Module 3: Physical Layer

Introduction to Networks v7.0
(ITN)

The Physical Connection

- Before any network communications can occur, a physical connection to a local network must be established.
- This connection could be wired or wireless, depending on the setup of the network.
- This generally applies whether you are considering a corporate office or a home.
- A Network Interface Card (NIC) connects a device to the network.
- Some devices may have just one NIC, while others may have multiple NICs (Wired and/or Wireless, for example).
- Not all physical connections offer the same level of performance.

Physical Components

Physical Layer Standards address three functional areas:

- Physical Components
- Encoding
- Signaling

The Physical Components are the hardware devices, media, and other connectors that transmit the signals that represent the bits.

- Hardware components like NICs, interfaces and connectors, cable materials, and cable designs are all specified in standards associated with the physical layer.

3.1 Physical media

Copper Cabling

Copper cabling is the most common type of cabling used in networks today. It is inexpensive, easy to install, and has low resistance to electrical current flow.

Limitations:

- Attenuation – the longer the electrical signals have to travel, the weaker they get.
- Interference - which can distort and corrupt the data signals, divided to: Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI).
- Crosstalk- Caused by undesired capacitive, inductive, or conductive coupling from one circuit or channel to another.

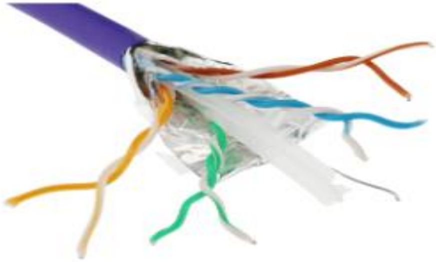
Mitigation:

- Limiting the length of the copper cable will mitigate attenuation.
- Using metallic shielding and grounding will mitigate EMI and RFI.
- twisting opposing circuit pair wires together will mitigate crosstalk.

physical media

Types of Copper Cabling

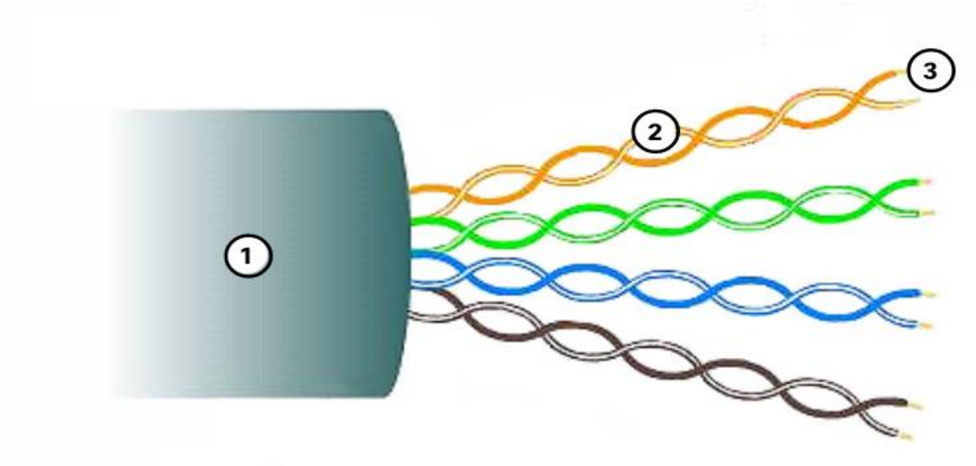
Unshielded Twisted-Pair (UTP) Cable



Shielded Twisted-Pair (STP) Cable

Coaxial Cable

Unshielded Twisted Pair (UTP)



RJ-45 Connector

- UTP is the most common networking media.
- Interconnects hosts with intermediary network devices.
- Terminated with RJ-45 connectors

Key Characteristics of UTP

(1) The outer jacket protects the copper wires from external damages.

(2) Twisted pairs protect the signal from interference.

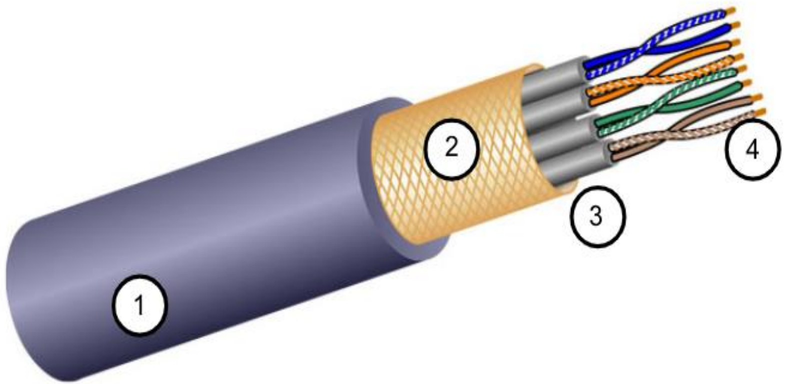
(3) Color-coded plastic insulation protect the signal from crosstalk.

Copper Cabling

UTP Categories

UTP Category	Data Rate	Max. Length	Cable Type	Application
CAT1	Up to 1Mbps	-	Twisted Pair	Old Telephone Cable
CAT2	Up to 4Mbps	-	Twisted Pair	Token Ring Networks
CAT3	Up to 10Mbps	100m	Twisted Pair	Token Rink & 10BASE-T Ethernet
CAT4	Up to 16Mbps	100m	Twisted Pair	Token Ring Networks
CAT5	Up to 100Mbps	100m	Twisted Pair	Ethernet, FastEthernet, Token Ring
CAT5e	Up to 1 Gbps	100m	Twisted Pair	Ethernet, FastEthernet, Gigabit Ethernet
CAT6	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (55 meters)
CAT6a	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (55 meters)
CAT7	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (100 meters)

Shielded Twisted Pair (STP)

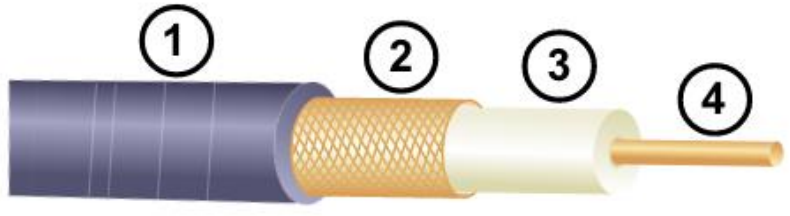


- Better noise protection than UTP
- More expensive than UTP
- Harder to install than UTP
- Terminated with RJ-45 connectors
- Interconnects hosts with intermediary network devices

Key Characteristics of STP

1. The outer jacket protects the copper wires from external damage
2. Braided or foil shield provides EMI/RFI protection
3. Foil shield for each pair of wires provides EMI/RFI protection
4. Color-coded plastic insulation protect the signal from crosstalk.

Coaxial Cable



Commonly used in the following situations:

- Wireless installations - attach antennas to wireless devices
- Cable internet installations - customer premises wiring

Key Characteristics

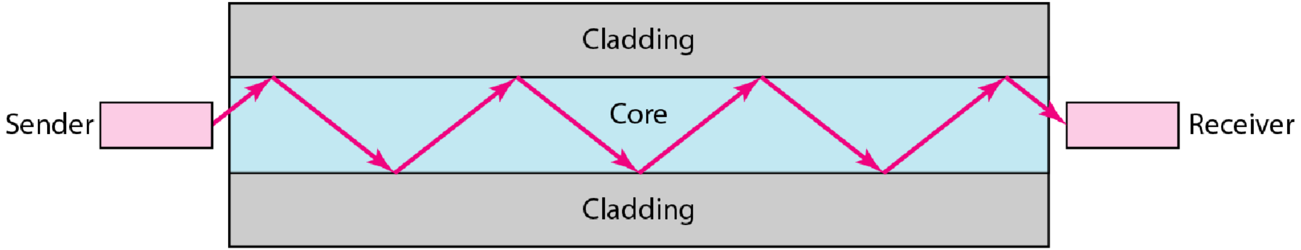
1. Outer cable jacket to prevent minor physical damage
2. A metallic foil, acts as the second wire in the circuit and as a shield for the inner conductor.
3. A layer of flexible plastic for isolate the two wires
4. A copper conductor is used to transmit the electronic signals.

Coaxial Connectors

BNC	N type	F type

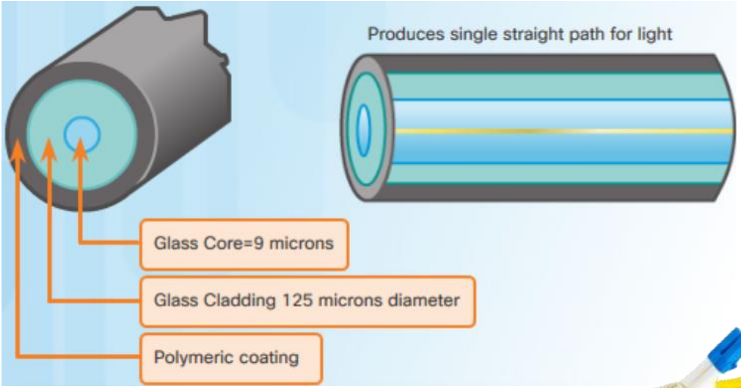
Properties of Fiber-Optic Cabling

- Made of flexible, extremely thin strands of very pure glass
- Uses a **laser or LED** to encode bits as pulses of light
- The fiber-optic cable acts as a **wave guide** to transmit light between the two ends with minimal signal loss
- Not as common as UTP because of the involved **cost.**
- Transmits data over **longer distances** at **higher bandwidth** than any other networking media
- Less susceptible to **attenuation**, and completely immune to **EMI/RFI**



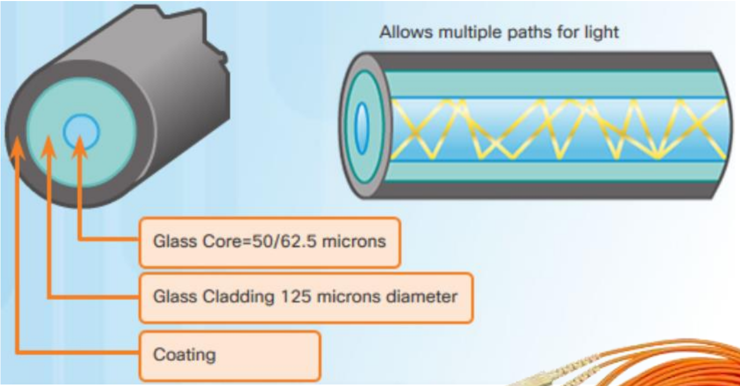
Types of Fiber Media

Single-Mode Fiber (SMF)



- Very small core
- Uses expensive LASERs
- Higher Bandwidth (< 100 Gbps)
- A achieved distance 100 km

Multi-Mode Fiber (MMF)



- Larger core
- Uses less expensive LEDs
- Less Bandwidth (< 100 Mbps)
- A achieved distance 1 km

MMF has greater **dispersion** than SMF, with a the maximum cable distance for MMF is 550 meters.

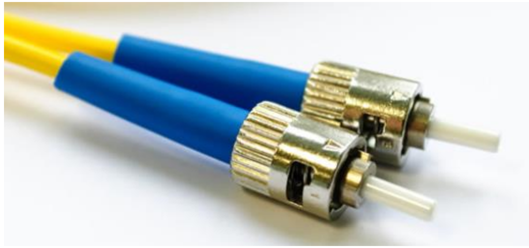
* **Dispersion** refers to the spreading out of a light pulse over time. Increased dispersion means increased loss of signal strength.

Fiber-Optic Cabling Usage

Fiber-optic cabling is now being used in four types of industry:

1. **Enterprise Networks -** Used for backbone cabling applications and interconnecting infrastructure devices
2. **Fiber-to-the-Home (FTTH) -** Used to provide always-on broadband services to homes and small businesses
3. **Long-Haul Networks -** Used by service providers to connect countries and cities
4. **Submarine Cable Networks -** Used to provide reliable high-speed, high-capacity solutions capable of surviving in harsh undersea environments at up to transoceanic distances.

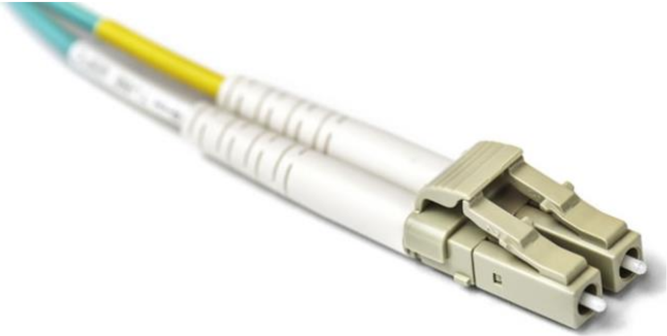
Fiber-Optic Connectors



Straight-Tip (ST) Connectors

Lucent Connector (LC) Simplex Connectors

Subscriber Connector (SC) Connectors



Duplex Multimode LC Connectors

Fiber versus Copper

Optical fiber is primarily used as backbone cabling for high-traffic, point-to-point connections between data distribution facilities and for the interconnection of buildings in multi-building campuses.

Implementation Issues	UTP Cabling	Fiber-Optic Cabling
Bandwidth supported	10 Mb/s - 10 Gb/s	100 Mb/s - 100 Gb/s
Distance	Relatively short (1 - 100 meters)	Relatively long (2 - 100) km
Immunity to EMI and RFI	Low	High (Completely immune)
Immunity to electrical hazards	Low	High (Completely immune)
Media and connector costs	Lowest	Highest
Installation skills required	Lowest	Highest
Safety precautions	Lowest	Highest

Properties of Wireless Media

It carries electromagnetic signals representing binary digits using radio or microwave frequencies. This provides the greatest mobility option. Wireless connection numbers continue to increase.

Some of the limitations of wireless:

- **Coverage area** - Effective coverage can be significantly impacted by the physical characteristics of the deployment location.
- **Interference** - Wireless is susceptible to interference and can be disrupted by many common devices.
- **Security** - Wireless communication coverage requires no access to a physical strand of media, so anyone can gain access to the transmission.
- **Shared medium** - WLANs operate in half-duplex, which means only one device can send or receive at a time. Many users accessing the WLAN simultaneously results in reduced bandwidth for each user.

Types of Wireless Media

In general, a Wireless LAN (WLAN) requires the following devices:

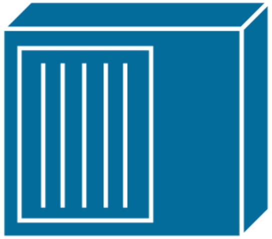
- ✓ **Wireless Access Point (AP)** - Concentrate wireless signals from users and connect to the existing copper-based network infrastructure
- ✓ **Wireless NIC Adapters** - Provide wireless communications capability to network hosts

The IEEE and telecommunications industry standards for wireless data communications cover both the data link and physical layers. These standards are:

- ❑ **Wi-Fi (IEEE 802.11)** - Wireless LAN (WLAN) technology
- ❑ **Bluetooth (IEEE 802.15)** - Wireless Personal Area network (WPAN) standard
- ❑ **WiMAX (IEEE 802.16)** - Uses a point-to-multipoint topology to provide broadband wireless access
- ❑ **Zigbee (IEEE 802.15.4)** - Low data-rate, low power-consumption communications, primarily for Internet of Things (IoT) applications

3.2 Physical Layer Connecting Devices

Hubs



1- Hubs

- ✓ Acts in the physical layer (deals with bits)
- ✓ Used to connect stations adapters in a **star topology**
- ✓ Hub receives a bit from an adapter and sends it to all the other adapters **without implementing any access method**.
- ✓ replicate the received frame onto all other links without filtering (forwarding a frame to a designated destination or dropping it).
- ✓ Multiple Hubs can be used **to extend** the network length
- ✓ Hub forms a single collision domain, and a single Broadcast domain

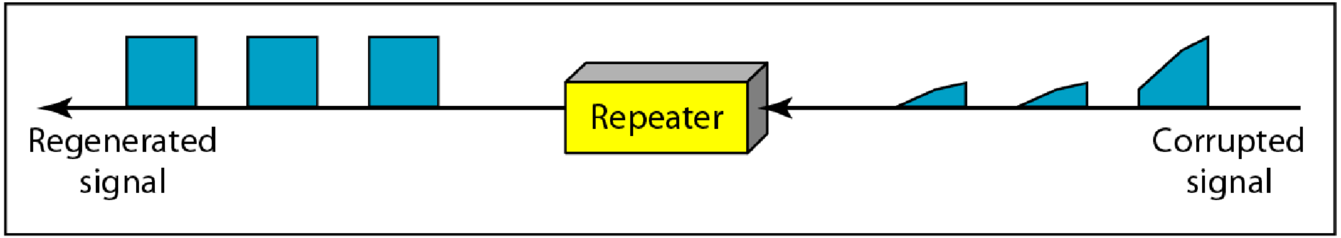
Repeaters

2- Repeaters

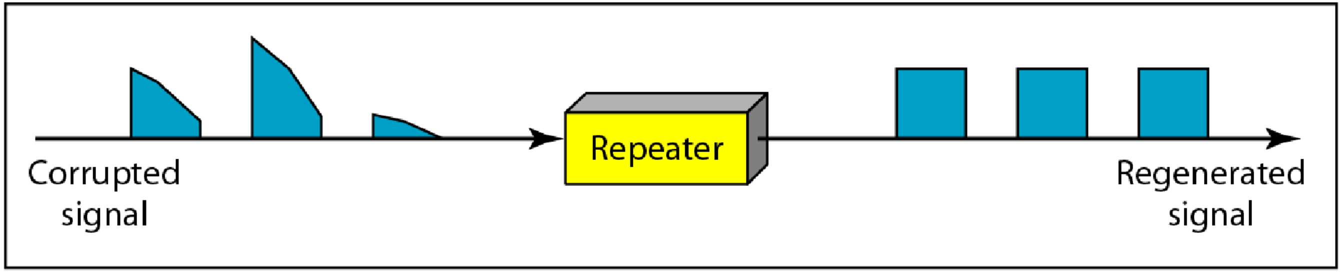
- A **physical layer** device (deals with bits)
- When a bit arrives, the repeater receives it and **regenerates** it and transmits it to all other interfaced devices
- Used in LAN to connect cable segments and **extend** the maximum cable length (extending the geographical LAN range)

- Repeaters do not implemented for access method (**collision** will happened if any two connected segments transmit at the same time**)**

Repeaters(contd.)



a. Right-to-left transmission.



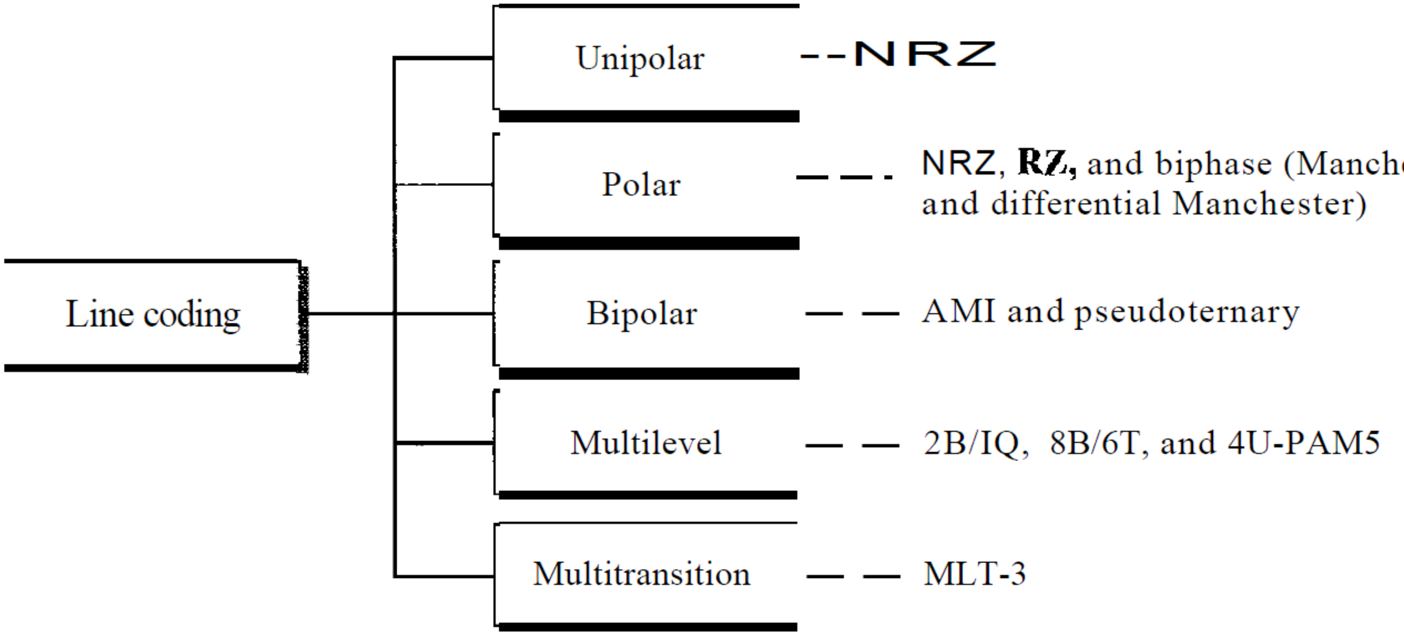
b. Left-to-right transmission.

Function of Repeaters for regenerates corrupted signal

3.3 Encoding and Signaling

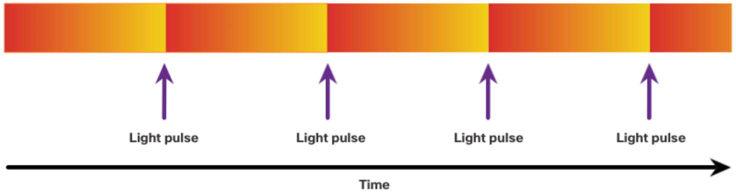
Encoding

- Encoding converts the stream of bits into a format recognizable by the next device in the network path.
- This ‘coding’ provides predictable patterns that can be recognized by the next device.
- The following chart shows a scheme of line coding methods:

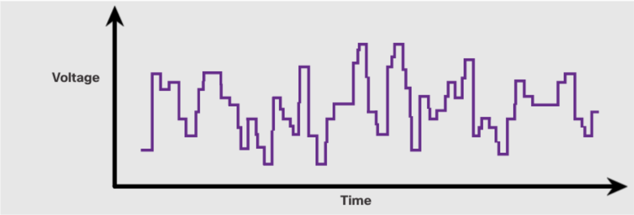


Signaling

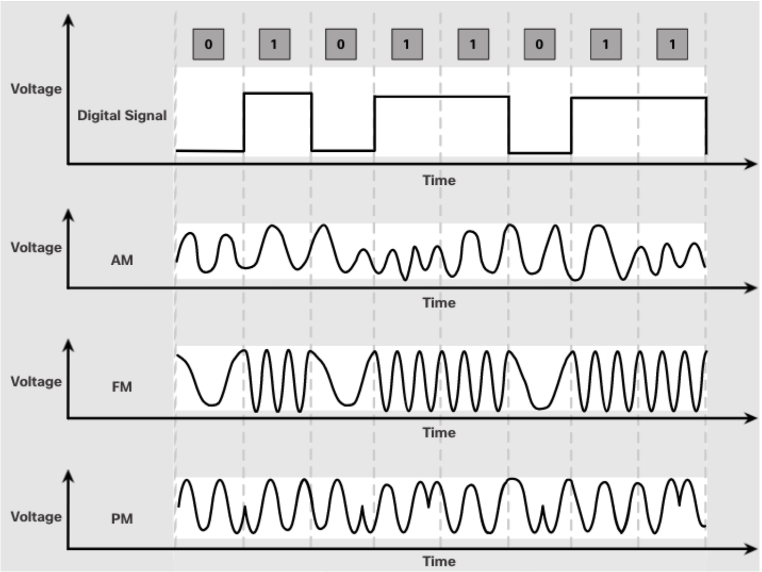
- The signaling method is how the bit values, “1” and “0” are represented on the physical medium.
- The method of signaling will vary based on the type of medium being used.



Light Pulses Over Fiber-Optic Cable



Electrical Signals Over Copper Cable



Microwave Signals Over Wireless

Bandwidth

- **Bandwidth** is the capacity at which a medium can carry data.
- Digital bandwidth measures the amount of data that can flow from one place to another in a given amount of time; how many bits can be transmitted in a second.
- Physical media properties, current technologies, and the laws of physics play a role in determining available bandwidth.

Unit of Bandwidth	Abbreviation	Equivalence
Bits per second	bps	1 bps = fundamental unit of bandwidth
Kilobits per second	Kbps	1 Kbps = 1,000 bps = 10^3 bps
Megabits per second	Mbps	1 Mbps = 1,000,000 bps = 10^6 bps
Gigabits per second	Gbps	1 Gbps – 1,000,000,000 bps = 10^9 bps
Terabits per second	Tbps	1 Tbps = 1,000,000,000,000 bps = 10^{12} bps

Bandwidth Terminology

❖ Throughput

A measure of the transfer of bits across the media over a given period of time

Example 3-1

A network with bandwidth of 10Mbps 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 one-fifth (2Mbps/10 Mbps) of the bandwidth in this case.

Propagation time & Transmission time

- **Propagation speed:** speed for the bits travels from source to destination
- **Propagation time :** The time required for a signal or wave to travel from one point of a transmission medium to another.

$$\textbf{Propagation time (delay)} = \frac{distance\ (in\ meter)}{Propagation\ speed\ (in \frac{m}{s})}$$

- **Transmission time :** Also considered the propagation delay, or the amount of time it takes one bit to go from the start of the link to its destination.

- **Transmission speed:** speed at which all the bits arrive at the destination (difference between the first and last bit)

$$\textbf{Transmission time (delay)} = \frac{Message\ size\ (in\ bit)}{bandwidth\ (in\ bps)}$$

- **Latency:** Amount of time, including delays, for data to travel from one given point to another

Latency = Transmission time +Propagation time + Queuing time + Processing time

Example 3-2

Example 3-2

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 1Gbps ? Assume that the distance between the sender and the receiver is $12{,}000\ \text{km}$ and light travels at $2.4 \times 10^{8}\ \text{m/s}$.

Solution

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

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

Note :

Bandwidth >> message → Depend Propagation time & Ignore Transmission time

Example 3-3

Example 3-3

What are the propagation time and the transmission time for a 5-Mbyte message (an image) if the bandwidth of the network is 1Mbps ? Assume that the distance between the sender and the receiver is $12{,}000\ \text{km}$ and light travels at $2.4 \times 10^8\ \text{m/s}$.

Solution

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

$$\text{Transmission time} = \frac{5{,}000{,}000 \times 8}{10^6} = 40\ \text{s}$$

Note :

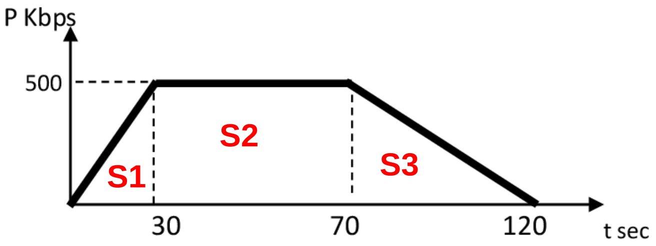
Bandwidth << message → Depend Transmission time & Ignore Propagation time

Example 3-4

Example 3-4

A network link is transferring data in (120)sec. The throughput for this link is shown in figure below. Calculate:

1) Size of data shown in figure.
2) Average data transfer rate for the whole time.
3) Amount of data transferred between 70-120 sec



Solution

1) Size of data = Area from 0 to120

$$= S1 + S2 + S3$$

$$= \frac{1}{2}(30)(500) + (40)(500) + \frac{1}{2}(50)(500)$$

$$= 40000 \text{ Kb}$$

Example 3-4 (contd.)

$$2)\ \text{Average data transfer rate} = \frac{\text{Size of Data}}{\text{Time}}$$

$$= \frac{40000\ \text{kb}}{120\ s} = 333.34\ \text{Kbps}$$

$$3)\ \text{Amount of data transferred} = \text{Area from } (70 - 120)$$

$$= \frac{1}{2}\,(50)(500)$$

$$= 12500\ \text{Kb}$$

Example 3-5

Example 3-5

A 30 Mbit MP3 file was sent from a source host to a destination host. All links in the path between source and destination have a transmission rate (BW) of 10Mbps. Assume that the propagation speed is $2 * 10^8$ m/s and the distance of each link is $10{,}000\ \text{km}$. Compute the Latency if:

a) There is only **one** link between source and destination.

b) There are **three** links between source and destination passing through **two** routers. Assume that the processing time of the router is $0.01 sec$

Solution-a:

Propagation time (delay) = $\frac{distance\ (in\ meter)}{Propagation\ speed\ (in \frac{m}{s})} = \frac{10^7}{2*10^8}$ = 0.05 sec

Transmission time (delay) = $\frac{Message\ size\ (in\ byte)}{bandwidth\ (in\ bps)} = \frac{30 * 10^6}{10^7}$ = 3 sec

Example 3-5 (continued)

Latency = Transmission delay + Propagation delay
= 3 sec + 0.05 sec = 3.05 sec

Solution-b:

Latency = 3 Transmission delay +3 Propagation delay +2 Processing time (waiting time)

$$= 3 * 3 + 3 * 0.05 + 2 * 0.01$$

$$= 9 + 0.15 + 0.02 = 9.17 \text{ sec}$$