is enough
    - If two systems are connected to two different networks, there is often a need for Source-to destination delivery



- **Function of Network Layer**

o **Logical Addressing**

  - Physical addressing implemented by Data link layer handles addressing problem locally
  - If a packet is going from one network to another, we need another addressing system to help distinguish source & destination systems
  - Network layer adds Header to the data coming from upper layers that among other things include LOGICAL ADDRESS of the sender and receiver

o **Routing**

  - When independent networks or links are connected together to create an "internetwork", the internetworking devices route packets to their final destination
  - Routers are those internetworking devices
  - One of the functions of Network layer is to define this route

✓ **<u>Example Network Layer</u>**

- We want to send data from a node with network address 'A' and physical address 10, located on one LAN to
- A node with network address P and physical address 95 located on another LAN
- Because the two nodes are present on two different networks, we cannot use physical address only
- We need a Network address that can pass us from the Network boundaries
- The packet therefore contains the logical address which remains the same from source to destination
- The physical address will change when packet moves from one network to the other
- The box with R is a Router

Summary

- The OSI Model
- Function of Layers

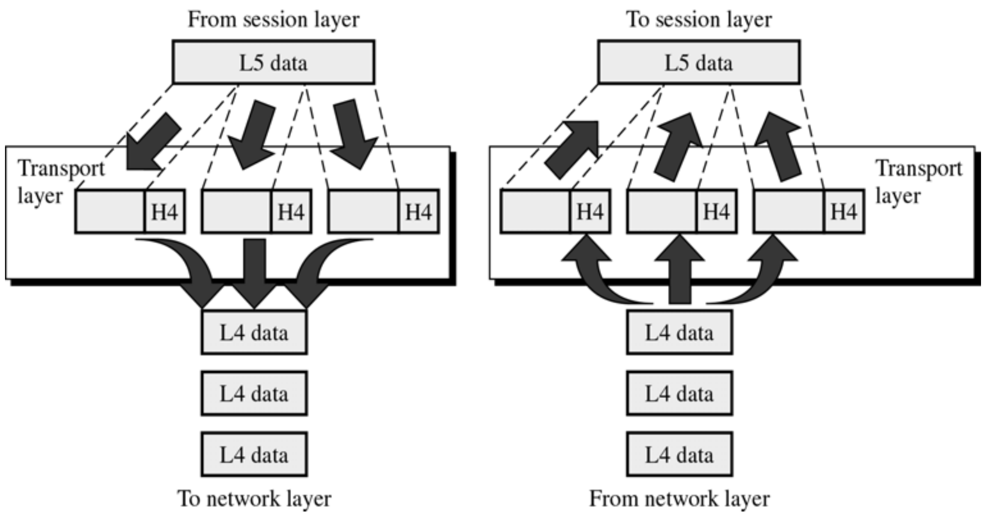
Reading Sections

- Section 3.1,3.2, "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

LECTURE #9

Transport Layer

- Responsible for Source-to-Destination delivery of Entire Message
- Network Layer oversees source-to-destination delivery of the entire packets but it does not recognize any relationship b/w those packets
- Network layer treats each packet independently
- Transport Layer ensures that whole message arrives at the destination intact



- **Functions of Transport Layer**

  - **Service Point Addressing**

    - Computers run several programs at the same time
    - Source-to-Destination delivery means delivery not only from only from one computer to the other but also from a specific process on one computer to a specific process on the other
    - Transport layer header includes a type of address called Service Point Address or PORT Address
    - Network layer each packet to the correct computer while Transport layer gets entire message to the correct process on that comuter

  - **Segmentation and Reassembly**

    - Message is divided into transmittable segments
    - Each segment contains a sequence number
    - These sequence no.s enable Transport layer at the receiving m/c to reassemble message correctly at the destination and to identify and replace lost packets

- **Connection Control**

  - Transport layer can be either connection-less or connection-oriented
  - **Connectionless**

    Treats each segment as an independent packet and delivers it to the transport layer of the destination m/c

  - **Connection-Oriented**

    A connection is established first with Transport layer before delivering the packet.

  - After all data is Tx. , the connection is disconnected

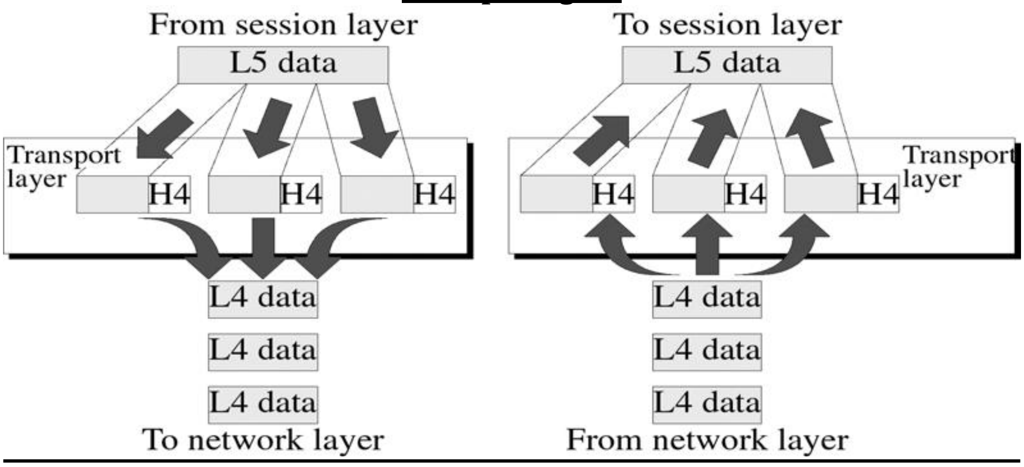
- **Flow Control**

  - Like Data link layer, Transport layer is also responsible for Flow control
  - Flow control is performed end-to-end rather than across a single link

- **Error Control**

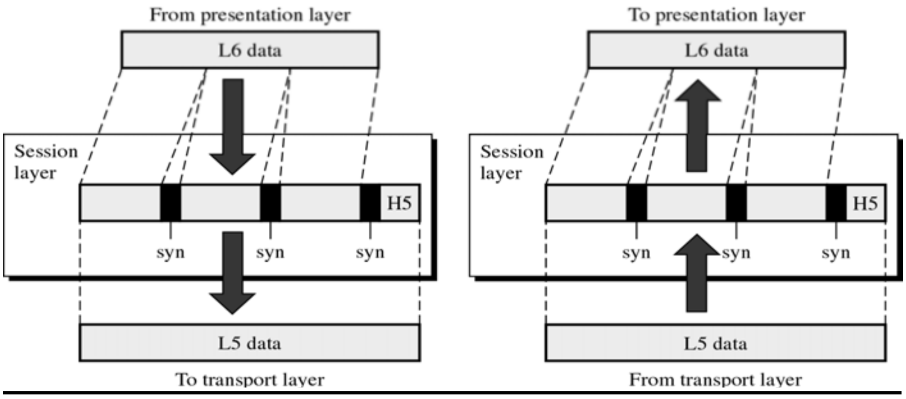
  - Like data link layer, Transport layer is responsible for the Error Control
  - Error control is performed end-to-end
  - This layer makes sure that entire message reaches Rx Transport layer w/o error
  - Error can be a result of Lost, damaged or duplicated data and usually Re Tx is done

Example Figure



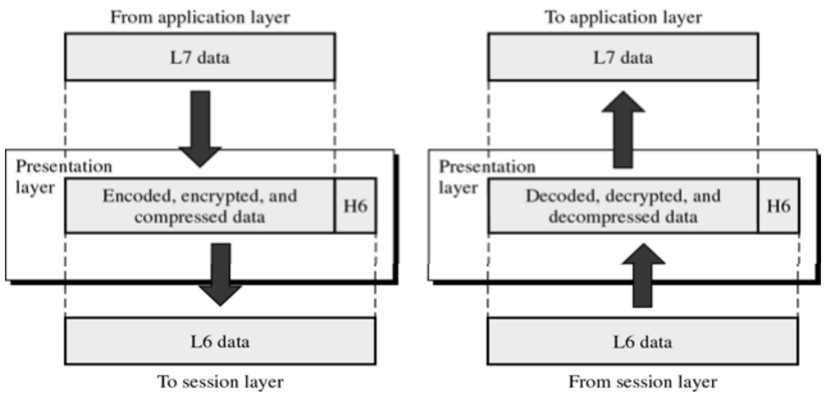
Session Layer

- Session layer is the Network Dialog Controller
- Establishes, Maintains, and Synchronizes the interaction between communicating systems



- **Function of Session Layer**
  - **Dialog Control**
    - Session layer allows two systems to enter into a dialog.
    - It allows communication between two processes to take place either in half duplex or full duplex mode
  - **Synchronization**
    - Session layer allows a process to add check points (synchronization points) in a stream of data
    - If a system is sending a file of 2000 pages, it is advisable to insert check points after every 100 page to ensure that each 100 page unit is received and acknowledged independently
    - In this case, if a crash happens during the transmission of page 523 , retransmission at page 501
    - Page 1-500 need not be retransmitted

- **Presentation Layer**
  - This layer is concerned with Syntax and Semantics of info exchange between two systems



Summary

- The OSI Model
- Functions of Layers

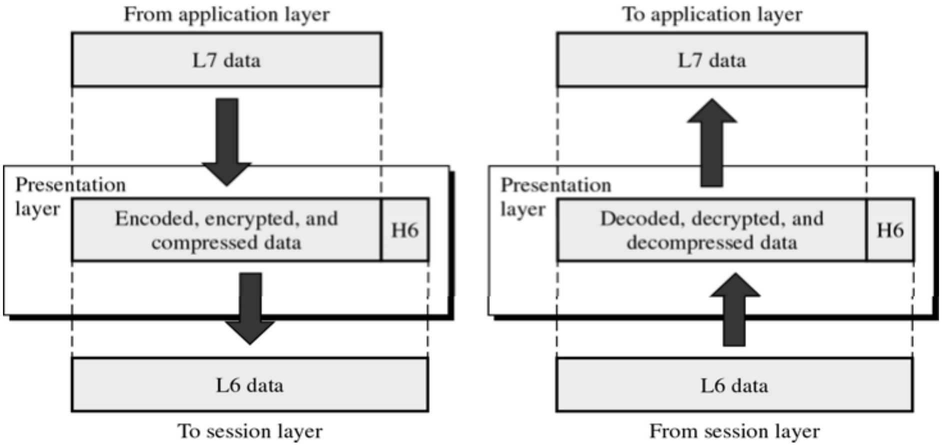
Reading Sections

- Section 3.2 “Data Communications and Networking” 4th Edition by Behrouz A. Forouzan

LECTURE #10

Presentation Layer

- This layer is concerned with Syntax and Semantics of info exchange between two systems

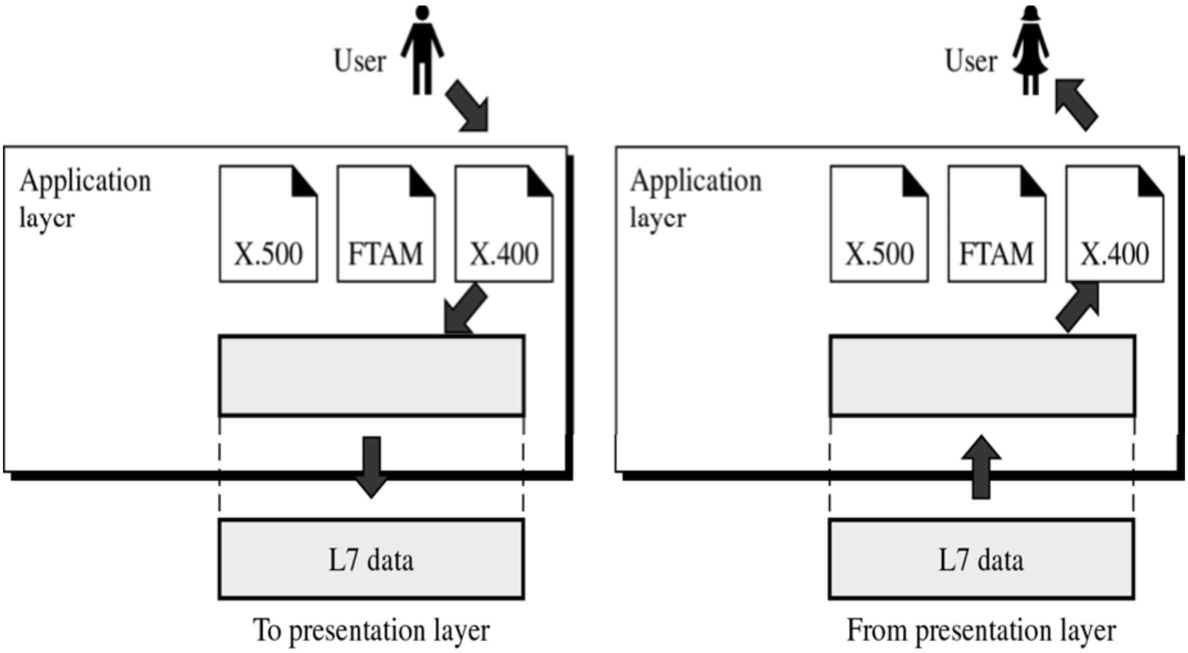


- **Functions of Presentation Layer**
  - **Translation**
    - The processes (running programs) in two systems are usually exchanging info in the form of character strings, numbers and so on…..
    - The info should be changed to bit streams before being transmitted
    - Because different computers use different ENCODING SYSTEMS, presentation layer is responsible for interoperability b/w these different encoding methods
    - The presentation layer at the sender changes the info from its sender-dependent format to the common format
    - The presentation at the receiver changes info from common to the receiver dependent format
  - **Encryption**
    - To carry sensitive info , a system must be able to assure privacy
    - Encryption means that sender transforms original info to another form and sends the resulting message out over the network
    - Decryption reverses the original process to transform message back to its original form
  - **Compression**
    - Data compression reduces the number of bits to be transmitted

- Data compression becomes particularly important in transmission of multimedia such as text, audio and video

- **Application Layer**
  - Enables the user either human or software to access the network
  - It provides user interface and support for the services such as Electronic mail, Remote File access and Transfer, Shared Database Management and other services

Application Layer Figure



  - In the figure, of many application services available, only three services are shown
    - X-400 (message Handling Services)
    - X-500 (Directory Services)
    - File Transfer, Access& Management (FTAM)
  - In this example user uses X-400 to send an e-mail message
  - No headers or trailers are added at this layer

- **Application Layer Functions**

  - **Network Virtual Terminal**

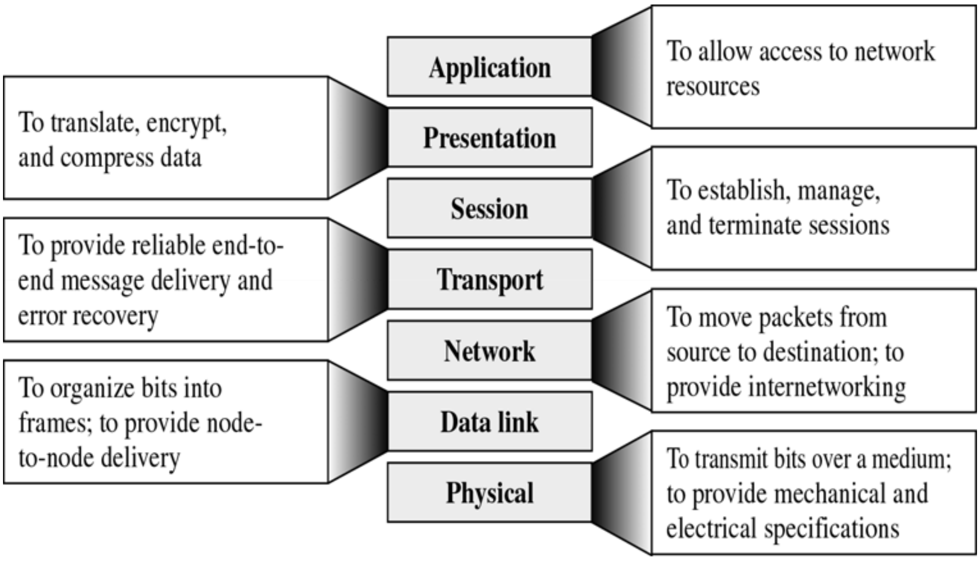
    - NVT is a software version of a physical terminal and allows a user to log on to a remote host
    - To do so the application created emulation of terminal at the remote host
    - Users computer talks to the software terminal which in turn talks to the host *& vice versa
    - Remote host believes it is communication with one of its own terminals and allow you to log on

- **File Transfer, Access & Manage.(FTAM)**
  - This application allows a user to access file on the remote computers to make changes or read data
  - The purpose of this access is to Retrieve files from a remote computer and to manage or control files in that remote computer

- **Mail Services**
  - This application provides the basis for email forwarding and storage

- **Directory Services**
  - Provides distributed database sources and access for global info about various objects and services

Summary of Layer Functions

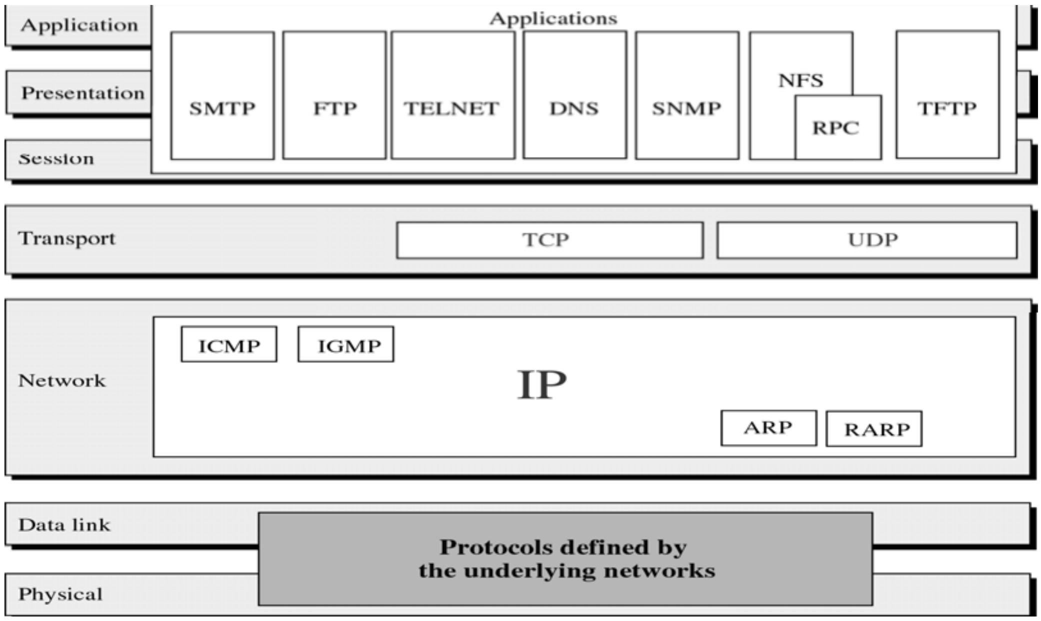


TCP/IP Protocol Suite

- Transmission Control Protocol / Internetworking Protocol
- Developed Prior to OSI Model
- Widely used in the Internet Today

- **Layers in TCP/IP Protocol Suite**
  - Physical (physical standards)
  - Data Link (N/w Interface)
  - Network (Interconnectivity)
  - Transport(Transport Functions)
  - Application(Session , Pres, app of OSI)

TCP/IP Protocol Suite



Summary

- The OSI Model
- Functions of Layers
- TCP/IP Protocol Suite

Reading Sections

- Section 3.2, 3.3 “Data Communications and Networking” 4th Edition by Behrouz A. Forouzan

LECTURE #11

Signals

- **Need For Signals**

  - One of the major concerns of Physical layer is moving information in the form of electromagnetic signals across a TX medium
  - Information can be voice, image, numeric data, characters or any message that is readable and has meaning to the destination user (human or m/c)
  - Generally, the info usable to a person or application is not in a form that can be transmitted over a network
  - For Example, you cannot roll up a photograph, insert it into the wire and transmit it across the city
  - You can transmit however an encoded description of the photograph
  - The binary digits must be converted into a form that TX. Medium can accept
  - TX. Media work by conducting energy along a physical path. So the data stream of 1s and 0s must be turned into energy in the form of EM signals

- **Analog and Digital**

  - Both data and signals that represent them can take either analog or digital form

  - **ANALOG**

    - Analog refers to something that is continuous in time
    - *Continuous*– A set of specific points of data and all possible points b/w them

  - **DIGITAL**

    - Digital refers to something that is discrete
    - *Discrete*– A set of specific points of data with no points in between

  - Data can be Analog or Digital

    - Example of ANALOG Data is **Human voice**
    - When somebody speaks, a continuous wave is created in the air.
    - This can be captured by a Microphone and converted to an Analog Signal
    - An example of DIGITAL data is Data stored in the memory of a computer in the form of 1s and 0s. It is usually converted to a digital signal when it is transferred from one position to the other inside or outside the computer

  - Signals can be Analog or Digital

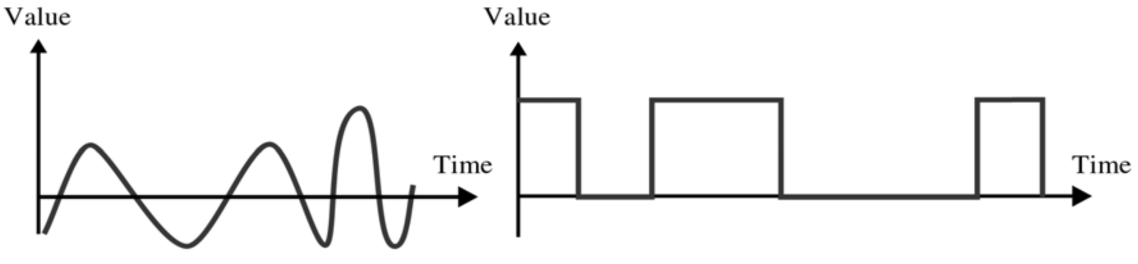
- **ANALOG Signal**

- It is a continuous waveform that changes smoothly over time
- As the wave moves from value ‘ A’ to value ‘B’, it passes through and includes an infinite number of values along its path

- **DIGITAL Signal**

  - A digital signal is discrete. It can have only a limited number of defined values, often as simple as 1s and 0s
  - The transition of a digital signal from value to value is instantaneous like a light being switched ON and OFF

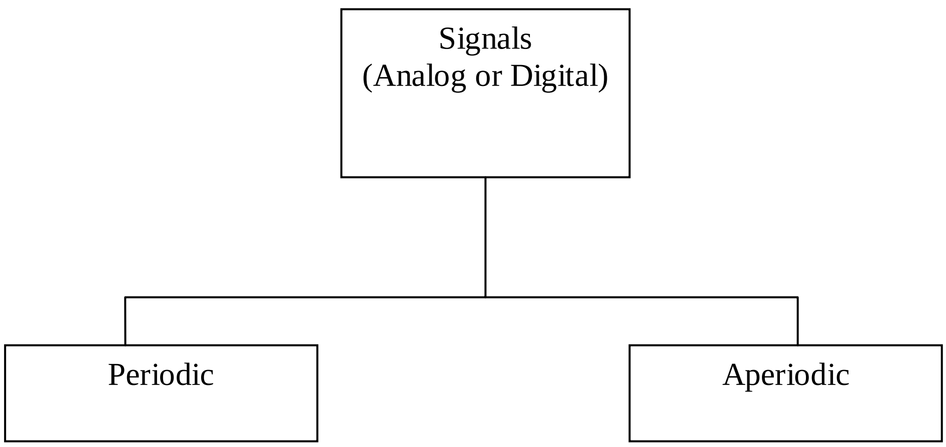
Analog and Digital Signals



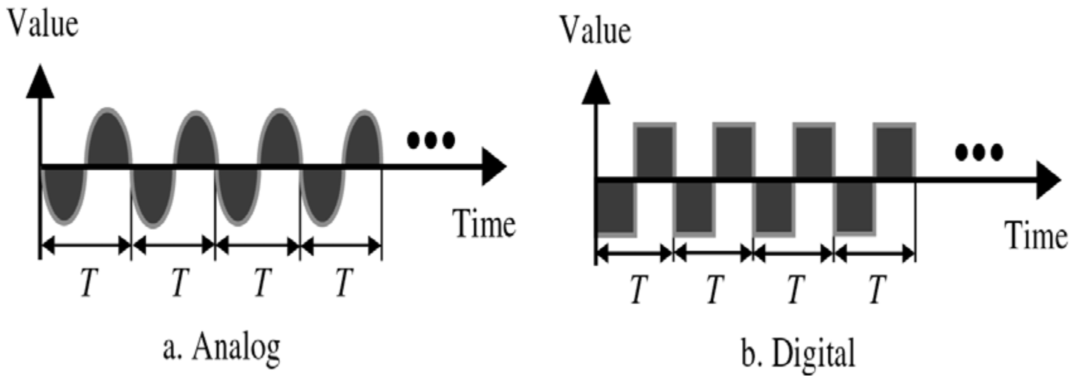
a. Analog signal b. Digital signal

- We illustrate signals usually by plotting them on a pair of perpendicular axis
- Vertical axis represent the value or the strength of the signal
- Horizontal axes represent the passage of time
- The curve representing the Analog signal is smooth and continuous, passing through an infinite number
- The vertical lines of the digital signal shows the sudden jump the signal makes from value to value. The flat highs and the lows represent that those values are fixed
- In short, Analog signal varies continuously w.r.t Time whereas Digital signal varies instantaneous

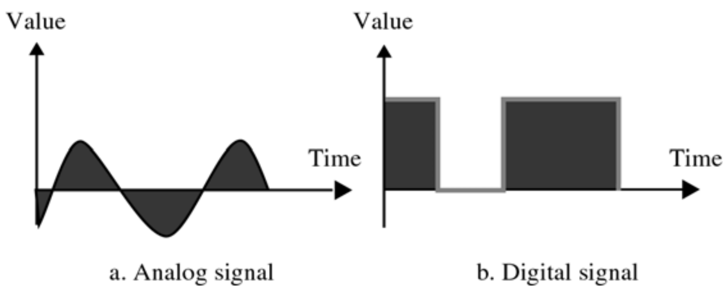
Periodic and Aperiodic Signals



- **Periodic Signals**
  - A signal is called Periodic if it completes a pattern within a measurable time frame called a Period and then repeats that pattern over identical subsequent Periods
  - The completion of one full pattern is called a CYCLE
  - Period: Time required (in Seconds) to complete one full cycle, represented by 'T'



- **Aperiodic Signals**
  - An Aperiodic or Non-Periodic signal is the one that changes constantly without exhibiting a pattern or cycle that repeats over time



  - **Fourier Transform**
    It has been proved by a technique called FOURIER TRANSFORM that any Aperiodic signal can be decomposed into an infinite number of Periodic Signals

- **ANALOG SIGNALS**
  - Analog signals can be classified as Simple or Composite
  - Simple Analog Signal(Sine Wave)
    – Cannot be decomposed into simpler signal
  - Composite Analog Signal
    – Composed of multiple sine waves

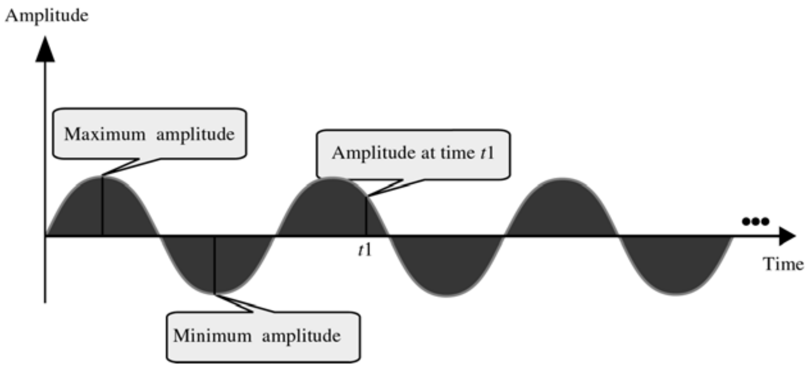
- **Sine Waves**
  - Sine Waves are the most fundamental form of Periodic Analog Signals
  - The curve oscillates over the course of a cycle smoothly and consistently

- Each cycle consists of a single arc above the time axis followed by a single arc below it
- Sine Waves can be fully described by three characteristics:

  - Amplitude
  - Period/Frequency
  - Phase

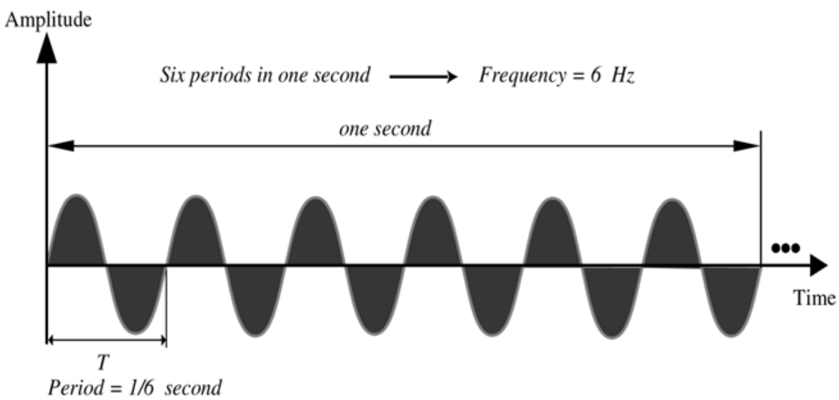
Amplitude

- Amplitude of a signal is the value of the signal at any point on the wave
- It is equal to the vertical distance from a given point on the wave form to the horizontal axis
- The maximum amplitude of the sine wave is equal to the highest value it reaches on the vertical axis
- Amplitude measured in Volts, Amperes or Watts



Period & Frequency

- Period: Amount of time (in seconds) a signal need to complete one cycle
- Frequency: Number of cycles completed in one second
- Unit of Period: Period is expressed in seconds



- Communication industry uses 5 units to measure period
- Frequency is measured in hertz, There are 5 units used in Hertz

Seconds____Hertz
Milliseconds.Kilohertz
Microseconds____Megahertz
Nanoseconds___Gigahertz
Picoseconds____Terahertz

Summary

- Signals
- Analog and Digital
- Analog and Digital Data & Signals
- Periodic & Aperiodic Signals
- Sine Waves and its Characteristics

Reading Sections

- Section 4.1, 4.2, 4.3“Data Communications and Networking” 4th Edition by Behrouz A. Forouzan

LECTURE #12

Problems 4.3
A Sine wave has a frequency of 6 Hz. What is its period?
Solution

$$T = \frac{1}{f} = \frac{1}{6} = 0.17\,\text{sec}$$

Problems 4.5
A Sine wave completes one cycle in 4 seconds. What is its frequency?
Solution:

$$f = \frac{1}{T} = \frac{1}{4} = 0.25\,Hz$$

Another Way to look at Frequency

- Measurement of the rate of change
- The rate at which a sine wave moves from its lowest to its highest point is its frequency
- A 40 Hz signal has half the frequency of a 80 Hz signal, therefore each cycle takes twice as long to complete one cycle I.e. to go from its lowest to its highest
- Change in a short Time = High Frequency

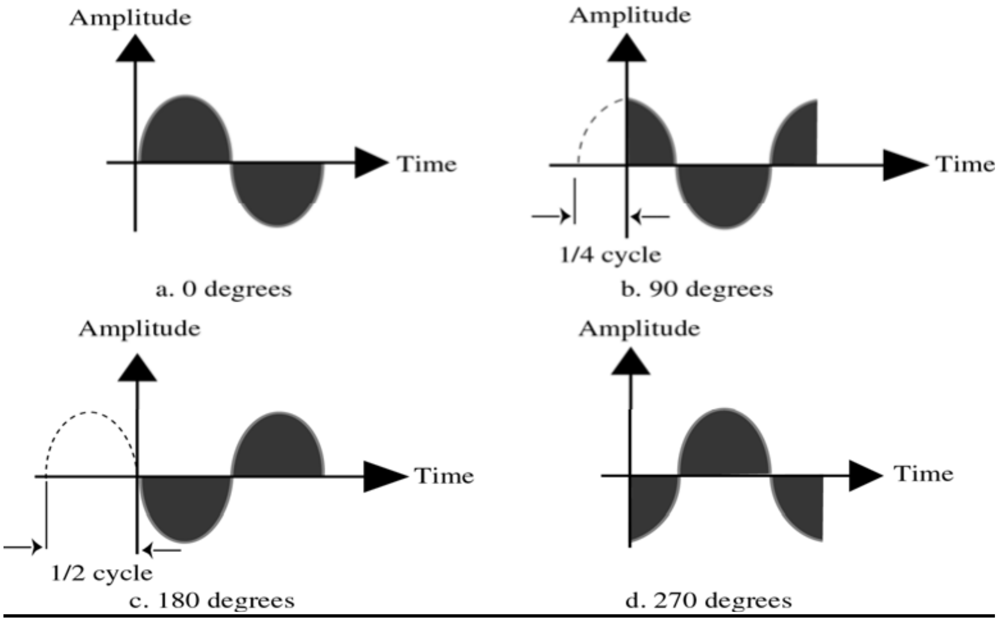
Two Extremes Frequency

- What if a signal does not change at all?
- What if it maintains a constant voltage level the entire time?
  - ./ In such cases , Frequency is going to be zero

- If a signal does not change, it will never complete any cycles, and frequency is no. of cycles in 1 second so Freq = 0
- No change at all ⇒
  - Zero frequency
- Instantaneous changes ⇒
  - Infinite frequency

Phase

- Phase describes the position of the waveform relative to time zero
- If we think of the wave as something that can be shifted backward or forward along the time axis
- Phase describes the amount of that shift
- It indicates the status of the first cycle
- Phase is measured in Degrees or Radians
- 360 degrees – 2 pi Radians
- A phase shift of 360 degrees correspond to a shift of a complete period
- A phase shift of 180 degree correspond to a shift of half a period
- A phase shift of 90 degree correspond to a shift of quarter a period



Problem 4.7
A sine wave is offset $\frac{1}{6}$ of a cycle with respect to time zero. What is its phase?
Solution

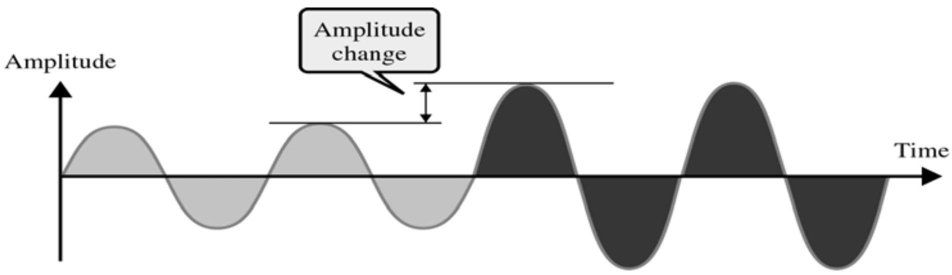
One Cycle = 360 Degrees

$\frac{1}{6}$ of a cycle = $\frac{360}{6}$ = 60 Degrees

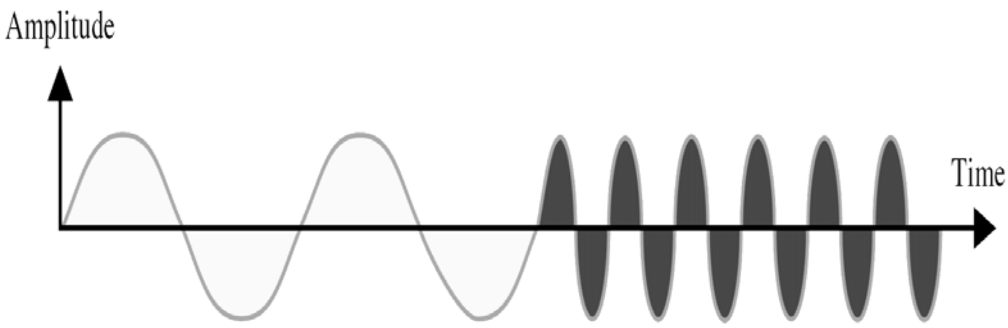
Control of Signals

- Signal can be controlled by three attributes:
    - Amplitude
    - Frequency
    - Phase

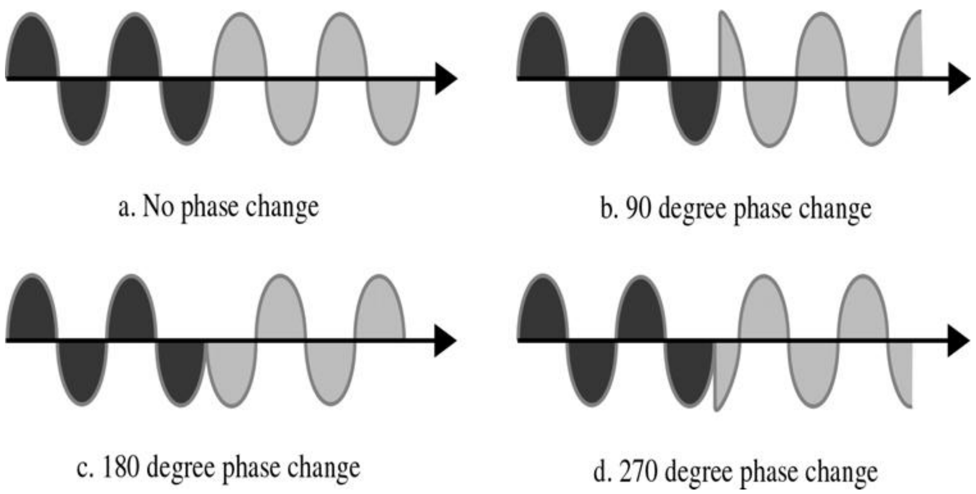
Control of Signals- Amplitude



Control of Signals- Frequency

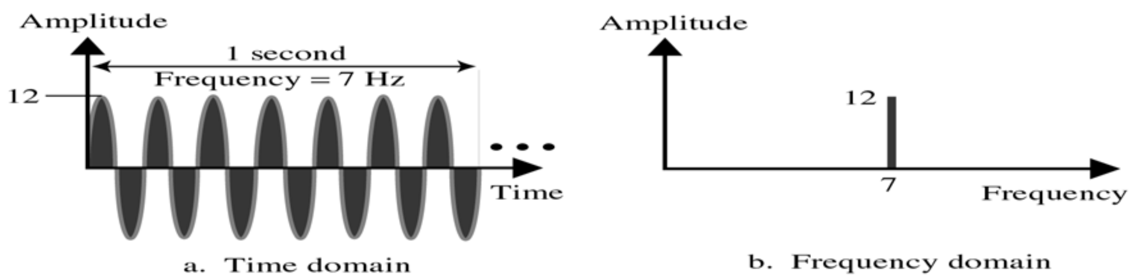


Control of Signals- Phase

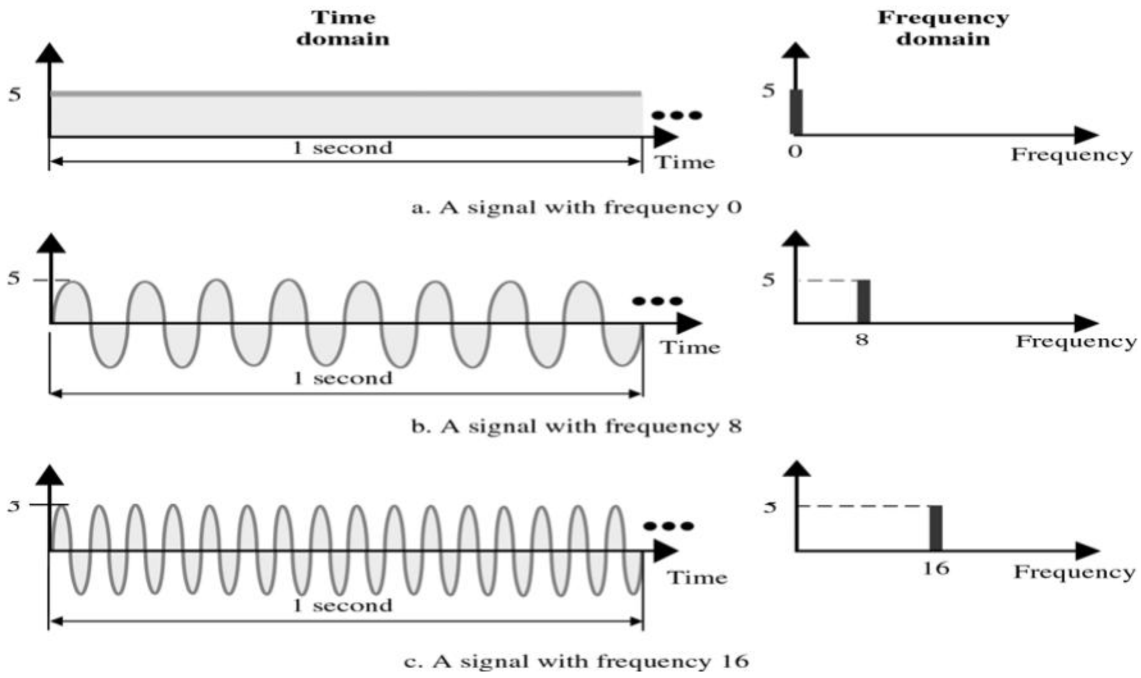


Time and Frequency Domain

- Time Domain plots show changes in signal amplitude w.r.t Time
- It is an Amplitude versus Time Plot
- Phase and Frequency are not explicitly measured on a Time domain plot
- To show the relationship between amplitude and Frequency, we can use what is called a ***Frequency Domain Plot***



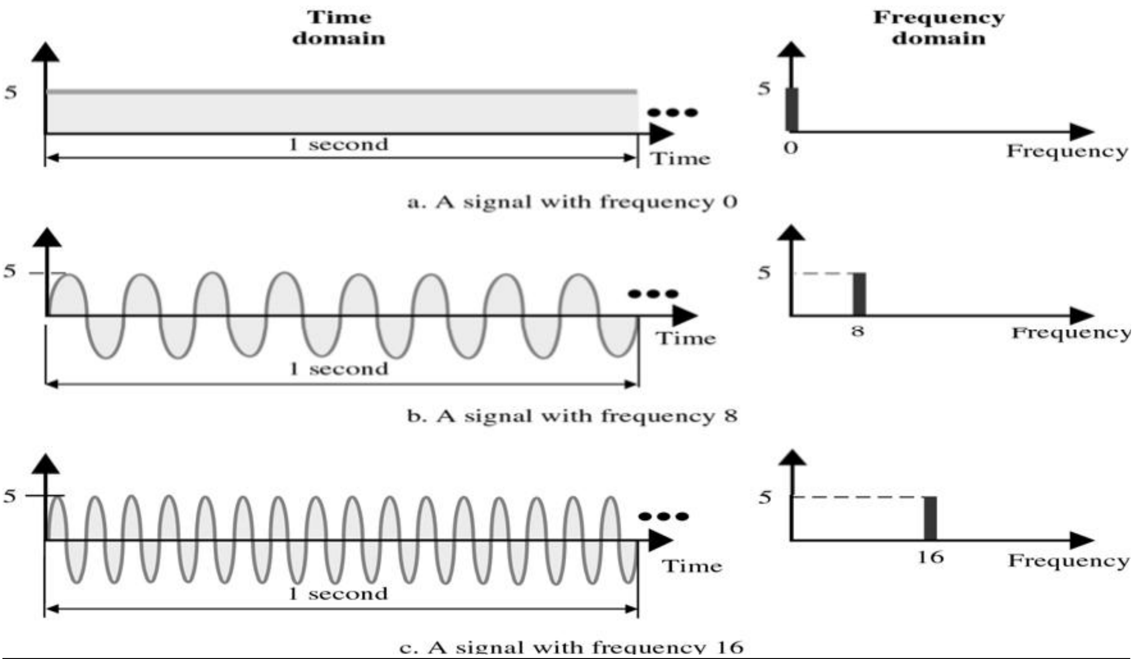
Time and Frequency Domain Example



- o Figure compares the time domain (instantaneous amplitude w.r.t Time) and the Frequency domain (Max amplitude w.r.t Frequency)
- o Low Frequency signal in frequency domain corresponds to a signal with longer period in Time domain & vice versa.
- o A signal changing rapidly in Time domain corresponds to High frequency in Frequency domain
- o Figure shows 3 signals with different frequencies and its time and frequency domain presentations

Composite Signals

- o Second type of Analog Signals, that is composed of multiple sine waves
- o So far we have been focused on simple periodic signals or sine waves
- o Many useful sine waves do not change in a single smooth curve b/w minimum and maximum amplitude.
- o They jump, slide , wobble and spikeAs long as as any irregularities are consistent, cycle after cycle, a signal is still Periodic
- o It can be shown that any periodic signal no matter how complex can be decomposed into a collection of sine waves, each having a measurable amplitude, frequency & phase
- o We need FOURIER ANALYSIS to decompose a composite signal into its components



- Figure shows a periodic signal decomposed into two sine waves
- First sine wave (middle one) has a frequency of '6' while the second sine wave has a frequency of '0'
- Adding these two signals point by point results in the top graph
- Original signal looks like a sine wave that has its time axis shifted downward
- This shift is because of DC Component or zero frequency component in the signal
- If you look at the signal in time domain, a single point is there while in frequency domain , two component freq.'s are there

Summary

- Sine Waves and its Characteristics
- Control of Signals
- Time and Frequency Domain
- Composite Signals

Reading Sections

- Section 4.4, 4.5 "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

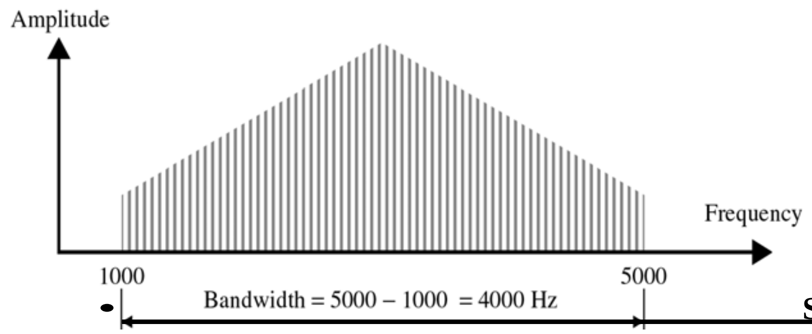
LECTURE #13

Frequency Spectrum / Bandwidth

- **Frequency Spectrum**: of a signal is the collection of all the component frequencies it contains
- It is shown using a Frequency domain graph
- Bandwidth: of a signal is the width of the frequency spectrum
- In other words ,Bandwidth refers to the range of the component frequencies and Frequency Spectrum refers to the elements within that range

How to calculate Bandwidth?

- To calculate Bandwidth, subtract the lowest frequency from the highest frequency



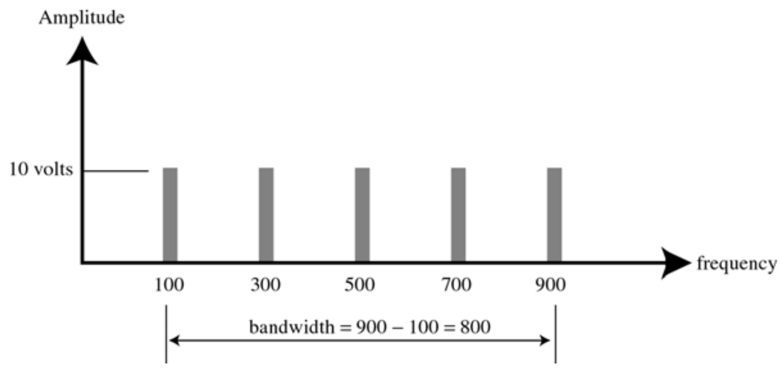
SLIDE

Example 4.8

If a periodic signal is decomposed into five sine waves with frequencies 100, 300, 500, 700, and 900 Hz, what is the Bandwidth?

Solution

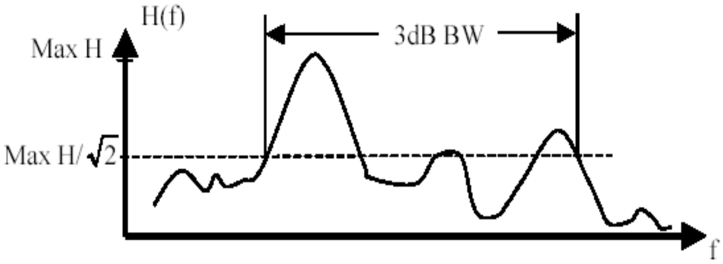
$$B = f_h - f_l = 900 - 100 = 800Hz$$



- **Other Definitions of Bandwidth**
  - **3 dB Bandwidth or Half Power Bandwidth**

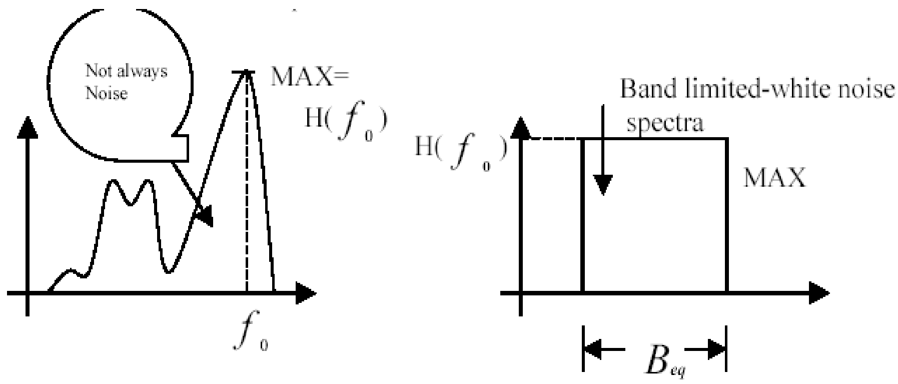
$|H(f)|$

For the magnitude spectra of $|H(f)|$, the range of the spectrum that does not fall lower than $\frac{1}{\sqrt{2}}$ times the max.



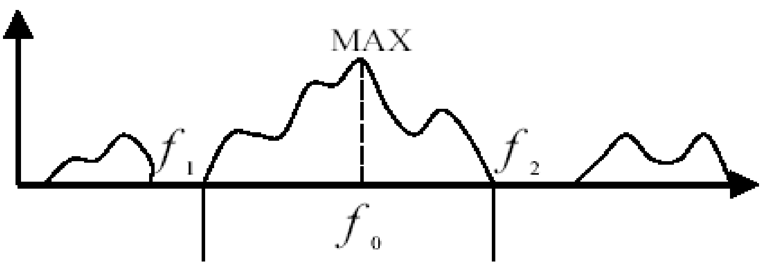
- **Equivalent Noise Bandwidth**

The width of a fictitious rectangular spectrum created to have the same power in the rectangular band as the power of the signal in positive frequencies



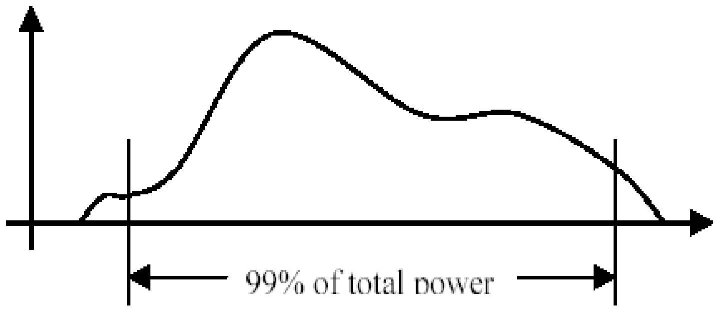
- **Null-to-Null Bandwidth or Zero Crossing Bandwidth**

If the maximum frequency in a spectrum is f_o ,the first null above and below f_o will be f_1 and f_2 , where $|f_1 - f_2|$ is the Null-to-Null Bandwidth



- **Power Bandwidth**

Frequency Band in which 99% of the total power resides

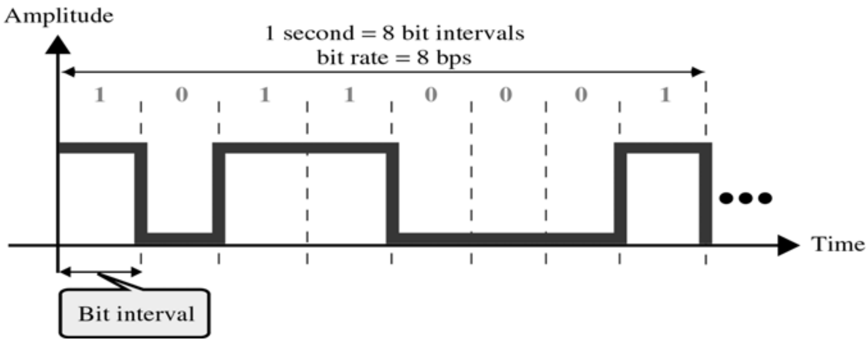


- **Digital Signals**
  In addition to being represented by Analog Signals, data can also be represented by a Digital signal

- **Bit Interval and Bit Rate**
  Most digital signals are aperiodic and thus Period and Frequency are not the appropriate terms to describe them

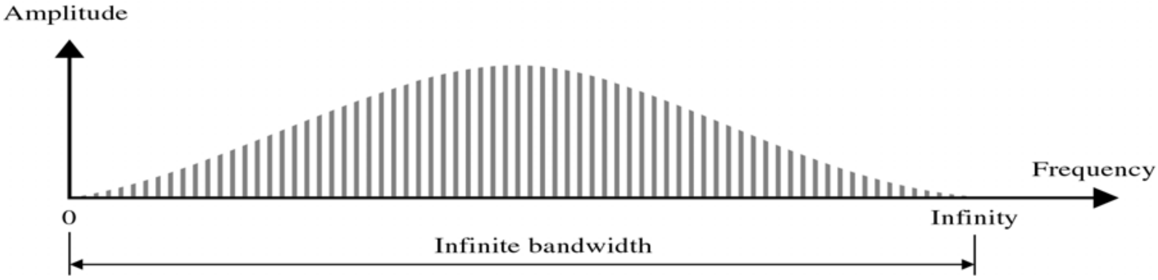
  - Bit Interval (seconds)
    - Time required to send one single bit

  - Bit Rate (bps)
    - Number of bits sent per second

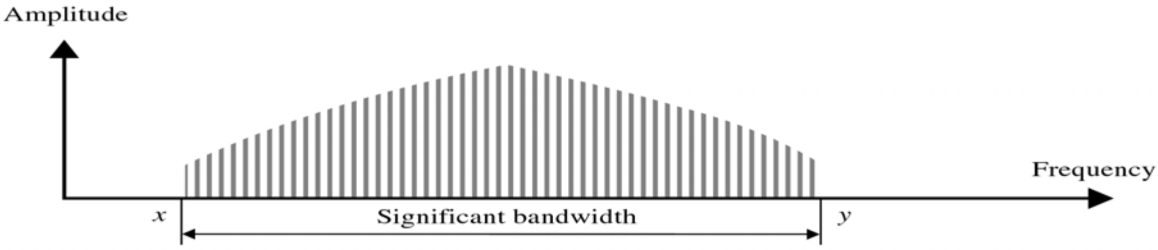


Frequency Spectrum of a Digital Signal

- Frequency spectrum of a digital signal contains an infinite number of frequencies with different amplitudes
- Ideally we want to send all the components but if we send only those components whose amplitudes are significant , we can still recreate the digital signal with reasonable accuracy at the receiver



a. Spectrum for exact replica



b. Significant spectrum

Summary

- Frequency Spectrum and Bandwidth
- Other Definitions of Bandwidth
- Digital Signals

Reading Sections

- Section 4.4, 4.5, 4.6 "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

LECTURE #14

Conversions

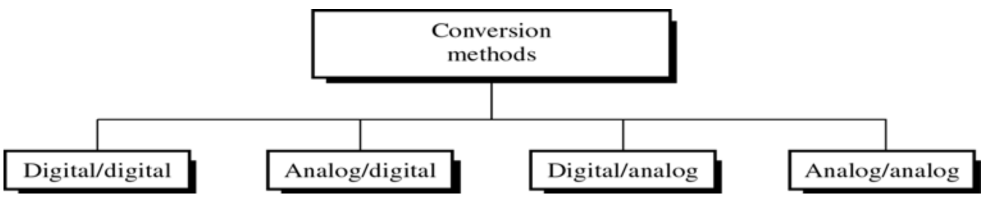
Introduction

- Information must be transformed into signals before it can be transported across the communication media
- How info is transformed depends on its original format and on the format used by the communication device
- If you want to send a letter by a smoke signal, you need to know which smoke patterns make which words in your message before building the fire
- Words are the Information and the puffs of smoke are representation of that information

Introduction to the type of Conversions

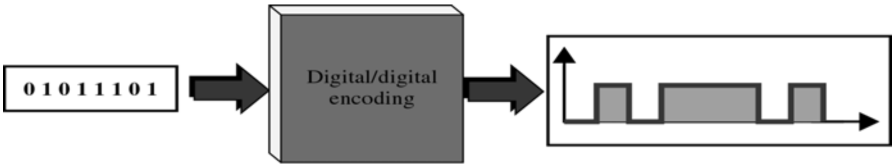
- Data stored in the computer is in the form of 0's and 1's. To be carried from one place to the other, data is usually converted to digital signals
- This is called **"*Digital-to-Digital Conversion*" or "*Encoding digital data into digital signals*"**
- Sometimes we need to convert an analog signal to the digital signal
- For Example, conversion of Telephone conversation to digital signal for a no. of different reasons such as to decrease the effect of noise
- This is called **"*Analog-to-Digital Conversion*" or "*Digitizing an Analog Signal*"**
- We might want to send a digital signal coming out of computer through a medium designed for analog signals
- For example, To send data from one place to the other using a Telephone line
- This is called **"*Digital-to-Analog Conversion*" or "*Modulating a digital Signal*"**
- Often an analog signal is sent over long distances using analog media
- For Example, voice or music from a radio station which is an analog signal is transmitted through the air, however the frequency of voice or music is not suitable for this kind of Tx.
- The signal should be carried by a higher frequency signal
- This is called **"*Analog-to-Analog Conversion*" or "*Modulating an analog Signal*"**

Types of Conversions



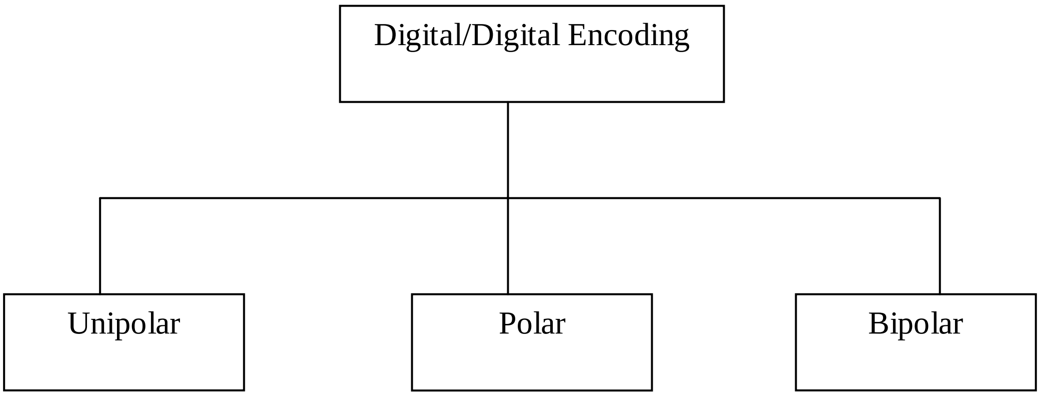
- **Digital-to-Digital Conversion**
  - Digital-to-Digital conversion/encoding is the representation of digital information by digital signal

- For Example when you Tx data from Computer to the Printer, both original and transmitted data have to be digital
- In this type of encoding, 1's and 0's generated by the computer are translated into voltage pulses that can be propagated over the wire

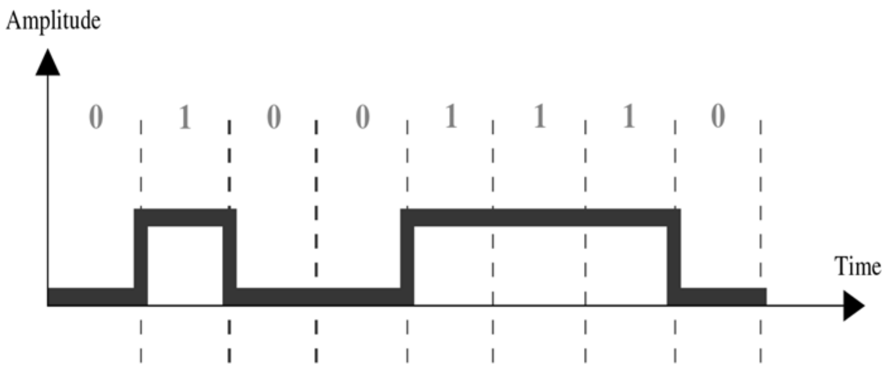


- Figure shows the relationship between digital information, digital-to-digital encoding hardware , and the resultant digital signal

Types of Digital-to-Digital Encoding



- **UNIPOLAR**
  - Encoding is simple , with only one technique in use
  - Simple and Primitive
  - Almost Obsolete Today
  - Study provides introduction to concepts and problems involved with more complex encoding systems



- Digital Transmission system works by sending voltage pulses on the Tx. Medium
- One voltage level stands for binary 0 while the other stands for binary 1
- It is called Unipolar because it uses only one polarity

- This polarity is assigned to to one of the two binary states usually a '1'
- The other state usually a 0 is represented by zero voltage
- Figure shows the idea: 1's are encoded as +ve values, and 0's are encoded as –ve values

Pros and Cons of Unipolar Encoding

- **PROS**
  - Straight Forward and Simple
  - Inexpensive to Implement
- **CONS**
  - DC Component
  - Synchronization

DC Component

- Average Amplitude of a unipolar encoded signal is non-zero
- This is called DC Component I.e. a component with zero frequency
- When a signal contains a DC Component, it cannot travel through a Tx. Medium that cannot handle DC components

Synchronization

- When the signal is unvarying, Rx. Cannot determine the beginning and ending of each bit
- Synchronization Problem can occur when data consists of long streams of 1's or 0's
- Therefore, Rx has to rely on a TIMER

- Consider we have a bit rate of the signal to be 1000bps
  - 1000 bits in 1 second
  - 1 bit in 0.001 second
- So if a +ve voltage lasts 0.005 sec, it reads five 1's
- Sometimes it stretches to 0.006 seconds and an extra one bit is read by the Rx
  - Solution:
    - ***Separate Parallel Line***

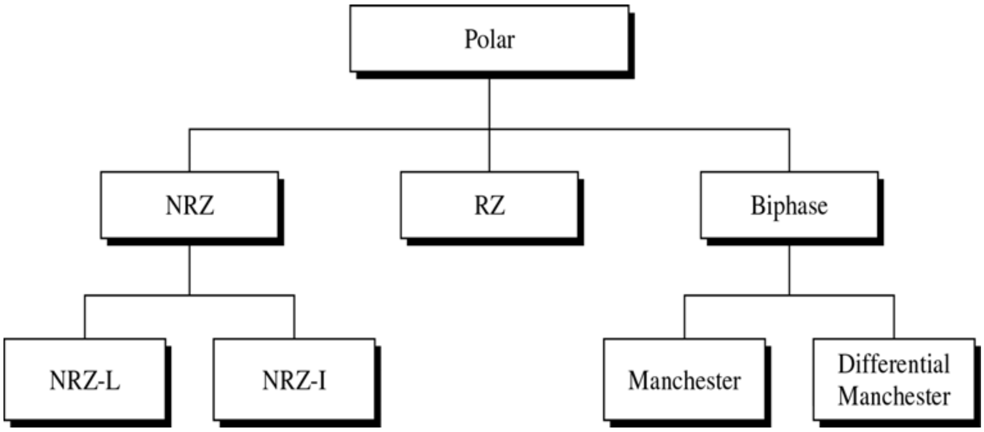
- Carries a clock pulse and allows receiver to resynchronize its timer to that of the signal
- Doubling no. of Tx lines increase Cost and proves uneconomical

- **POLAR**

  Encoding has 3 subcategories:
  - Non Return to Zero (NRZ),-- Return to Zero (RZ)
  - Bi phase
  - Two of which have multiple variations of their own

  - Polar encoding uses two voltage levels
    - One positive and one negative

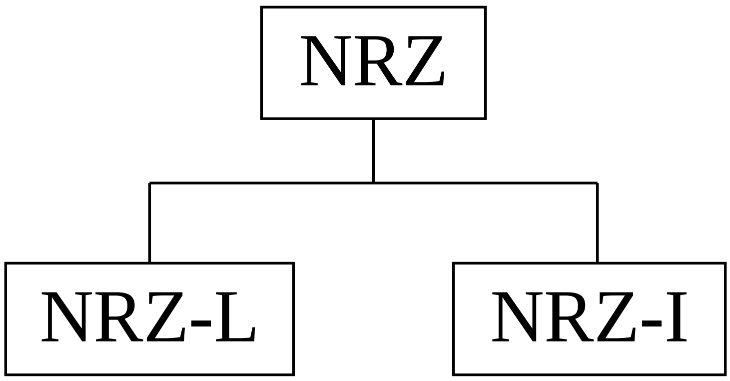
Y By using two voltage levels, average voltage level on the line is reduced and DC Component problem of unipolar encoding is alleviated



Types of Polar Encoding

Non Return to Zero (NRZ)

- In NRZ Encoding, the level of signal is either positive or negative



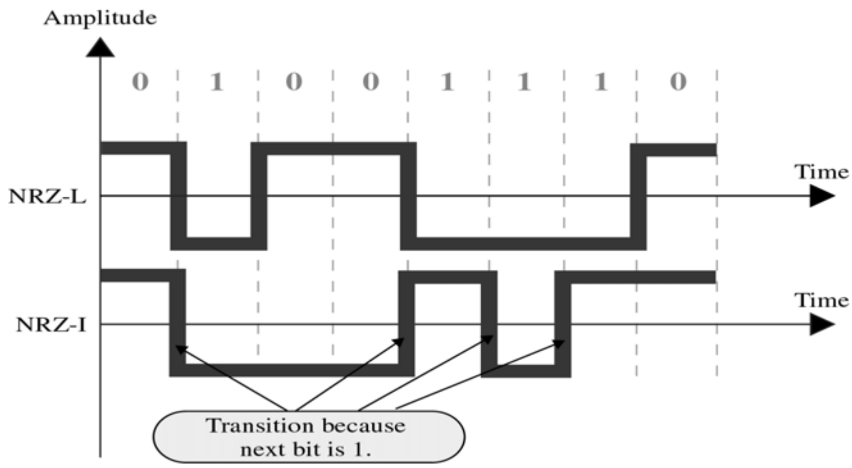
- **NRZ-L**
  - Level of the signal depends on the type of bit it represents
  - A +ve voltage usually means the bit is a 1 and a –ve voltage means the bit is a 0 (vice versa)

  •**Problem with NRZ-L:** When long streams of 0's or 1's are there in data, Rx receives a continuous voltage and should determine how many bits are sent by relying on its clock , which may or may not be synchronized with the sender clock

- **NRZ-I**

  - The inversion of the level represents a 1 bit

- A bit 0 is represented by no change
- NRZ-I is superior to NRZ-L due to synchronization provided by signal change each time a 1 bit is encountered
- The string of 0's can still cause problem but since 0's are not as likely, they are less of a problem



Summary

- Introduction to the Encoding Techniques
- Digital-To-Digital Encoding
- Types of Digital-To-Digital Encoding
- UniPolar Encoding
- Polar Encoding
  - NRZ

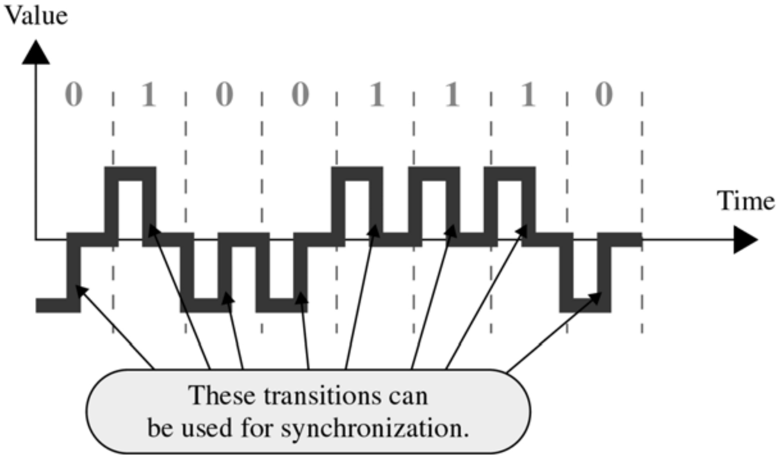
Reading Sections

- Section 5.1, "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

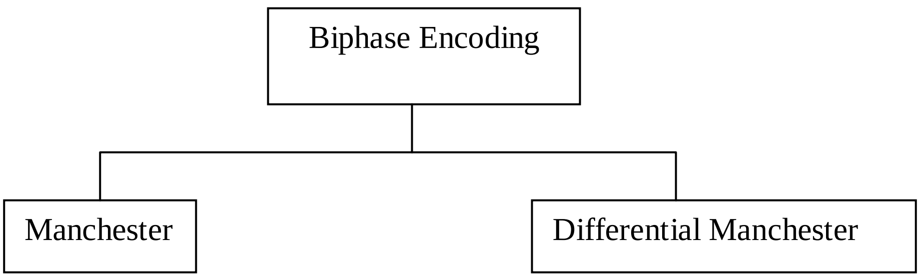
LECTURE #15

Conversions

- **Return to Zero (RZ)**
  - Any time, data contains long strings of 1's or 0's, Rx can loose its timing
  - In unipolar, we have seen a good solution is to send a separate timing signal but this solution is both expensive and full of error
  - A better solution is to somehow include synch in encoded signal somewhat similar to what we did in NRZ-I but it should work for both strings of 0 & 1
  - One solution is RZ encoding which uses 3 values : Positive, Negative and Zero
  - Signal changes not b/w bits but during each bit
  - Like NRZ-L , +ve voltage means 1 and a –ve voltage means 0, but unlike NRZ- L, half way through each bit interval, the signal returns to zero
  - A 1 bit is represented by positive to zero and a 0 is represented by negative to zero transition
  - The only problem with RZ encoding is that it requires two signal changes to encode one bit and therefore occupies more BANDWIDTH
  - But of the 3 alternatives we have discussed, it is most effective



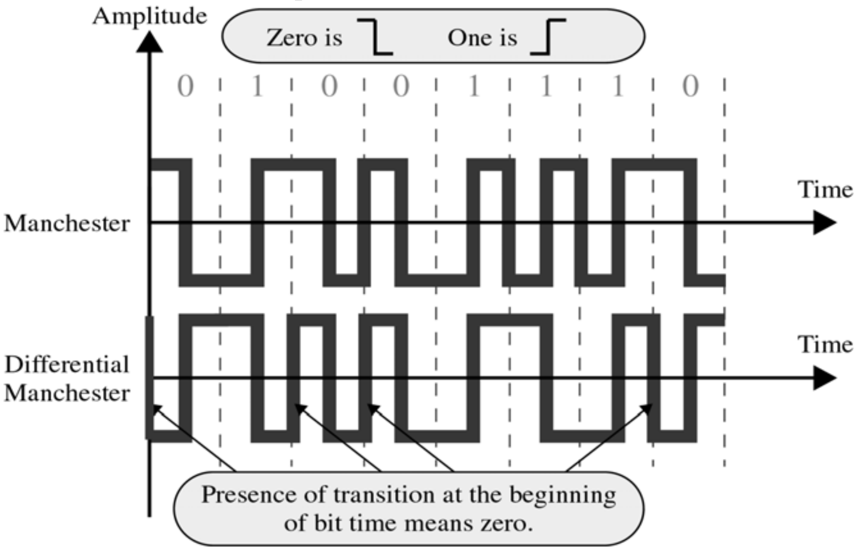
- **Biphase Encoding**
  - Best existing solution to the problem of Synchronization
  - Signal changes at the middle of bit interval but does not stop at zero
  - Instead it continues to the opposite pole



- **Manchester**

  - Uses inversion at the middle of each bit interval for both synchronization and bit representation

    - Negative-to-Positive Transition= 1
    - Positive-to-Negative Transition = 0
    - By using a single transition for a dual purpose, Manchester acheives the same level of synchronization as RZ but with only two levels of amplitude

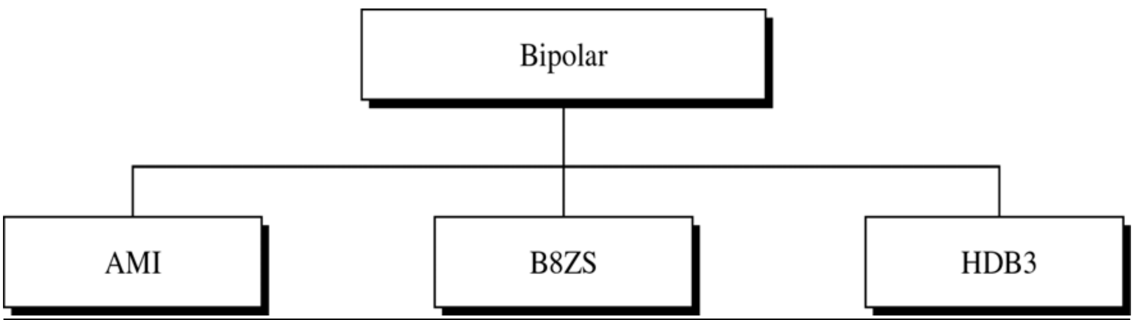


- **Differential Manchester**

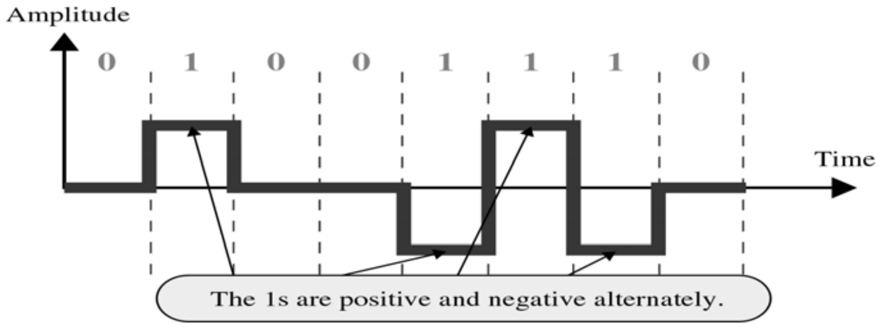
  - Inversion at the middle of the bit interval is used for Synchronization but presence or absence of an additional transition at the beginning of bit interval is used to identify a bit
  - A transition means binary 0 & no transition means binary 1
  - Requires 2 signal changes to represent binary 0 but only one to represent binary 1

- **Bipolar Encoding**
  - Like RZ, it uses three voltage levels:
  - Unlike RZ, zero level is used to represent binary 0
  - Binary 1's are represented by alternate positive and negative voltages

Types of Bipolar Encoding



- **Alternate Mark Inversion (AMI)**
  - Simplest type of Bipolar Encoding
  - Mark -7 Comes from Telegraphy (1)
  - Alternate Mark Inversion means Alternate '1' Inversion
  - Pseudoternary



  - By inverting on each occurrence of 1, AMI accomplishes 2 things:
    - The DC component is zero
    - Long sequence of 1's stay synchronized
  - No mechanism of ensuring synch is there for long stream of 0's
- Two variations are developed to solve the problem of synchronization of sequential 0's
  - B8ZS -7 used in North America
  - HDB3 -7 used in Europe & Japan
- Both modify original pattern of AMI only on case of long stream of zeroes

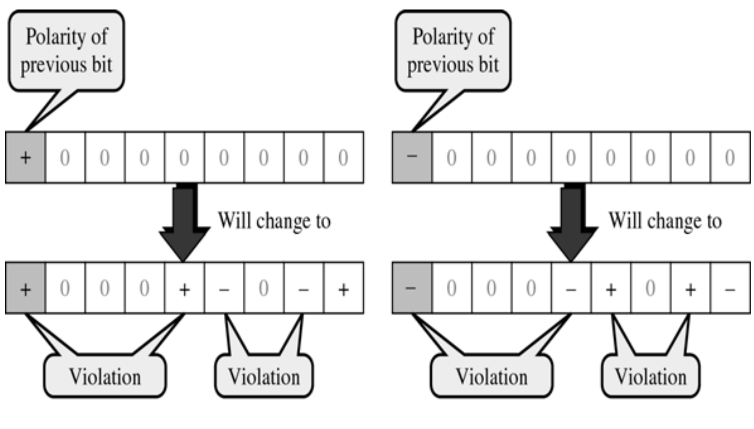
- **B8ZS**

  Convention adopted in North America to provide synch for long string of zeros

  Difference b/w AMI and B8ZS occurs only when 8 or more consecutive zeros are encountered

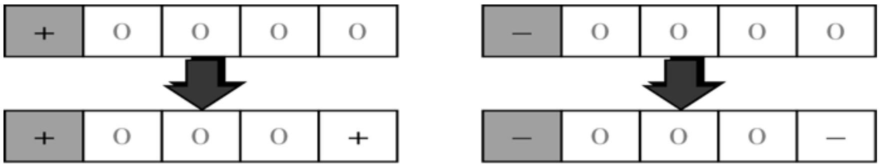
  Forces artificial signal changes called VIOLATIONS

  Each time eight 0's occur , B8ZS introduces changes in pattern based on polarity of previous 1 (the '1' occurring just before zeros)

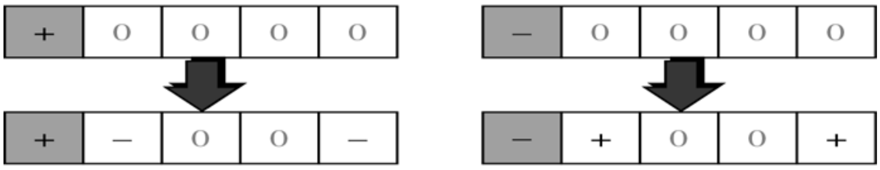


(a) (b)

- **HDB3**
  Alteration of AMI adopted in Europe and Japan
  Introduces changes into AMI, every time four consecutive zeros are encountered instead of waiting for eight zeros as in the case of B8ZS



(a) If the number of 1s since the last substitution is odd



(b) If the number of 1s since the last substitution is even

  As in B8ZS, the pattern of violations is based on the polarity of the previous 1 bit
  Unlike B8ZS, HDB3 also looks at the no. of 1's that have occurred since the last substitution

Summary

- Types of Digital-To-Digital Encoding
- Polar Encoding
  - Return to Zero (RZ) Encoding
  - Biphase Encoding
- Bipolar Encoding

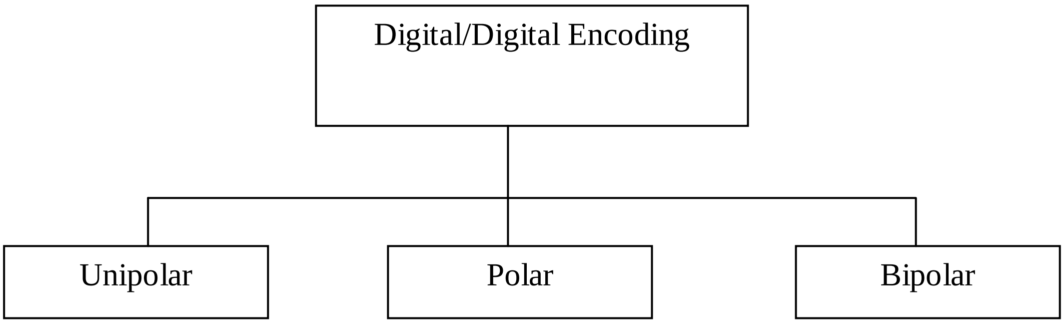
Reading Sections

- Section 5.1, "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

LECTURE #16

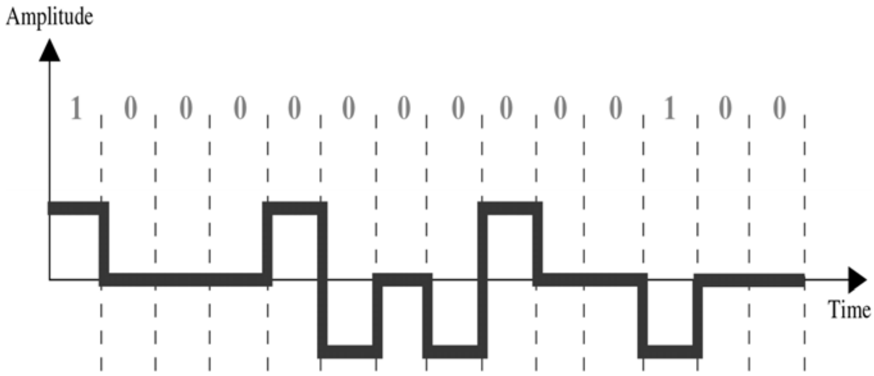
Conversions

Types of Digital-to-Digital Encoding

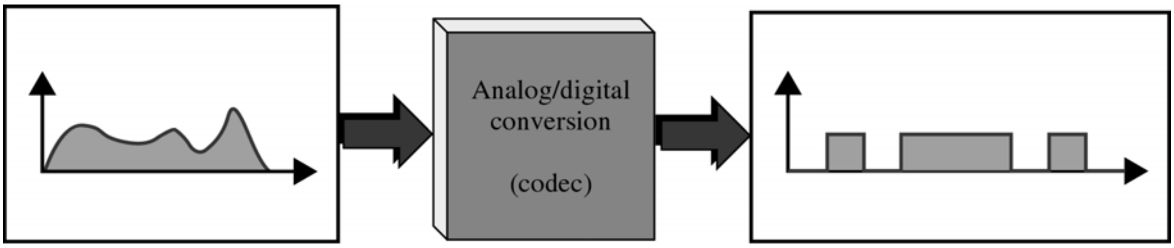


Example 5.1

- Using B8ZS, encode the bit stream 10000000000100. Assume that the polarity of the first 1 is positive**.**



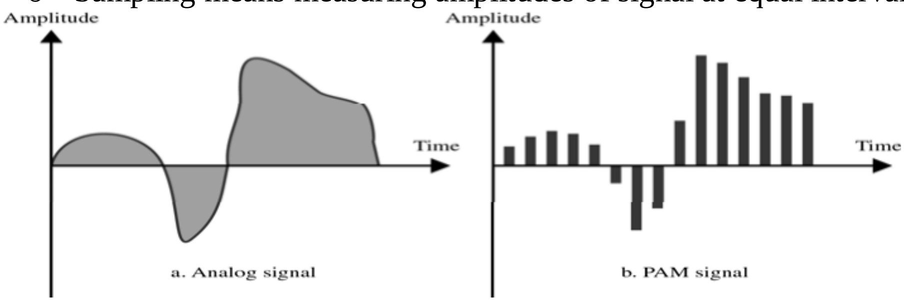
- **Analog-to-Digital Conversion**
  - We sometimes need to digitize an analog signal
  - To send human voice over a long distance, we need to digitize it, since digital signals are less prone to Noise
  - This is called ***Analog-to-Digital Conversion*** or ***Digitizing an Analog Signal***
  - This type of conversion requires a reduction of potentially infinite number of values in the analog signal so that it can be converted to digital bit stream with minimum loss of information.



- CODEC -7 Coder Decoder
- Digital signal signals can take any of the forms discussed previously
- Problem is how to convert analog signal from infinite number of values to discrete no. of values without scarifying quality

Ÿ **Pulse Amplitude Modulation**

- First step in Analog-to-Digital Conversion
- This technique takes an Analog signal, Samples it, and Generates a series series of Pulses based on the results of Sampling
- Sampling means measuring amplitudes of signal at equal intervals



- The original signal is sampled at equal intervals
- PAM uses a technique called Sample & Hold means At a given moment , signal level is read, then held briefly
- The pulses are of any amplitude (still analog not digital). To make them digital, we need PCM

Ÿ **Pulse Code Modulation**

- Modifies pulses created by PAM to a complete digital signal
- Four Separate Processes:
  - ./ PAM
  - ./ Quantization
  - ./ Binary Encoding
  - ./ Digital/Digital Encoding

./ **Quantization**

PCM's first step is Quantization

"Quantization is a method of assigning integral values in a specific range to sampled instances"

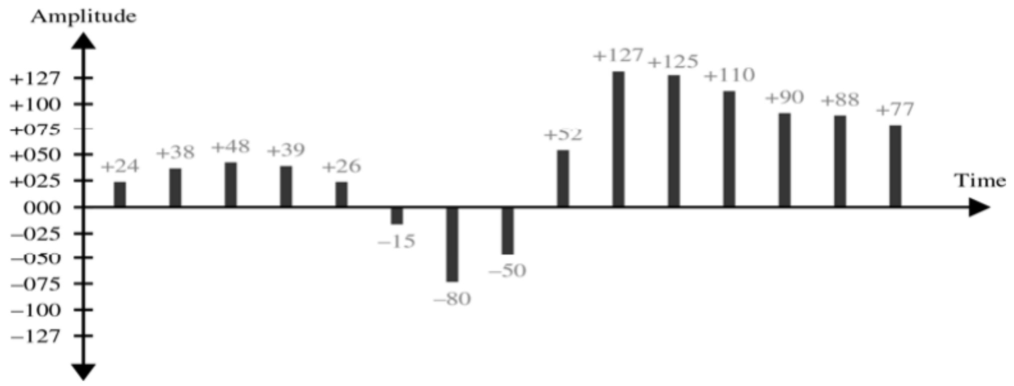


Figure shows a simple method of assigning sign and magnitude values to quantized samples

./ Results of Binary Encoding

+024	00011000	–015	10001111	+125	01111101
+038	00100110	–080	11010000	+110	01101110
+048	00110000	–050	10110010	+090	01011010
+039	00100111	+052	00110110	+088	01011000
+026	00011010	+127	01111111	+077	01001101

Sign bit
+ is 0 – is 1

Each value is translated into its seven bit binary equivalent. The eight bit indicates the sign

Y Result of PCM

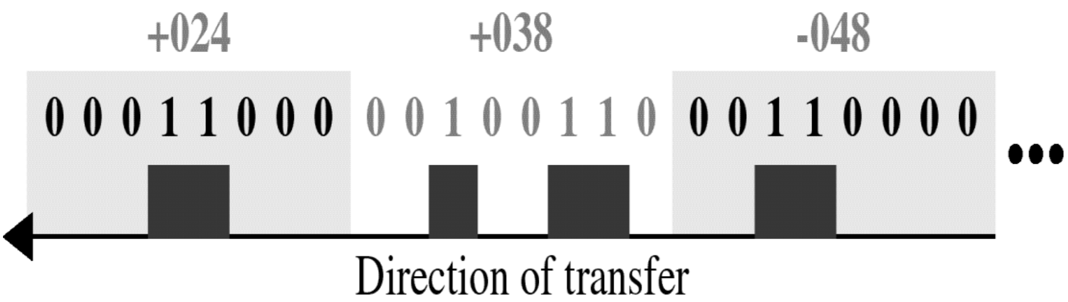
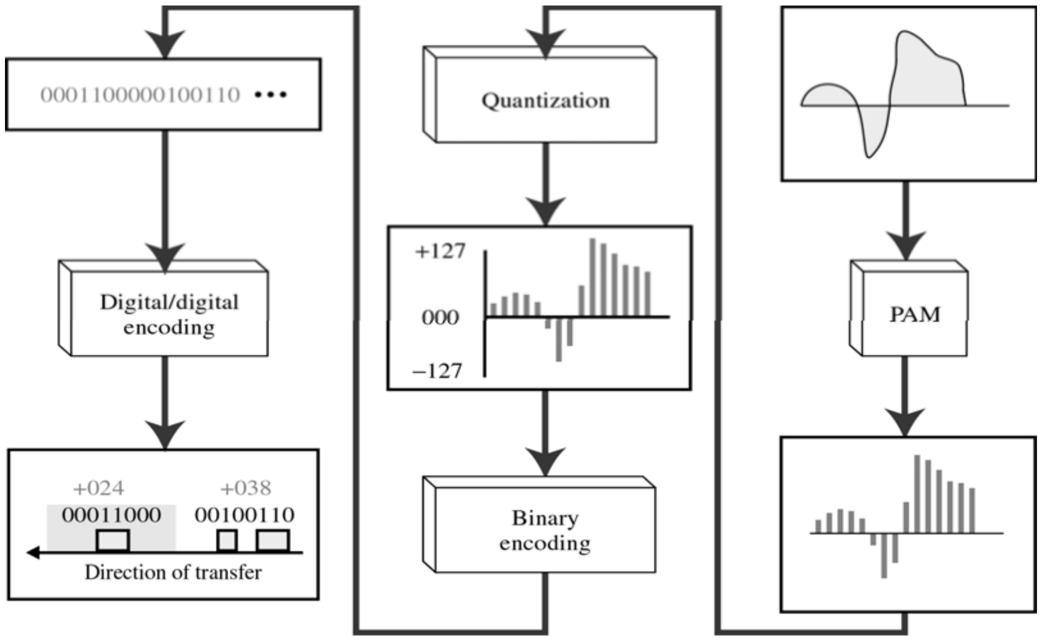
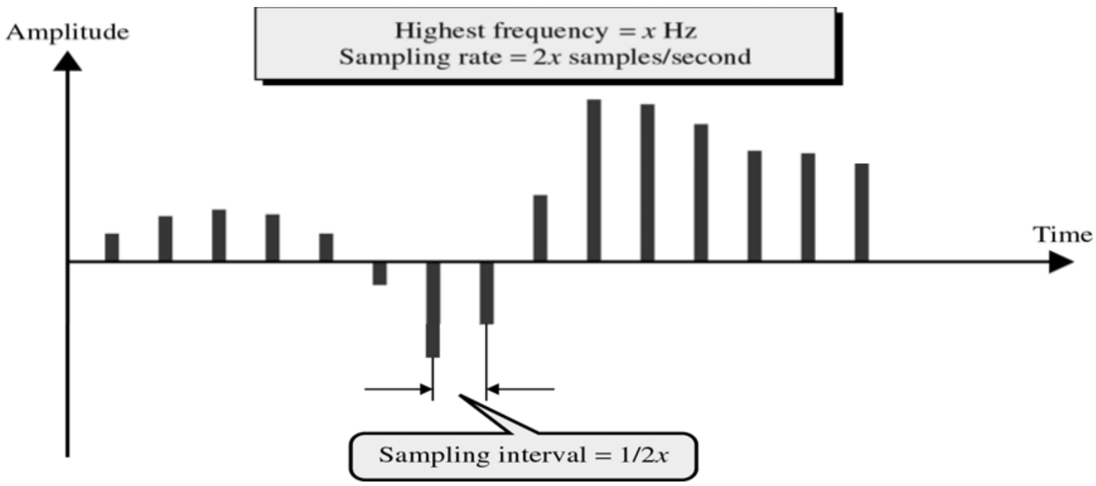


Figure shows the result of PCM of original signal encoded finally into a unipolar signal
Only first 3 values are shown

Y Full PCM Process



- **Sampling Rate**
  - The accuracy of any digital reproduction of an analog signal depends upon the o. of samples taken
  - How many samples are sufficient?
  - ***<Nyquist theorem>***
    - **The sapling rate must be at least twice the highest frequency**



- **Bit Rate**
  - Sampling Rate given by **Nyquist Theorum**
  - No. of bits per sample chosen according to the Precision needed at the receiver end.

$$BitRate = SamplingRate \times No.ofbits / sample$$

Summary

- Analog-to-Digital Conversion
- Pulse Code Modulation (PCM)
  - Pulse Amplitude Modulation (PAM)
  - Quantization
  - Binary Encoding
  - Digital-To-Digital Conversion

Reading Sections

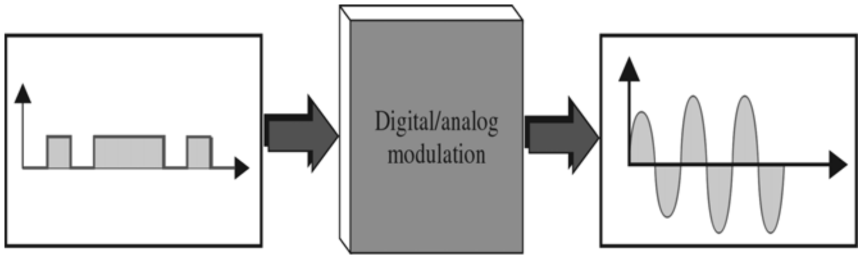
- Section 5.2, "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

LECTURE #17

Conversion

Digital To Analog Conversion

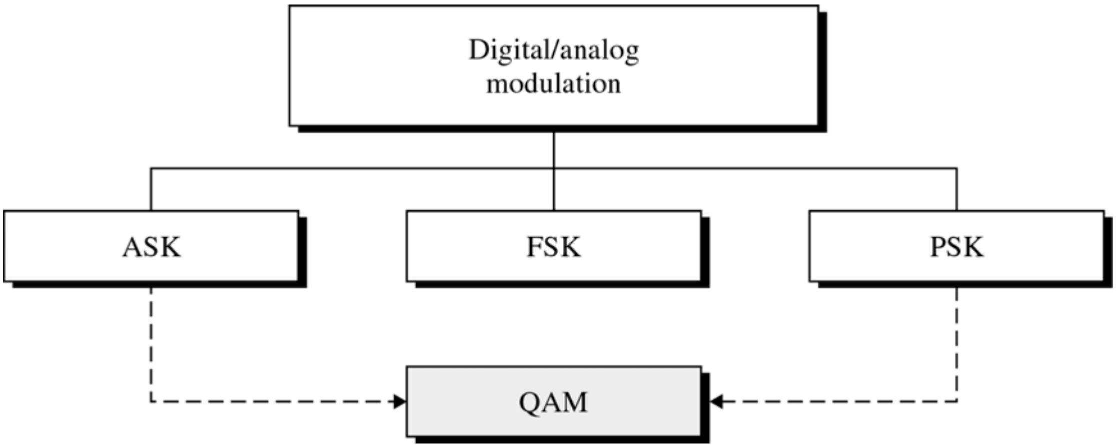
- Process of changing one of the characteristics of an analog signal based on the info in a digital signal
- When you Tx data from one computer to the other using a public telephone line
- Original data is digital but because telephone wires carry analog signal, original data must be converted
- Digital data must be modulated on an analog signal that has been manipulated to look like two distinct values corresponding to binary 1 to binary 0



- **Figure** shows the relationship b/w digital info the digital to analog conversion hardware & resultant analog signal
- **Variation in Characteristics of Sine Wave**
  - A sine wave is defined by 3 characteristics:
    - Amplitude
    - Frequency
    - Phase
      - By changing one aspect of a simple electrical signal back & forth,we can use it to represent digital data
  - When we vary any one of these characteristics ,we create a second version of that wave
  - If we than say that the original wave represents binary 1,the variation can represent binary 0 or vice versa
  - So by changing one aspect of a simple electrical signal back & forth,we can use it to represent digital data
- **Mechanisms for Modulating Digital Data to Analog Signals**
  - Any of the three characteristics listed above can be altered in this way, giving us at least 3 mechanisms for modulating digital data into analog signals
    - Amplitude shift keying(ASK)
    - Frequency shift keying(FSK)
    - Phase shift keying (PSK)

- **Fourth Mechanism**
    - In addition, there is a fourth and better mechanism that combines changes in both amplitude and phase called Quadratue Amplitude Modulation(QAM)
    - QAM is the most efficient of these options and is the mechanism used in all modern modems

Types of digital to analog modulation



- **Aspects of Digital to Analog Conversion**
    - Before we discuss specific methods of digital to analog modulation,two basic issues must be defined:
        - Bit/Baud rate
        - Carrier signal

        - **Bit Rate & Baud Rate**
        - Two terms used frequently in data communication
            - –Bit rate
            - –Baud rate
            - •**Bit rate**: no of bits transmitted during one second
            - •**Baud rate**: no of signal units per second that are required to represent that bit
- **Bit Rate & Baud Rate**
- In discussion of computer efficiency, bit rate is more important –we want to know how long it takes to process each piece of info
- In data transmission, however ,we are more concerned with how efficiently we can more that data from place to place, whether in pieces or blocks
- The fewer signal units required, the most efficient the system and less bandwidth required to transmit more bits ,so we are more concerned with baud rate
- The baud rate determines the B.W required to send the signal

- **Relationship b/w bit rate &band rate**

- Bit rate equals the baud rate times the no. of bits represented by each signal units
- The baud rate equals the bit rate divided by the no. of bits represented by each signal shift
- Bit rate is always greater than or equal to Baud rate

- **Analogy for Bit rate &Baud rate**
  - In transportation a band is analogous to a car,a bit is analogous to a passenger
  - A car can carry one or more passengers
  - If1000 cars can go from one point to another carrying only one passenger(only driver),than 1000 passengers are transported
  - However, if each car carries four passengers, then 4000 passengers are transported
  - Note that the number of cars, not the numbers of passengers determines the traffic and therefore the need for wider highway
  - Similarly, the baud determines the required bandwidth, not the bit rate

Example 5.6
An analog signal carries 4 bits in each signal element.If 1000 signal elements are sent per second, find the Baud Rate and Bit Rate?

Solution:

–Baud Rate= Number of Signal Elements

–Baud Rate =1000 bauds/second

–Bit Rate=Baud Rate * Number of bits per signal element

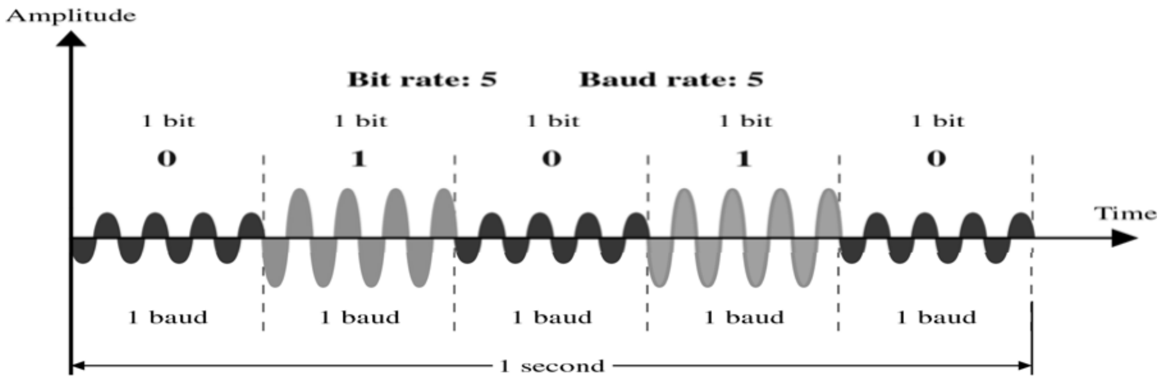
–Bit Rate= 1000 * 4 = 4000 bps

- **Carrier Signals**
- In analog TX. The sending device produces a high frequency signal, that acts as a basis for the information signal
- This base signal is called the ***Carrier Signal*** or ***Carrier Frequency***
- The receiving device is tuned to the frequency of the carrier signal that it expects from the sender
- **I=**Digital info is then modulated on the carrier signal by modifying one or more of its characteristics (Amplitude, Frequency, Phase)
- This kind of modification is called Modulation and info signal is called a Modulating Signal

- **Amplitude Shift Keying (ASK)**

  - In ASK, the strength of carrier signal is varied to represent binary 1 or 0
  - Both frequency and phase remain constant, while the amplitude changes
  - Which voltage represents 1 and which represents 0 can be chosen by System Designer
  - A bit duration is the period of time that defines one bit
  - The peak amplitude of the signal during each bit duration is constant and its value depends on the bit (1 or 0)

- Speed of transmission during ASK is limited by the physical characteristics of Tx. Medium

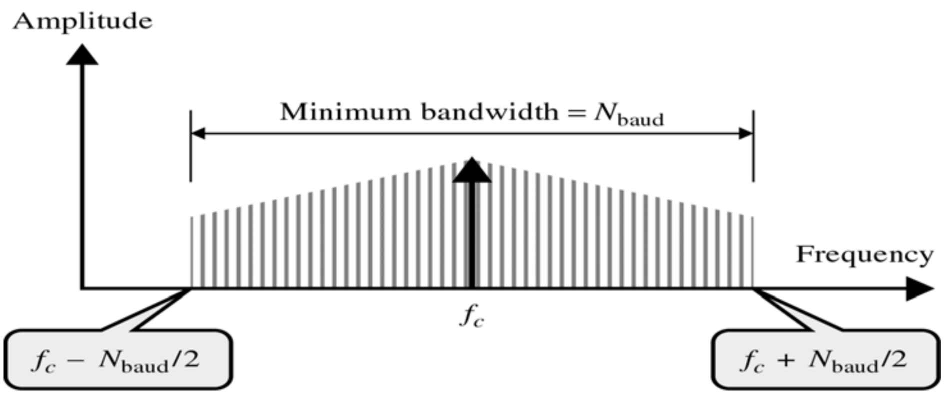


- **Effect Of Noise on ASK**

- ASK is highly susceptible to noise interference
- **NOISE**: Unintentional voltages introduced onto a line by various sources such as Heat or Electromagnetic Radiation from other sources
- These unintentional voltages combine with signal to change the amplitude
- A 1 can be changed to 0 and a 0 to a 1
- ASK relies solely on Amplitude for recognition
- Noise usually affects the amplitude, therefore ASK is the modulating method, that is most affected by Noise

- **On-Off Keying (OOK)**
  - A popular ASK Technique
  - In OOK, one of the bit values is represented by no voltage
  - The advantage is the reduction in the amount of energy required to transmit Information

- **Bandwidth for ASK**
  - Bandwidth of a signal is total range of frequencies occupied by that signal
  - When we decompose an ASK modulated signal, we get a spectrum of many simple frequencies
  - The most significant ones are those b/w, fc-Nbaud/2 and fc+Nbaud /2 with carrier frequency fc at the middle



- Bandwidth requirements for ASK are calculated using the formula:

- BW=(1+d) * Nbaud
- BW = Bandwidth
  - Nbaud= Baud Rate
- d= factor related to condition of line (min.value = 0)

Example 5.8

Find minimum bandwidth required for an ASK signal TX at 2000 bps. TX. Mode is half duplex

Solution:

–In ASK, Baud Rate= Bit Rate

–Therefore, Baud Rate = 2000

–Also ASK requires a minimum bandwidth equal to its Baud Rate

–Therefore Minimum BW = 2000 Hz

Summary

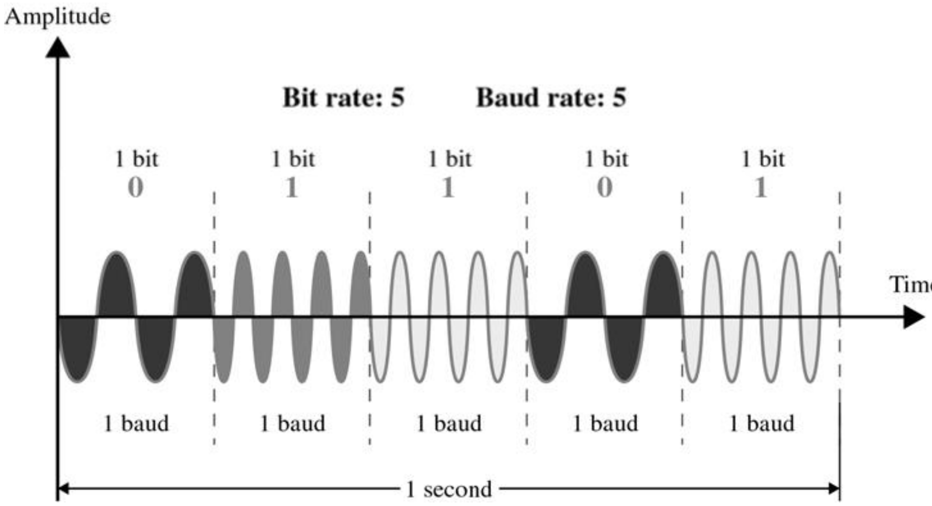
- Digital-to Analog Conversion
- Bit Rate and Baud Rate
- Carrier Signals
- Amplitude Shift Keying (ASK)

Reading Sections

- Section 5.3, "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

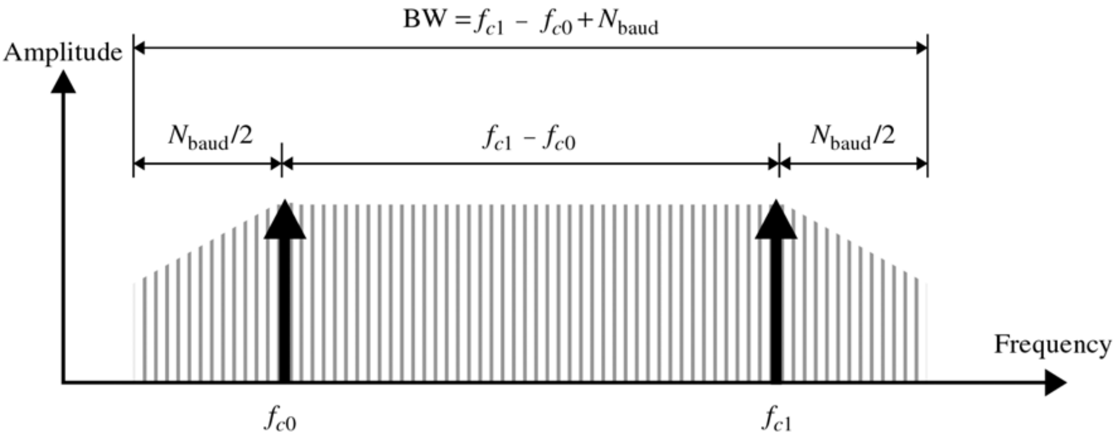
LECTURE #18

- **Frequency Shift Keying (FSK)**
  - Frequency of signal is varied to represent binary 1 or 0
  - The frequency of the signal during each bit duration is constant and depends on the bit (0 or 1)
  - Both peak amplitude and phase remains constant



- **Effect of Noise on FSK**
  - Avoids most of the Noise problems of ASK
  - Because Rx device is looking for specific frequency changes over a given number of periods, it can ignore voltage spikes
  - The limiting factors of FSK are the physical capabilities of the carrier

Y **BW of FSK**



- Although FSK shifts between two carrier frequencies, it is easier to analyze as two co-existing frequencies
- BW required for FSK is equal to the Baud rate of the signal plus the frequency shift
- Frequency Shift=Difference b/w two carrier frequencies
- BW= (fc1 – fc0) +Nbaud

Example 5.11

Find the minimum BW for an FSK signal transmitted at 2000 bps. TX is in half duplex mode and carrier must be separated by 3000 Hz

Solution:

For FSK, if fc1 and fc2 are the carrier frequencies, then:
BW=Baud Rate + (fc1 – fc0)
Baud rate is the same as bit rate
BW=2000 + (fc1 – fc0) = 2000 + 3000 = 5000 Hz

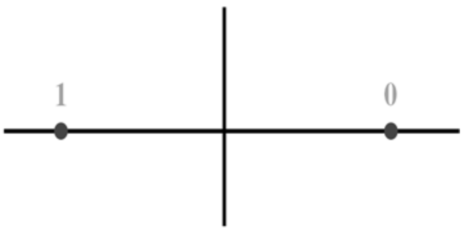
- **Phase Shift Keying (PSK)**

  - In PSK, phase of carrier is varied to represent binary 1 or 0
  - Both peak amplitude and frequency remains constant as the phase changes
  - For Example: if we start with a phase of 0 degrees to represent binary 0 , then we can change the phase to 180 degrees to send binary 1
  - The phase of signal during duration is constant and its value depends upon the bit (0 or

    - **2PSK**
      - The above method is often called 2 PSK, or Binary PSK, because two different phases (0 and 180 degrees) are used

Bit	Phase
0 1	0 180

Bits

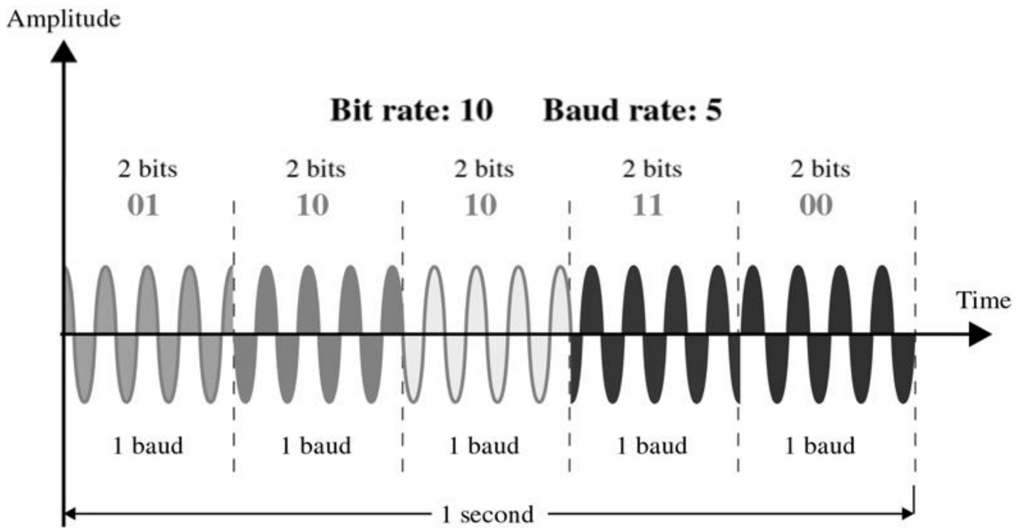


Constellation diagram

      - Figure makes this point clear by showing the relationship of phase to bit value
      - A second diagram called constellation diagram or phase state diagram shows same relationship by illustrating only the phases

- **Effect of Noise on PSK**
  - PSK is not susceptible to the noise degradation that affects ASK, nor to the bandwidth limitations of FSK
  - Smaller variations in signal can be detected reliably by the receiver

    - **4PSK**

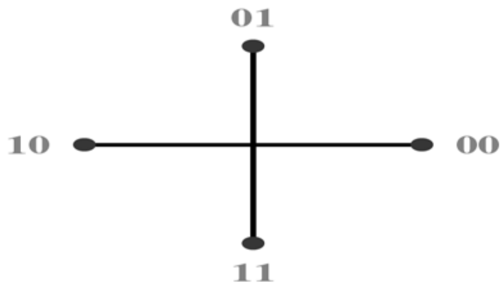


- o Based on the above two facts, instead of utilizing only two variations of a signal, each representing one bit, we can use four variations and let each phase shift represent two bits

Y **4PSK**

Dibit	Phase
00	0
01	90
10	180
11	270

Dibit
(2 bits)



Constellation diagram

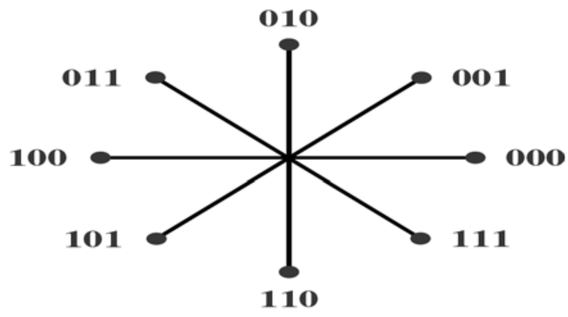
Y **BW for PSK**

- o Minimum bandwidth required for PSK transmission is the same as ASK
- o As we have seen max bit rate in PSK is much greater than that of ASK
- o So while max baud rate of ASK and PSK are the same for a given BW, PSK bit rate using the same BW can be two or more times greater

Y **8 PSK**

Tribit	Phase
000	0
001	45
010	90
011	135
100	180
101	225
110	270
111	315

Tribits
(3 bits)



Constellation diagram

- **QAM**

  - **<u>Limitations of PSK:</u>**

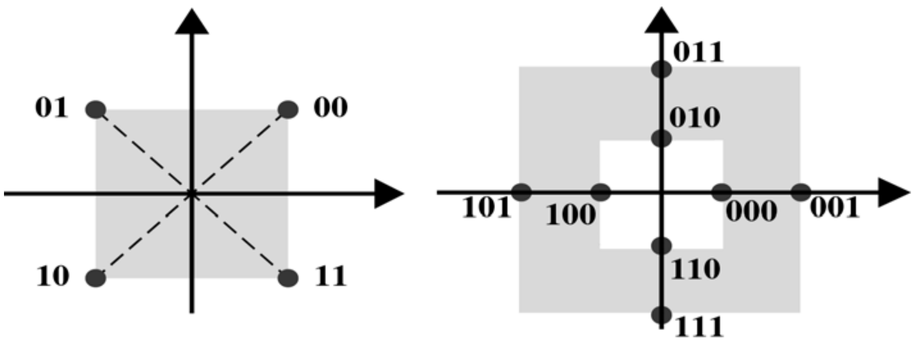
    –PSK is limited by the ability of the equipment to distinguish small differences in phase

    –This factor limits its potential bit rate

    –So far we have been changing only of the characteristics of the sine wave, But what if we alter two

- What should these two characteristics be?
- BW limitations make combination of FSK with other changes practically useless
- Why not combine ASK and PSK?
- ‘x’ variation in phase and ‘y variations in amplitude result into a total of x * y variations and corresponding no. of bits per variation

<u>Quadrature Amplitude Modulation (QAM)</u>



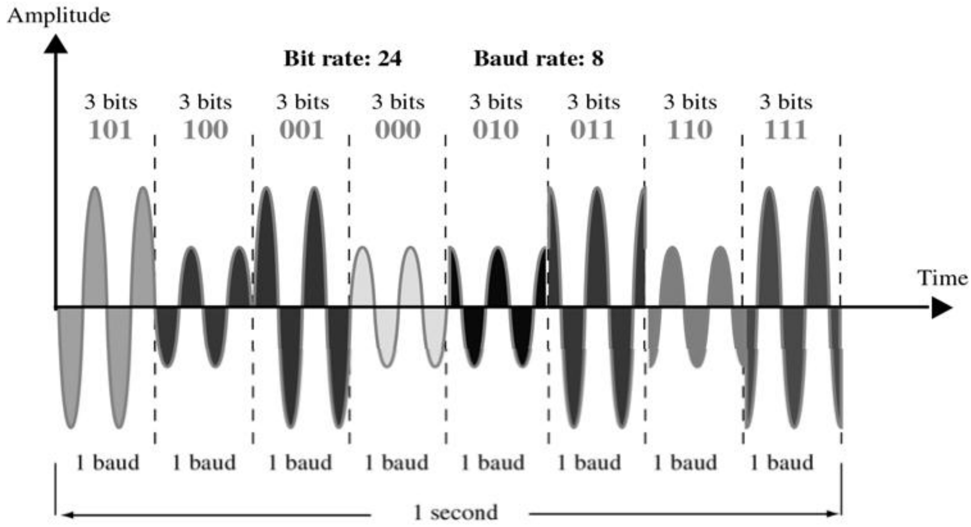
4-QAM
1 amplitude, 4 phases

8-QAM
2 amplitudes, 4 phases

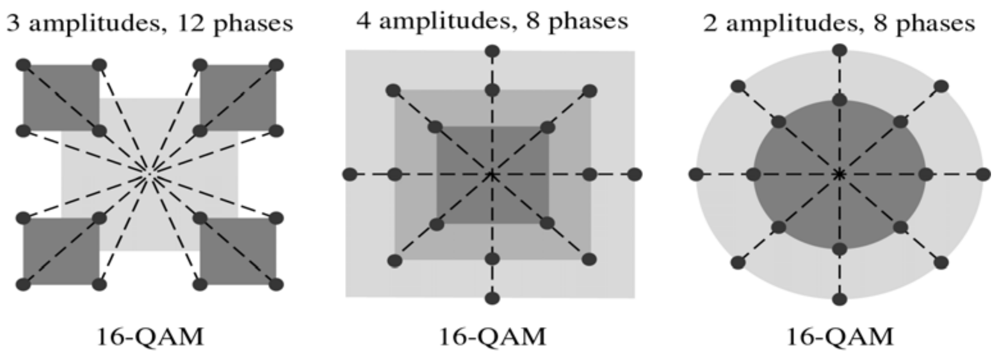
Y **Variation of QAM**
- Variations of QAM are numerous
- Any measurable amount changes in amplitude can be combined with any measurable no. of changes in Phase

Y **4 QAM & 8 QAM (Figure)**
- In both case no. of amplitude shifts is more than the no. of phase shifts
- Because amplitude changes are susceptible to Noise , number of phase shifts used by QAM is always larger than the amplitude shifts

Time domain plot of 8 QAM



Three possible variations of 16 QAM



- **Bandwidth for QAM**
  - BW required for QAM is the same as in the case of ASK and PSK
  - QAM has the same advantages as PSK over ASK
    - Bit Baud Comparison

Bit Baud Comparison

Consult book section 5.3

Example 5.11

A constellation diagram consists of eight equally spaced points on a circle. If bit rate is 4800 bps, what is the Baud Rate?

Solution:

Constellation indicates 8 PSK with the points 45 degree apart
Baud Rate= 4800 / 3 = 1600 baud

Summary

- Digital-to Analog Conversion
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)
- Quadrature Amplitude Modulation (QAM)

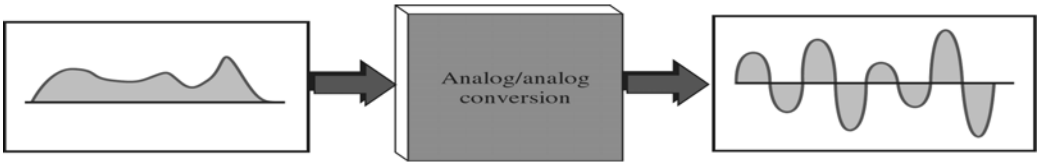
Reading Sections

- Section 5.3, “Data Communications and Networking” 4th Edition by Behrouz A. Forouzan

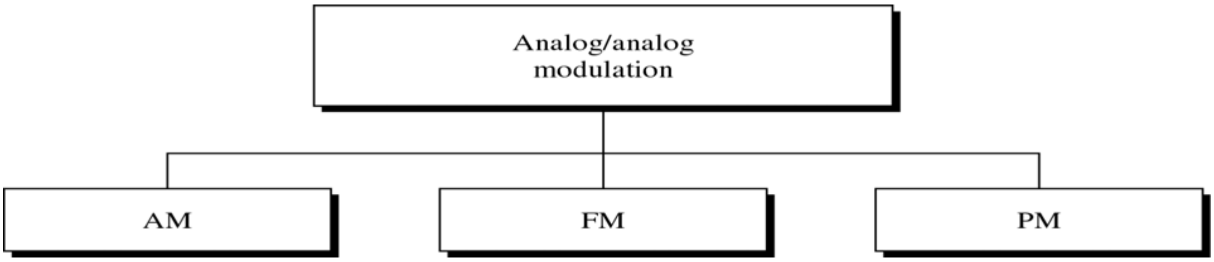
LECTURE #19

Conversions

- **Analog To Analog Conversion**
  - Representation of Analog information by an Analog signal
  - For Example: Radio

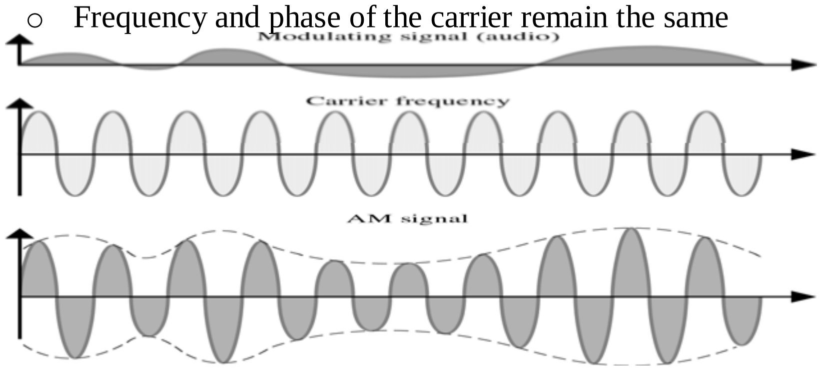


Y **Analog To Analog Conversion Methods**



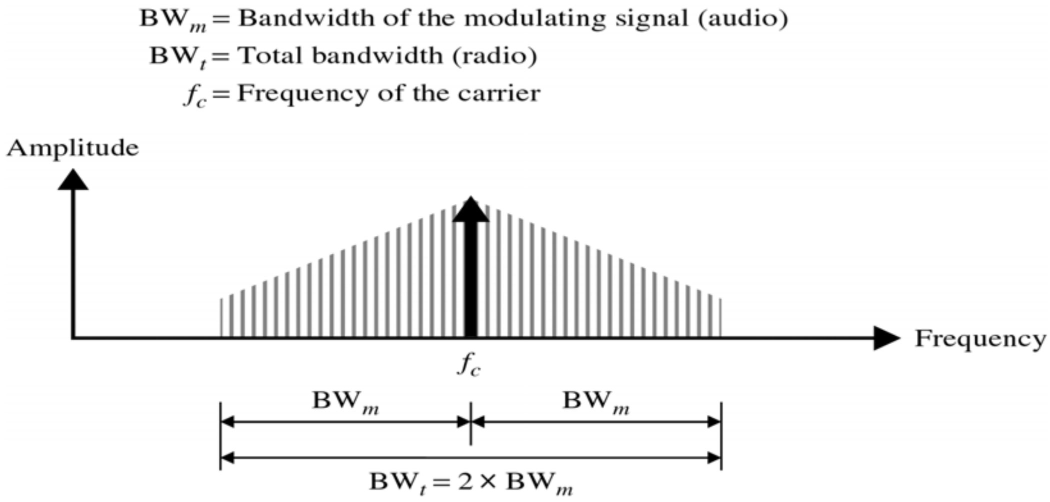
- **Amplitude Modulation (AM)**

  - Amplitude of carrier signal is changed according to the amplitude of modulating signal
  - Frequency and phase of the carrier remain the same

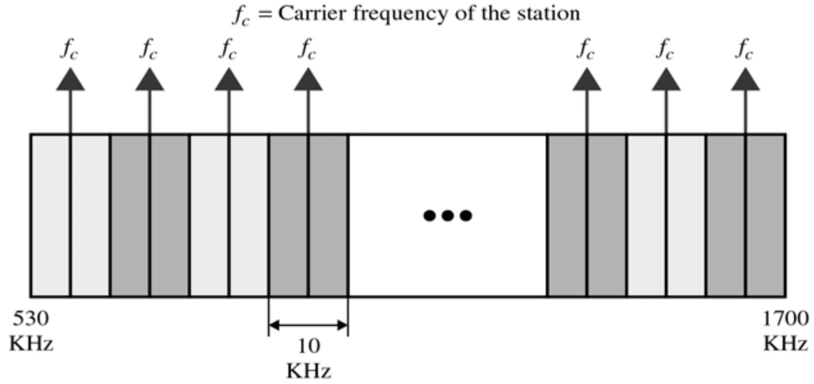


./ **AM Bandwidth**

Bandwidth of AM signal (modulated signal) = 2 * bandwidth of modulating signal
Significant spectrum of AM audio = 5 KHz
⇒ 10 KHz bandwidth for an AM station



<u>**AM Band Allocation**</u>



Example 5.18

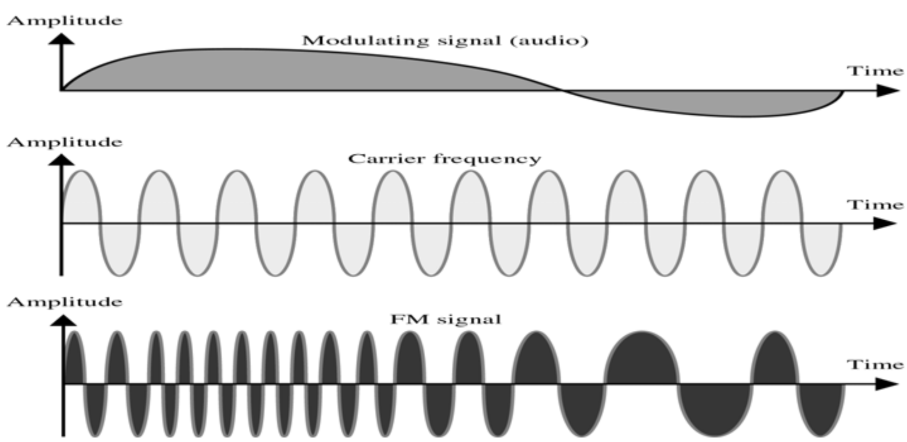
We have an audio signal with a BW of 4 KHz. What is the BW needed, if we modulate the signal using AM?

Solution:

–AM signal requires twice the BW of original signal

–BW = 2 * 4 KHz = 8 KHz

- **Frequency Modulation (FM)**
  - o Frequency of carrier signal is changed according to the amplitude of modulating signal
  - o Amplitude and Phase of the carrier signal remain constant



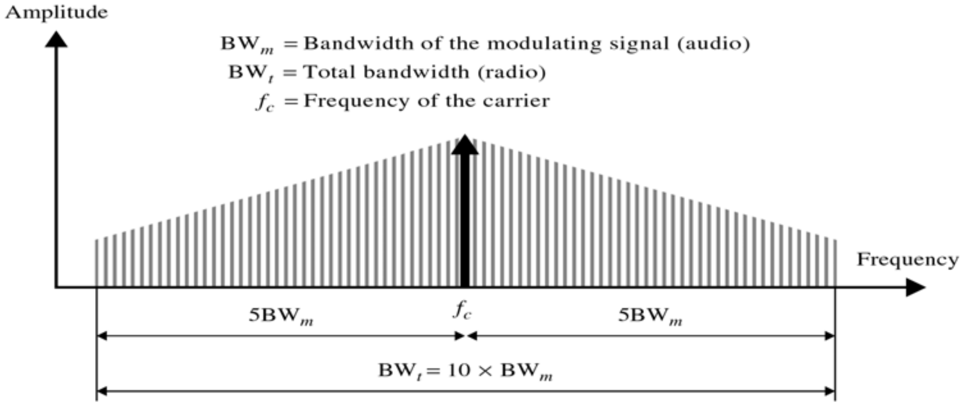
./ **FM Bandwidth**

Bandwidth of FM signal (modulated signal) = 10 * bandwidth of modulating signal

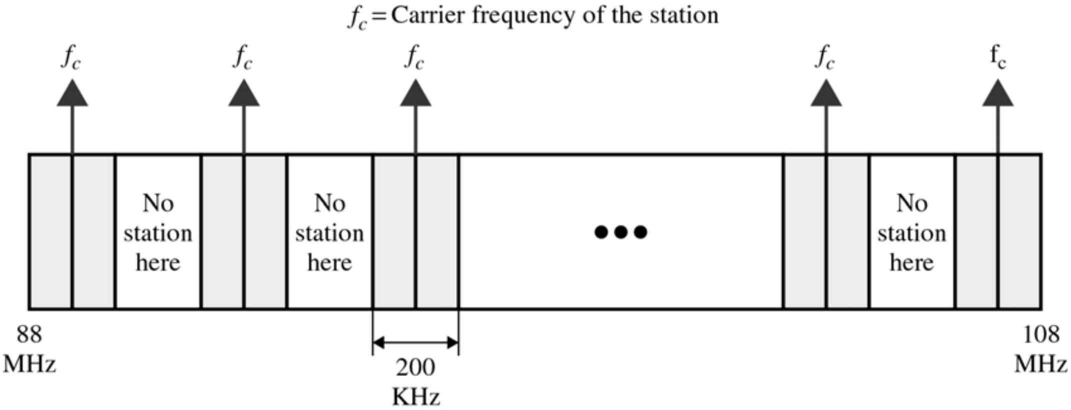
Significant spectrum of FM audio = 15 KHz

⇒ Minimum 150 KHz bandwidth

FM Band



FM Band Allocation



Example 5.19

We have an Audio signal with a BW of 4 MHz. What is the BW needed if we modulate the signal using FM?

Solution:

–BW = 10 * 4 MHz = 40 MHz

- **Phase modulation (PM)**
  - Simpler hardware requirements
  - Phase is modulated with the amplitude
  - Amplitude & Frequency of the carrier signal remain constant

Summary

- Analog-to Analog Conversion
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)
- Quadrature Amplitude Modulation (QAM)

Reading Sections

- Section 5.4, "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

LECTURE #20

Introduction

Q: How do we relay encoded data from the generating device to the next device?

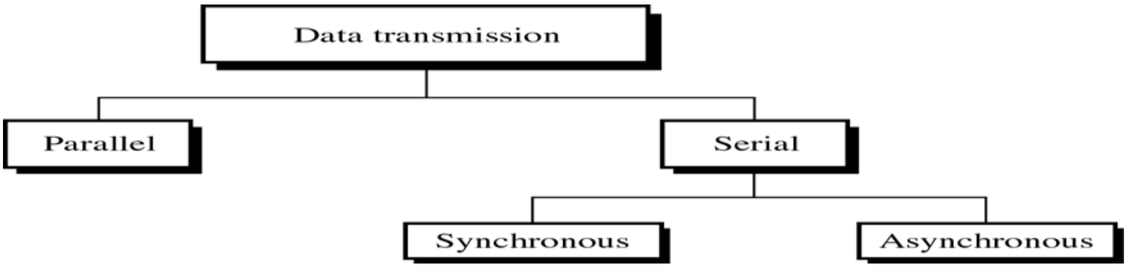
A: Interface

–Defined by several popular standards

–Physical layer of the OSI model

–Mechanical/electrical/functional specifications

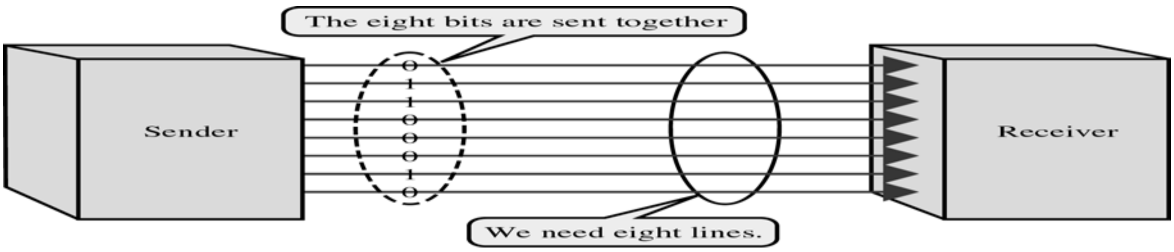
- **Digital Data Transmission**
  Do we send one bit at a time or do we group bits into larger groups and if so, How?



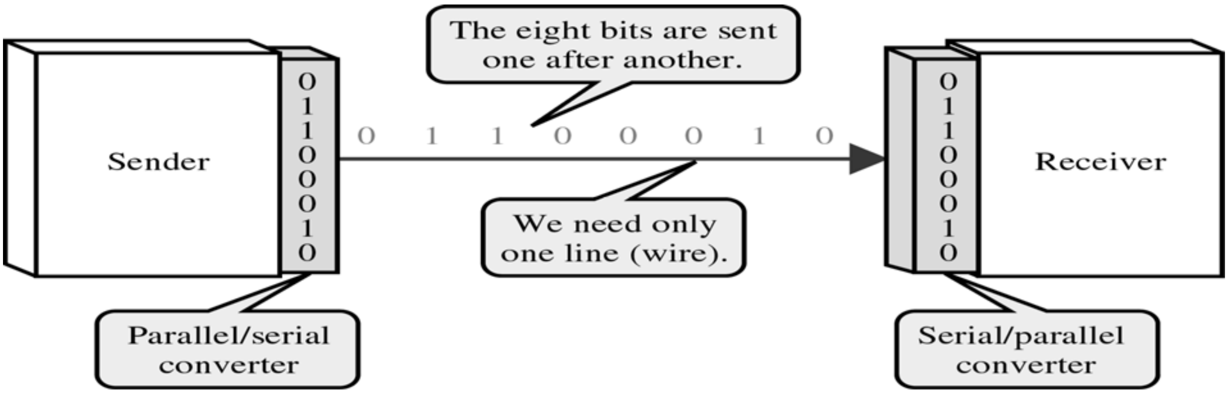
- **Parallel Transmission**

o Binary data consisting of 1s and 0s may be organized into groups of ‘n’ bits each

o By grouping we can send data *‘n’* bits at a time instead of one bit



- **Serial Transmission**
  - o One bit follows another, so we need only one channel rather than ‘n’ to transmit data between two devices
  - o Conversion devices are required at the interface



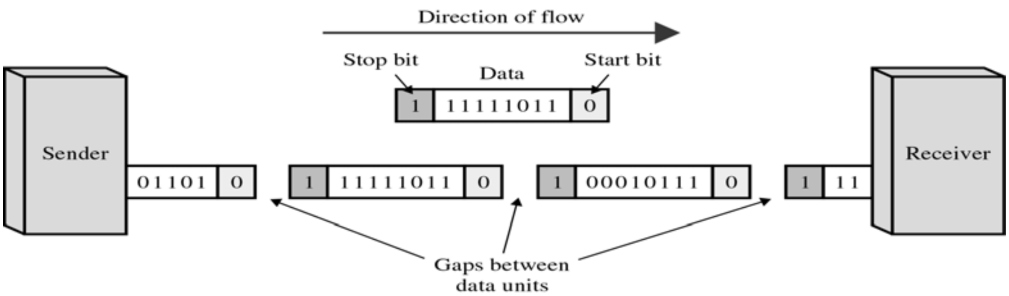
- **Advantage**
  - COST

- **Types of Serial Transmission**
  - There are two types of Serial Transmission:

    - Asychronous Transmission
    - Synchronous Transmission

Asynchronous Transmission

- It is so named because the timing of the signal is unimportant. Instead information is received and translated by agreed upon patterns
- Start and Stop Bits



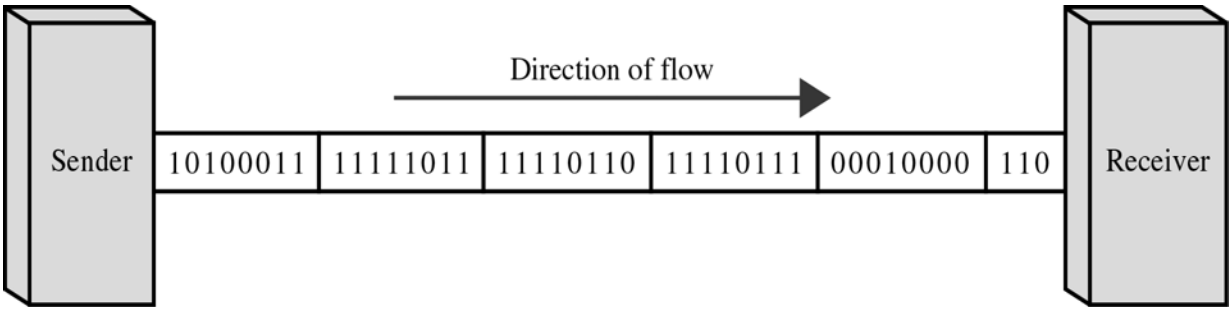
Asynchronous Transmission

- Advantages
  - Cheap
  - Effective

- **Disadvantages**
  - Slow

Synchronous Transmission

- Data is transmitted as an unbroken string of 1's and 0's and the receiver separates that string into the bytes or characters it need to reconstruct the information



Synchronous Transmission

- Advantage
  - Speed

Summary Introduction to Interfaces

- Digital Data Transmission
- Parallel Transmission
- Serial Transmission
- Asynchronous Transmission
- Synchronous Transmission

Reading Sections

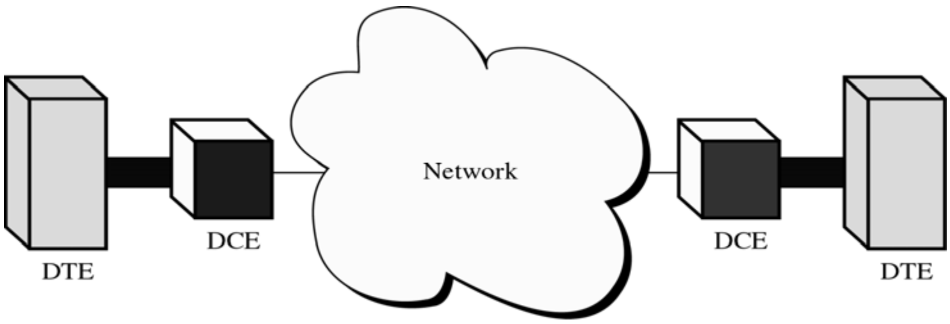
- Section 6.1,6.2, “Data Communications and Networking” 4th Edition by Behrouz A. Forouzan

LECTURE #21

DTE-DCE Interface

- There are 4 basic functional units involved in communication of data:
  –A DTE and DCE on one end
  –A DTE and DCE on the other end

  - **DTE**: Any device that is a source of or destination of digital data
  - **DCE**: Any device that transmits/receives signal through network



- The DTE generates the data and passes it along with any control information to a DCE
- The DCE converts the signal to a format appropriate to the TX medium and introduces it onto the network link
- When the signal arrives at the receiving end this process is reversed

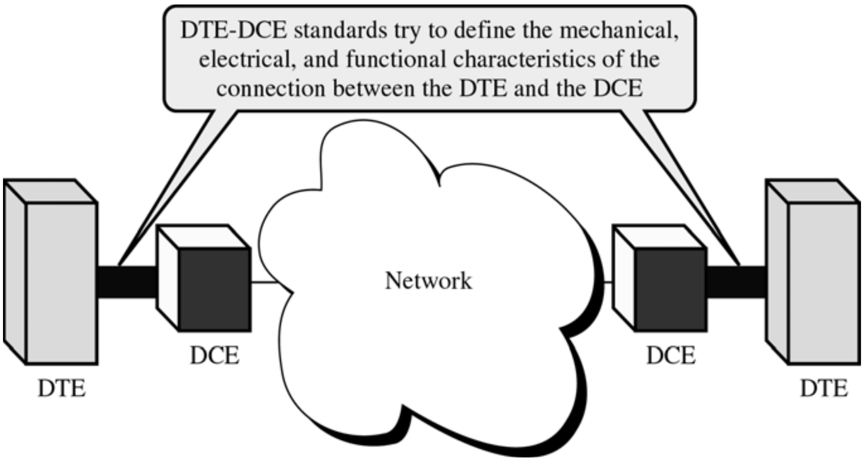
  - **DTE**
    - DTE includes any unit that functions either as a source of or as a destination for binary digital data
    - At the physical layer, it cab a terminal, microcomputer, computer , printer or any other device that generates or consumes digital data
    - DTEs do not often communicate with each other directly with each other
    - Think of DTE as your Brain.
    - Your and your friends brains are DTEs
    - The vocal chords or mouth are DCEs
    - Air is TX Meduium

  - **DCE**
    - DCE includes any functional unit that transmits or receives data in the form of an analog or digital signal through a network
    - At the physical layer, a DCE takes data generated by a DTE, converts it to the appropriate signal and then introduces it to the comm link
    - Commonly used DCEs at the physical layer include MODEMS

- In any n/w , a DTE generates digital data and passes it on to a DCE, the DCE converts the data to a form acceptable to the TX medium and sends the converted signal to another DCE on the network
- The second DCE takes the signal off, converts it to a suitable form for its DTE and delivers it
- To make this communication possible, the sending and receiving DCEs must use the same modulation method

•The two DTEs need not be coordinated with each other but they need to be coordinated with their respective DCEs and the DCEs must be coordinated so that data translation occurs w/o loss of integrity

- **Standards**



Many standards have been developed to define the connection b/w the DTE and a DCE

  - Though the solution differ, each standard provides a model for mechanical, electrical and functional characteristics of the connection
  - Electronic Industries Organization (EIA) and ITU-T

- **EIA 232 Interface**
  - Standard developed by EIA
  - Defines Mechanical, Electrical and Functional characteristics of the interface b/w DTE and a DCE
  - Originally issued in 1962 as the RS 232 standard
  - Revised several times, recent version EIA 232-D
  - Defines not only the type of connectors to be used but also the specific cable and plugs and the functionality of each pin

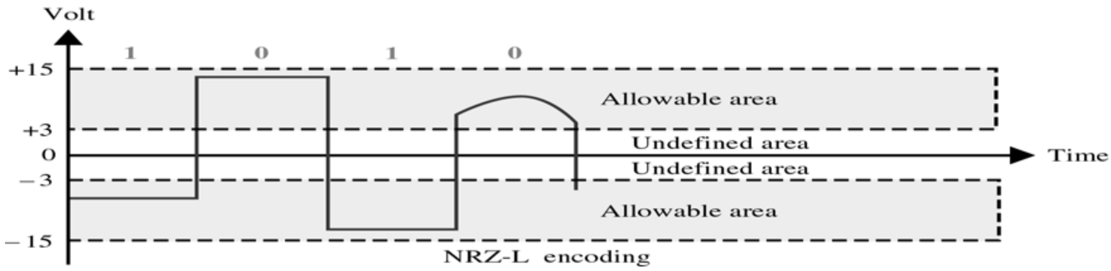
Y **Mechanical Specifications**

  - EIA 232 standard defines interface as a 25-wire cable with a male and a female DB 25 pin connector attached to either end.
  - The length of the cable may not exceed 15 meters(50 feet)
  - A DB 25 connector is a plug with 25 pin or receptacles each of which is attached to a single wire with a specific function
  - With this design, EIA has created the possibility of 25 separate interactions b/w a DTE and a DCE
  - Fewer are actually used but standard allows for future inclusion of functions

- o EIA 232 calls for a 25 wire cable terminated at one end by by a male connector and at the other end by a female connector
- o Male refers to a plug with each wire in the cable attaching to a pin
- o Female refers to a receptacle with each wire in cable connecting to a metal tube or sheath

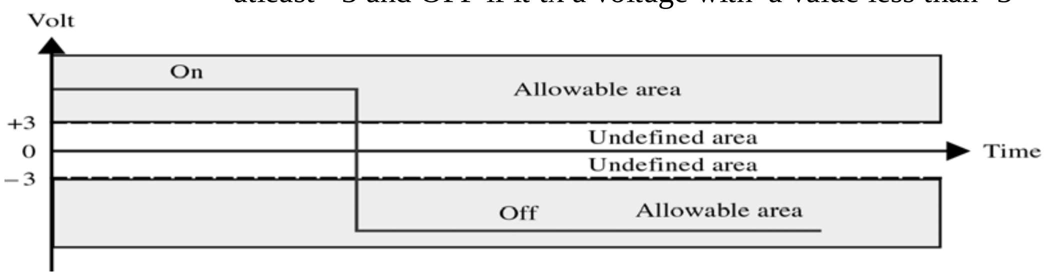
Ÿ **Electrical Specifications (Sending data)**

- o EIA 232 states that data must be tx as binary 1's and 0's using NRZ-L encoding with 0 defines as a positive and 1 defined as a negative voltage
- o However rather than defining a single range bounded by highest and lowest amplitudes, EIA 232 defines two distinct ranges , one for +ve voltages and one for -ve



- o The receiver accepts any voltage that falls within these ranges as valid signals
- o To be recognized as data, the amplitude of the signal must fall b/w 3 and 15 volts or b/w –3 and –15 volts
- o Degradation of noise will in misinterpretation of bits
- o A square wave is shown to be converted into a curve by noise and it covers many voltages
- o If the rx were looking for a fixed voltage, or only for pulses that held a single voltage for their entire duration,degradation would have made it unrecoverable.

  - **Electrical Specifications (Control & Timing)**
  - o Only 4 wires out of 25 in EIA 232 are used for data functions.
  - o Remaining 21 are reserved for functions like Control, Timing, Grounding and Testing
  - o Any of the functions is considered ON if it transmits a voltage of atleast +3 and OFF if it tx a voltage with a value less than -3



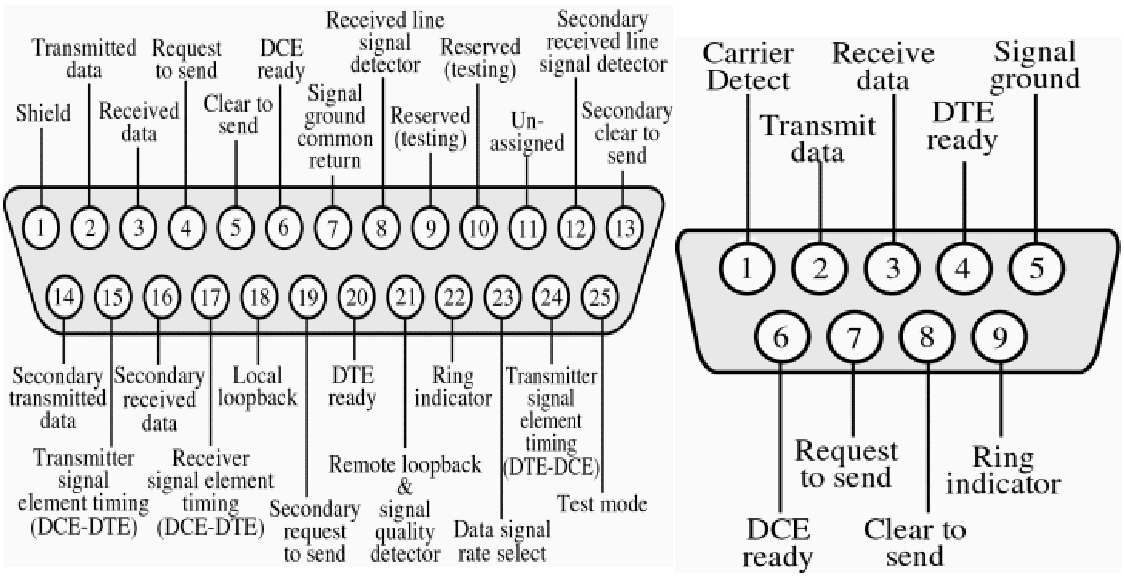
  - o The specification for control signals is conceptually reversed from that for data transmission
  - o A positive voltage means ON and a negative voltage means OFF

- **Electrical Specifications**
  (BIT rate)
  - o A final important function of electrical specifications is definition of Bit Rate
  - o EIA 232 allows for a maximum bit rate of 20Kbps although in practice it is often is exceeded

Y **Functional Specifications**

- o Two different implementations of EIA 232 are available:
  –DB 25
  –DB 9
- o DB 25 connector defines the functions assigned to each of the 25 pins in the DB 25 connector

Functional Specifications



- o Figure shows the ordering and functionality of each pin of a male connector
- o Female connector will be a mirror image of the male so that pin 1 in the plug matches tube 1 in the receptacle and so on
- o Each comm function has a mirror or answering function for traffic in the opposite direction to allow for full duplex operation
- o For Example, pin 2 is for transmitting data and pin 3 is for receiving data
- o Pin 9 and 10 are for future use
- o Pin 11 is yet unassigned

- **<u>DB9 IMPLEMENTATION</u>**
  - o Most of the pins in DB 25 implementation are not necessary ina single asynchronous connection
  - o A simpler 9 pin version of EIA 232 is shown in the figure

Functioning Steps

•Step 1: Preparation

–Preparation of the interface between DTE and DCE

•Step 2: Readiness

–Checks if all four devices are ready

•Step 3: Set up

–Set up the connection between two DCEs

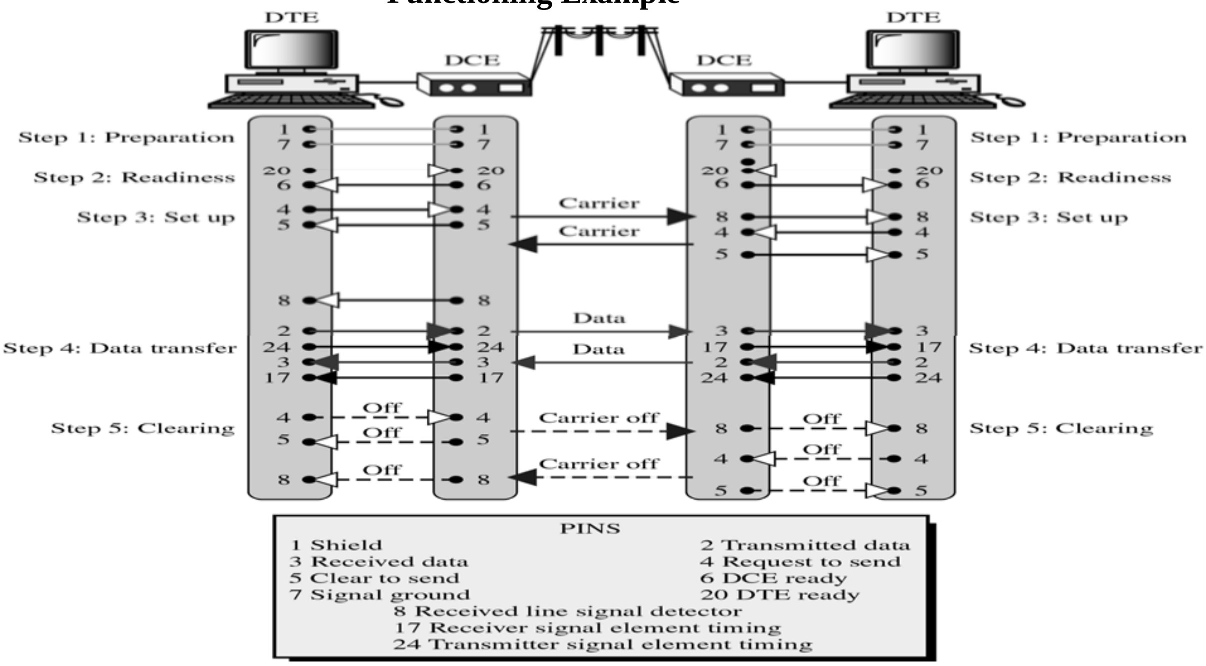
•Step 4: Data Transfer

–DTE -> DCE -> DCE -> DTE

•Step 5: Clearing

–Turning OFF the connection

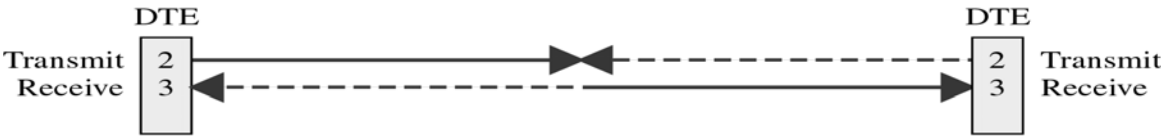
Functioning Example



- Step1: Preparation of interfaces for TX. The two grounding circuits,1(shield) and 7 (ground) are active b/w the two devices
- Step 2 ensures that all four devices are ready for TX. First the sending DTE activates pin 20 and sends a Dte ready message to its DCE . DCE answers by activating pin6 . Same sequence is performed by remote computer
- Step3: sets up the physical connection b/w the sending and the receiving modems.
- First the DTE activates pin 4 and sends its DCE a request to send message. The DCE transmits a carrier signal to the idle receiving modem
- When receiving modem detects the carrier signal, it activates pin 8, telling its computer that a TX is about to begin .
- After tx the carrier signal, sending DCE activates pin 5 sending its DTE a clear to send message. The remote computer and modem do the same step
- Step4: Data transfer procedure
- Initiating computer transfers its data stream to its modem over circuit 2accompanied by the timing pulse of circuit 24.
- Modem converts digital data to an analog signal and sends it over the network
- Responding modem retreives the signal, converts it back to digital and passes it to DTE via circuit 3 and timing pulse of 17
- Step5: Once both computers have completed their transmission, both computers deactivate their request-to-send circuits , modems turn off their carrier signals, their received line signal detectors and their clear to send circuits

- **NULL MODEM**
  - Suppose you need to connect two DTEs in the same building, for example two workstations
  - Modems are not needed to connect two compatible devices directly
  - The TX never needs to cross analog lines, such as telephone lines and therefore does not need to be modulated
  - But you do need an interface to handle the exchanging , just as EIA 232 DTE-DCE cable does
  - The solution is a NULL Modem
  - A null modem provide DTA –DTE interface w/o DCEs
  - But why use a Null Modem
  - If all you need is the interface, why not just a a standard EIA 232 cable?

a. DTEs connected through DCEs

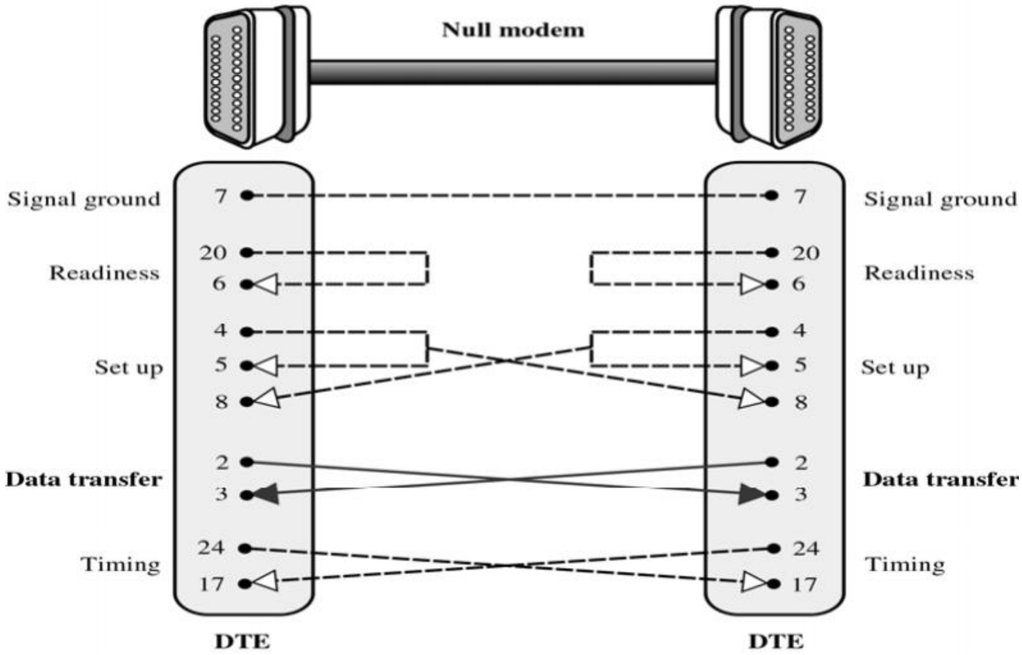


b. DTEs connected directly

  - Part a shows a connection using a telephone network
  - Part b shows what happens when we use the same connections between two DTEs
  - The receive circuit is void because it has been isolated completely for the TX
  - The tx cct 2 endsup full of collision noise

NULL MODEM Crossing Connections

  - Whereas EIA 232 DTE-DCE interface cable has a female connector at the DTE and a male connector at the DCE end, a null modem has female connectors at both ends to allow it to connect to the EIA 232 DTE ports which a male



Summary

- DTE-DCE Interface
- DTE-DCE Interface Standards
- EIA-232
- Null Modem

Reading Sections

Section 6.2,6.3, “Data Communications and Networking” 4th Edition by Behrouz A. Forouzan

LECTURE #22

Other Interface Standards

- o Both Data Rate and Cable LENGTH are restricted by EIA 232
- o Data rate to 20 Kbps and Cable length to 50 feet
- o To meet need of users requiring more speed or distance , the EIA and ITU-T has introduces additional standards: EIA 49, EIA 530 and X.21
  - **EIA 449**
- o Mechanical specifications of EIA 448 define a combination of two connectors , on with 37 pins (DB 37) and one with 9 pins (DB 9) for a combined 46 pins
- o The functional specifications of EIA 449 give the DB 37 pins properties similar to those of the DB 25.
- o The major functional difference b/w 25 and 37 pin connectors is that all functions relating to the secondary channel have been removed from DB 37
- o Because the secondary channel is seldom used, EIA 449 separates those functions out and puts them in the second, 9 pin connector (DB9)
- o In this way, a second channel is available to systems that need it

  Y **EIA 449 (PINS)**
  - o To maintain compatibility with EIA 232, EIA 449 defines two categories of pins to be used in exchanging data, control, and timing information
    - ./ Category 1 pins
    - ./ Category 2 pns
    - ./ **Category 1 and 2 pins**

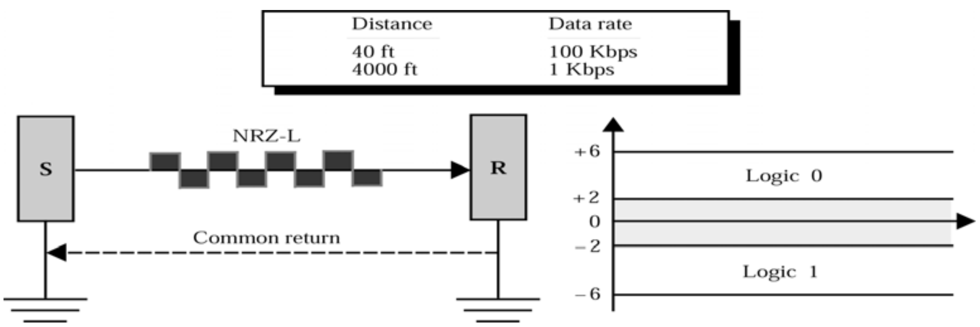
      Category 1 includes those pins whose functions are compatible with EIA 232

      Category 2 pins are those that have no equivalent in EIA 232 or have been redefined

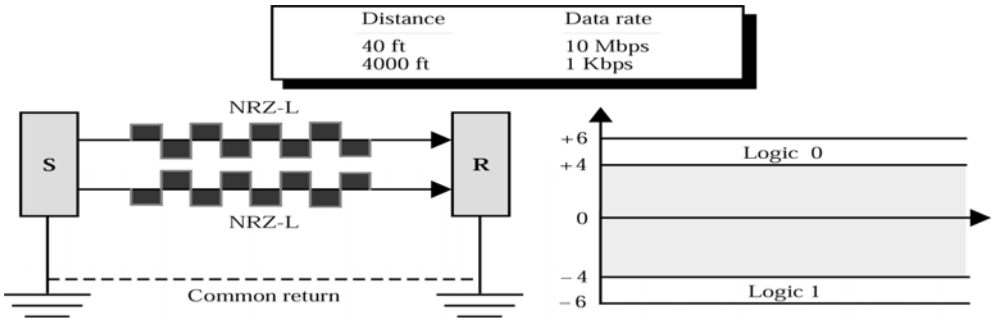
      DB9 connector here is different from the one that is previously discussed

  Y **Electrical Specifications RS423, RS 422**

  EIA 449 uses two standards to define its electrical specifications:
  - RS-423: Unbalanced Mode
  - RS-422: Balanced Mode
  - **RS 423 Unbalanced Mode**
    - o Unbalanced Circuit Specification
    - o Unbalanced means that it defines only one line for propagating a signal
    - o All signals in this standard use a common return or a ground to complete the circuit



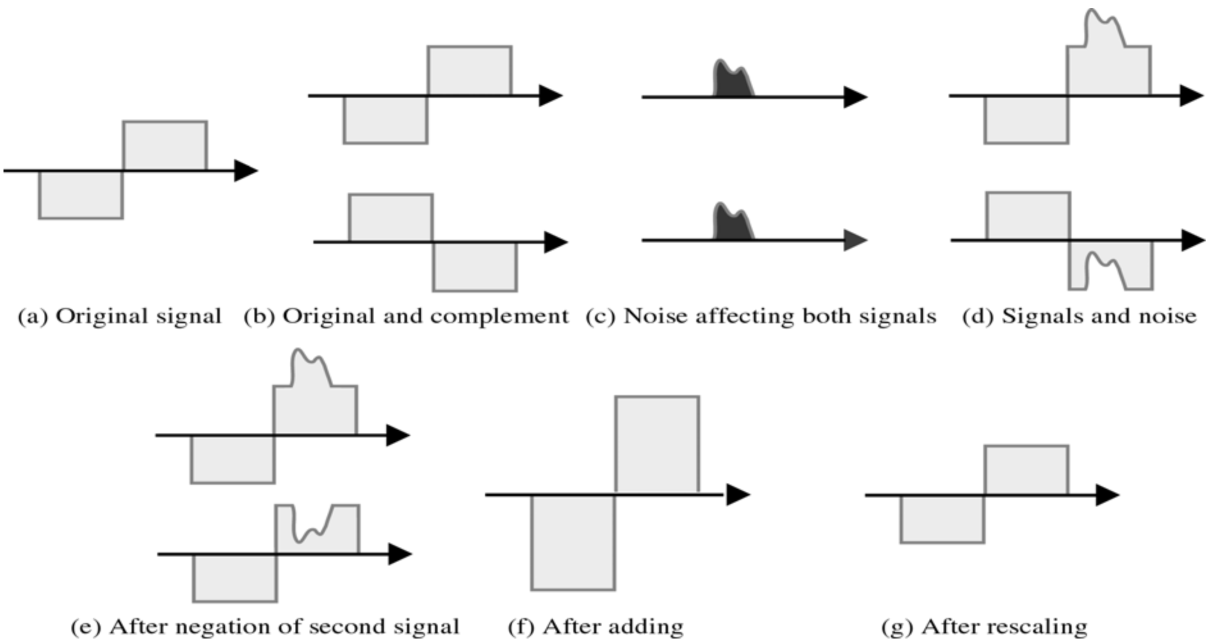
- In unbalanced mode, EIA 449 calls for the use of only the first pin of each pair of category 1 pins and all category 2 pins
- **RS 422 Balanced Mode**
  - Balanced circuit specification
  - Defines two lines for the propagation of each signal
  - Signal again uses a common return



  - EIA utilizes all pairs of pins in category 1 but does not use the category 2 pins
  - The ration of data rate to distance is much higher in this case than EIA 232
  - In balanced mode two lines carry same signal which are not identical to each other
  - Signal on one line is the complement of the other

Canceling of Noise in the Balanced Mode

When plotted, complement of the signal looks like the mirror image of the signal

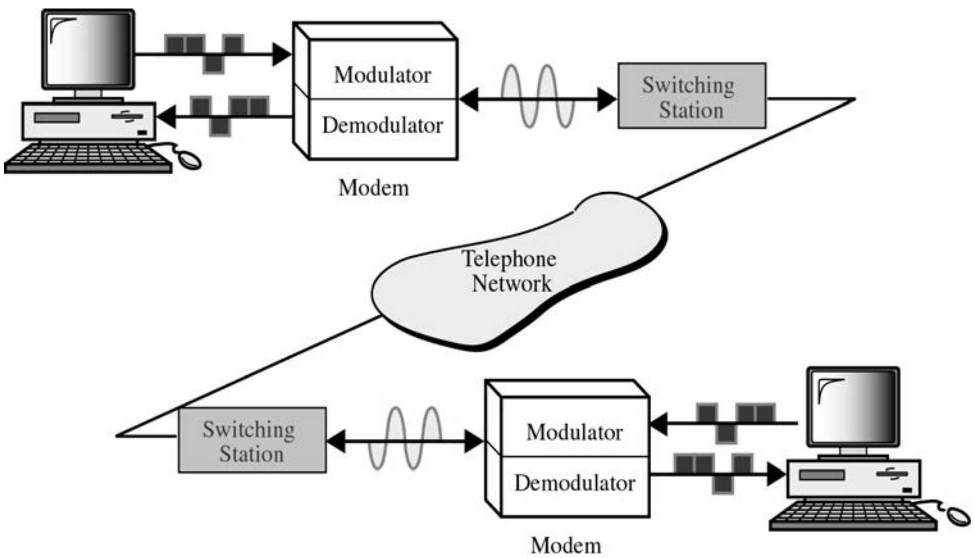


- **EIA 530**

- EIA 449 provides much better functionality than EIA 232
- However it requires a DB 37 connector that industry has been reluctant to use because of the widespread use of DB 25
- To encourage acceptance of EIA 449, EIA developed a version of EIA-449 that uses DB 25 pins
- Pin functions of EIA 530 are essentially those of EIA 449 CATEGORY 1 pins plus three pins from category 2
- EIA 530 does not support a secondary circuit

- **X.21**
- Eliminates most of control pins of EIA standards
  - Control signals are encoded to control characters
  - Send control characters within the data line
  - More control information for digital telephony
- For digital communication between devices over a network, rather than just between DTE and DCE
- DB-15, Work with balanced circuits at 64Kbps

- **MODEMS**
- Most familiar type of a DCE
- We require modem to connect to the internet
- MODEM is a composite word for modulator and Demodulator
- Modulator converts a digital signal into an analog signal using ASK, FSK, PSK or QAM
- A demodulator converts an analog signal into a digital signal
- While a demodulator resembles an analog-to-digital converter, it is not infact a converter of any kind
- It does not sample the signal to create a digital signal
- It just reverses the process of modulation that is it performs demodulation

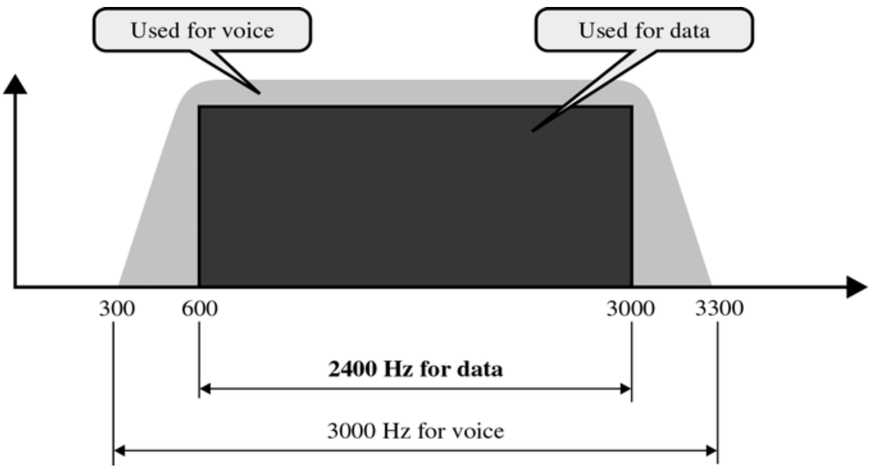


- Shows the relationship of a modulator with a demodulator
- Two PCs at the end are DTEs, and the modems are the DCEs

- DTE creates a digital signal and relays it to the Modem via an interface via an interface
- Modulated signal is received by the demodulation function of the second modem
- This modem takes this ASK, FSK, PSK or QAM signal and decodes it into whatever format its computer can accept
- It then relays the digital signal to the computer via an interface
- Each DCE must be compatible with both its own DTE and the other DCE

- **Transmission Rate**
  - Modems are often described as high speed or low speed to indicate how many bits per second a specific device is capable of transmitting or receiving
  - Limitations on the transmission rate of the Modem
- **Bandwidth**
  - Data rate of a link depends upon the type of encoding uses and the bandwidth of the medium
  - The medium bandwidth is related to the inherent limitation of the physical property of the medium
  - Every line has a range of frequencies it can pass
  - If the frequency of a signal is too ow, it cannot overcome the capacitance of the line
  - If frequency is too high, it can be impeded by the inductance of the line
  - So every line has an upper limit and a lower limit on frequencies of the signals
  - This limited range is called Bandwidth

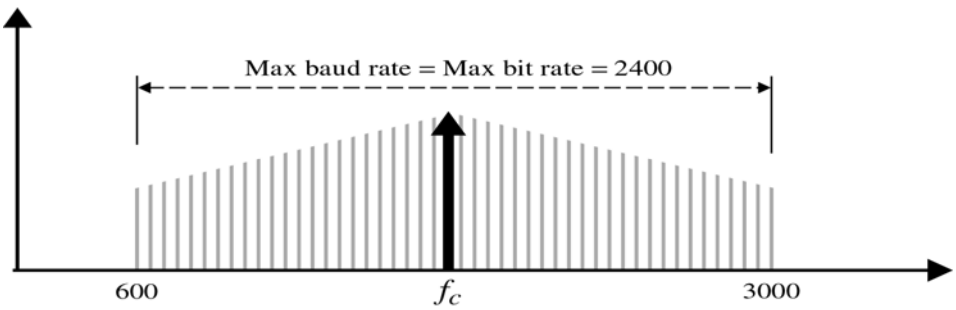
Telephone Line Bandwidth



- Traditional telephone lines can carry fre's b/w 300 Hz and 3300 Hz giving them a BW of 3000Hz
- All of this range is used for transmitting voice where a great deal of interference and distortion can be accepted w/o any loss of intelligibility
- Data signal require a high degree of accuracy , so edges of this range are not used for data comm
- Effective BW of telephone line used for data transmission is 2400 Hz covering a range from 600 Hz to 3000Hz
  - **Modem Speed**
  - Each type of Analog conversion manipulates signal differently:

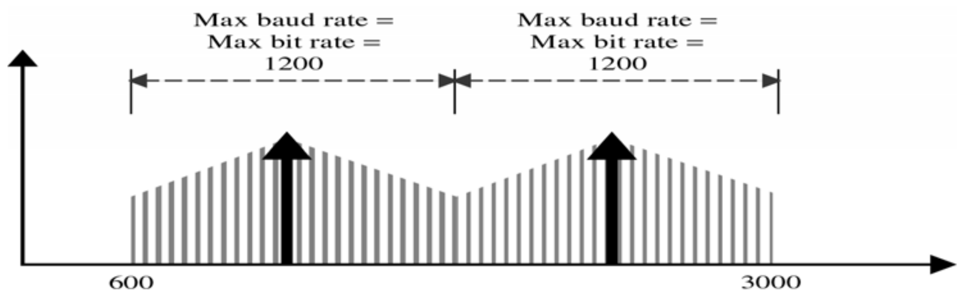
- ASK manipulated Amplitude
- FSK manipulates Frequency
- PSK manipulates Phase
- QAM manipulate both phase and amplitude
- **Modem Speed-ASK**

  - BW required for ASK is equal to the baud rate of the signal
  - Assuming that entire link is being used by one signal, as in Simplex or Half Duplex, the maximum baud rate for ASK modulation is equal to the entire BW of the transmission medium



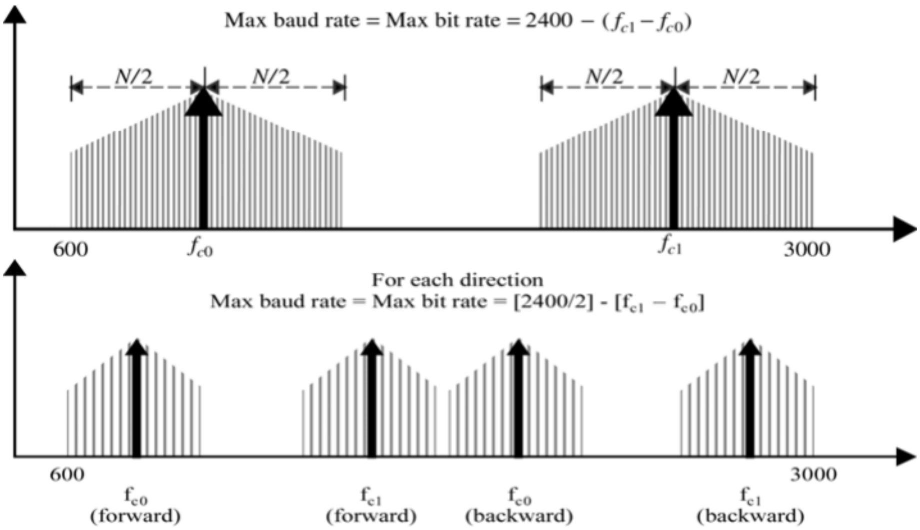
  - Because the effective BW of a telephone line IS 2400 Hz, the maximum baud rate is also 2400
  - Baud rate and bit rate are equal for ASK, so maximum bit rate is also 2400 bps

Modem Speed-ASK (Full Duplex)



- For full duplex TX, only half of the total bandwidth cab be used in either directions
- Therefore the maximum speed for ASK in full duplex mode is 1200 bps
- Noise problem makes it impractical for use in Modems

- **Modem Speed-FSK**
  - BW required for FSK is equal to the baud rate of the signal plus the frequency shift
  - So maximum baud rate becomes equal to the BW transmission medium minus the frequency shift



- Maximum Baud rate is therefore 2400 minus the frequency shift
- And bit rate is also 2400 minus frequency shift
- In full duplex mode it is equal to 1200 minus the frequency shift

- **Modem Speed-PSK & QAM**
  - Minimum BW for PSK or QAM is the same as for ASK but the bit rate can be greater depending upon the number of bits that can be represented by each signal unit
  - **Modem Speed-PSK & QAM on two wire Twisted pair Telephone line**

Comparisons of bit rates: HDX and FDX

2-PSK	2400	1200
4-PSK,4-QAM	4800	2400
8-PSK,8-QAM	7200	3600
16-QAM	9600	4800
32-QAM	12000	6000

Summary

- EIA-449
- EIA-530
- X.21
- Modems

Reading Sections

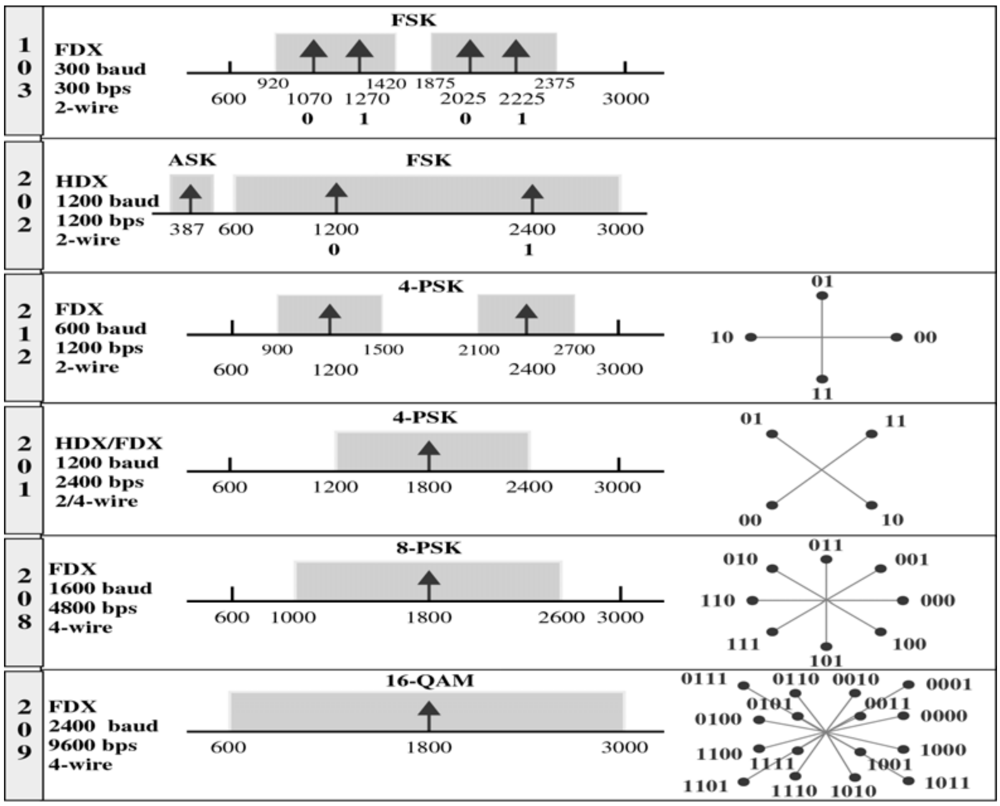
- Section 6.4, 6.5, “Data Communications and Networking” 4th Edition by Behrouz A. Forouzan

LECTURE #23

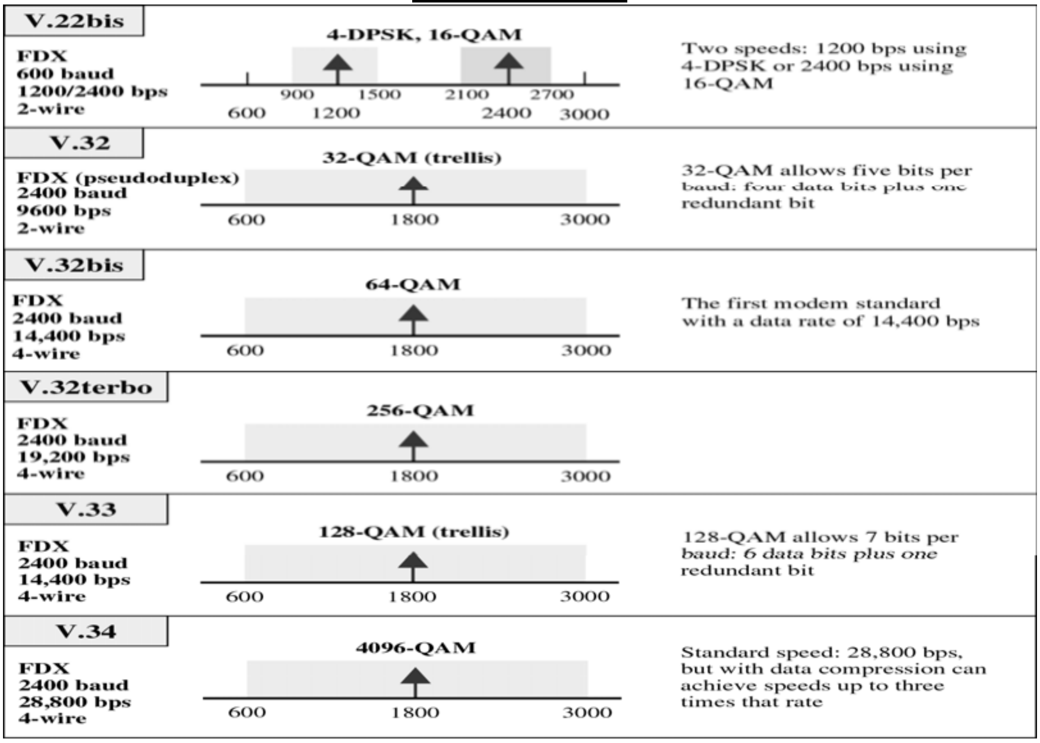
Modem Standards

- Bell modems
  - First commercial modems by Bell Telephone Co.
  - Developed in early 1970s
- ITU-T modem standards
  - V-series: Today's most popular modem standards
  - Bell modem compatible: V.21/22/23/26/27/29
- Intelligent modems
  - Hayes (or Hayes-compatible) modems
  - Modem is controlled by instructions (*AT commands*)
  - Automatic answering, dialing, etc.

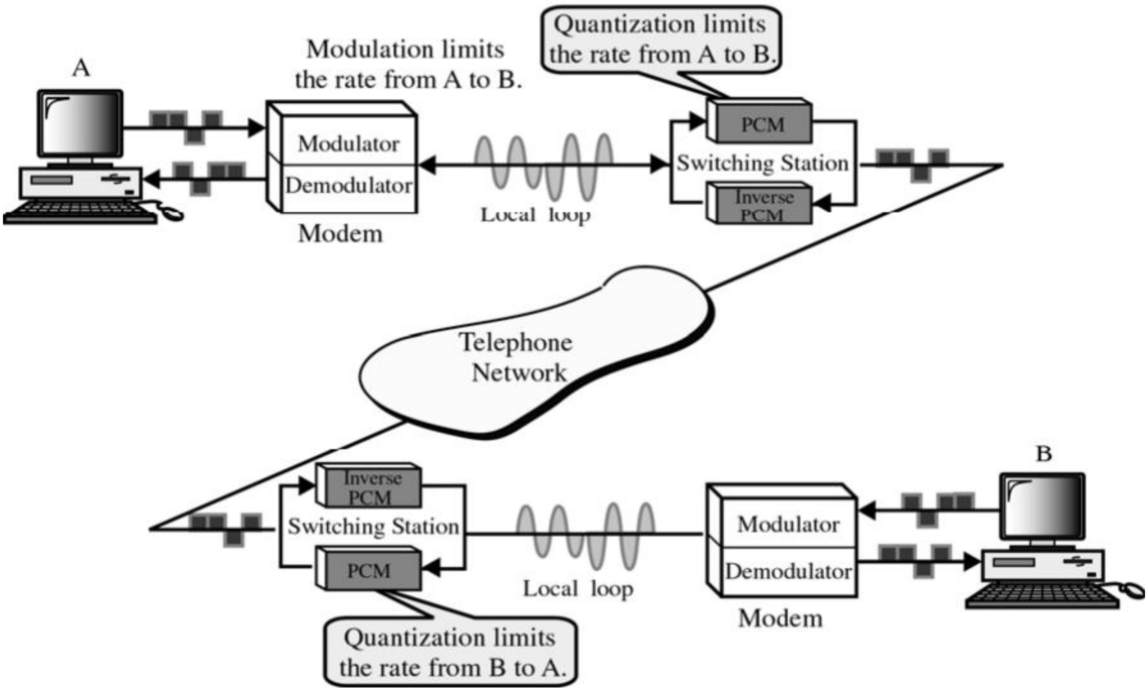
BELL Modems



ITU-T Modems



- **Traditional Modems**
  - Traditional modems are limited to a data rate of 33.6 Kbps as determined by Shannon's formula Data rate $\propto$ Signal-to-noise ratio
  - New modems with bit rated of 56 Kbps are wide spread now



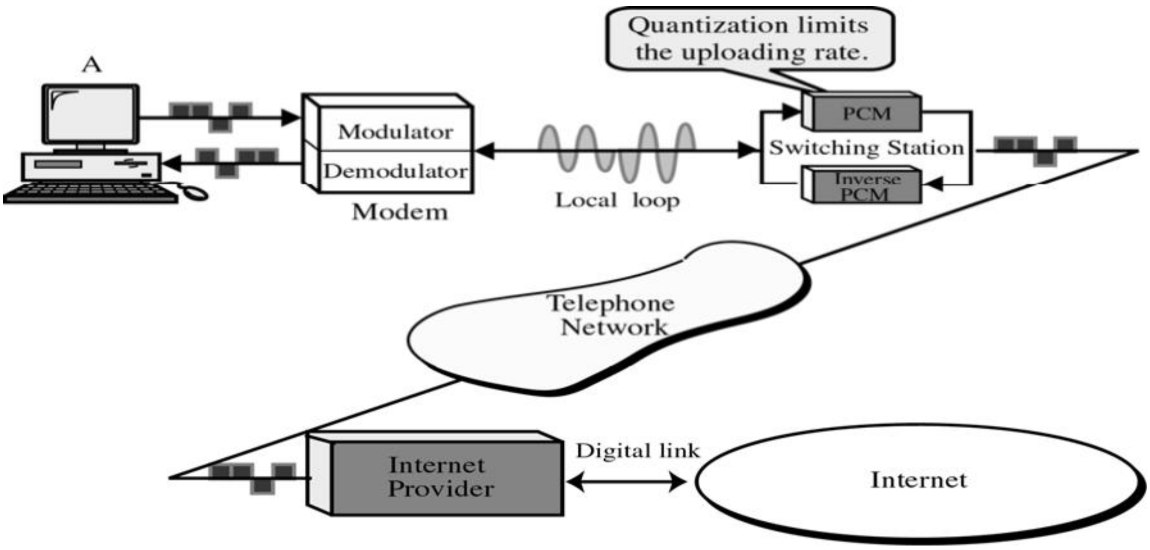
- TX of data from A to B
- Digital data is modulated by the modem at site A
- Analog data is sent from the modem to to the switching station at site A using the local loop

- o At the switching station, analog data is converted digital using PCM
- o Digital data travels through the digital network of telephone company and arrives at the switching station of site B
- o At the switching station , digital data is converted to analog using inverse PCM
- o Analog data is sent from switching station at site B to the modem using the local loop
- o Analog data is demodulated by modem at site B
- o The limiting factor is step 3. Here the analog signal is quantized to create digital signal. The quantization noise resulting from this process limits the data rate to 33.6 Kbps
- o The TX of data from site B to site A follows the same steps and again the limiting factor is quantization.

•RESULT:
The maximum data rate in each direction is limited to 33.6 Kbps

- **56K Modems**

- o If one side is an ISP and the signal does not have to pass through a PCM converter , quantization is eliminated in one direction and data rate can be increased to 56 Kbps



Y **Uploading**

- o Transmission of data from the subscriber to the ISP(UPLOADING) follows the following steps:
- o Digital data is modulated by Modem at site A
- o Analog data is sent from the modem to the switching station at site A on the local loop
- o At the switching station, data is converted to digital signal using PCM
- o Digital data travel through the digital network of the telephone network of the telephone company and is received by the ISP computer
- o The limiting factor is again step 3
- o However user does not need high data rate since in this direction only small blocks of data is sent

Y **DOWNLOADING**

- Tx of data from ISP to the modem at site A follows these steps:
- Digital data is sent by the computer of ISP through the digital telephone network
- At the switching station, digital data is converted to analog using inverse PCM
- Analog data is sent from the switching station at site A to the modem on the local loop
- Analog data is demodulated by modem at site A
- Note that in this direction there is no quantization of data using PCM.
- The limitation when uploading is not an issue an here a
- Data can be sent at 56 Kbps
- This is what user is looking for since larger files are typically downloaded from internet

  - **RESULT**

    The maximum data rate in the uploading direction is still 33.6 Kbps but the data rate in downloading direction is now 56 Kbps

- Why 56Kbps?
  - Switching stations of the telephone company use PCM/Inverse PCM for digitizing voice
  - 8000 samples/sec * 7 bits/sample = 56 Kbps

Summary

- MODEM Standards
  - Bell Modems
  - ITU-T Modems
- Traditional MODEMS
- 56k MODEMs
- Cable Modems

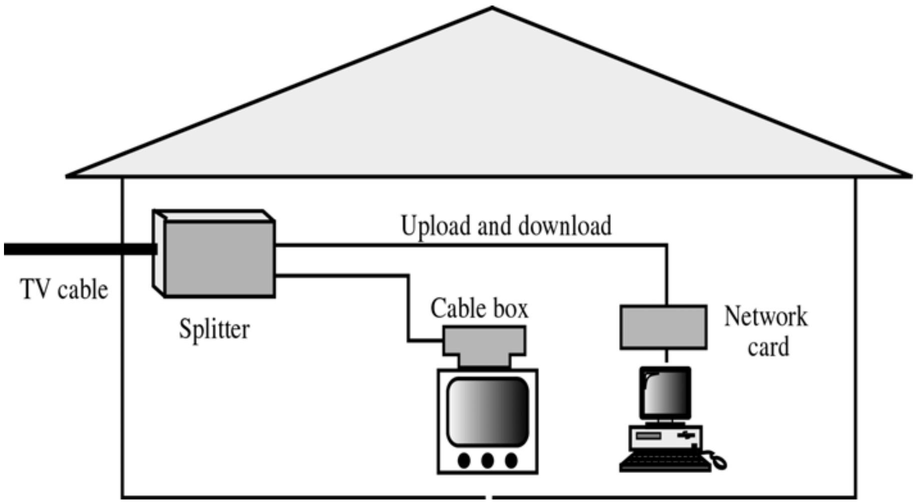
Reading Sections

- Section 6.4, 6.5, 6.6,"Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

LECTURE #24

Cable Modems

- Data rate limitation of traditional modems is mostly due to the narrow BW of the local loop telephone line (4Khz)
- If higher BWs are available, one can design a modem that can handle much higher data rates
- Fortunately, cable TV provides residential premises with a coaxial cable that has a BW of up to 750 MHz and sometimes even more
- This BW is normally divided into 6MHz bands using FDM
- Each band provides a TV Channel
- Two bands can be left aside to allow a user to download and upload the information from the internet

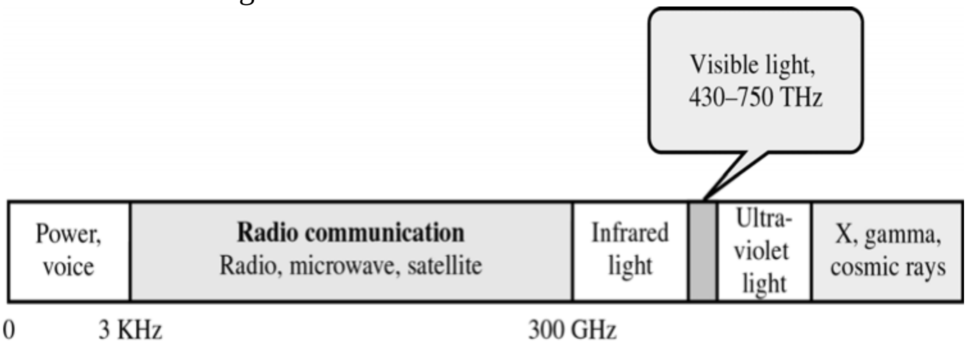


- Instead of the traditional cable box, we show a splitter
- The splitter directs the TV bands to the TV set and the Internet access bands to the PC

- **DOWNLOADING:** Downloading requires a 6 MHz BW in the range above 40MHz. The demodulation technique used is 64 QAM (6 bits at a time)
  - This means that a user can download info at a rate of 6MHz * 6 = 36Mbps
  - However PCs are not yet capable of receiving data at this rate
    - ./ Currently rate is b/w 3 and 10 Mbps
- **UPLOADING:** Requires a 6MHz BW in a range below 40MHz
  - At this low frequency, home appliances can create a noise environment that effects modulation
  - The modulation technique uses is QPSK (4 bits at a time)
  - This means that user can Upload info at a rate of 6 MHz * 2=12 MHz
  - Presently uploading rate is b/w 500Kbps and 1Mbps

Electromagnetic Energy

- Signals are transmitted from one device to another in the form of electromagnetic energy
- Electromagnetic signals can travel through Vacuum, Air or other transmission media
- Electromagnetic energy, a combination of electrical and mechanical fields vibrating in relation to each other includes power, voice, video, radio waves, infrared light, visible light and ultra violet light

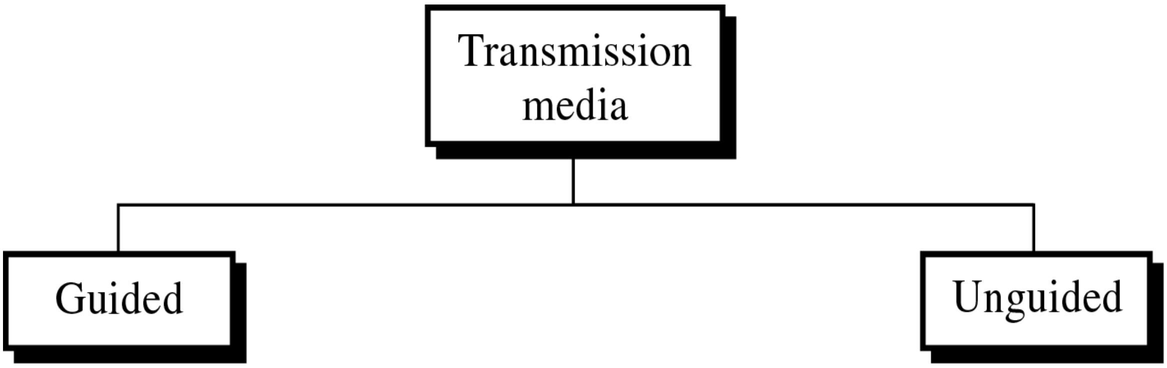


- Each of the above constitute a portion of the Electromagnetic Spectrum:

  - Not all the portions of the spectrum are currently usable for Telecommunications
  - Voice-band frequencies are generally tx as current over metal cables, such a twisted pair or coaxial cable

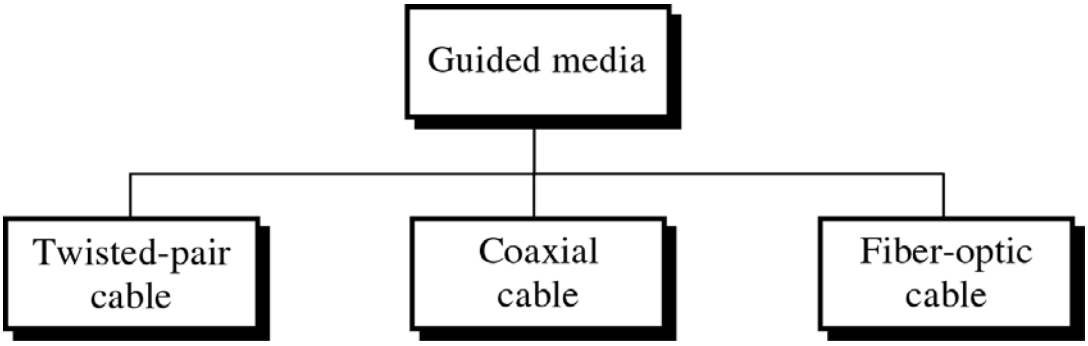
- Radio frequencies can travel through air or space but require specific transmitting and receiving mechanisms
- Visible light, the third type of Electromagnetic energy currently used for communications is harnessed using fiber optic cable

  - **Classes of Transmission Media**



  - Two classes of Transmission Media:
    - –Guided Media
    - –Unguided Media
    - Ɣ **Guided Media**

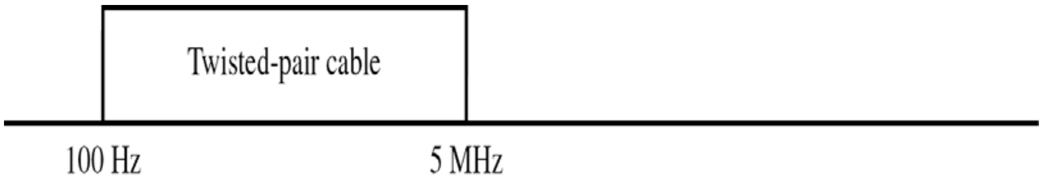
    Guided Media, are those media that provide a conduit from one device to another



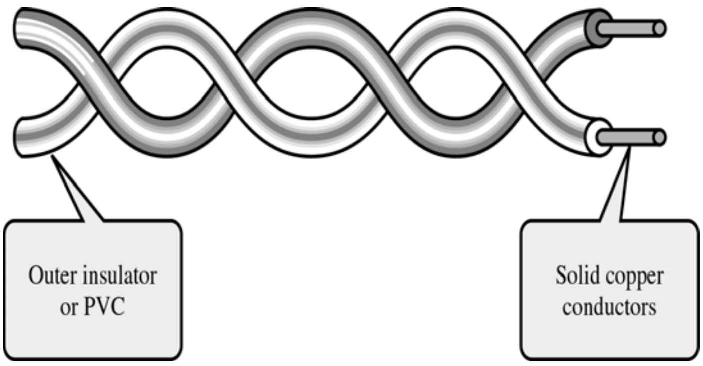
- **Twisted Pair Cable**
  - Twisted pair comes in two forms:

    –Unshielded Twisted Pair (UTP) cable
    –Shielded Twisted Pair (STP) cable

- **Frequency range for Twisted Pair Cable**



- **Unshielded Twisted Pair (UTP) Cable**
  - UTP cable is the most common type of Telecommunication Medium in use today
  - Although mostly used in Telephone systems,, its frequency range is suitable for transmitting both data and voice



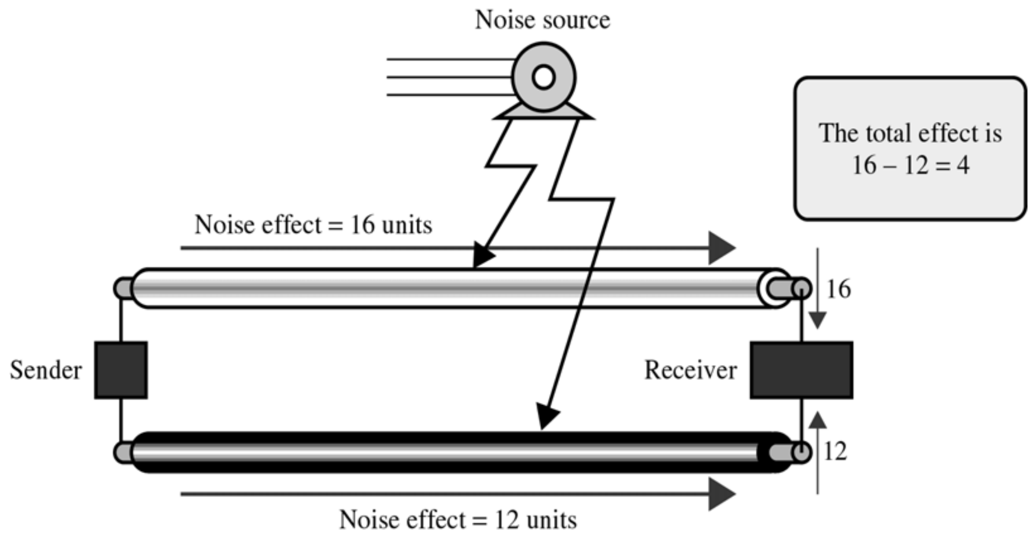
  - A twisted pair consists of two conductors (usually copper) , each with its own colored plastic insulation.
  - The plastic insulation is color banded for identification

- Colors are used both to identify the specific conductors in a cable and to indicate which wires belong in pairs and how they relate to other pairs in a large bundle

Parallel Flat Wire

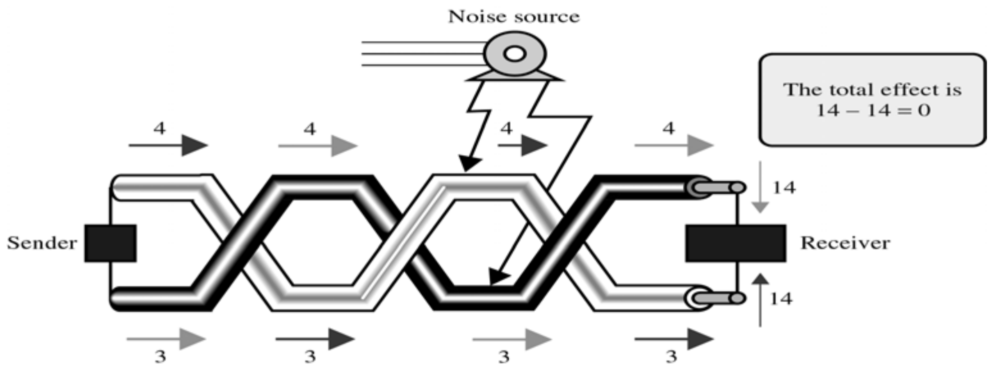
- In the past, two parallel flat wires were used for communication.
- However, EM interference from devices such as motor can create noise over those wires

- **Effect of noise on Parallel Flat Wire**



- If the two wires are parallel, the wire closest to the source of the noise gets more interference and ends up with a higher voltage level than the wire further away
- This results in an uneven load and a damaged signal

- **Noise Effect on Twisted-Pair**
  - If the two wires are twisted around each other at regular intervals (b/w 2 & 12 twists per foot), each wire is closer to the noise source for half the time and is away for the other half
  - Twisting does not always eliminate the impact of Noise but it does significantly reduce it

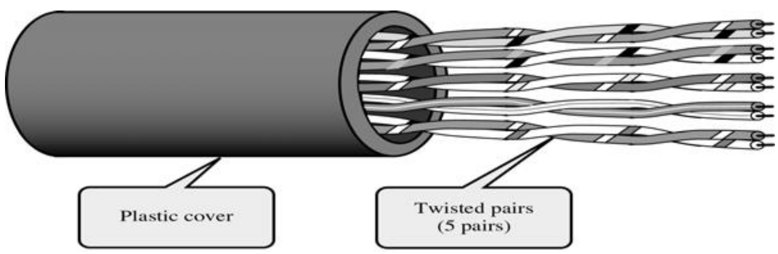


- o With twisting, therefore the cumulative effect of the interference is equal on both wires
- o Each section of wire has a “Load” of 4 when it is on the top of the twist and ‘3’ when it is on the bottom
- o The total effect of the noise at the receiver is therefore 0 (14-14)

- **Advantage of UTP**

  - Advantages of UTP are:
    - –Cost
    - –Ease of Use
  - Its cheap, flexible and easy to install
  - Higher grades of UTP are used in many LAN technologies including Ethernet and Token Ring

Cable with 5 UTP of wires



- **Categories of UTP Cable**
  EIA has developed standards to grade UTP cables by quality.
  Categories are determined by cable quality, with 1 as the lowest and 5 as the highest
  Each EIA category is suitable for certain uses and not for others

  •**Category 1**
  - –Basic Twisted pair cabling used in Telephone system
  - –Fine for voice but inadequate for all but low-speed data communication

  •**Category 2**

–The next higher grade, suitable for voice and for data transmission of up to 4Mbps

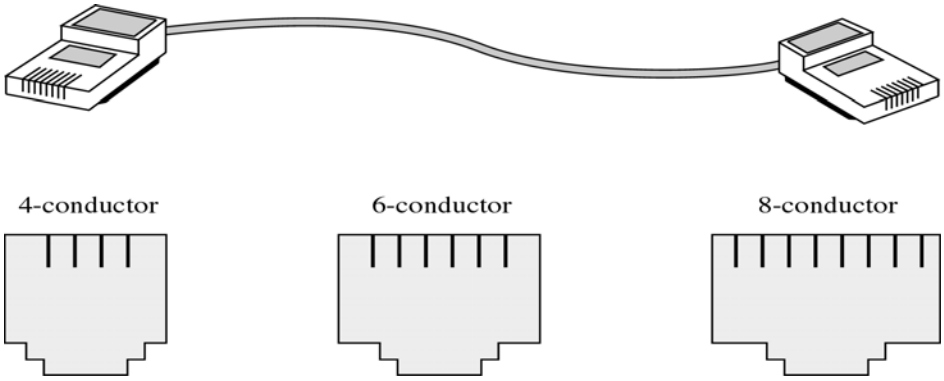
- **Category 3**
  - –Required to have at least 3 twists per foot
  - –Can be used for for data tx ofup to 10Mbps
  - –Now the standard cable for most telephone lines
- **Category 4**
  - –Must have at least 3 twists per foot
  - –Possible tx rate of 16 Mbps
- **Category 5**
  - –Used for data transmission of up to 100 Mbps

- **UTP Connectors**

o UTP is mostly connected to the networked devices via a type of snap-in plug like that used with telephone jacks

o Connectors are either male (plug) or female (the receptacle)

o Male connectors snap into female connectors and have a repressible tab (key) that locks them in place



o Each wire in the cable is attached to one conductor (or pin) in the connector

o The most frequently used of these plugs is an RJ 45 connector with 8 conductors, one for each wire of 4 twisted pairs

Summary

- Cable Modems
- Electromagnetic Spectrum
- Transmission Media and its Types
- Guided Media
- Twisted Pair
- Coaxial Cable
- Optical Fiber

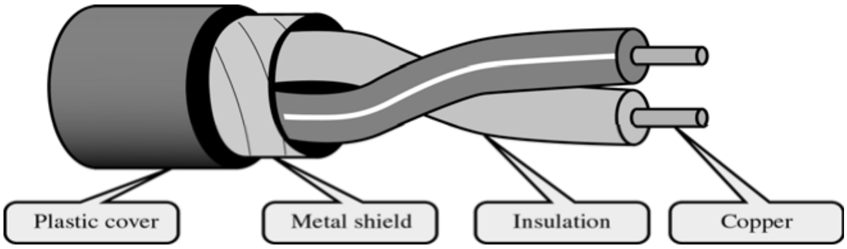
Reading Sections

- Section 6.6, 7.1, "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

LECTURE #25

Shielded Twisted Pair (STP)

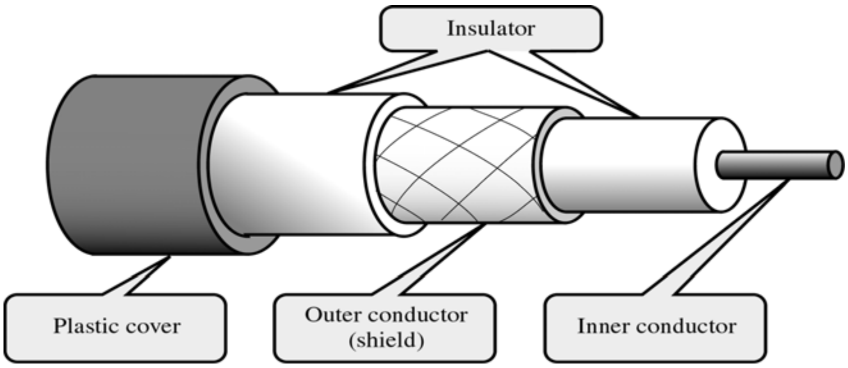
- Has a metal foil or braided-mesh covering that encases each pair of insulated conductors



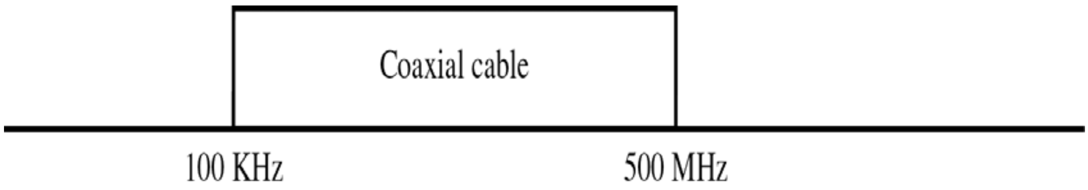
- The metal casing prevents the penetration of EM noise
- It also can eliminate a phenomenon called Crosstalk, which is the undesired effect of one circuit (or channel) on another circuit (or channel)
- It occurs when one one line picks up some of the signals traveling down another line.
- This effect can be experienced during telephone conversations when one can hear other conversations in the background
- Shielding each pair of twisted pair can eliminate most crosstalk
- STP Cable has the same quality considerations and uses the same connectors as UTP but the shield must be connected to a ground
- STP is more expensive than UTP but is less susceptible to noise

Coaxial Cable

- Instead of having two wires, coaxial cable has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath
- This is in turn encased in an outer conductor of metal foil, braid or a combination of the two
- The outer metallic wrapping serves both as a shield against Noise and as the second conductor which completes the circuit
- This outer conductor is also enclosed in an insulating sheath and the whole cable is protected by a plastic cover



- **Frequency Range of Coaxial Cable**
  Coax carries signals signals of higher frequency ranges than twisted pair cable



Y **Coaxial Cable Standards**

Different coaxial cable designs are categorized by their Radio government (RG) ratings

Each RG number denotes a unique set of physical specifications, including

- –the wire gauge of inner conductor
- – the thickness and type of inner insulator
- –Construction of the shield
- –Size and type of outer casing

Each cable defined by RG rating is adapted for a specialized function:

- •RG-8
  - –Used in Thick Ethernet
- •RG-9
  - –Used in Thick Ethernet
- •RG-11
  - –Used in Thick Ethernet
- •RG-58
  - –Used in Thin Ethernet
- •RG-59
  - –Used for TV

Y **Coaxial Cable Connectors**

- o Over the years, a no. of connectors have been designed for use with coaxial cable
- o Most common of the connectors is called “BARREL connector” because of its shape
- o Of the barrel connectors, the most popular is the Bayonet Network Connector (BNC)
- o BNC connector pushes on and locks into place with half turn
- o Other types of barrel connectors either screw together and so require more effort to install or push on w/o locking which is less secure
- o Coaxial cables are familiar in Cable TV and VCR hookups that employ both threaded and alip on style
- o Two other commonly used connectors are **T-connectors and Terminators**

•A **T-connector** (used in Thin Ethernet) allows a secondary cable or cables to branch off from a main line

•**Terminators** are required for bus topologies where one main cable acts as a backbone with branches to several devices but does not itself terminate in a device

If main cable is left un terminated, any signal tx over the line echoes back and interferes with the original signal

A terminated absorbs the wave at the end and eliminates this echo

- **Optical Fiber**
  - Until this point we have discussed conductive (metal) cables that transmit signals in the form of current
  - Optical fiber is made of glass or plastic
  - It transmits signals in the form of light

- **The Nature of Light**

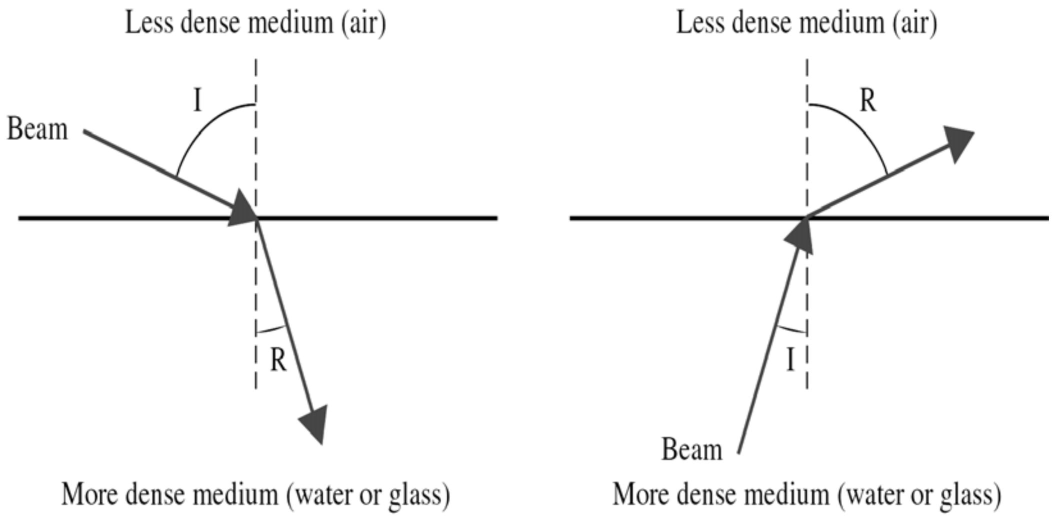
  The speed of light
  - –300,000 Km/sec in a vacuum
  - –Depends on the density of the medium through which it is traveling
  - –The higher the density, the slower the speed

- **Refraction**
  - Light travels in a straight line as long as it is moving through a single uniform structure
  - If a ray of light traveling through one substance enters another (more or less dense) substance, its speed changes abruptly causing the ray to change direction
  - This phenomenon is called Refraction

- **Example of Refraction**
  - A pencil sticking out of a glass of water appears bent because the light by which we see it changes direction as it moves from air to water

- **Direction of Refraction**

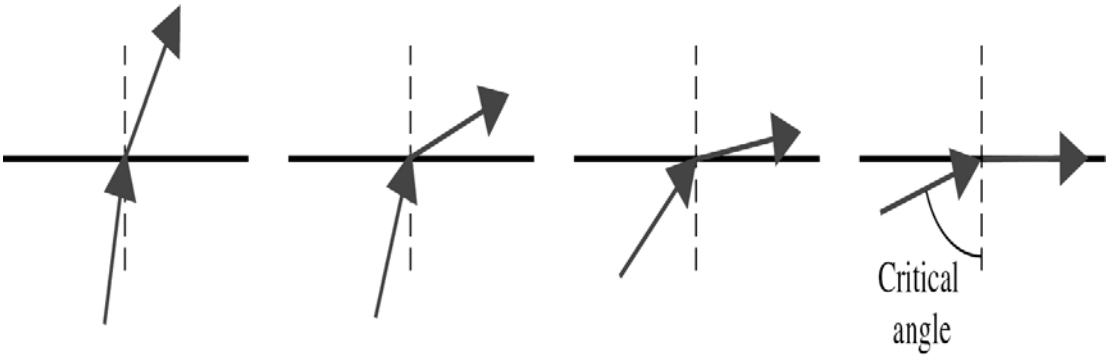
  Direction in which a light is refracted depends upon the density of a medium



a. From less dense to more dense medium b. From more dense to less dense medium

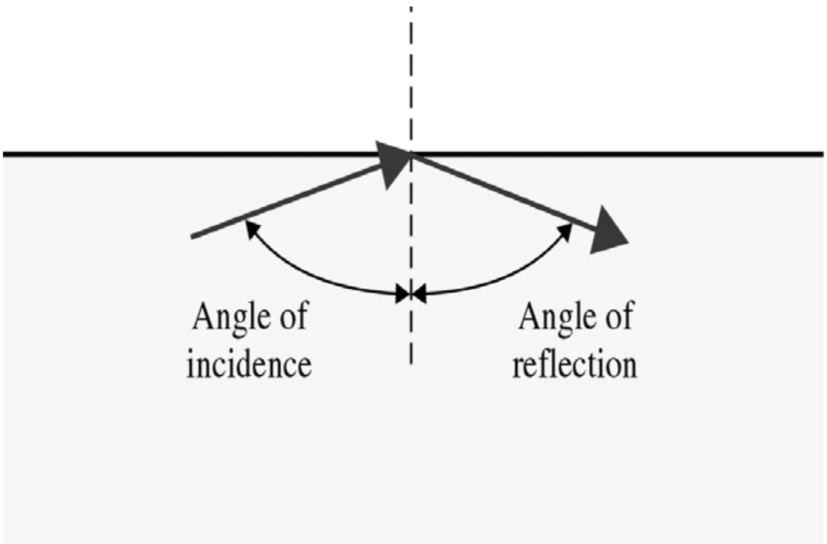
- A beam of light moves from a less dense into a more dense medium bend towards vertical axis
- Incident angle is 'I' and Refracted angle is 'R'

- **Critical Angle**



  - We have a beam of light moving from a more dense to a less dense medium
  - We gradually increase the angle of incidence measured from vertical axis
  - As angle of incidence increases, so does the angle of refraction
  - The angle at which refracted line lies on the horizontal axis is called

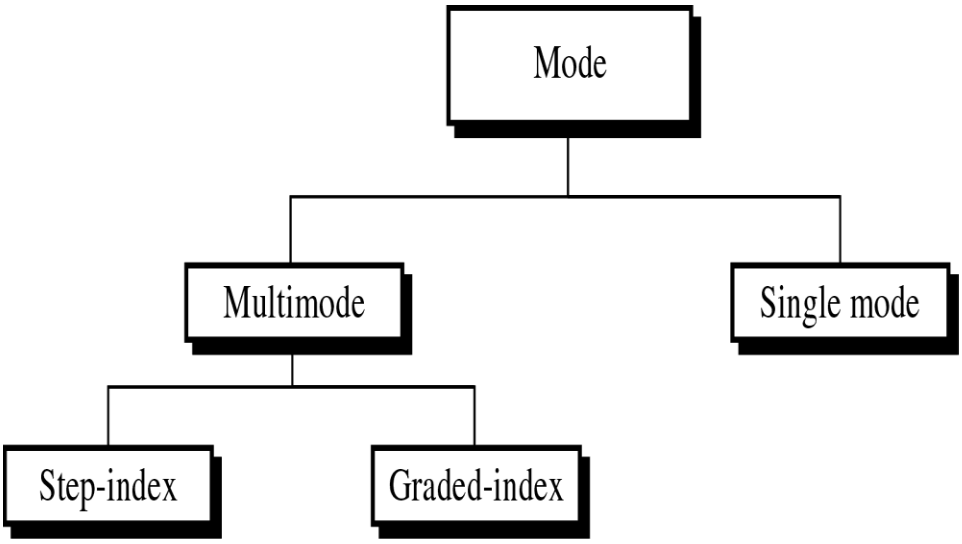
  - **Critical Angle**
- **Reflection**



- When angle of incidence becomes greater than critical angle, reflection occurs
- Light no longer passes into the less denser medium but is reflected back into the same medium
- The Angle of Incidence (I) = Angle of Reflection (R)

- **Optical Fibers & Reflection**
- Optical fibers use Reflection to guide light through a channel
- A glass or plastic CORE is surrounded by a CLADDING of less dense glass or plastic
- The difference in the density of CORE and CLADDING is such that the beam of light moving through the core is reflected off the cladding
- Information is encoded onto a beam of light as a series of ON-OFF flashes that represent 1 and 0 bits

- **Propagation Modes**



  - Fiber Technology supports two modes for the propagation of light
    - Multimode
    - Single Mode

  Each of these modes require fiber with different physical characteristics

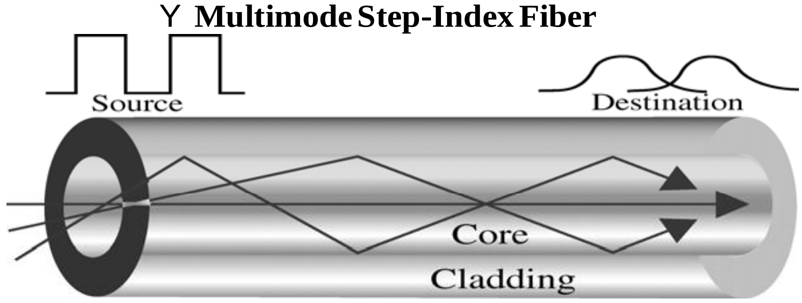
  - There are two further sub categories of Multimode Fiber:
    - Multimode Step-Index Fiber
    - Multimode Graded-Index Fiber

- **Multimode Fiber**

- Multiple beams from a light source move through the core in different paths

- Two types of the Multimode fiber:
  - Multimode Step Index Fiber
  - Multimode Graded Index Fiber

- **Multimode Step-Index Fiber**

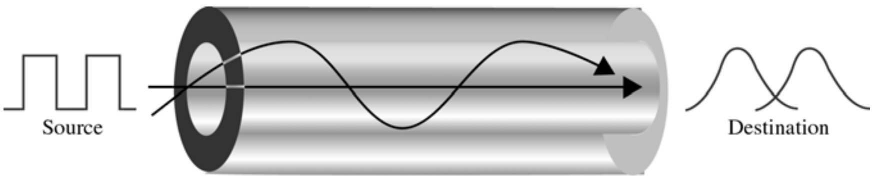


- Density of the CORE remains constant from the center to the edges
- A beam of light moves through this constant density in a straight line until it reaches the interface of the core and the cladding
- At the interface, there is an abrupt change to lower density, that alters the angle of the beam's motion
- Step Index-7 Suddenness of this change
- Some beams travel straight and reach the destination without reflecting
- Some strike the interface of core and cladding at an angle smaller than critical angle and penetrate cladding and are lost

- Others hit edge of the core at angles greater than critical angle and bounce back and forth to the destination

  - **Disadvantage of Multimode Step-Index Fiber**
  - Each beams angle is equal to its angle of reflection
  - If I is small, R is small and the beam will require more bounces and it will take more time to reach the destination
  - If I is large, R is large and beam will reach destination quickly
  - In other words there is a difference is Path Lengths that results into a distortion at the receiver
  - This distortion limits the data rate and make Multimode Step index fiber inadequate for precise applications

  - **Multimode Graded-Index Fiber**
  - The solution to the above problem is Multimode Graded Index Fiber
  - A grade index fiber is the one with varying densities
  - Density is highest at the center of the core and decreases gradually to its lowest at the edge



- The signal is introduced at the center of the core
- The horiz beams move straight to the receiver
- Beams at other angles moves through the series of constantly changing densities
- Each density difference causes each beam to refract into a curve
- Signal can be reconstructed with far greater precision as all the beams reach the receiver at almost the same time

Summary

- Transmission Media and its Types
- Guided Media
  - Twisted Pair
  - Coaxial Cable
  - Optical Fiber

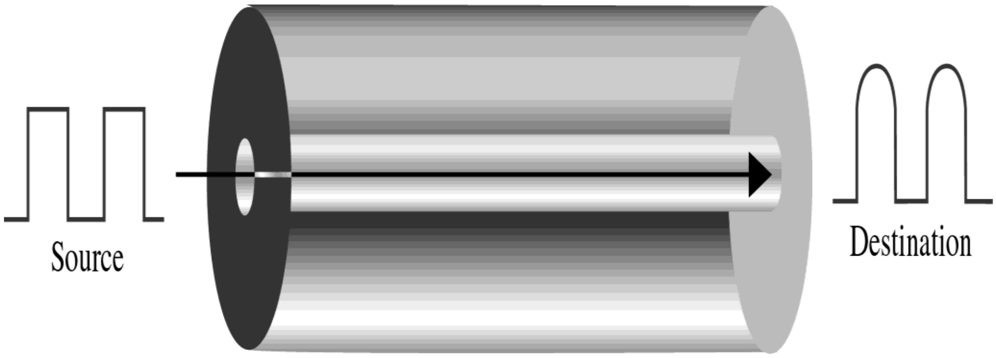
Reading Sections

- Section 7.1, "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

LECTURE #26

Single Mode Fiber

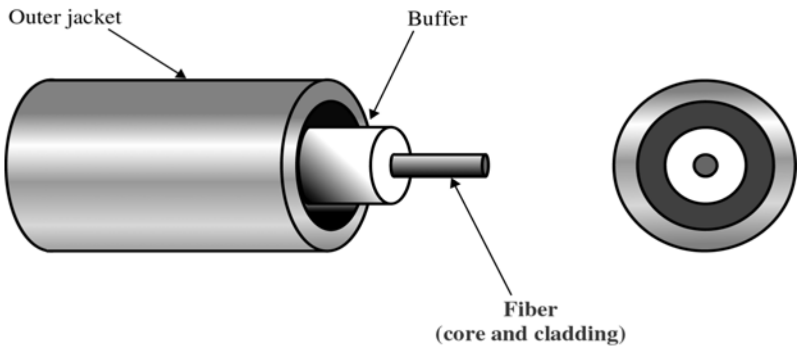
- o Uses step index fiber and a highly focused source of light that limits beams to a small range of angles all close to the horizontal
- o Single Mode fiber is manufactured with a much smaller Diameter than Multimode
- o All of the beams arrive at the destination together and can be recombined without distortion to the signal



- **Fiber Sizes**
  - o Optical Fibers are defined by the ratio of the diameter of their Core to the diameter of their Cladding
  - o Both the diameters are expressed in Microns (Micrometers)

Fiber type	Core	Cladding
62.5/125	**62.5**	**125**
50/125	**50**	**125**
100/140	**100**	**140**
8.3/125	**8.3**	**125**

- **Cable Composition**



- o A core is surrounded by cladding forming the Fiber.
- o In most cases, fiber is covered by a Buffer layer that protects it from moisture.
- o Finally the entire cable is encased in an outer jacket
- o Both core and cladding can be made of either glass or plastic but must be of different densities
- o In addition the inner core must be ultra pure and completely regular in size and shape
- o Chemical differences in material and even small variations in the size or shape of the core alter the angle of reflection and distort the signals

- o Some applications can handle a certain amount of distortion and their cables can be made cheaply but others depend on complete uniformity
- o The outer jacket can be made of several materials including Teflon, Plastic, Fibrous Plastic, metal tubing

Each of these materials have a purpose:

–Plastic is lightweight and cheap but do not provide structural strength and can emit fumes when burnt

–Metal tubing provides strength but is costly

–Teflon is lightweight and can be used in open air but it is expensive and does not increase cable strength

Light Sources for Optical Cable

- o For tx to occur the sending device must have a light source and the receiving device with a photosensitive cell (Photodiode)
- o Photodiode converts the light into current usable by the computer

•The light source can either be an LED or an ILD

Y **LED:**

–Cheaper but provide Unfocused light that strikes the boundaries of channel at uncontrollable angles

–Limited to short distance use

Y **LASER:**

–Can be focused to a narrow range allowing control over angle of incidence

- **Fiber Optic Connectors**
  - o Importance of Connectors
  - o If connector is over tight, two cores can be compressed and angle of reflection of the signal will be altered
  - o All of popular connectors are Barrel shaped that come in male and female versions
  - o The cable has a male connector that fixes into a female connector attached to the device to be connected
- **Advantages of Optical Fiber**

  The major advantages of Fiber over twisted pair and coaxial cable are:

•**Noise Resistance:**

–Because fiber uses light rather than electricity, noise is not a factor

–External light the only form of possible interference is blocked from the channel by the Outer jacket

•**Less Signal Attenuation**

–Fiber optic Transmission distance is significantly greater than other media

–A signal can run miles w/o regeneration

•**Higher Bandwidth**

–Can support higher BWs and higher data rates

–High rates are not utilized by absence of signal generation and reception technology

Disadvantages of Optical Fiber

•**COST**

–Expensive

–No impurities or imperfections can be tolerated, so manufacturing is costly

–Laser light sources can be expensive

•**INSTALLATION**

–Roughness & Cracking of core cannot be tolerated

–All connections must be perfectly alligned

- **Disadvantages of Optical Fiber**

•**Fragility**

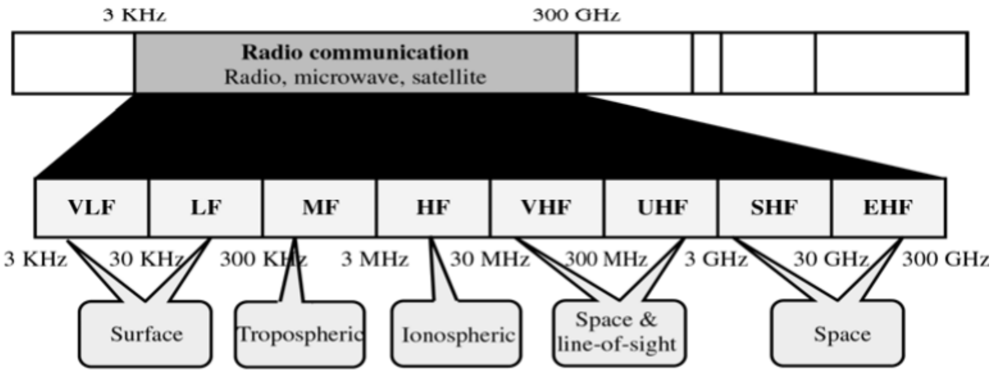
–Glass fiber is very fragile

–Can not be used in extreme conditions where hardware portability is required

- **Unguided Media**
  - Unguided Media or Wireless Communication transport Electromagnetic waves without a physical conductor
  - Instead signals are broadcast through Air and are available to anyone who has a receiver capable of receiving them

Y **Radio Frequency Allocation**
  - The section of EM spectrum defined as Radio Communication is divided into 8 ranges called BANDS
  - BANDS are rated from very low frequency (VLF) to extremely high frequency (EHF)

VLF	Very low frequency	VHF	Very high frequency
LF	Low frequency	UHF	Ultra high frequency
MF	Middle frequency	SHF	Super high frequency
HF	High frequency	EHF	Extremely high frequency



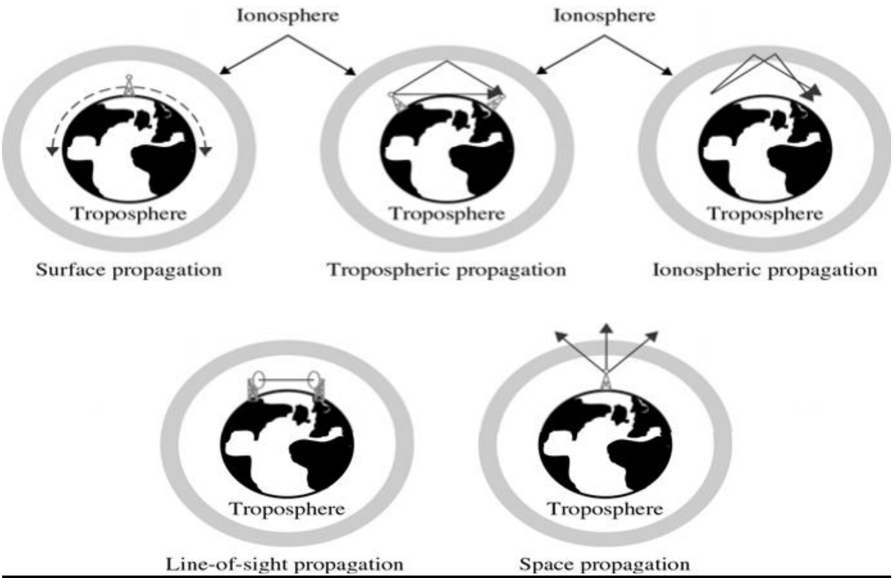
Y **Propagation of Radio Waves**

Radio Wave transmission utilizes five different types of propagation:

Y **Types of Propagation**:

- Surface
- Tropospheric
- Ionospheric
- Line-of-Sight
- **Space**

Radio Technology considers the earth as surrounded by two layers of atmosphere:



• **TROPOSHERE**

- It is the portion of the atmosphere extending outwards approx. 30 miles from the earth's surface
- It contains what we call as AIR
- Clouds, wind, Temp. variation and weather in general occur in the Troposhere as does jet plane travel

• **IONOSPHERE**

- It is the layer of atmosphere above the troposhere but below space
- It is beyond what we think of as atmosphere

• **Surface Propagation**

- In surface propagation, radio waves travel through the lowest layer of the atmosphere, hugging the earth
- At the lowest frequencies signal emanate in all direction from the tx antenna and follow the curvature of the planet
- Distance depends on the amount of power in the signal

• **Troposhpheric Propagation**

This can work in two ways:

- **Line-of-Sight**:
  - A signal can be directed in a straight from Antenna to antenna
- **Broadcast:**
  - Signal is broadcasted at an angle into the upper layers of the troposphere from where it is reflected back to earth's surface

- The first method demands that both transmitter and receiver be placed within line-of-sight distances and is limited by the curvature of the earth
- The second method allows greater distances to be covered

• **<u>Ionoshpheric Propagation</u>**

- Higher frequency radio waves are radiated towards the ionosphere where they are reflected back to the earth
- The difference in density between troposhphere and ionosphere causes each radio wave to speed up and change direction bending back to earth
- Allows greater distances to be covered by lower power output

• **<u>Line of Sight Propagation</u>**

- Very high frequencies signals are transmitted in straight line from antenna to antenna
- Antennas must be directional facing each other or either tall enough or close enough to each other to avoid earth's curvature
- Radio waves can reflect of the objects in the middle and can reach late to the receiver. These late signals distort signal

• **<u>Space Propagation</u>**

- A broadcast signal is received by the orbiting satellites which rebroadcasts the signal to the intended receiver on the earth

Summary

- Guided Media
- Optical Fiber Cable
- Unguided Media
- Radio Frequency Allocation
- Propagation of Radio Waves

Reading Sections

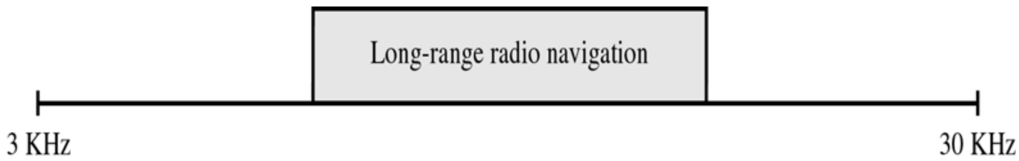
• Section 7.1,"Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

LECTURE #27

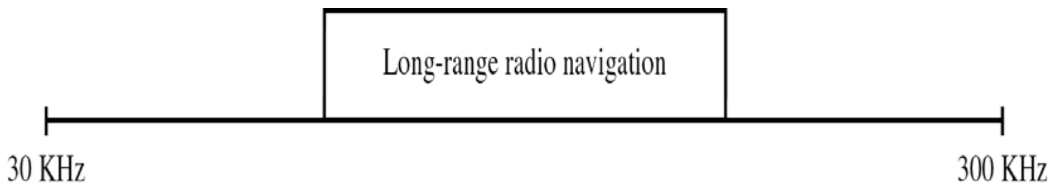
Propagation of Specific Signals

- The type of propagation used in radio transmission depends upon the frequency of the signal
- Each frequency is suited for a specific layer of atmosphere and is most efficiently transmitted and received by technologies adapted to that layer

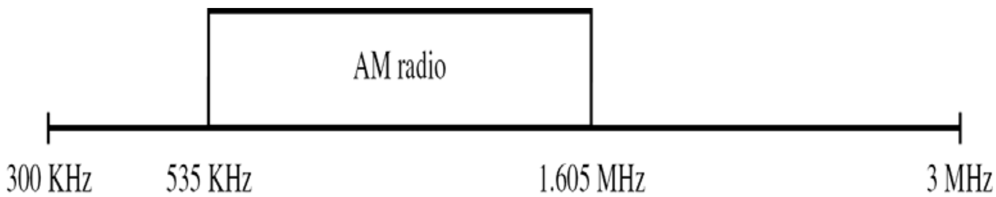
- **Very Low Frequency (VLF) (Figure)**
  - VLF waves are propagated as surface waves through air
  - Do not suffer much attenuation in TX but are susceptible to high levels of atmospheric noise I.e. electricity and heat
  - Used for Long-range radio navigation and Submarine Communication



- **Low Frequency (LF) (Figure)**
  - Also propagated as surface waves
  - Used for Long-range radio and for navigational locators
  - Attenuation is greater in the day time when absorption of waves by natural obstacles increases

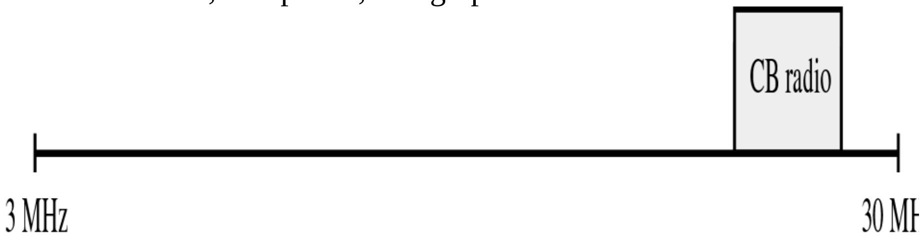


- **Middle Frequency (MF)**
  - Propagated in the Troposhere
  - These frequencies are absorbed by Ionosphere
  - The distance they cover is limited by the angle needed to get the signal reflect from the troposhere and not enter ionosphere
  - Absorption increases during the day time
  - Used for AM Radio

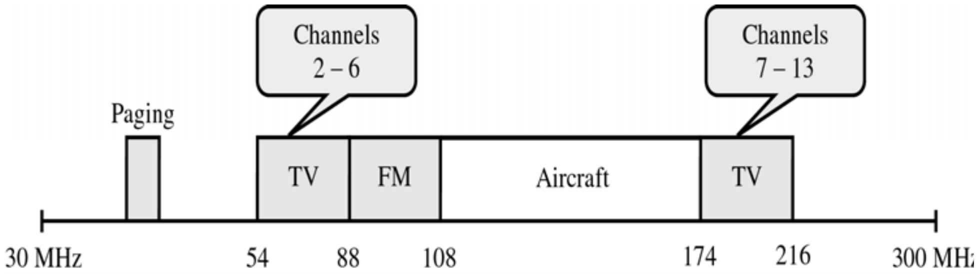


- **High Frequency (HF) (Figure)**
  - Use ionospheric propagation

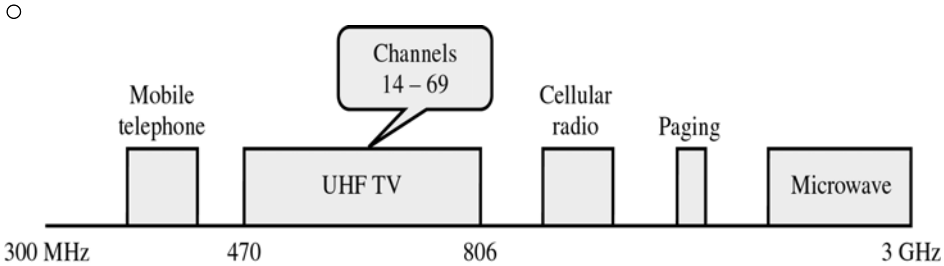
- These frequencies move into the ionosphere where the density difference reflects them back on earth
- Used for Citizen's Band Radio, International Broadcasting, Military Communication, Telephone, Telegraph and Fax



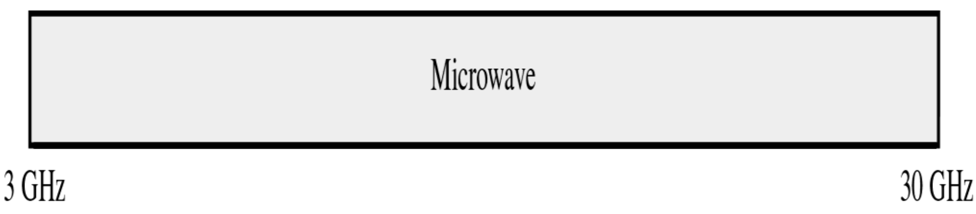
- **Very High Frequency (VHF) (Figure)**
  - Most VHF waves use line-of-sight propagation
  - Used for VHF Television, FM Radio, Aircraft AM Radio
  -



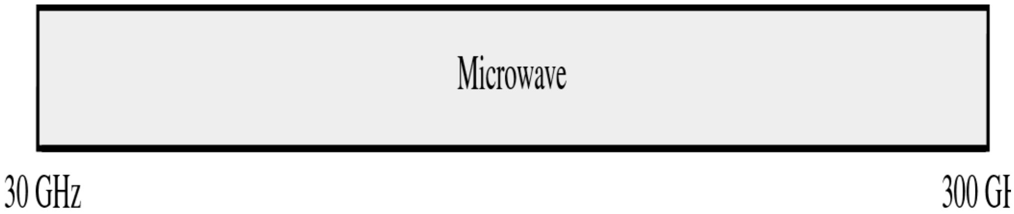
- **Ultra High Frequency (UHF) (Figure)**
  - Always use line-of-sight propagation
  - Used for UHF Television, Mobile Telephone, Cellular Radio, Paging, Microwave Links
  - Note that microwave communication begins at 1GHz in UHF and continues into SHF and EHF band
  -



- **Super High Frequency (SHF) (Figure)**
  - SHF waves are TX using mostly line-of-sight and some Space propagation
  - Used for Terrestrial and Satellite Microwave and Radar Communication

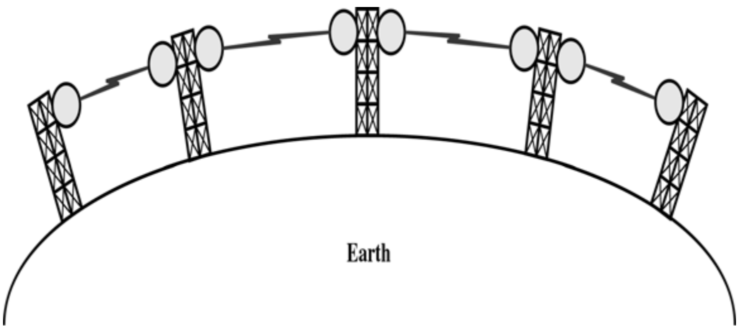


- **Extremely High Frequency (EHF) (Figure)**
    - o Use space propagation
    - o Used for Radar , Satellite and Experimental Communication
    - o



Terrestrial Microwave

- o Microwaves do not follow the curvature of earth and therefore require line-of-sight TX and RX equipment
- o Distance covered by line-of-sight signal depends to a large extent on the height of the antennas
- o Height allows the signal to travel farther by crossing a lot of obstacles like low hills and buildings
- o Microwave signals propagate in one direction at a time, which means that two frequencies are necessary for 2-way communication such as telephone conversation
- o One frequency is reserved for MICROWAVE communication in one direction and the other for TX in the other direction
- o Each frequency requires its own transmitter & receiver combined in a Transceiver nowadays



Y **Repeaters**

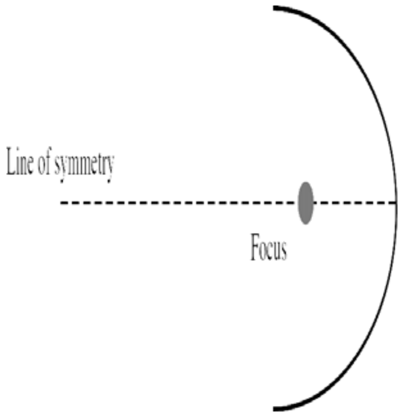
- o To increase distance for terrestrial microwave, a system of repeaters can be installed with each antenna
- o A signal received by one antenna can be converted back to the transmittable form and relayed to the next antenna
- o The distance required b/w repeaters varies with frequencies of the signal and the environment in which the antennas are found
- o A repeater may broadcast the regenerated signal either at original frequency or a new frequency depending on system
- o Used in Telephone systems worldwide

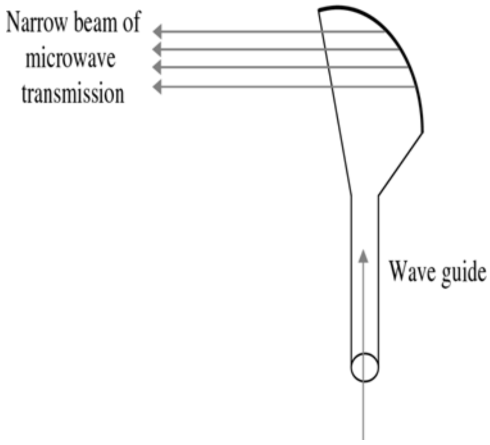
Y **Antennas**

Two types of Antennas are used for Microwave communication:

–Parabolic Dish

–Horn





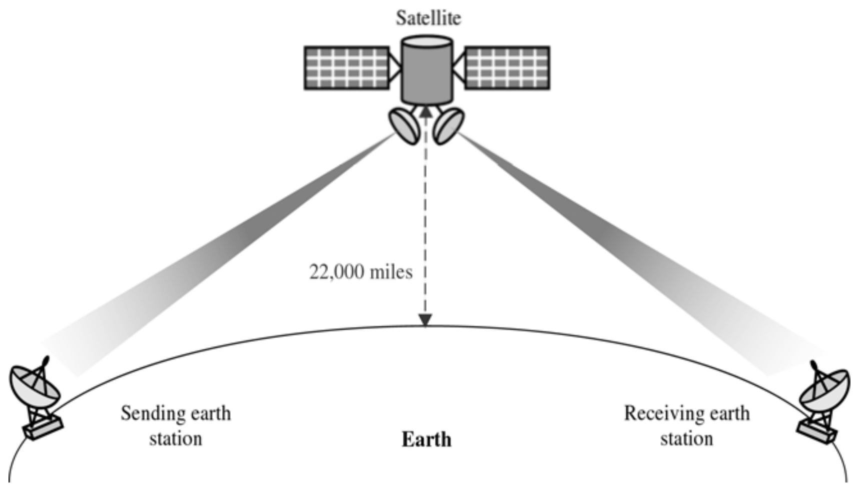
- **Parabolic Dish**

  - Based on the geometry of a Parabola
  - Every line parallel to the line of symmetry (line of sight) reflects off the curve at an angle such that they intersect in a common point called FOCUS
  - Parabolic dish works like a funnel catching a wide range of waves and directing them to a common point
  - In his way most of the signal is recovered than would be possible with a single-point receiver

- **HORN**
  - Outgoing transmissions are broadcast through a horn aimed at the dish. The microwaves hit the dish and and are deflected outward in a reversal of the receipt path
  - A horn antenna looks like a gigantic scoop
  - Outward TXs are directed upward a stem and are deflected outward in a series of narrow parallel beams

Satellite Communication

- Satellite TX is much like line-of-sight transmission in which one of the stations is the satellite orbiting around the earth
- The principle is similar to the terrestrial microwave with a satellite acting as a Super tall antenna and Repeater



- o Although in satellite TX, signals must still travel in straight line, the limitations imposed on distance by curvature of earth are reduced
- o In this way satellites can span Continents and oceans with one bounce off the satellite
- o Satellite can provide TX capability to and from any location on earth no matter how remote
- o This advantage makes high quality communication available to underdeveloped parts of the worked at almost no cost
- o Satellites themselves are very expensive but leasing a freq or time on one can be cheap

- **Geosynchronous Satellite**
  - o Line of sight propagation requires the sending and receiving antennas must be locked into each other
  - o To ensure continuous communication, satellites must move with the same speed as earth. So that they seem fixes w.r.t earth
  - o These satellites are called Geosynchronous Satellites

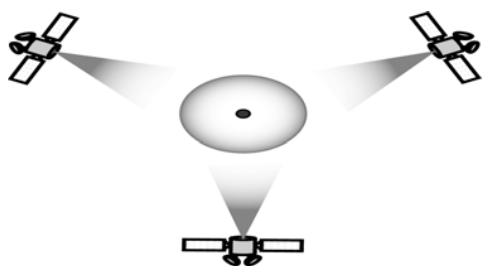


Figure shows 3 satellites in geosynchronous orbit each 120 degree from one another so that whole earth can be covered

- **Satellite Frequency Bands**

Each satellite sends and receives over two bands

–Uplink: From the earth to the satellite

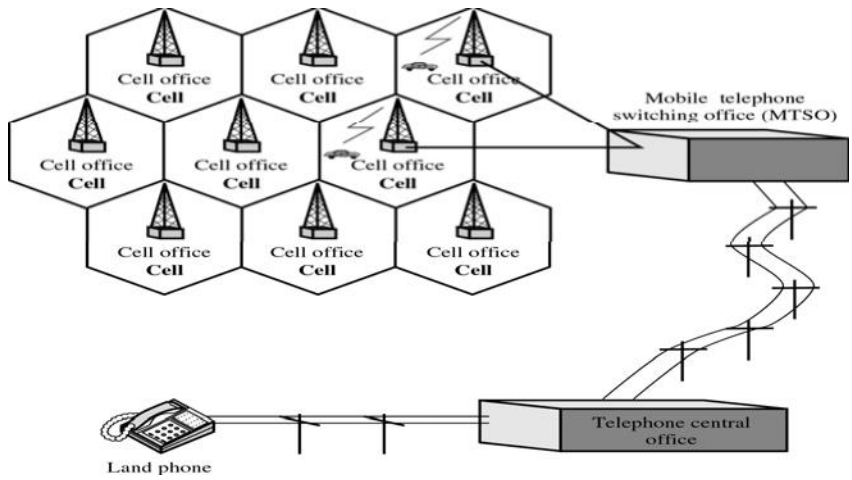
–Downlink: From the satellite to the earth

Band	***Downlink***	***Uplink***
C	3.7-4.2 GHz	5.925-6.425 GHz
Ku	11.7-12.2 GH	14-14.5 GHz
Ka	17.7-21 GHz	27.5-31 GHz

Cellular Telephony

- Each service area is divided into small ranges called *cells*
- Each cell office is controlled by a switching office called MTSO

Operations of Cellular Telephony



•Transmitting

–Mobile phone sends the number to the closest cell office

–Cell office -7 MTSO -7 Telephone office

–MTSO assigns an unused voice channel

•Receiving

–Telephone office sends the signal to MTSO

–MTSO sends queries to each cell (paging)

–If mobile phone is found and available, assigns a channel

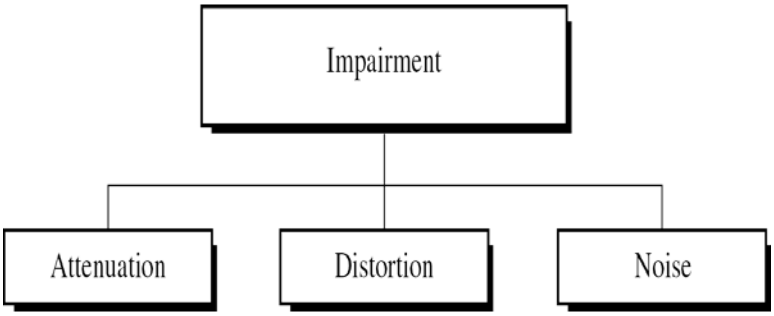
•Handoff

–MTSO monitors the signal level every few seconds

–If the strength diminishes, MTSO seeks a new cell and changes the channel carrying the call

Transmission Impairments

Transmission media are not perfect
What is sent is not what is received



- **Attenuation**
  - Attenuation means *loss of energy*
  - Some of electrical energy is converted to heat

- **Decibel (dB)**

  Relative strengths of two signals or a signal at two points

  dB = 10 $\log_{10}$ (P_2/P_1)

  P_2 and P_1 are signal powers

  Negative dB means attenuation
  Positive dB means amplification

Example 7.1
Imagine a signal travels through a transmission medium and its power is reduced to half. This means P_2=(1/2)P_1. Calculate Attenuation?
Solution:

–$10\log_{10}(P_2/ P_1)= 10\log_{10}(0.5\, P_1/ P_1)$
$=10(-0.3)= -3$ dB

- **Distortion**
  - Distortion means that the signal changes its form or shape
  - Distortion occurs in a composite signal

Summary
- Frequency Ranges
- Microwave Communication
- Satellite Communication
- Cellular Telephony
- Transmission Impairments

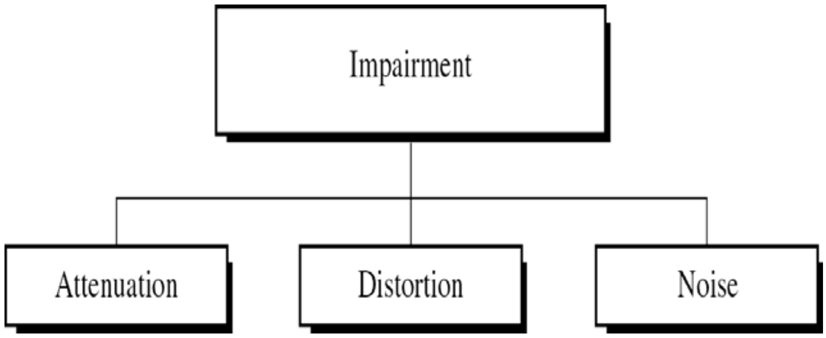
Reading Sections

- Section 7.2, 7.3 "Data Communications and Networking" 4th Edition by Behrouz A. Forouzan

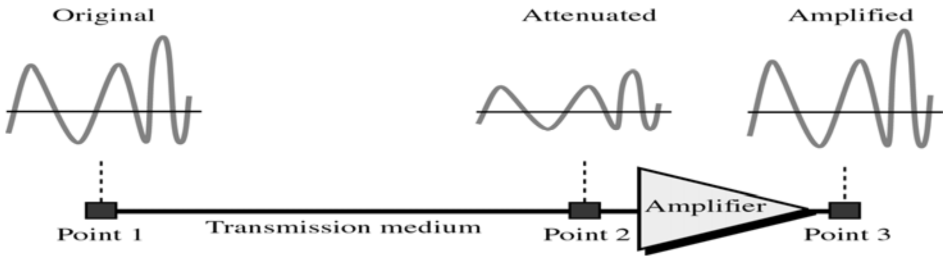
LECTURE #28

Transmission Impairments

TX Media are not perfect
Imperfections cause impairments in the signal through the medium
This means that the signal at the beginning and the end of the medium are not the same
What is sent is not what is received



- **Attenuation**
  - Loss of Energy
  - When a signal travels through a medium, it looses some of its energy in order to overcome the resistance of the medium
  - That is why wire carrying electric signals get hot
  - Some of the electrical energy in the signal is converted to heat
  - To compensate for this loss Amplifiers are used to amplify the signal to heat



- **Decibel (dB)**
  - Measures the relative strength of the two signals or a signal at 2 different points
  - dB is negative if a signal is attenuated
  - dB is positive if a signal is Amplified

Relative strengths of two signals or a signal at two points
dB = 10 $\log_{10} (P_2/P_1)$
P_2 and P_1 are signal powers

Negative dB means attenuation
Positive dB means amplification

Example 7.1

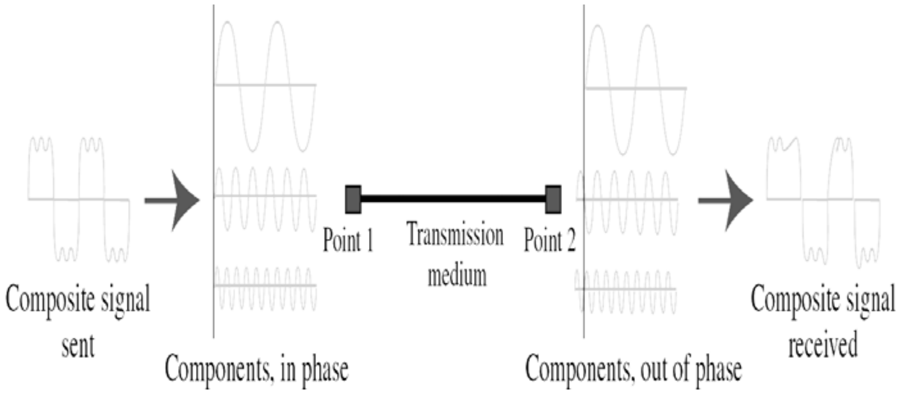
Imagine a signal travels through a transmission medium and its power is reduced to half. This means $P_2=(1/2)P_1$. Calculate Attenuation?

Solution:

─$10\log_{10}(P_2/ P_1)= 10\log_{10}(0.5\ P_1/ P_1)$

$=10(-0.3)= -3$ dB

- **Distortion**
  - Distortion means that the signal changes its form or shape
  - Distortion occurs in a composite signal
  - Signal changes its form or shape
  - Occurs in a composite signal, made of different frequencies
  - Each signal component has its own speed



- **NOISE**
  - Thermal Noise

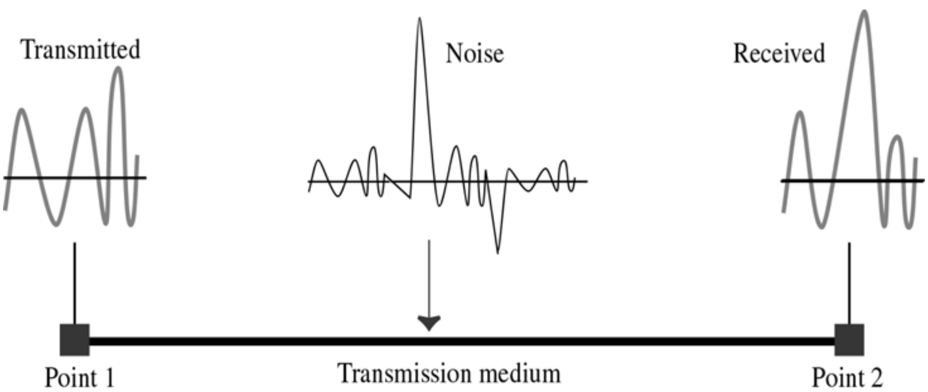
    ─Due to random motion of electrons in a wire that creates an extra signal not originally sent by TX

  - **Induced Noise**

    ─Comes from sources like Motors and Appliances
  - **Crosstalk:**

    ─Effect of one wire on another
  - **Impulse Noise**

    ─Spike (A signal with high energy in a very short period of time) that comes from power lines, lightening etc,.



- **Performance of Medium**

Three concepts are used to measure the performance of TX Media:

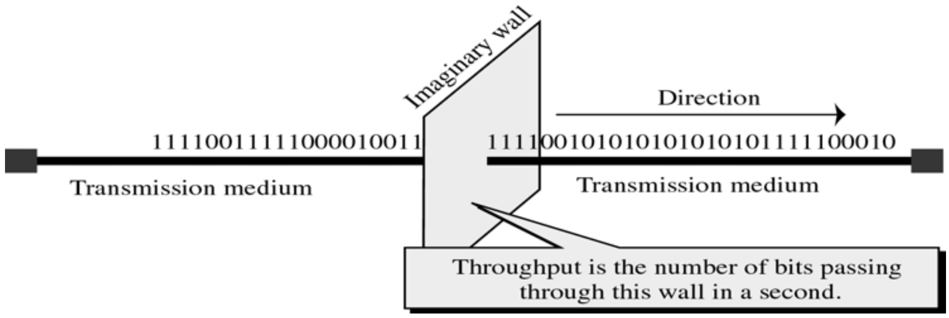
–Throughput

–Propagation Speed

–Propagation Time

Throughput

- Measurement of how fast data can pass through a point
- In other words, if we consider any point in the TX Medium as a wall through which bits pass, then throughput is the number of bits that can pass this wall in second



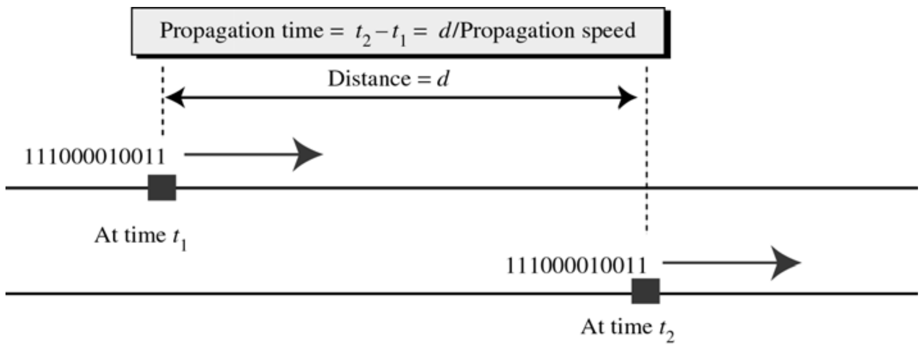
Propagation Speed

- Propagation speed measures the distance a signal or a bit can travel through a medium in one second
- The propagation speed of EM signals depend on the medium and the frequency of the signal

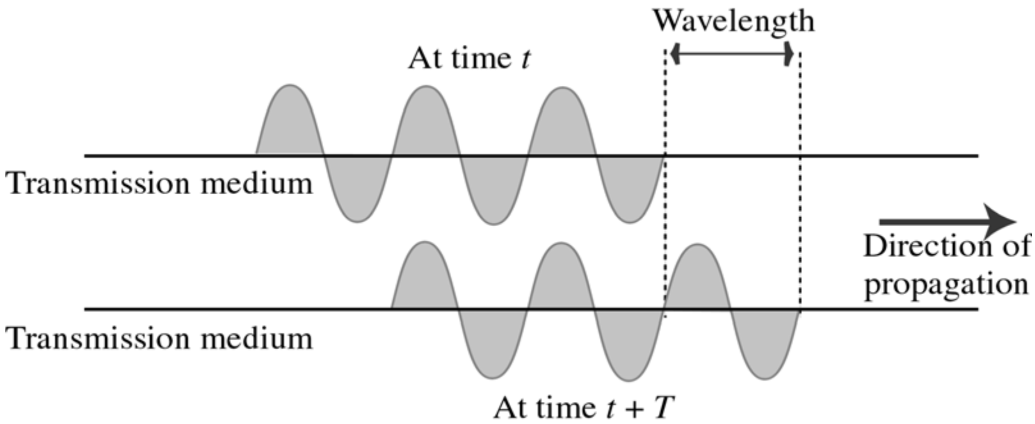
Propagation Time

- Measures the time required for a signal (or a bit) to travel from one point of the TX medium to another
- The propagation time is calculated as:

Propagation time = $\frac{Distance}{PropagationSpeed}$



- **WAVELENGTH**
  - Another characteristic of a signal traveling through the TX Medium
  - This concept binds the frequency of the signal to the propagation speed of medium
  - It is customary to talk about wavelength when talking about TX of light in Optical Fiber



- The wavelength is the distance a simple signal can travel in one period
- The wavelength depends on both the frequency and the medium

–Wavelength = Propagation speed * period
–Wavelength = Propagation speed / frequency

- **Shannon Capacity**
  In 1944, Claude Shannon introduced a formula to determine the theoretical highest data rate for a channel:

  $C = B \log_2 (1 + S/N)$ in bps
  –B: bandwidth of the channel
  –S/N: signal to noise ratio

<u>Examples</u>

- Extremely noisy channel
  - $S/N \approx 0$
  - $C = B \log2 (1+0) = 0$
- Telephone line
  - Bandwidth is 3000 Hz, S/N ratio is 3162 (35 dB)
  - $C = 3000 \log2 (1+3162) = 34,860$ bps

Media Comparison
When evaluating the suitability of a particular medium to a specific application, 5 factors should be kept in mind:

•**<u>COST</u>**: This is the cost of materials plus installation
•**<u>SPEED</u>**: Speed is the max no. of bits per second that a medium can transmit reliably
–Speed varies with frequency, with physical size of medium and Transmission Equipment
•**<u>ATTENUATION:</u>** Tendency of EM signal to become weak or distorted over signal
•**<u>EM Interference:</u>** EMI is the susceptibility of the medium to external EM energy introduced into the link that interferes with the intelligibility of a signal
–Familiar effects of EMI are static(audio) and snow (visual)

• **SECURITY:** How easy it is for an unauthorized device to listen on the link?

–Twisted pair is intercept able

–Optical Fiber is more secure

Summary

- Transmission Impairments
- Performance of Transmission Medium
- Wavelength
- Shannon Capacity
- Media Comparison

Reading Sections

- Section 7.4, 7.5, 7.6. 7.7, “Data Communications and Networking” 4th Edition by Behrouz A. Forouzan