Computer Networks

Lecture by:

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Chapter 2: Physical Layer

Topics:

- Network Monitoring: delay, latency, throughput
- Transmission media: twisted pair, coaxial, fiber optic, line of sight, satellite
- Multiplexing, circuit switching, packet switching, VC switching, telecommunication switching system (Networking of telephone exchange)
- ISDN: Architecture, interface and signaling

Network Performance

- Bandwidth
- Throughput
- Latency
- Bandwidth Delay product
- Jitter

Bandwidth

- The maximum amount of data that can be carried from one point to another in a given time period.
- For Digital Devices
  - Channel Capacity
  - Bandwidth is expressed in bits per second (bps)
- For Analog Devices
  - Refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.
  - Bandwidth is Expressed in cycle per sec OR Hz

Throughput

- The rate of successful message delivery over a communication channel.
- Throughput is usually measured in bits per second
- system throughput or aggregate throughput
  - sum of the data rates that are delivered to all terminals in a network

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution

We can calculate the throughput as

$$\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}$$

The throughput is almost ….. of the bandwidth in this case.

Bandwidth versus throughput

bandwidth is the theoretical *capability of the connection, the throughput is the actual data rate of a specific application.*

Delay

- Delay is the time required for a signal to traverse the network
- Propagation Delay
  - Propagation speed - speed at which a bit travels though the medium from source to destination
  - Propagation delay - Time taken for the first bit to travel from the sender to the receiver
  - Distance (Link Length)/Propagation speed

- Transmission Delay
  - Transmission speed - The amount of time from the beginning until the end of a message transmission
  - Transmission delay - Amount of time required to push all of the packet's bits into the wire
  - Transmission Delay = Message size/bandwidth
  - Also called Store and Forward Delay
  - Function of Packet Length
  - Nothing to do with distance between the nodes

What are the propagation time and the transmission time for a 2.5-kbyte message (an e-mail) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 × 10^8 m/s.

Solution

We can calculate the propagation and transmission time as

Propagation time = Distance / Speed

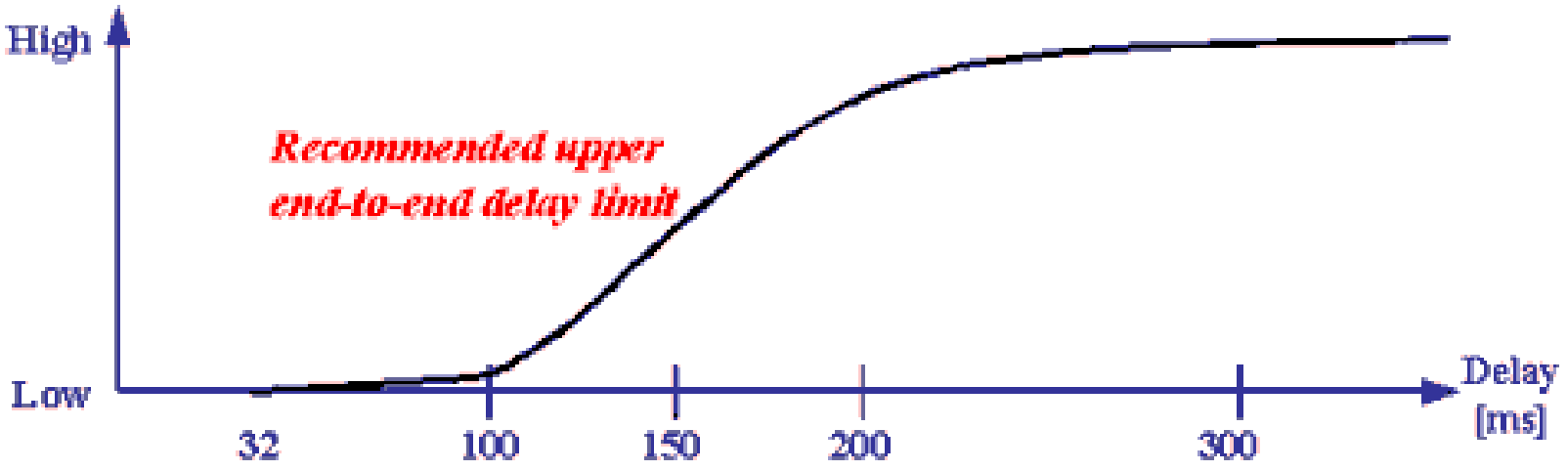
Transmission time = Packet Size / bandwidth of link

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{2500 \times 8}{10^9} = 0.020 \text{ ms}$$

Delay's Effect on User Experience

- <100 ms: users will not notice the delay.
- 100 ms ~ 300 ms: users will notice a slight hesitation.
- >300 ms: the delay is obvious to the users.



Latency

- Latency = Propagation delay + Transmission delay + Queuing time +Processing time
- *Network latency is the delay that is introduced by the network*
- several kinds of delays that happens in data communication over a network
- Low Latency
  - Network which experiences Low Delay
- High Latency
  - Network which experience High Delay

Jitter

- Jitter is the variation in the time between packets arriving, caused by network congestion, timing drift, or route changes.
- causes of jitter are electromagnetic interference (EMI) and crosstalk with other signals.

Bandwidth Delay Product

- Product of a data link's capacity (in bits per second) and its round-trip delay time (in seconds).
- A network with a large bandwidth-delay product > 10^5 bits is commonly known as a long fat network

Transmission Medium

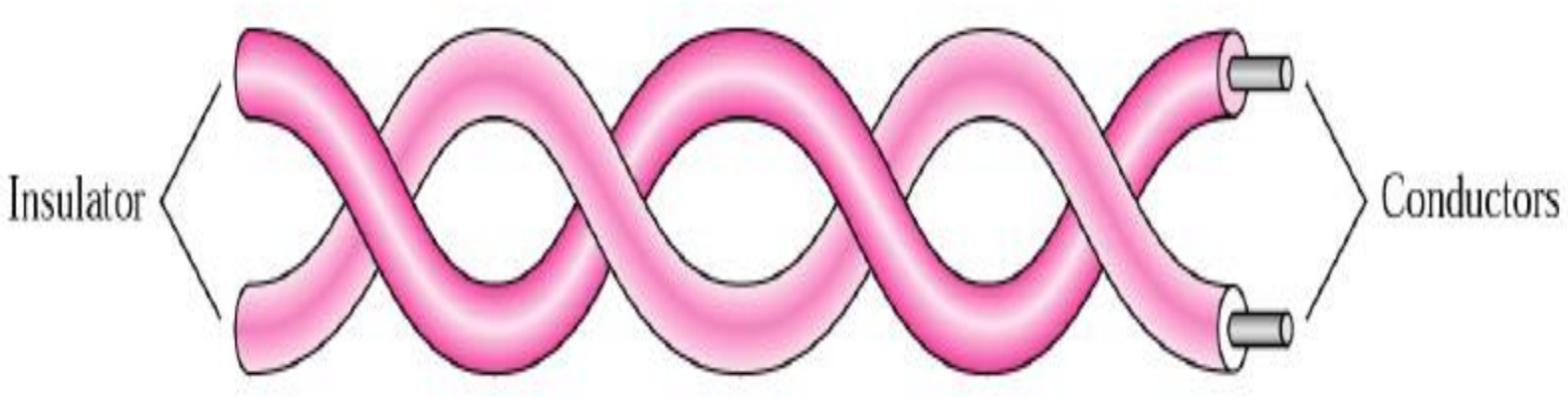
- Anything that can carry information from a source to a destination
- Classes (Types)
  - Guided Transmission Media
  - Unguided Transmission Media
- Guided Transmission Media
  - provide a physical path along which the signals are propagated.
- Unguided Transmission Media
  - employ an antenna for transmitting through air or vacuum

- Guided Transmission media
  - Magnetic
  - Twisted pair
  - Coaxial
  - Fiber
- Unguided Transmission media
  - Bluetooth
  - Wi-Fi /WLAN (Wireless LAN)
  - Infrared
  - Satellite Communication
    - Microwaves
    - Radio Waves

Magnetic Media

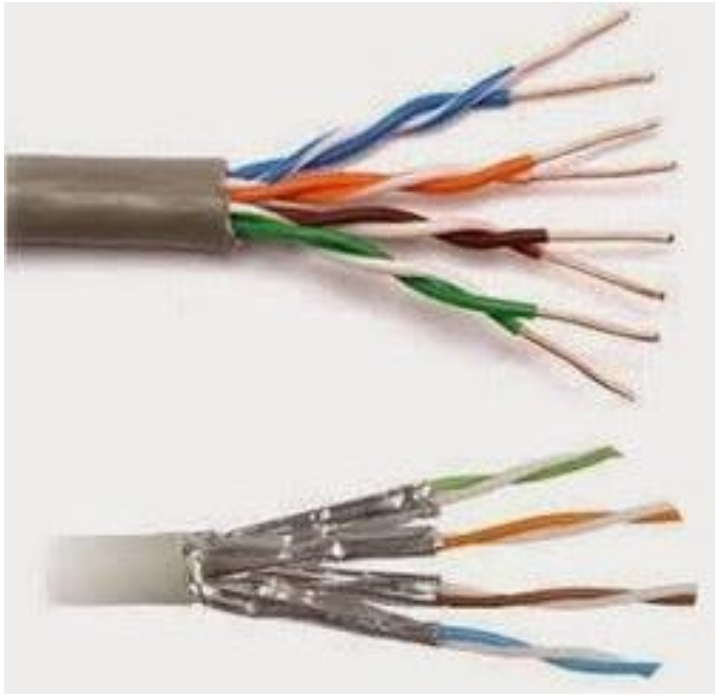
- One tape can hold approx 200GB of data.
- You can put about 1000 tapes in a 60 x 60 x 60 cm box (that's 2' x 2' x 2') for a total capacity of 200 terabytes = 1600 terabits = 1.6 petabits.
- Moving a box of tapes is quite easy and efficient.
- Unless the tapes spend days in transit, they will be much faster than any network.

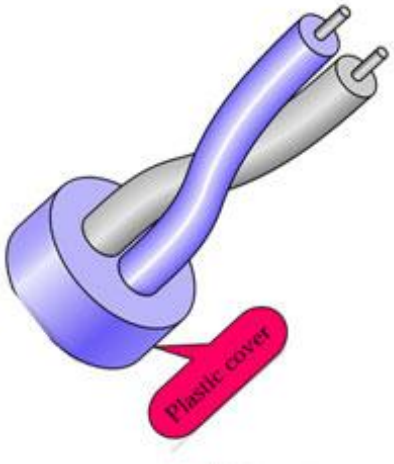
Twisted Pair Cable

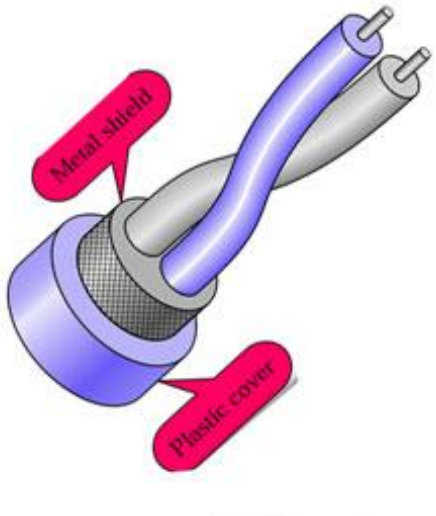


A twisted pair consists of two insulated copper wires arranged in a regular spiral pattern.
The purpose of twisting the wire is to eliminate electrical interference from other wires and outside sources.
Twisting the wires cancels any electrical noise from the adjacent pair.

Twisted Pair Cable: STP and UTP

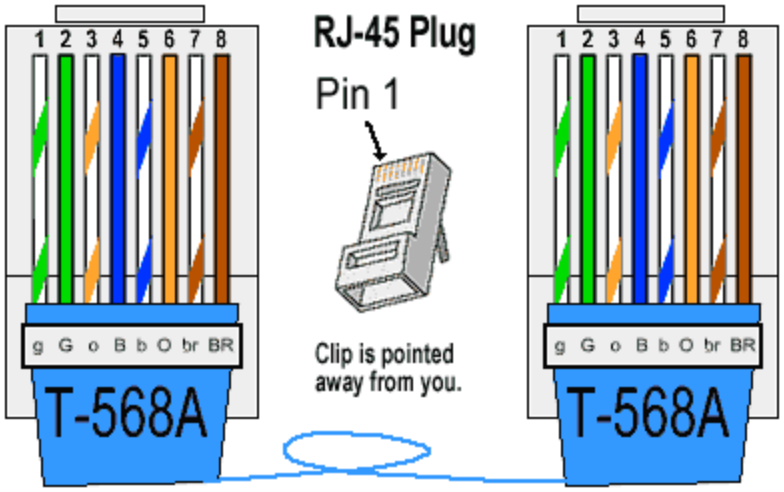




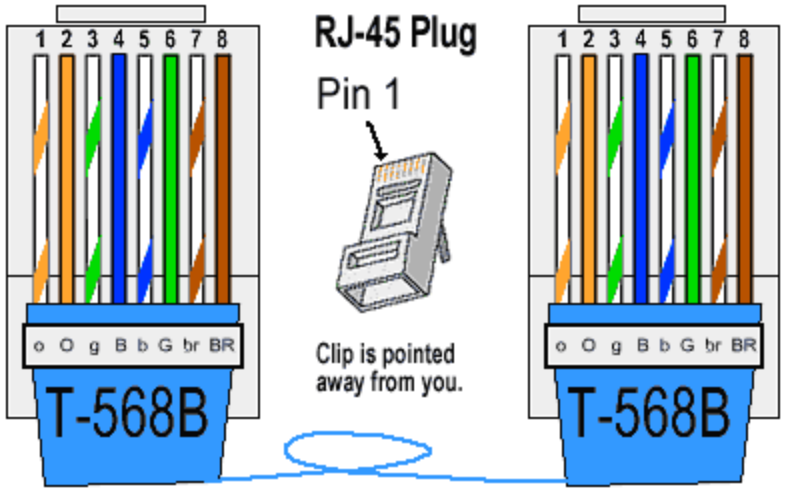


Twisted Pair

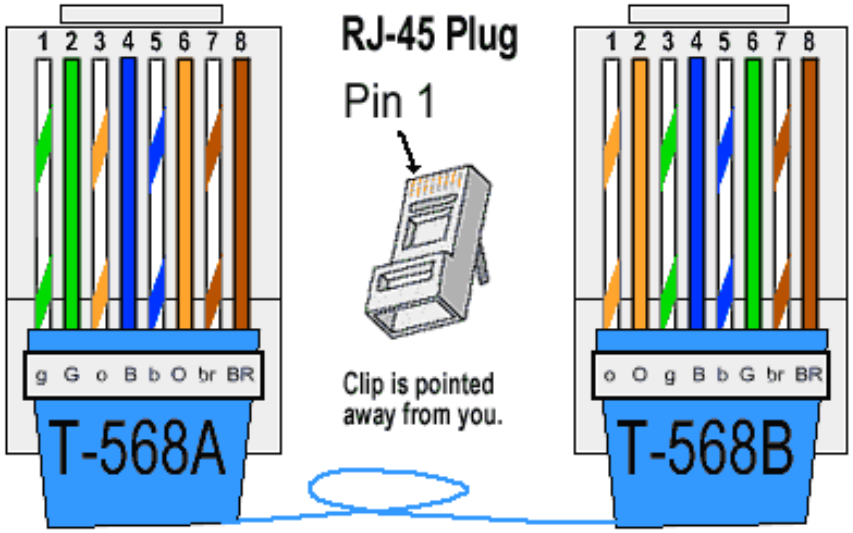
- Advantages
  - Protect against cross talk & interference
  - Easy to add computers to network
  - Well understood technology
  - Less expensive
- Disadvantages
  - Least secure
  - Distance limitations
  - Requires more expensive hubs



T-568A Straight-Through Ethernet Cable



T-568B Straight-Through Ethernet Cable



RJ-45 Crossover Ethernet Cable

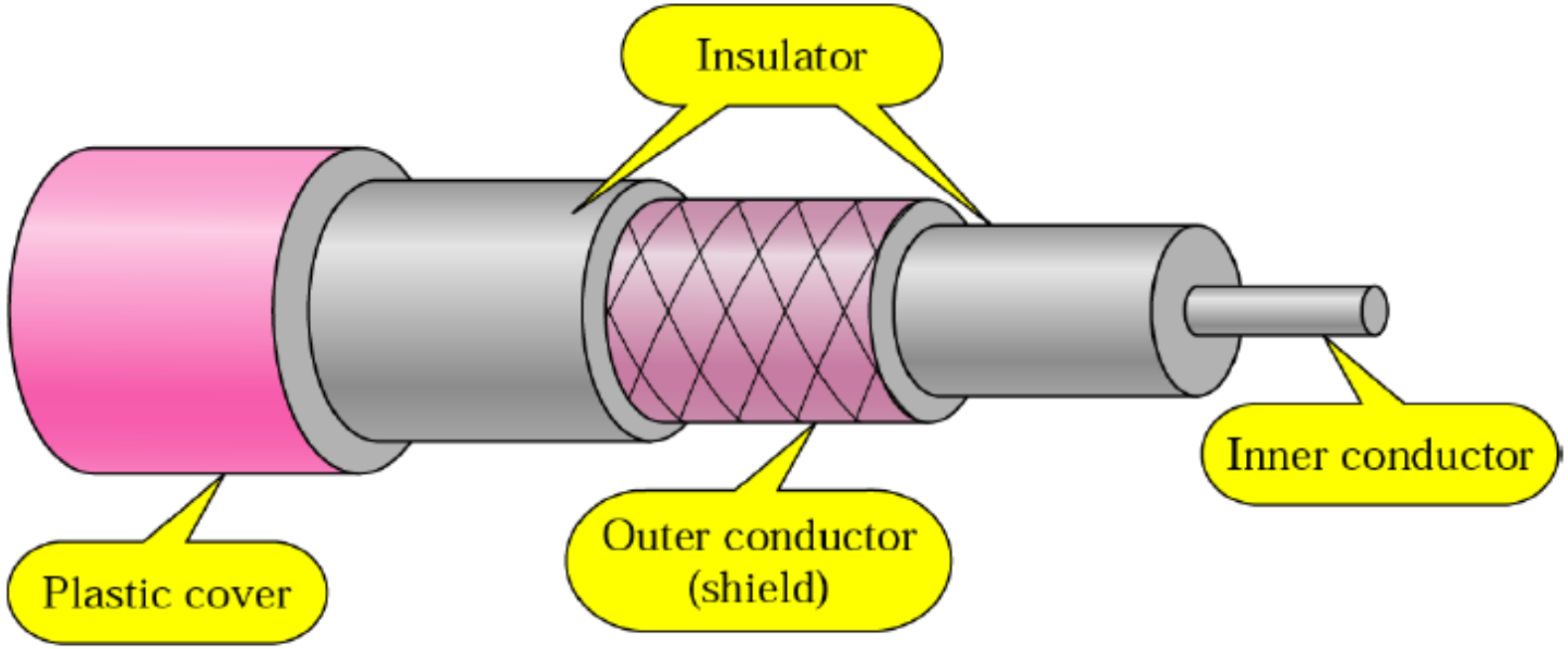
- A straight-through cable has identical ends.
- A crossover cable has different ends.
- A straight-through is used as a patch cord in Ethernet connections.
- A crossover is used to connect two Ethernet devices without a hub or for connecting two hubs.
- A crossover has one end with the Orange set of wires switched with the Green set.
- Odd numbered pins are always striped, even numbered pins are always solid colored.
- Brown is always on the right, and pin 1 is on the left.
- Orange set of wires are used for transmission of data
- Green set of wires are used for receiving data

Twisted Pair Types

- **Category 1**—Used for telephone communications. Not suitable for transmitting data.
- **Category 2**—Capable of transmitting data at speeds up to 4 megabits per second (Mbps).
- **Category 3**—Used in 10BASE-T networks. Can transmit data at speeds up to 10 Mbps.
- **Category 4**—Used in Token Ring networks. Can transmit data at speeds up to 16 Mbps.
- **Category 5** – a tighter twist, same number of wires, just less crosstalk and higher speeds (100 Mbps)

- **Category 6** (250 MHz) – 4 pairs of 24 American Wire Gauge (AWG) copper wires. 1 Gbps (up to 10 Gbps for Cat6a). Category 6 cable is currently the fastest standard for UTP.
- **Category 7** (600 MHz)- Speed of 10 Gbps for 100m.
- **Category 8** (2000 MHz) - Speed of 40 Gbps

Coaxial Cable



It consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor.
The inner conductor is held in place by either regularly spaced insulating rings or a solid dielectric material.
The outer conductor is covered with a jacket or shield.
Coaxial cable can be used over longer distances and support more stations on a shared line than twisted pair.

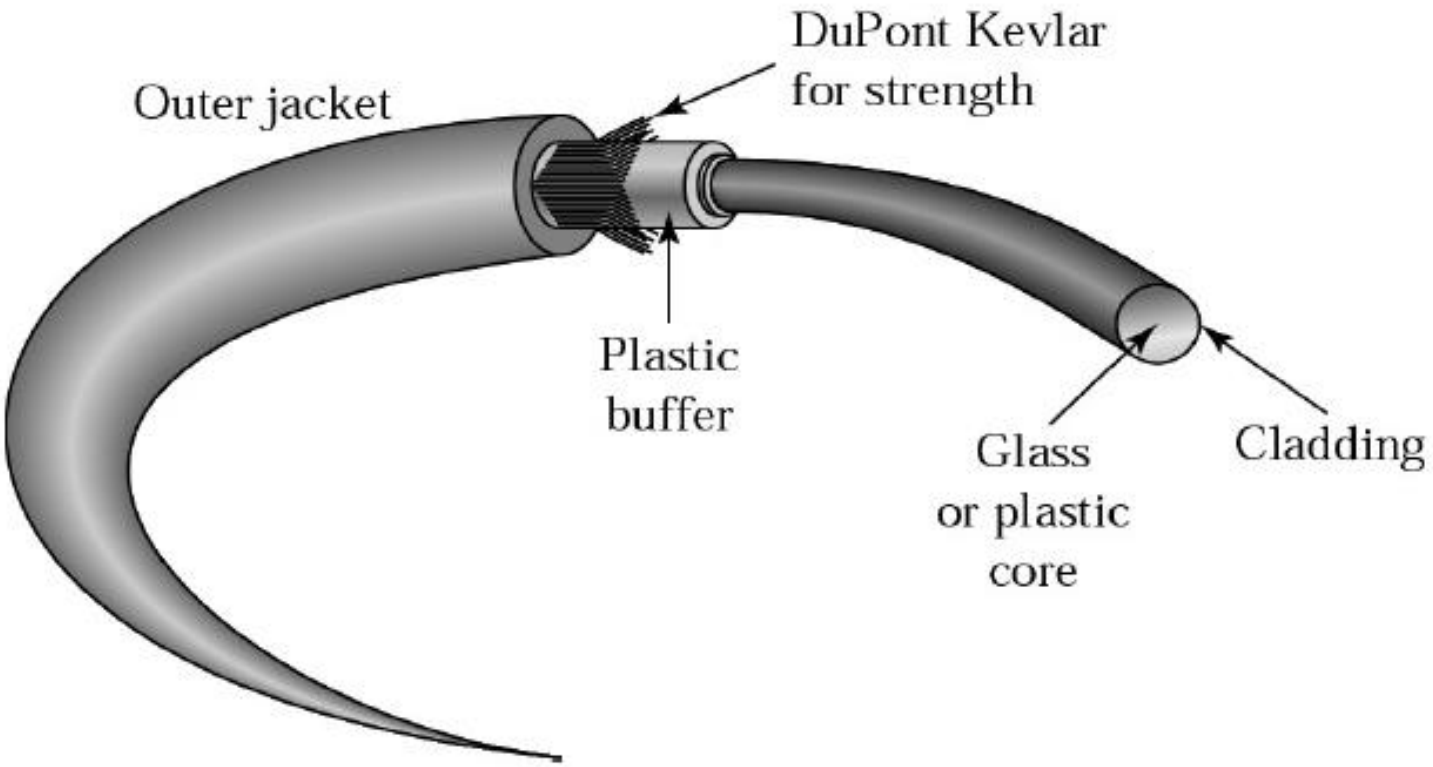
Coaxial Cable

- Advantages
  - Transmits up to 10Mbps over 500m
  - Easy to install
  - Low maintenance
  - Good resistance to noise over long distances
- Disadvantages
  - Inflexible
  - Low security
  - Limited distance

Thicknet and Thinnet

- **ThickNet**: This type of coaxial cabling is used with Ethernet 10Base5 networks and is able to span distances of up to 500 meters. RG-8/U cable is used as thick cable in thicknet based LAN network.
- **ThinNet:** A much thinner and more flexible type of coaxial cable, ThinNet is used on Ethernet 10Base2 networks and can span distances of up to 185 meters. RG-58/U is used as thin cable in thinnet based LAN network.

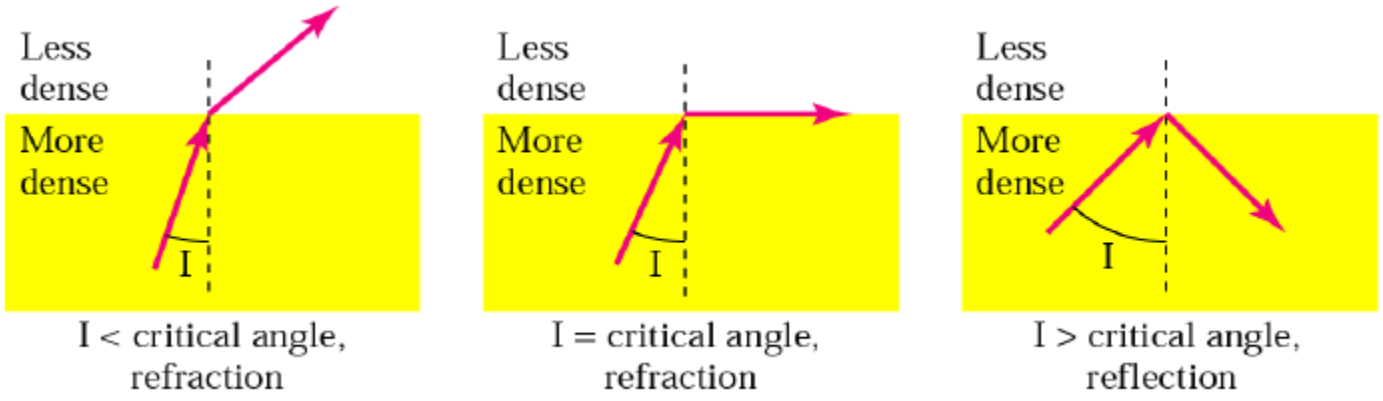
Optical fiber

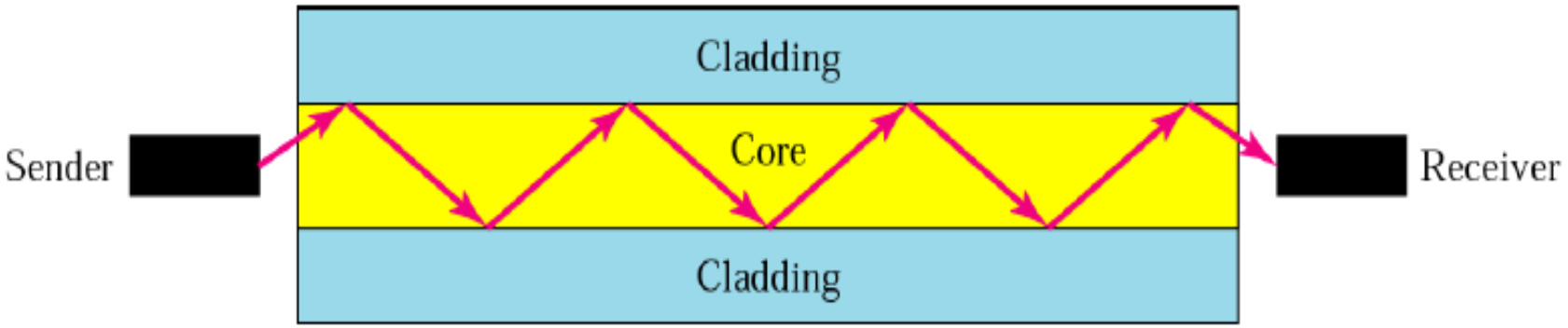


- We must have a light source in order to send the data. It sends a ray of light for each 1 bit, and no light for a 0 bit.
- We must have a detector to detect the light signal. The detector emits an electric pulse for each light ray it detects.
- The slowest part of the system is the conversion that happens at either end

Composition

- Consist extremely thin cylinder glass called Core
- Surrounded by a concentric layer known as cladding
- Each glass strand passes signals in only one direction, a cable includes two strands in separate jackets.


Less dense
More dense
I
I < critical angle, refraction
Less dense
More dense
I
I = critical angle, refraction
Less dense
More dense
I
I > critical angle, reflection


Cladding
Core
Cladding
Sender
Receiver

Fiber Optics: Advantages

- High data rate and wide bandwidth
- Low attenuation (data loss)
- Longer distance - 2 and 5 km with Multimode fiber or over 25 km with Single Mode fiber
- Small cable diameter fits anywhere
- No sparks if cut
- No shock hazard
- Secure communications
- Longer life expectancy than copper or coaxial cable
- Cabling of the future

Optical Fiber :Disadvantages

- Expensive
- Difficult to install
- Require two cables to transmit & receive data
- Require special connections

Optical Fiber : Types

1. Multimode (MM)
   - Larger Core Diameter
   - propagate more than one mode of light
   - Suited for Short distance Transmission
   - Bending losses should be avoided by using large bending radius
2. Single Mode (SM)
   - Only One mode of Light will propagate
   - Suited for Long distance transmission
   - Bending losses should be avoided by using large bending radius

Unguided Transmission Media

Bluetooth

- Developed by SIG (Special Interest Group)
- Bluetooth is defined by the IEEE 802.15 Standard.
- It defines Wireless PAN operable in an area of room or a hall.
- Used Technology Called FHSS
  - Frequency Hopping Spread Spectrum
- When two Bluetooth devices notice each other they create a network called a Piconet

Bluetooth Architecture

- Piconet
- Scatternet

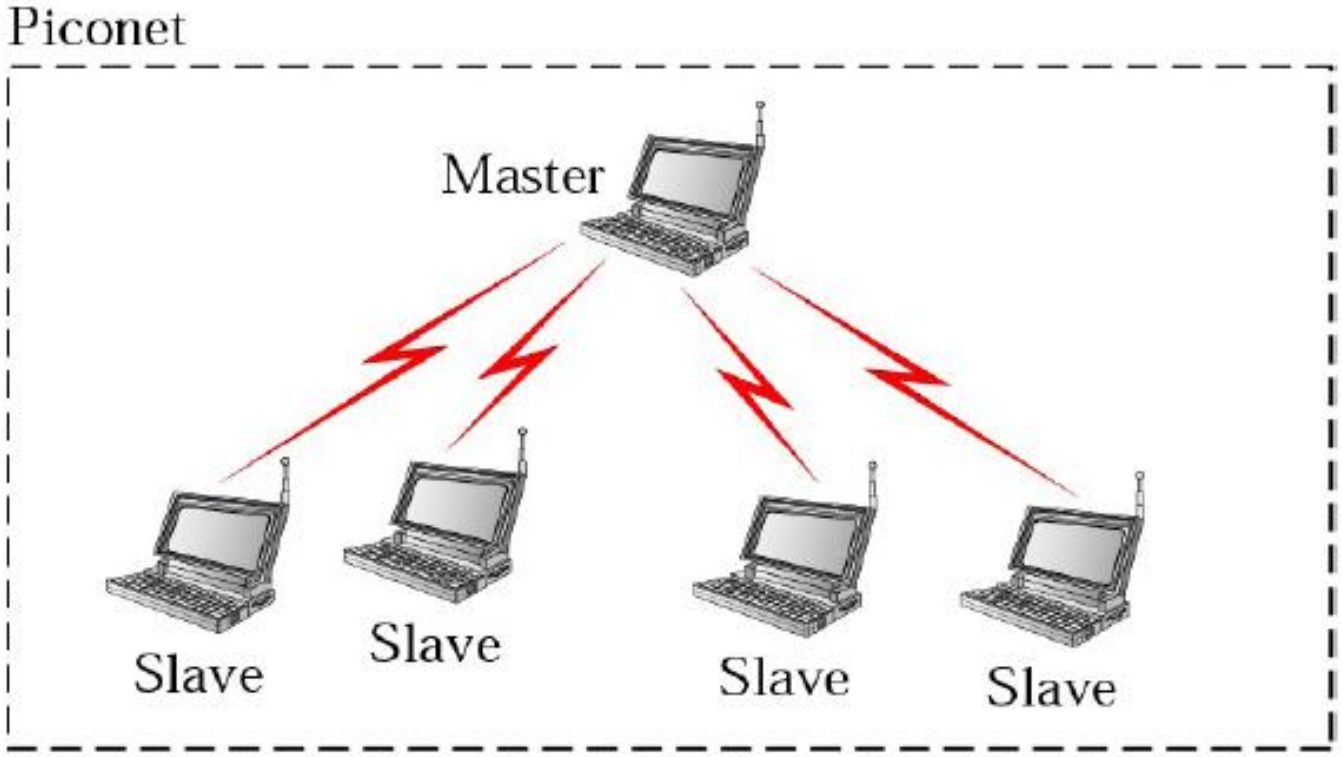


Figure: Piconet

- It uses a master/slave model to control when and where devices can send data.
  - a single master device can be connected to up to seven different slave devices.
  - Any slave device in the piconet can only be connected to a single master.
- The master coordinates communication throughout the piconet.
  - It can send data to any of its slaves and request data from them as well.
  - Slaves are only allowed to transmit to and receive from their master.
  - They can’t talk to other slaves in the piconet.

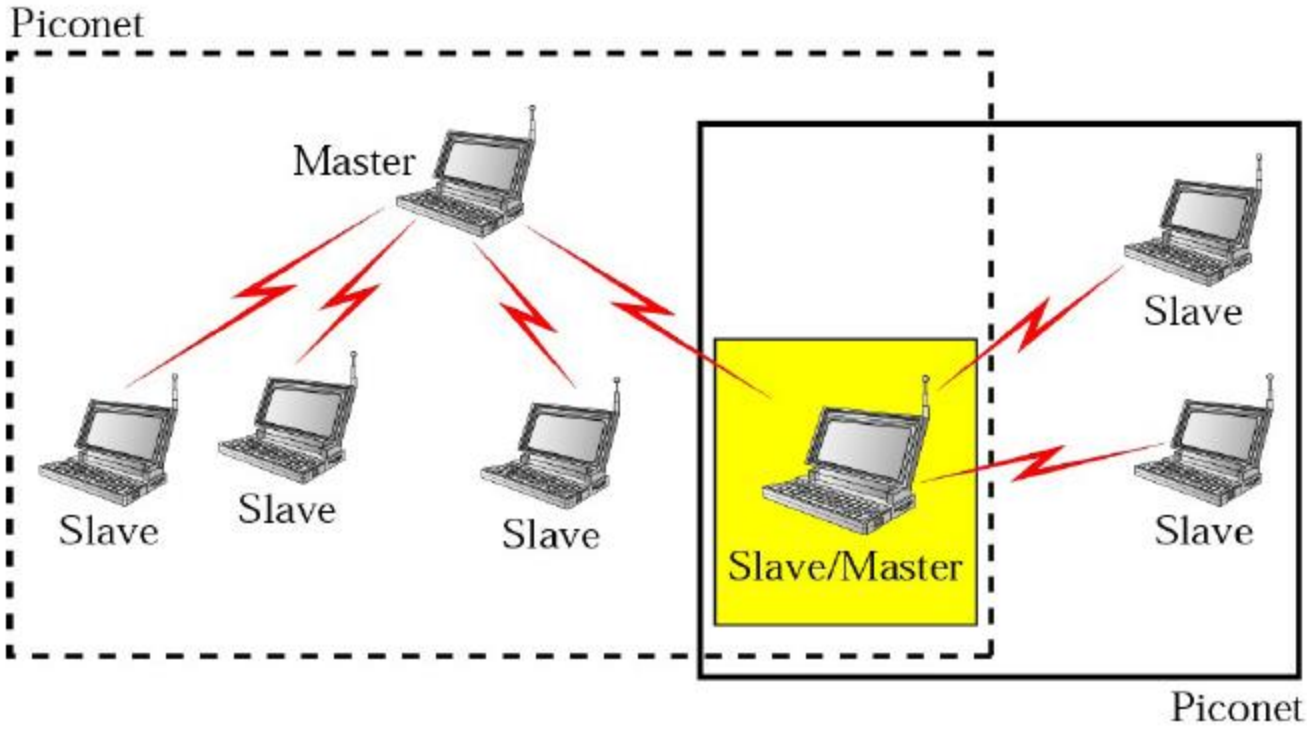


Figure: Scatternet

WiFi /Wireless LAN

- Popular wireless networking technology
- Use radio waves to provide wireless high-speed Internet
- Defined by IEEE 802.11 Standards
  - 802.11a
  - 802.11b
  - 802.11g
  - 802.11n
- WiFi-Alliance Owns the registered trademark of WiFi

Advantages

- Freedom – You can work from any location that you can get a signal.
- Setup Cost – No cabling required.
- Flexibility – Quick and easy to setup in temporary or permanent space.
- Scalable– Can be expanded with growth.
- Mobile Access – Can access the network on the move.

Disadvantages

- Speed – Slower than cable.
- Range – Affected by various medium.
- Reduced by walls, glass, water, etc
- Security – Greater exposure to risks
- Unauthorized access.

Infrared Transmission

- Unguided infrared waves are widely used for short-range communication.
- The remote controls used for televisions, VCRs, and stereos all use infrared communication.
- They are relatively directional, cheap, and easy to build
- have a major drawback: they do not pass through solid objects.

Satellite Communication

Basics: How do Satellites Work

- Two Stations on Earth want to communicate through radio broadcast but are too far away to use conventional means.
- The two stations can use a satellite as a relay station for their communication
- One Earth Station sends a transmission to the satellite. This is called a Uplink.
- The satellite Transponder converts the signal and sends it down to the second earth station. This is called a Downlink.

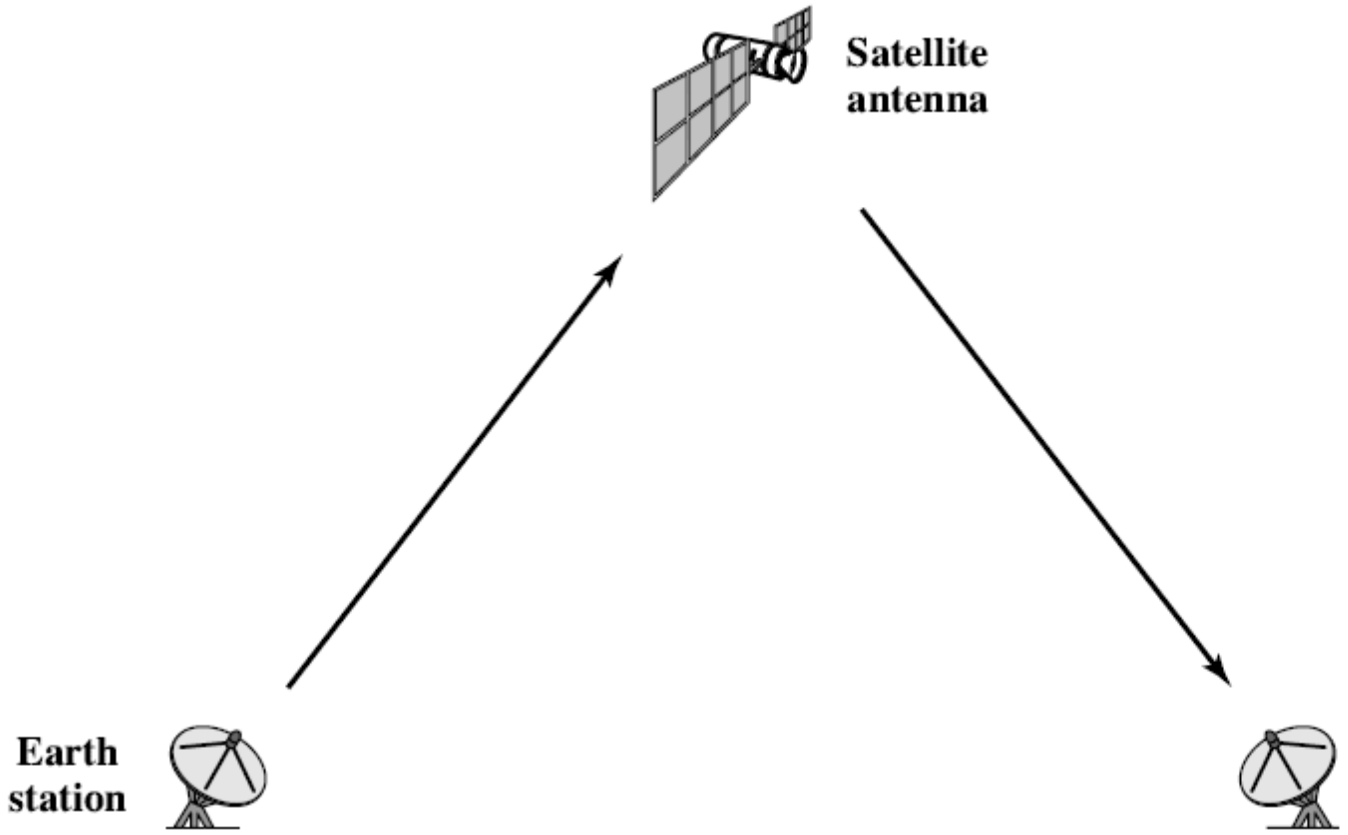
Advantages of Satellites

- The advantages of satellite communication over terrestrial communication are:
  - The coverage area of a satellite greatly exceeds that of a terrestrial system.
  - Transmission cost of a satellite is independent of the distance from the center of the coverage area.
  - Satellite to Satellite communication is very precise.
  - Higher Bandwidths are available for use.

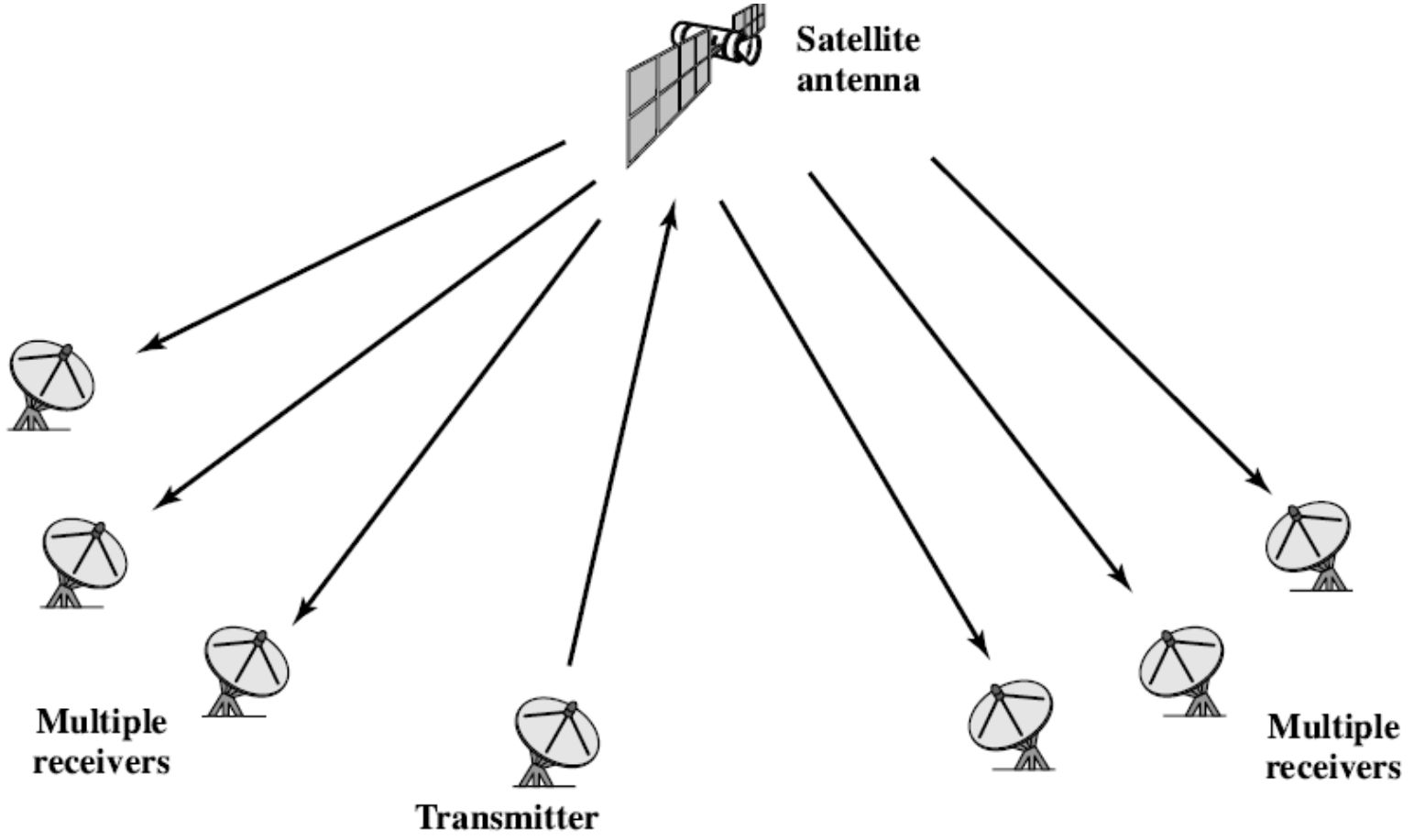
Disadvantages of Satellites

- The disadvantages of satellite communication:
  - Launching satellites into orbit is costly.
  - Satellite bandwidth is gradually becoming used up.
  - There is a larger propagation delay in satellite communication than in terrestrial communication.

Satellite Communication : Point to Point



Satellite Communication: Broadcast link



Geostationary Earth Orbit (GEO)

- These satellites are in orbit 35,786 km above the earth's surface along the equator.
- Objects in Geostationary orbit revolve around the earth at the same speed as the earth rotates. This means GEO satellites remain in the same position relative to the surface of earth.
- Geostationary satellites are commonly used for communications and weather-observation.
- The typical service life expectancy of a geostationary satellite is 10-15 years.

GEO Contd..

- Advantages
  - A GEO satellite's distance from earth gives it a large coverage area, almost a fourth of the earth's surface.
  - GEO satellites have a 24 hour view of a particular area.
  - These factors make it ideal for satellite broadcast and other multipoint applications.
- Disadvantages
  - A GEO satellite's distance cause it to have both a comparatively weak signal and a time delay in the signal, which is bad for point to point communication.
  - Because geostationary satellites circle the earth at the equator, they are not able to provide coverage at the Northernmost and Southernmost latitudes.

Low Earth Orbit (LEO)

- LEO satellites are much closer to the earth than GEO satellites, ranging from 500 to 1,500 km above the surface.
- LEO satellites don’t stay in fixed position relative to the surface, and are only visible for 15 to 20 minutes each pass.
- A network of LEO satellites is necessary for LEO satellites to be useful
- Starlink (SpaceX) used for Broadband internet, nearly 550 km orbit; thousands of satellites in constellation

LEO Contd..

- Advantages
  - A LEO satellite's proximity to earth compared to a GEO satellite gives it a better signal strength and less of a time delay, which makes it better for point to point communication.
  - Eliminates need for bulky receiving equipment.
  - Less waste of bandwidth.
- Disadvantages
  - A network of LEO satellites is needed, which can be costly
  - Smaller coverage area.

Medium Earth Orbit (MEO)

- A MEO satellite is in orbit somewhere between 8,000 km and 18,000 km above the earth's surface.
- MEO satellites are similar to LEO satellites in functionality.
- MEO satellites are visible for much longer periods of time than LEO satellites, usually between 2 to 8 hours.
- MEO satellites have a larger coverage area than LEO satellites.
- GPS (Global Positioning System) satellite orbiting at about 18000 Km are examples of MEO satellites.

MEO Contd..

- Advantage
  - A MEO satellite’s longer duration of visibility and wider footprint means fewer satellites are needed in a MEO network than a LEO network.
- Disadvantage
  - A MEO satellite’s distance gives it a longer time delay and weaker signal than a LEO satellite, though not as bad as a GEO satellite.

Radio waves

- Radio waves are a type of electromagnetic radiation with wavelengths in the electromagnetic spectrum longer than infrared light.
- Radio waves have frequencies from 3 KHz to as high as 300 GHz
- Transmitted through Omni-directional antennas
- Can travel long distances and penetrate walls
- Very sensible to interference

- Applications:
  - TV & radio broadcasting
  - Cordless phones

Microwave

- They range from 1 GHz to 300 GHz
- Unidirectional => Antennas must be aligned
- Propagation is line-of-sight (earth curvature is a problem)
- Cannot penetrate walls
- Higher data range than radio waves
- Part of the spectrum is regulated from authorities

Application

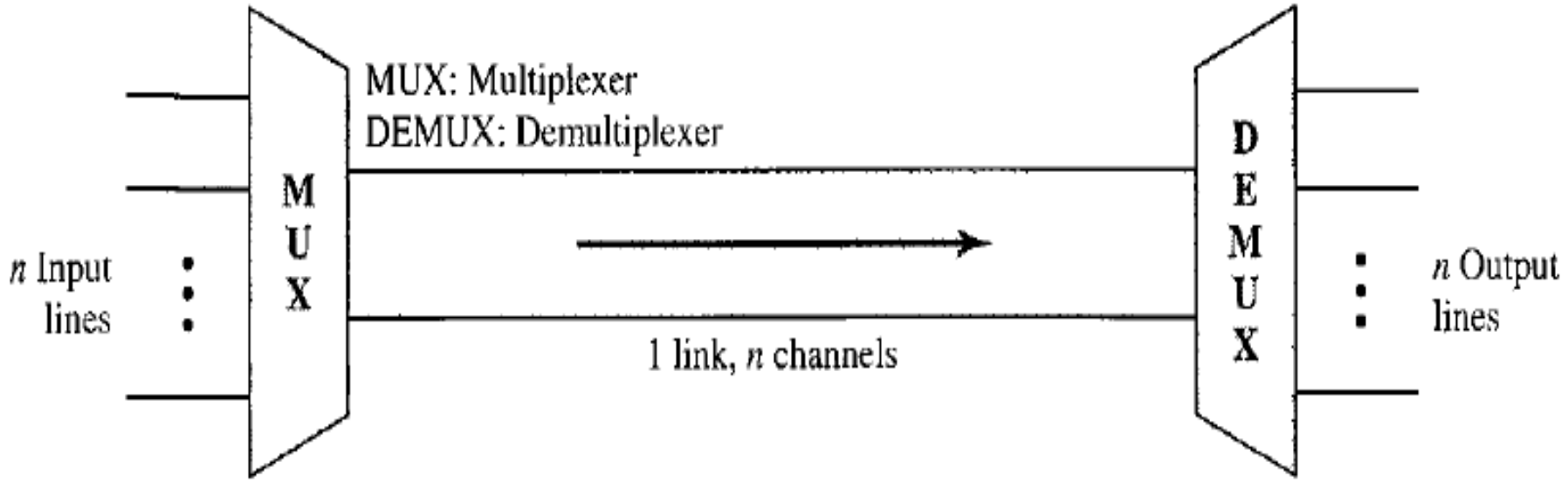
- long-distance telephone communication
- mobile phones
- television broadcast

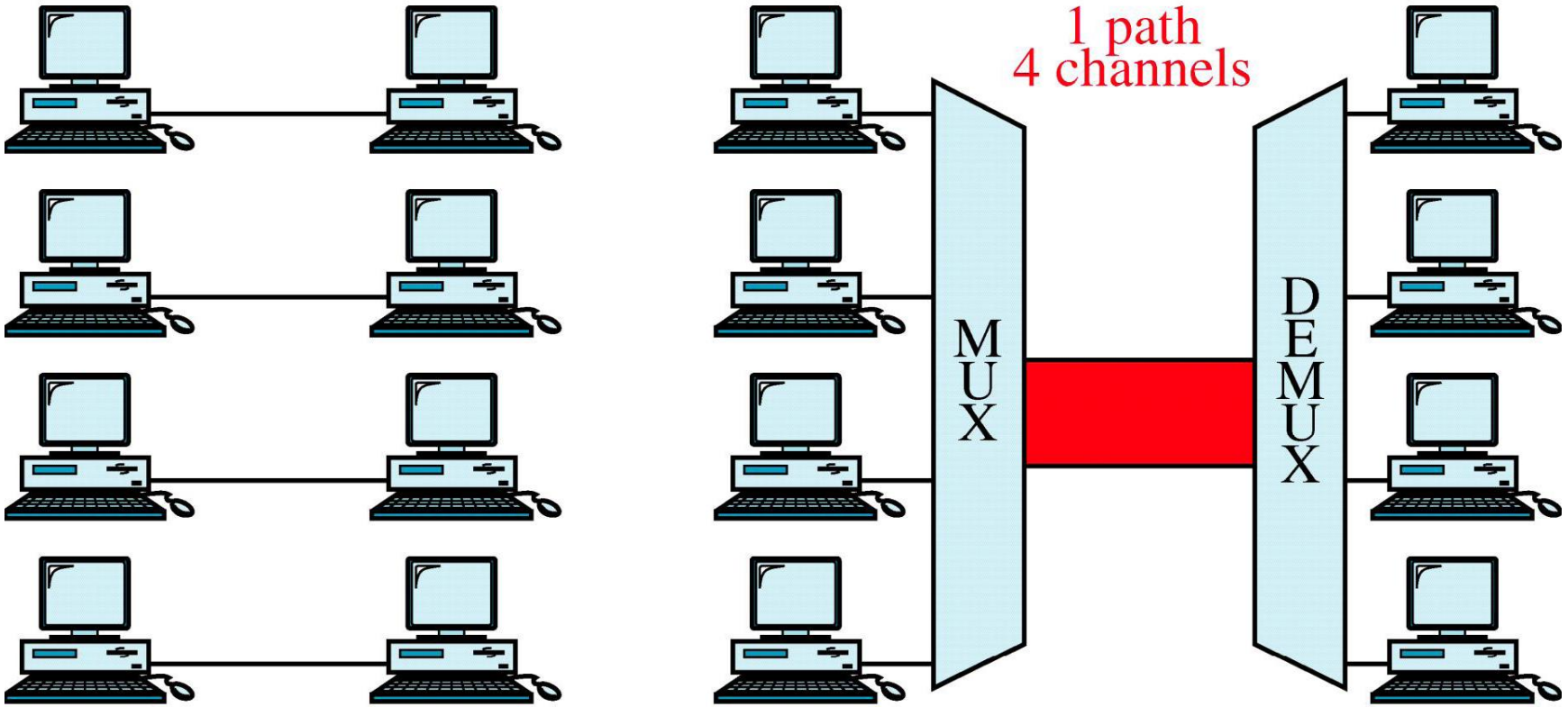
Factors to select media

- Cost
- Data rate and bandwidth
- Distance

Multiplexing

- It is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link.
- Multiplexing is done using a device called Multiplexer (MUX) that combine *n input lines to generate one output line i.e. (many to one).*
- At the receiving end a device called Demultiplexer (DEMUX) is used that separate signal into its component signals i.e. one input and several outputs *(one to many).*


MUX: Multiplexer
DEMUX: Demultiplexer
n Input lines
MUX
DEMUX
n Output lines
1 link, n channels



a. No multiplexing

b. Multiplexing

Types of Multiplexing

- Frequency Division Multiplexing.
- Wavelength Division Multiplexing.
- Time Division Multiplexing.
- Code Division Multiplexing.

Frequency Division Multiplexing (FDM)

- Rather than a single frequency, each channel is assigned a contiguous range of frequencies.
- Channels are separated from each other by *guard bands to make sure there is no interference among the channels.*
- FDM is used for FM radio broadcasting.
- FM frequency = 88 to 108 MHz.
- FDM is used in television broadcasting.
- First generation cellular telephone also uses FDM.

Channel	Frequencies Used
1	100 KHz - 300 KHz
2	320 KHz - 520 KHz
3	540 KHz - 740 KHz
4	760 KHz - 960 KHz
5	980 KHz - 1180 KHz
6	1200 KHz - 1400 KHz

Frequency assignment to channels with guard band between adjacent channels

Wavelength Division Multiplexing (WDM)

- In WDM different signals are *optical or light signals that are transmitted through optical fiber.*
- Various light waves from different sources are combined to form a composite light signal that is transmitted across the channel to the receiver.
- This Combining and the Splitting of light waves is done by using a PRISM.
- Prism bends beam of light based on the angle of incidence and the frequency of light wave.

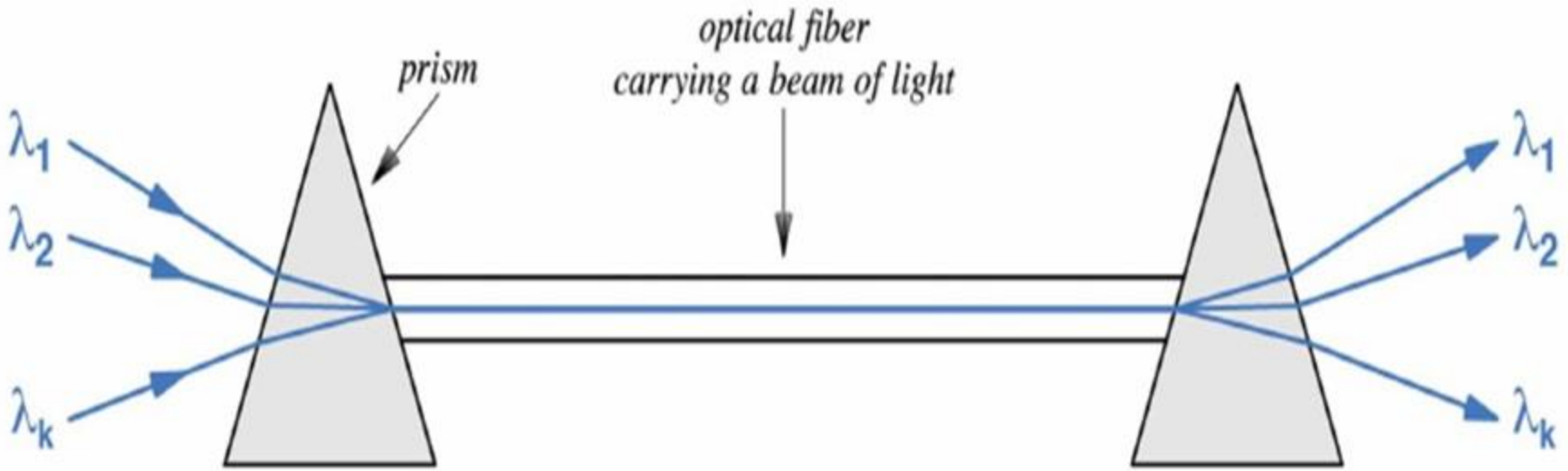
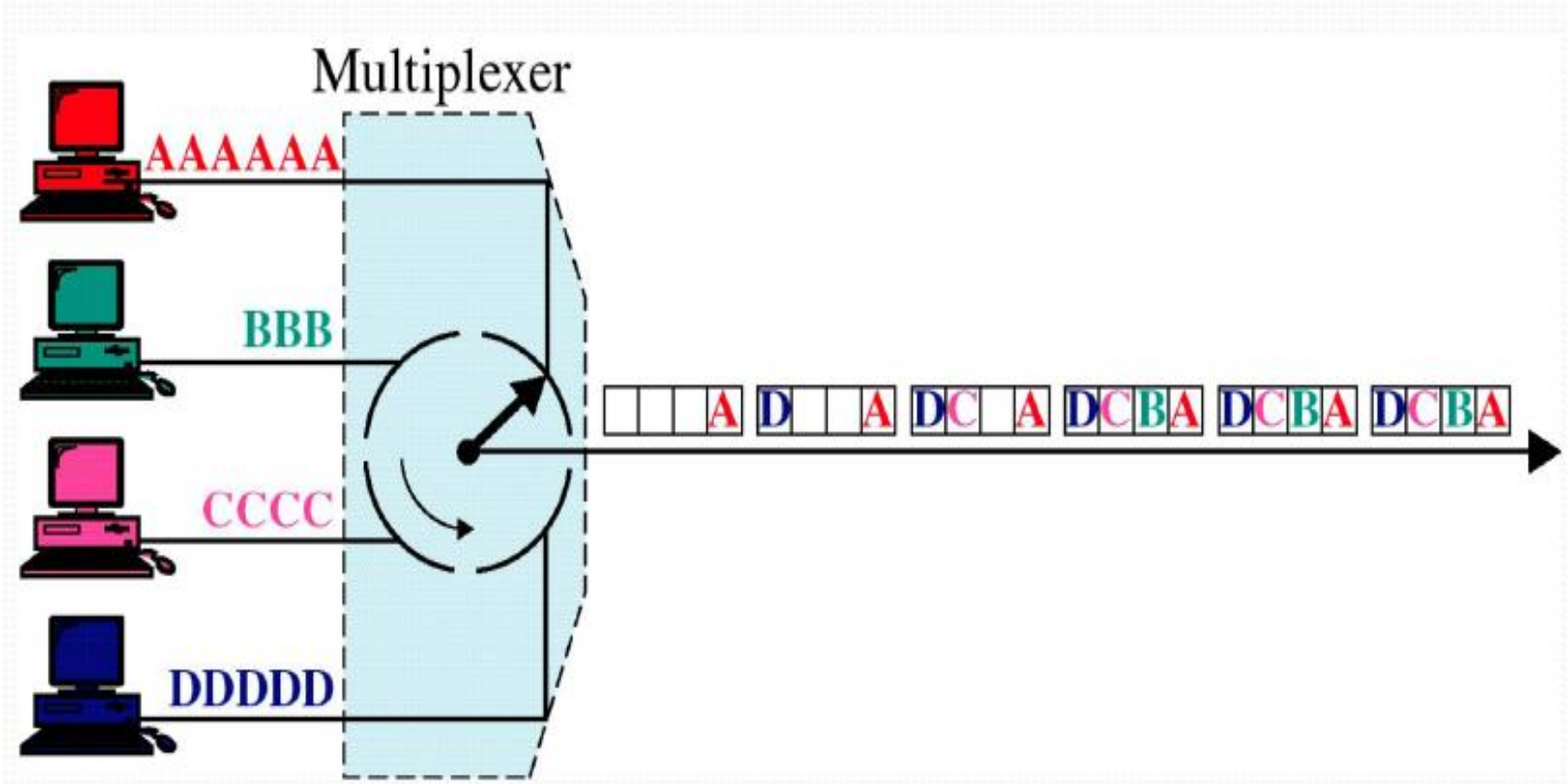


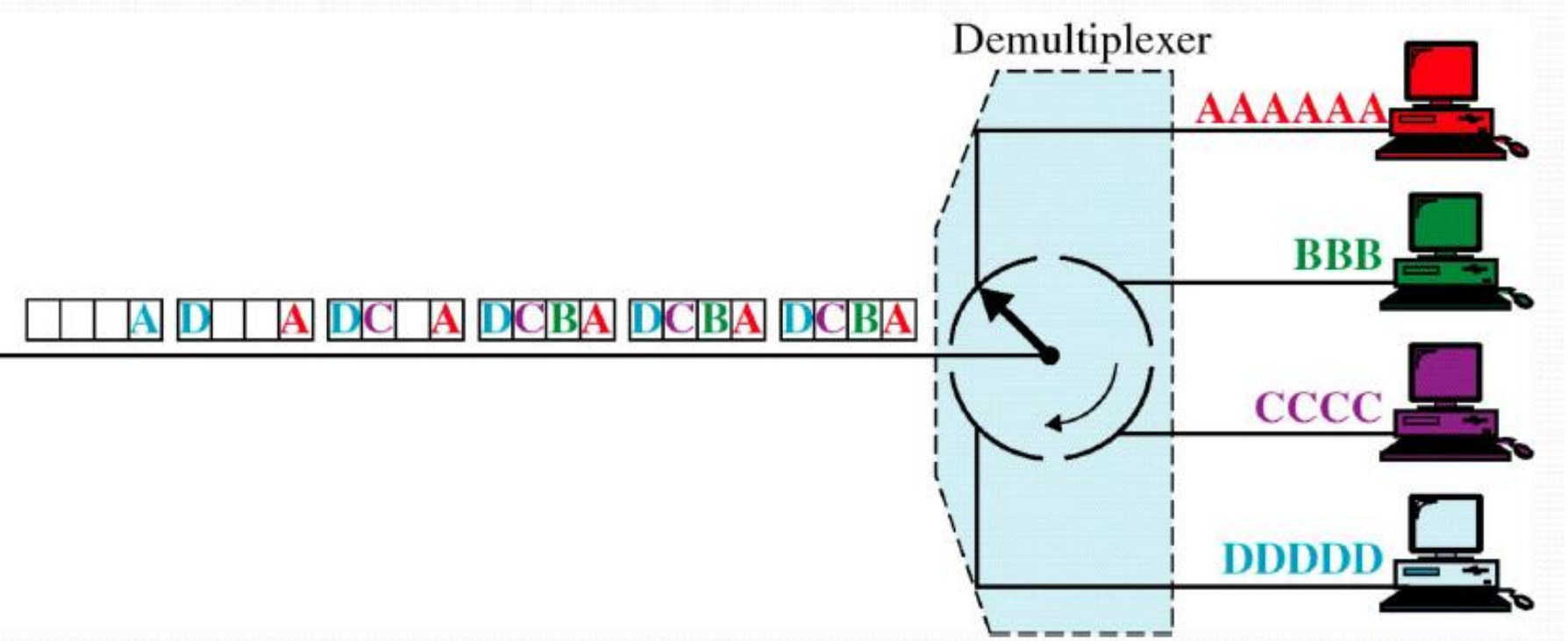
Illustration of prisms used to combine and separate wavelengths of light in wavelength division multiplexing technologies.

Time Division Multiplexing (TDM)

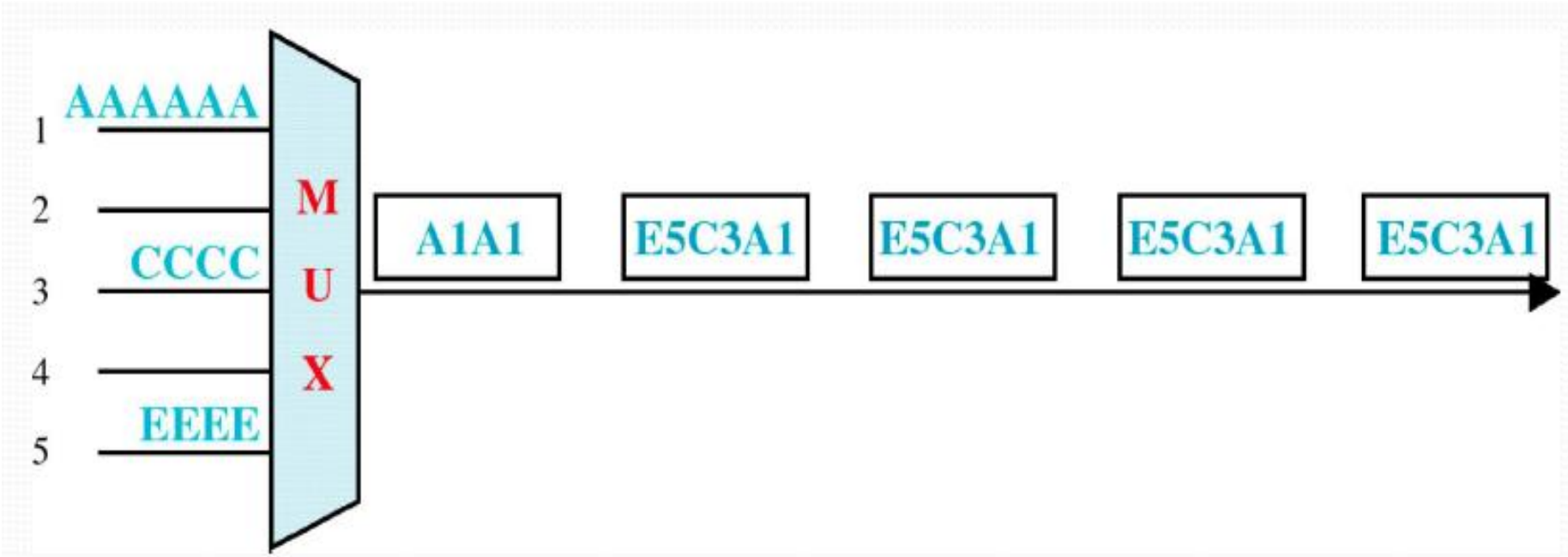
- All senders use the same frequency but at different points in time.
- Total time available in the channel is divided between several users.
- Each user is allotted a particular time interval called *time slot or slice.*
- Types of TDM
  - Synchronous TDM
  - Asynchronous (Statistical) TDM

Synchronous TDM




Demultiplexer
AAAAAA
BBB
CCCC
DDDDD
A
DA
DCA
DCBA
DCBA
DCBA

Asynchronous (Statistical) TDM

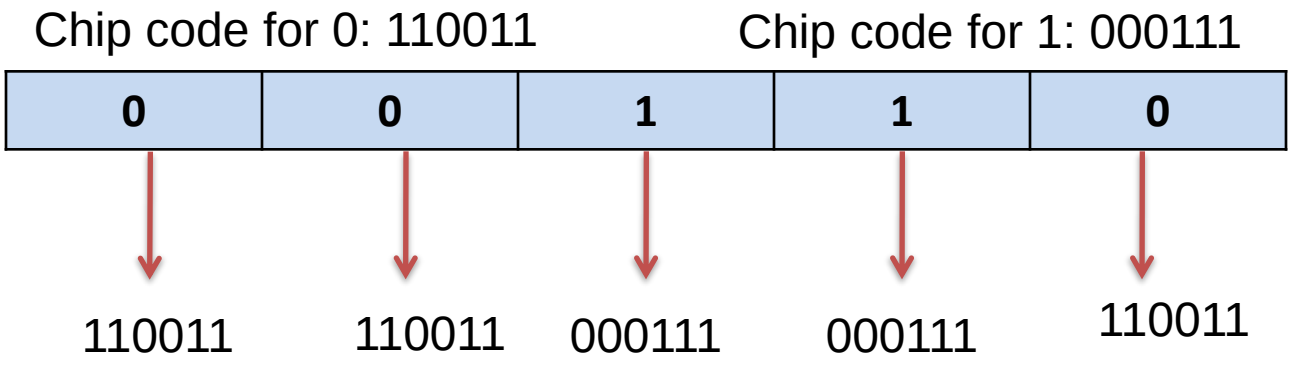


Code Division Multiplexing (CDM)

- Each channel has a unique code
- All channels use the same spectrum at the same time
- First used in military applications due to its inherent security features.
- Each sender is assigned a unique binary code: its *chip sequence*

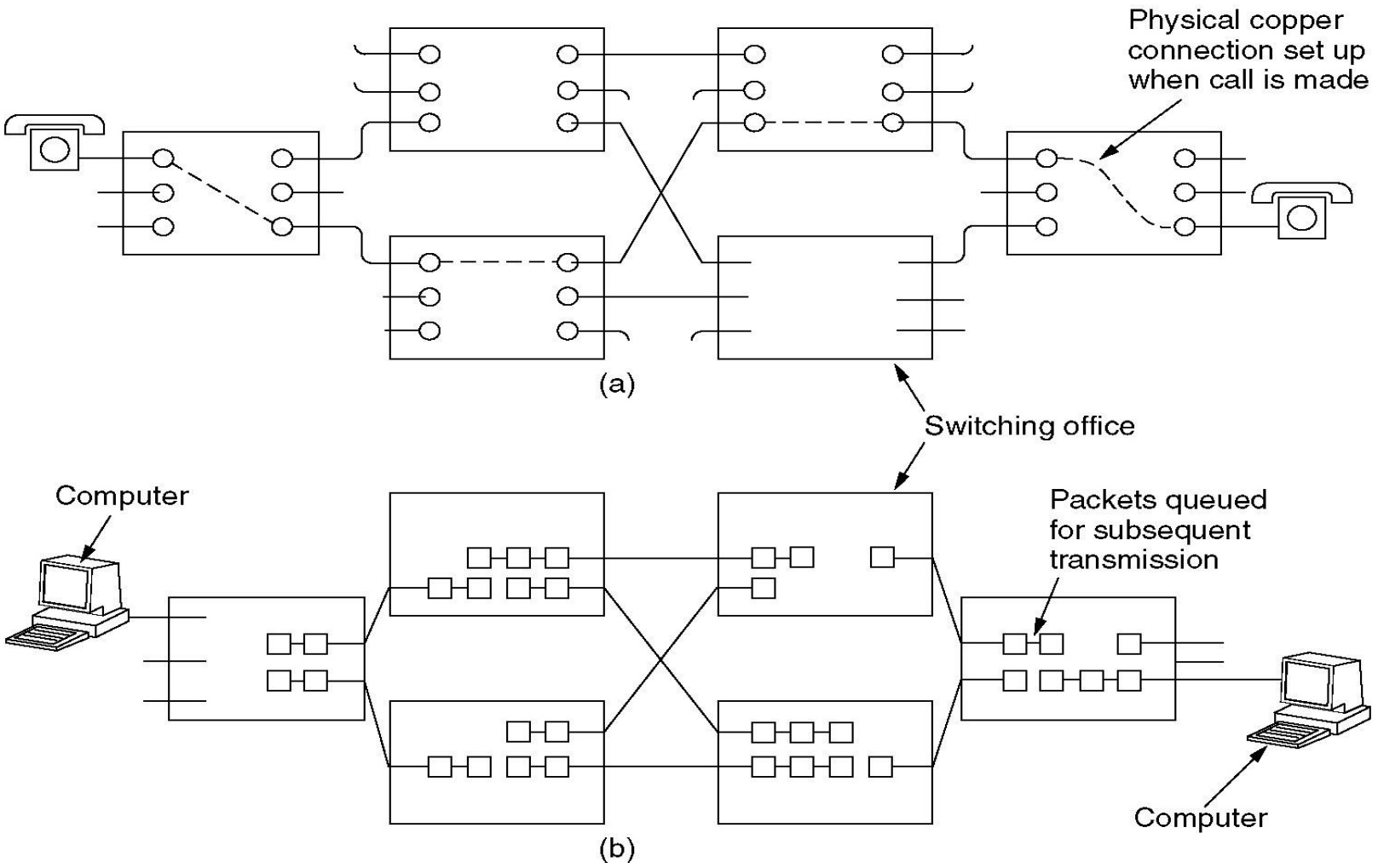
DSSS

- Direct Sequence Spread Spectrum
- The signal is spread over the entire spectrum, not specific frequencies within that spectrum.
- In DSSS, each bit sent is replaced by a sequence of bits called a chip code.
- XOR of the signal with pseudo-random number(chipping sequence)



Switching

- There are three different types of switching:
  - circuit switching
  - message switching
  - packet switching
- Circuit Switching
  - A physical connection is needed for the phone call to go through.
  - This used to be done by a person at a switchboard.
  - Now it is done automatically.
  - Setting up the circuit can still take time, depending on how far the call is going and how many switches it passes through.



(a) Circuit switching

(b) Packet switching

Message Switching

- No physical path is set up between the sender and receiver.
- The whole message (or block of data) is sent to the switching office.
- Once it has been received, it is inspected for errors and is then sent to the next switching office.
- This method is not used anymore.

Packet Switching

- There is no physical connection for packet switching.
- The data is broken up into packets by the sender and they are sent to the switching office.
- The first packet can easily be sent to the next switching office before the second packet has arrived.
- This makes packet switching useful for busy networks.
- Two Types of Packet Switching
  - Datagram Packet Switching
  - Virtual Circuit Packet Switching

Packet Switching: Datagram Packet Switching

- No need to establish the connection between the source and destination.
- Route chosen on packet by packet basis.
- Packets may be stored until delivered => (Store and Forward)
- Different packets may follow different routes.
- Packets may arrive out of order at the destination.

Packet Switching: Virtual Circuit Switching

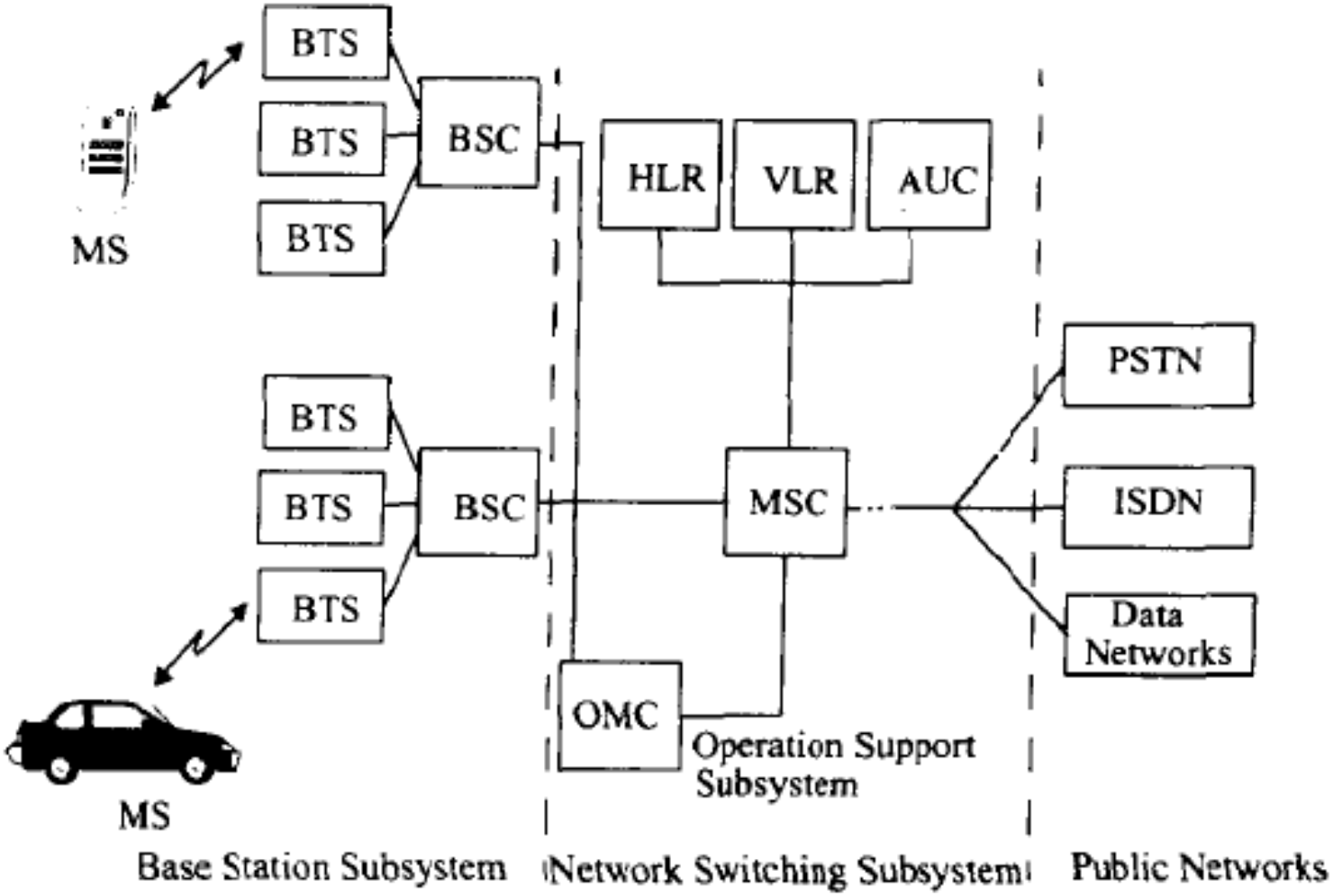
- Route is chosen at the start of session and it is only a logical connection.
- All Packets associated with a session follow the same path.
- Packets are labeled with a VC# designated the route.
- The VC number must be unique on a given link.
- Packets are forwarded more quickly. (No Routing Decisions)
- Example : Asynchronous Transfer Mode

Circuit vs Packet Switching

Item	Circuit-switched	Packet-switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
When can congestion occur	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Transparency	Yes	No
Charging	Per minute	Per packet

Comparison of Circuit and Packet Switching

Telecommunication switching system



GSM Architecture

ISDN

- Integrated Service Digital Network
- ITU Standard For global Digital Communication.
- It was Developed in 1984 to replace Analog Telephone System.
- Allow the Complete Integration of both Voice, Video and Data within a Single System.

ISDN Principles

- Support for switched and non-switched applications
  - both circuit-switched and packet-switched connections
  - also supports non-switched services in the form of dedicated lines
- Reliance on 64-kbps connections
  - fundamental block of ISDN
  - chosen because it was the standard rate for digitized voice

- Intelligence in the network
  - sophisticated services beyond simple setup a circuit-switched call
  - sophisticated network management and maintenance capabilities
- Layered protocol architecture
  - user access to ISDN protocol is a layered architecture that can be mapped to OSI model
    - Already developed standards for OSI may be used for ISDN (e.g. X.25)
    - New ISDN standard can be based on existing ones (LAPD based on LAPB)
    - Standards can be developed independently for various layers and functions

- Variety of configurations
  - More than one physical configuration is possible for implementing ISDN

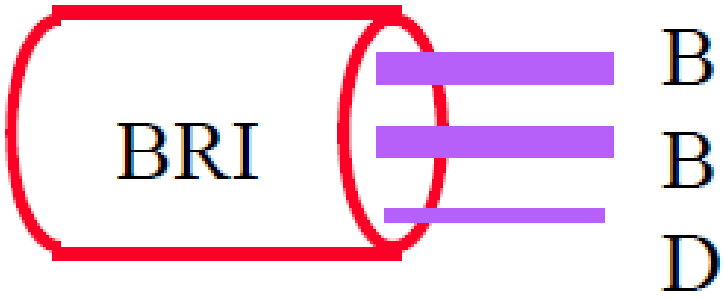
ISDN Channels

- B-channel
  - 64 kbps
  - basic user channel
  - can carry digital data, PCM-encoded digital voice, or a mixture of lower-rate traffic
  - supports circuit-switched, packet-switched
- D-channel
  - 16 or 64 kbps
  - carries signaling information to control circuit switched calls on B-channel
    - ➢who is calling
    - ➢type of call
    - ➢calling what number

- H-channel
  - 384 (H0), 1536 (H11), 1920 (H12) kbps
  - is a high-speed channel
  - can be used as a single trunk or subdivided by the user fast fax, video, high-speed data, high-quality audio and multiplexed information streams at lower data rates

ISDN Services Types

- Also called ISDN Interface
- Basic Rate Interface(BRI)
  - 2B channels + 1 D channel
  - 2 × 64 + 16= 144 kbps (192 kbps total)



- Primary Rate Interface(PRI)
  - Especially for LAN
  - T1 connection: 23B+D
    - American Standards
    - Data rate 23*64Kbps + 64Kbps + 8bits header
    - Information = 1544kbs = 1.544Mbps
  - E1 Connection: 30B+D
    - European Standards
    - 30*64Kbps + 64Kbps +64Kbps
    - 2048Kbps=2.048Mbps
    - Last D channel for Framing and Synchronization in E1 Connections

ISDN Architecture

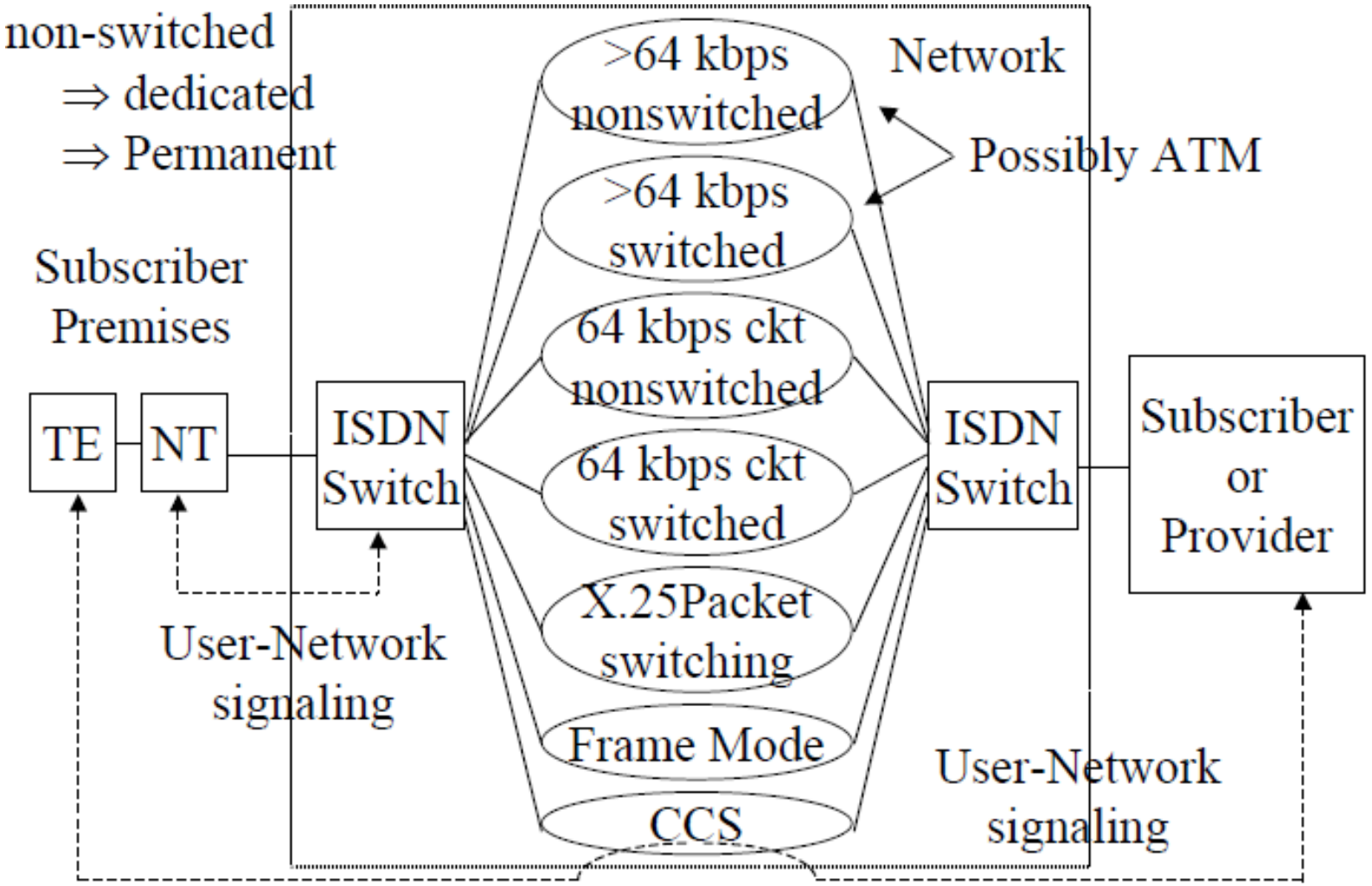


Fig: ISDN Architecture

ISDN Architecture

- Circuit-switched capabilities : 64-kbps
- Non-switched capabilities : 64 kbps dedicated link, higher data rate provided by BISDN
- Switched capabilities : > 64 kbps switched connections using ATM as part of BISDN
- Packet-switching capabilities : as provided by other data networks
- Frame-mode capabilities : supporting frame relay
- Common-channel signaling capabilities : used to control the network and provide call management.

ISDN Signaling

- The signaling method will be Common Channel Signaling (CCS).
  - the signaling information relating to a multiplicity of channels or functions or for network management, is conveyed over a single channel by addressed messages.
  - CCS will be able to operate in two modes:

    1) associated mode (i.e. signaling points, that are the origin and destination points of the messages are directly interconnected by a link)

    2) quasi-associated mode (i.e. messages pass through one or more signaling points other than those which are the origin or destination of the messages. The path is pre-determined).

THANK YOU !!