# Chapter 3

Physical layer

Transmission Medium:

A transmission medium can be broadly defined as anything that can carry information from a source to a destination. For example, the transmission medium for two people having a dinner conversation is the air. The air can also be used to convey the message in a smoke signal or semaphore. For a written message, the transmission medium might be a mail carrier, a truck, or an airplane.

In data communications the definition of the information and the transmission medium is more specific. The transmission medium is usually free space, metallic cable, or fiber-optic cable. The information is usually a signal that is the result of a conversion of data from another form.
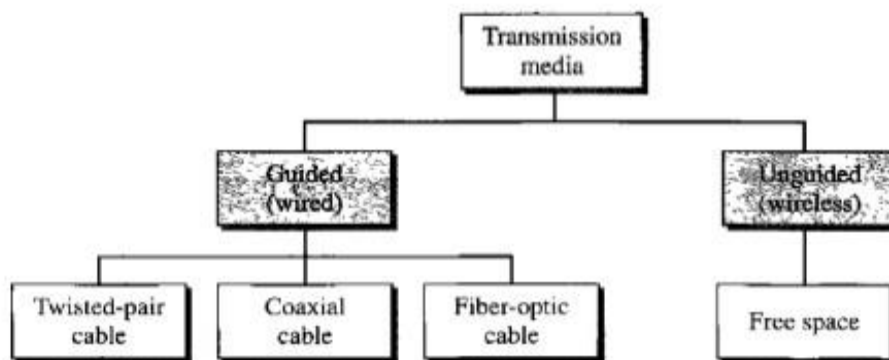

Guided Media:

Guided media, which are those that provide a conduit from one device to another, include twisted-pair cable, coaxial cable, and fiber-optic cable. A signal traveling along any of these media is directed and contained by the physical limits of the medium. Twisted-pair and coaxial cable use metallic (copper) conductors that accept and transport signals in the form of electric current. Optical fiber is a cable that accepts and transports signals in the form of light.

Shielded Twisted-Pair (STP) Cable

Another type of cabling used in networking is shielded twisted-pair (STP). As shown in the figure, STP uses two pairs of wires that are wrapped in an overall metallic braid or foil. STP cable shields the entire bundle of wires within the cable as well as the individual wire pairs. STP provides better noise protection than UTP cabling, however at a significantly higher price.

For many years, STP was the cabling structure specified for use in Token Ring network installations. With the use of Token Ring declining, the demand for shielded twisted-pair cabling has also waned. The new 10 GB standard for Ethernet has a provision for the use of STP cabling. This may provide a renewed interest in shielded twisted-pair cabling.

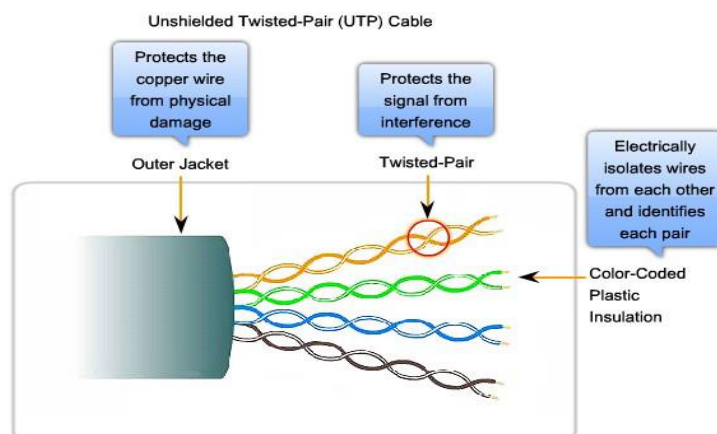Jacket   Braided Shield   Foil Shield   Twisted Pairs
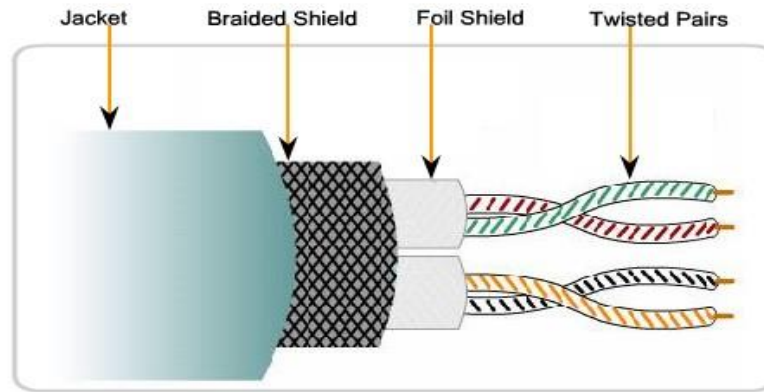
Unshielded twisted-pair (UTP)

Unshielded twisted-pair (UTP) cabling, as it is used in Ethernet LANs, consists of four pairs of color-coded wires that have been twisted together and then encased in a flexible plastic sheath. As seen in the figure, the color codes identify the individual pairs and wires in the pairs and aid in cable termination.

The twisting has the effect of canceling unwanted signals. When two wires in an electrical circuit are placed close together, external electromagnetic fields create the same interference in each wire. The pairs are twisted to keep the wires in as close proximity as is physically possible. When this common interference is present on the wires in a twisted pair, the receiver processes it in equal yet opposite ways. As a result, the signals caused by electromagnetic interference from external sources are effectively cancelled.

This cancellation effect also helps avoid interference from internal sources called crosstalk. Crosstalk is the interference caused by the magnetic field around the adjacent pairs of wires in the cable. When electrical current flows through a wire, it creates a circular magnetic field around the wire. With the current flowing in opposite directions in the two wires in a pair, the magnetic fields - as equal but opposite forces - have a cancellation effect on each other. Additionally, the different pairs of wires that are twisted in the cable use different number of twists per meter to help protect the cable from crosstalk between pairs.

Unshielded Twisted-Pair (UTP) Cable

Protects the copper wire from physical damage

Protects the signal from interference

Electrically isolates wires from each other and identifies each pair

Outer Jacket

Twisted-Pair

Color-Coded Plastic Insulation

UTP Cabling Standards

The UTP cabling commonly found in workplaces, schools, and homes conforms to the standards established jointly by the Telecommunications Industry Association (TIA) and the Electronics Industries Alliance (EIA). TIA/EIA-568A stipulates the commercial cabling standards for LAN installations and is the standard most commonly used in LAN cabling environments. Some of the elements defined are:

- Cable types
- Cable lengths
- Connectors
- Cable termination
- Methods of testing cable

The electrical characteristics of copper cabling are defined by the Institute of Electrical and Electronics Engineers (IEEE). IEEE rates UTP cabling according to its performance. Cables are placed into categories according to their ability to carry higher bandwidth rates. For example, Category 5 (Cat5) cable is used commonly in 100BASE-TX FastEthernet installations. Other categories include Enhanced Category 5 (Cat5e) cable and Category 6 (Cat6).

Cables in higher categories are designed and constructed to support higher data rates. As new gigabit speed Ethernet technologies are being developed and adopted, Cat5e is now the minimally acceptable cable type, with Cat6 being the recommended type for new building installations.

Co-axial Cable:

Coaxial cable (or coax) carries signals of higher frequency ranges than those in twisted-pair cable, in part because the two media are constructed quite differently. Instead of having two wires, coax has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath, which 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
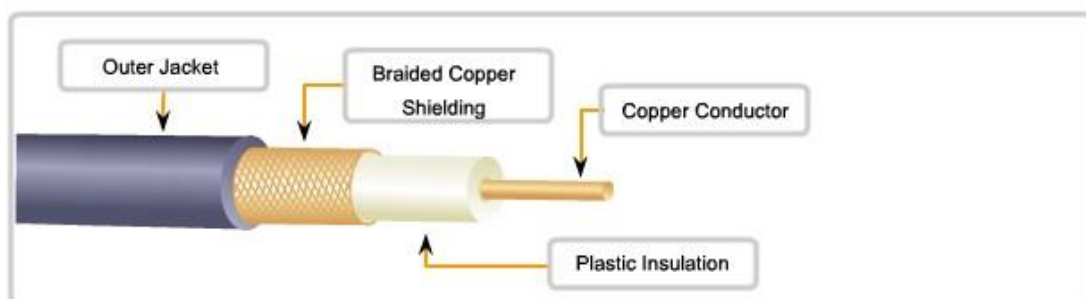
All the elements of the coaxial cable encircle the center conductor. Because they all share the same axis, this construction is called coaxial, or coax for short.

Uses of Coaxial Cable

The coaxial cable design has been adapted for different purposes. Coax is an important type of cable that is used in wireless and cable access technologies. Coax cables are used to attach

antennas to wireless devices. The coaxial cable carries radio frequency (RF) energy between the antennas and the radio equipment.

Coax is also the most widely used media for transporting high radio frequency signals over wire, especially cable television signals. Traditional cable television, exclusively transmitting in one direction, was composed completely of coax cable.

Cable service providers are currently converting their one-way systems to two-way systems to provide Internet connectivity to their customers. To provide these services, portions of the coaxial cable and supporting amplification elements are replaced with multi-fiber-optic cable. However, the final connection to the customer's location and the wiring inside the customer's premises is still coax cable. This combined use of fiber and coax is referred to as hybrid fiber coax (HFC).

In the past, coaxial cable was used in Ethernet installations. Today UTP offers lower costs and higher bandwidth than coaxial and has replaced it as the standard for all Ethernet installations.

Coaxial Cable Connectors

To connect coaxial cable to devices, we need coaxial connectors. The most common type of connector used today is the Bayone-Neill-Concelman (BNC), connector. Three types of connectors: the BNC connector, the BNC T connector, and the BNC terminator. The BNC connector is used to connect the end of the cable to a device, such as a TV set. The BNC T connector is used in Ethernet networks o branch out to a connection to a computer or other device. The BNC terminator is used at the end of the cable to prevent the reflection of the signal.

Fiber-optics

Fiber-optic cabling uses either glass or plastic fibers to guide light impulses from source to destination. The bits are encoded on the fiber as light impulses. Optical fiber cabling is capable of very large raw data bandwidth rates. Most current transmission standards have yet to approach the potential bandwidth of this media.

Principle of Fiber-optics:
It is based on the principle of Total internal Reflection.

(c) Optical fiber

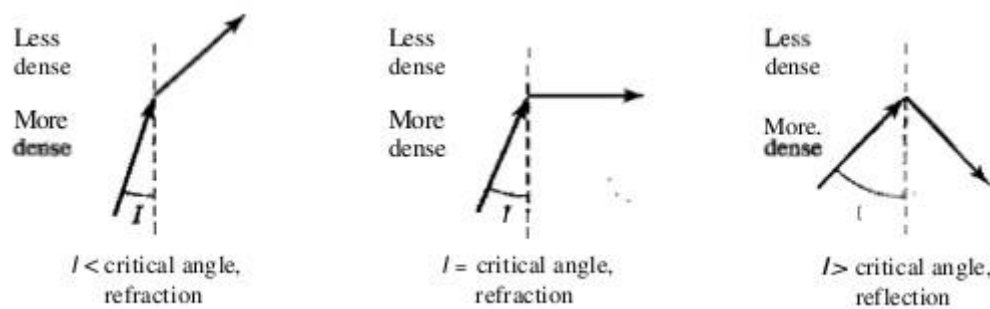Compiled By: Yogesh Deo, ME(ELX & COMM)
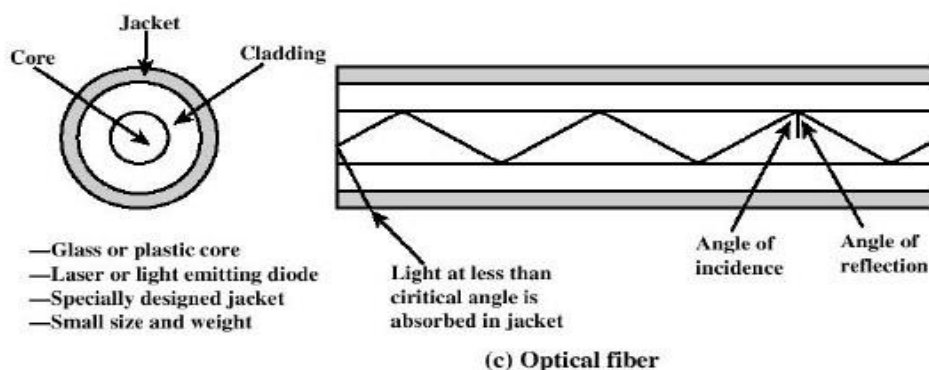
Figure: Bending of Light Ray

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 density of the two materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it as shown in fig below.
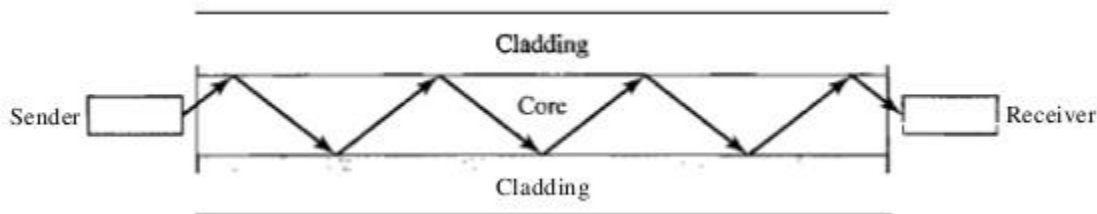
Fiber Compared to Copper Cabling:

Given that the fibers used in fiber-optic media are not electrical conductors, the media is immune to electromagnetic interference and will not conduct unwanted electrical currents due to grounding issues. Because optical fibers are thin and have relatively low signal loss, they can be operated at much greater lengths than copper media, without the need for signal regeneration. Some optical fiber Physical layer specifications allow lengths that can reach multiple kilometers.

Optical fiber media implementation issues include:
- More expensive (usually) than copper media over the same distance (but for a higher capacity)
- Different skills and equipment required to terminate and splice the cable infrastructure
- More careful handling than copper media.

At present, in most enterprise environments, 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. Because optical fiber does not conduct electricity and has low signal loss, it is well suited for these uses.

Propagation modes:

Current technology supports two modes (multimode and single mode) for propagating light along optical channels, each requiring fiber with different physical

characteristics. Multi- mode can be implemented in two forms: step-index or graded-index.

Single-mode optical fiber carries a single ray of light, usually emitted from a laser. Because the laser light is uni-directional and travels down the center of the fiber, this type of fiber can transmit optical pulses for very long distances.

- Single mode
    - The diameter of the core is reduced to the order of wavelength s.t. only a single angle or mode can pass
    - Superior performance

Single-mode 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. The single- mode fiber itself is manufactured with a much smaller diameter than that of multimode fiber, and with substantially lower density (index of refraction). The decrease in density results in a critical angle that is close enough to 90° to make the propagation of beams almost horizontal. In this case, propagation of different beams is almost identical, and delays are negligible. All the beams arrive at the destination "together" and can be recombined with little distortion to the signal

Multimode fiber typically uses LED emitters that do not create a single coherent light wave. Instead, light from an LED enters the multimode fiber at different angles. Because light entering the fiber at different angles takes different amounts of time to travel down the fiber, long fiber runs may result in the pulses becoming blurred on reception at the receiving end. This effect, known as modal dispersion, limits the length of multimode fiber segments.

Multimode Step-index:
In multimode step-index fiber, the 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 due to a lower density; this alters the angle of the beam's motion. The term step index refers to the suddenness of this change, which contributes to the distortion of the signal as it passes through the fiber .

- Three types of fiber transmission
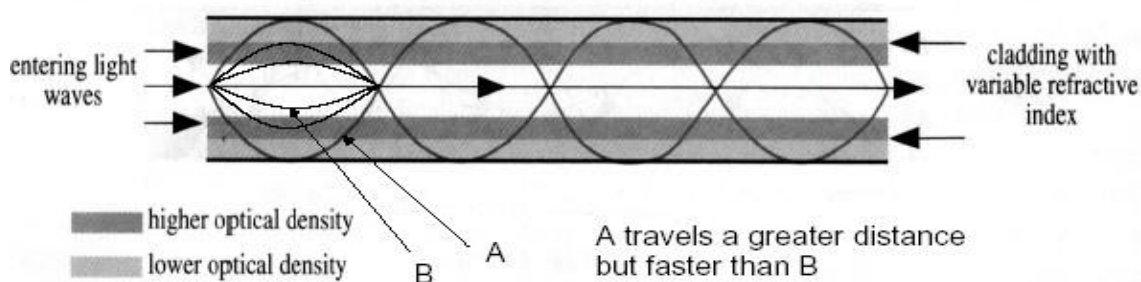   - Step index multimode
        - Variety of angles that reflect. Each angle defines a path or a mode
        - Limited data rate due to the different path lengths

path of light as it bounces off the cladding

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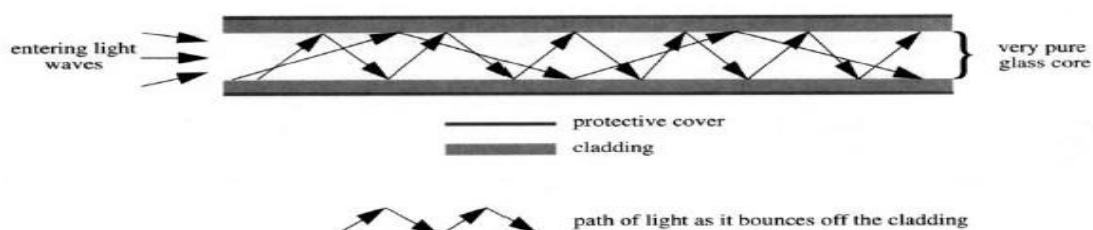
Multimode Graded-Index

Multimode graded-index fiber, decreases this distortion of the signal through the cable. The word index here refers to the index of refraction. As we saw above, the index of refraction is related to density. A graded-index fiber, therefore, is one with varying densities. Density is highest at the center of the core and decreases gradually to its lowest at the edge

- Graded index multimode
  - Use the fact that speed of light depends on the medium; light travels faster through less optically dense media
  - The boundary between core and cladding is not sharply defined; Moving out radially from the core, the material becomes gradually less dense

entering light waves

cladding with variable refractive index

higher optical density

lower optical density

A

B

A travels a greater distance but faster than B

Advantages and Disadvantages of Optical Fiber

Advantages
Fiber-optic cable has several advantages over metallic cable (twisted- pair or coaxial).

- **Higher bandwidth:** Fiber-optic cable can support dramatically higher bandwidths (and hence data rates) than either twisted-pair or coaxial cable. Currently, data rates and bandwidth utilization over fiber-optic cable are limited not by the medium but by the signal generation and reception technology available.
- **Less signal attenuation:** Fiber-optic transmission distance is significantly greater than that of other guided media. A signal can run for 50 km without requiring regeneration. We need repeaters every 5 km for coaxial or twisted-pair cable.
- **Immunity to electromagnetic interference:** Electromagnetic noise cannot affect fiber-optic cables.
- **Resistance to corrosive materials**: Glass is more resistant to corrosive materials than copper.
- **Light weight:** Fiber-optic cables are much lighter than copper cables.
- **Greater immunity to tapping**: Fiber-optic cables are more immune to tapping than copper cables. Copper cables create antenna effects that can easily be tapped.

Disadvantages
There are some disadvantages in the use of optical fiber.

- **Installation and maintenance**: Fiber-optic cable is a relatively new technology. Its installation and maintenance require expertise that is not yet available everywhere.
- **Unidirectional light propagation**: Propagation of light is unidirectional. If we need bidirectional communication, two fibers are needed.

- **Cost:** The cable and the interfaces are relatively more expensive than those of other guided media. If the demand for bandwidth is not high, often the use of optical fiber cannot be justified.

Wireless Networking

Unguided media transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication. Signals are normally broadcast through free space and thus are available to anyone who has a device capable of receiving them.
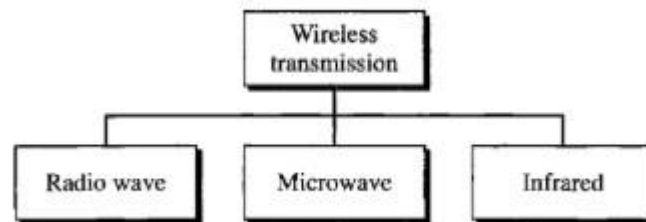

Figure: Wireless Transmission Waves

Unguided signals can travel from the source to destination in several ways: ground propagation, sky propagation, and line-of-sight propagation, as shown in Figure

Figure: Propagation Method

Band	Range	Propagation	Application
VLF (very low frequency)	3–30 kHz	Ground	Long-range radio navigation
LF (low frequency)	30–300 kHz	Ground	Radio beacons and navigational locators
MF (middle frequency)	300 kHz–3 MHz	Sky	AM radio
HF (high frequency)	3–30 MHz	Sky	Citizens band (CB), ship/aircraft communication
VHF (very high frequency)	30–300 MHz	Sky and line-of-sight	VHF TV, FM radio
UHF (ultrahigh frequency)	300 MHz–3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
SHF (superhigh frequency)	3–30 GHz	Line-of-sight	Satellite communication
EHF (extremely high frequency)	30–300 GHz	Line-of-sight	Radar, satellite

Radio Waves

Although there is no clear-cut demarcation between radio waves and microwaves, electromagnetic waves ranging in frequencies between 3 kHz and 1 GHz are normally called radio waves; waves ranging in frequencies between 1 and 300 GHz are called microwaves. However, the behavior of the waves, rather than the frequencies, is a better criterion for classification. Radio waves, for the most part, are omnidirectional. When an antenna transmits radio waves, they are propagated in all directions. This means that the sending and receiving antennas do not have to be aligned. A sending antenna sends waves that can be received by any receiving antenna. The omnidirectional property has a disadvantage, too. The radio waves transmitted by one antenna are susceptible to interference by another antenna that may send signals using the same frequency or band. Radio waves, particularly those waves that propagate in the sky mode, can travel long distances. This makes radio waves a good candidate for long-distance broadcasting such as AM radio. Radio waves, particularly those of low and medium frequencies, can penetrate walls.

This characteristic can be both an advantage and a disadvantage. It is an advantage because, for example, an AM radio can receive signals inside a building. It is a disadvantage because we cannot isolate a communication to just inside or outside a building. The radio wave band is relatively narrow, just under 1 GHz, compared to the microwave band. When this band is divided into subbands, the subbands are also narrow, leading to allow data rate for digital communications.

Omnidirectional Antenna
Radio waves use omnidirectional antennas that send out signals in all directions. Based on the wavelength, strength, and the purpose of transmission, we can have several types of antennas.

Applications
The omnidirectional characteristics of radio waves make them useful for multicasting, in which there is one sender but many receivers. AM and FM radio, television, maritime radio, cordless phones, and paging are examples of multicasting.

Microwaves

Electromagnetic waves having frequencies between 1 and 300 GHz are called microwaves. Microwaves are unidirectional. When an antenna transmits microwave waves, they can be narrowly focused. This means that the sending and receiving antennas need to be aligned. The unidirectional property has an obvious advantage. A pair of antennas can be aligned without interfering with another pair of aligned antennas. The following describes some characteristics of microwave propagation:

- Microwave propagation is line-of-sight. Since the towers with the mounted antennas need to be in direct sight of each other, towers that are far apart need to be very tall. The curvature of the earth as well as other blocking obstacles do not allow two short towers to communicate by using microwaves. Repeaters are often needed for long-distance communication.
- Very high-frequency microwaves cannot penetrate walls. This characteristic can be a disadvantage if receivers are inside buildings.

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- The microwave band is relatively wide, almost 299 GHz. Therefore wider subbands can be assigned, and a high data rate is possible.
- Use of certain portions of the band requires permission from authorities.

Applications

Microwaves, due to their unidirectional properties, are very useful when unicast (one-to-one) communication is needed between the sender and the receiver. They are used in cellular phones, satellite networks, and wireless LANs

Unidirectional Antenna

Microwaves need unidirectional antennas that send out signals in one direction. Two types of antennas are used for microwave communications: the parabolic dish and the horn.

a. Dish antenna   b. Horn antenna
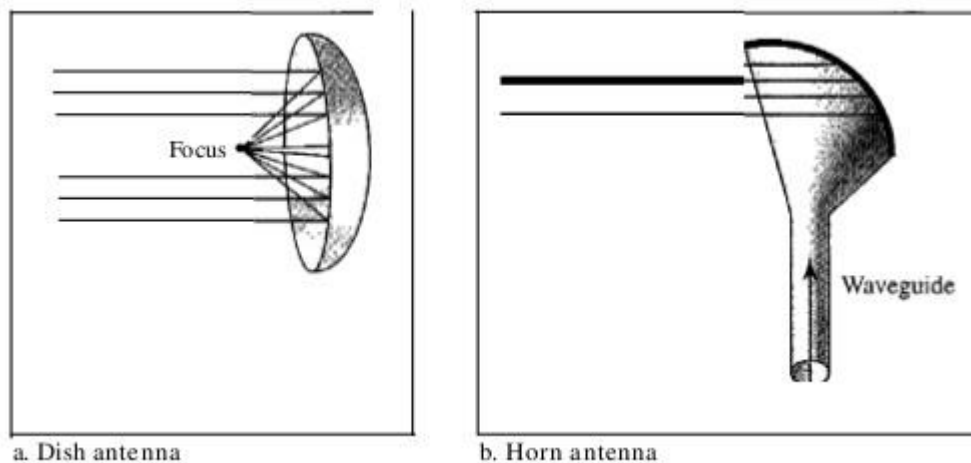
A parabolic dish antenna is based on the geometry of a parabola: Every line parallel to the line of symmetry (line of sight) reflects off the curve at angles such that all the lines intersect in a common point called the focus. The parabolic dish works as a funnel, catching a wide range of waves and directing them to a common point. In this way, more of the signal is recovered than would be possible with a single-point receiver.

A horn antenna looks like a gigantic scoop. Outgoing transmissions are broadcast up a stem (resembling a handle) and deflected outward in a series of narrow parallel beams by the curved head. Received transmissions are collected by the scooped shape of the horn, in a manner similar to the parabolic dish, and are deflected down into the stem.

Infrared

Infrared waves, with frequencies from 300 GHz to 400 THz (wavelengths from 1 mm to 770 nm), can be used for short-range communication. Infrared waves, having high frequencies, cannot penetrate walls. This advantageous characteristic prevents interference between one system and another; a short-range communication system in one room cannot be affected by another system in the next room. When we use our infrared remote control, we do not interfere with the use of the remote by our neighbors. However, this same characteristic makes infrared signals useless for long-range communication. In addition, we cannot use infrared waves outside a building because the sun's rays contain infrared waves that can interfere with the communication.

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Applications

The infrared band, almost 400 THz, has an excellent potential for data transmission. Such a wide bandwidth can be used to transmit digital data with a very high data rate. The Infrared Data Association (IrDA), an association for sponsoring the use of infrared waves, has established standards for using these signals for communication between devices such as keyboards, mice, PCs, and printers. For example, some manufacturers provide a special port called the IrDA port that allows a wireless keyboard to communicate with a PC. The standard originally defined a data rate of 75 kbps for a distance up to 8 m. The recent standard defines a data rate of 4 Mbps. Infrared signals defined by IrDA transmit through line of sight; the IrDA port on the keyboard needs to point to the PC for transmission to occur.

Infrared signals can be used for short-range communication in a closed area using line-of-sight propagation.

Satellite Communication:

- Uses satellite in geostationary (geosynchronous) orbit (36,000 km).
- Source transmits signal to satellite which amplifies or repeats it, and retransmits down to destinations.
- Optimum transmission in 1 - 10 GHz range; Bandwidth of 100'sMHz.
- Significant propagation delay 270ms.
- Total propagation delay is independent of distance between sender and receiver.
- Applications:
  - ➤ Long-distance telephones.
  - ➤ Television distribution
  - ➤ Private business networks.

(a) Point-to-point link via satellite microwave

Satellite Communications Configuration
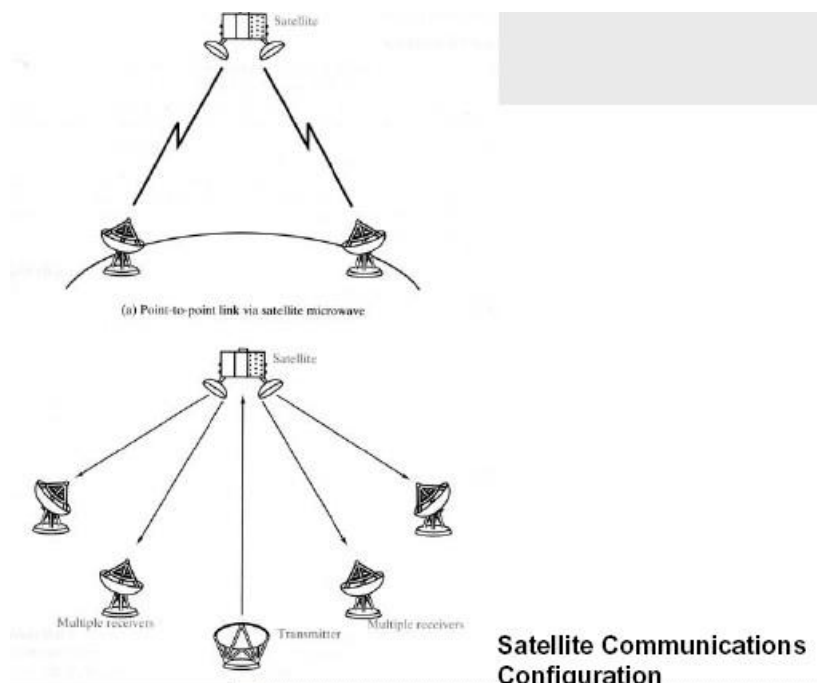
VSAT (Very Small Aperture System)

- For business data applications requiring high data rates for short periods of time.
- National Weather Service, news services, credit card verification, automatic tellers, car rental agencies.
- Commonly connects a central location with many remote ones.
- Communication between two sites is via a satellite and allows a low-cost small antenna dishes (5 ft).

Circuit Switching:

A dedicated path between the source node and the destination node is set up for the duration of communication session to transfer data. That path is a connected sequence of links between network nodes. On each physical link, a logical channel is dedicated to the connection. Communication via circuit switching involves three phases,

I. **Circuit Establishment:** Before any signals can be transmitted, an end-to-end (station-to-station) circuit must be established.

II. **Data Transfer:** The data may be analog or digital, depending on the nature of the network

III. **Circuit Disconnect:** After some period of data transfer, the connection is terminated, usually by the action of one of the two stations
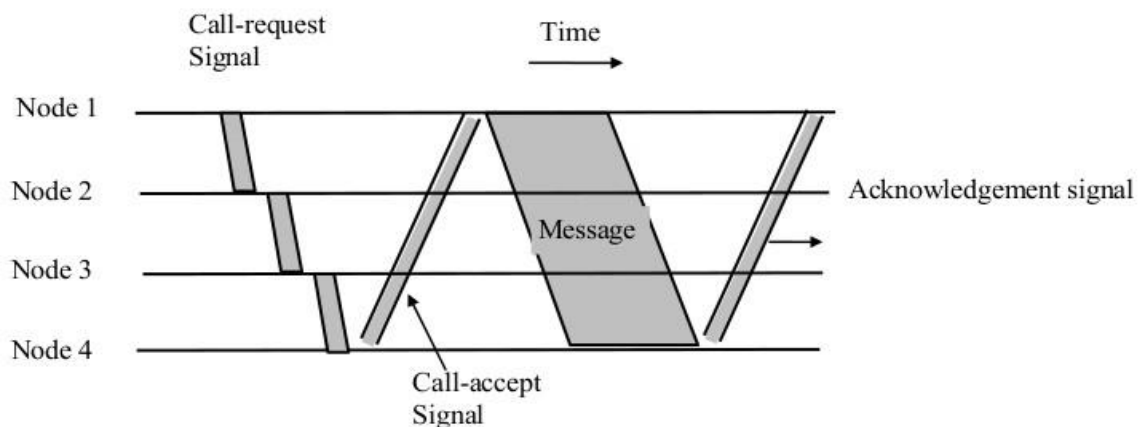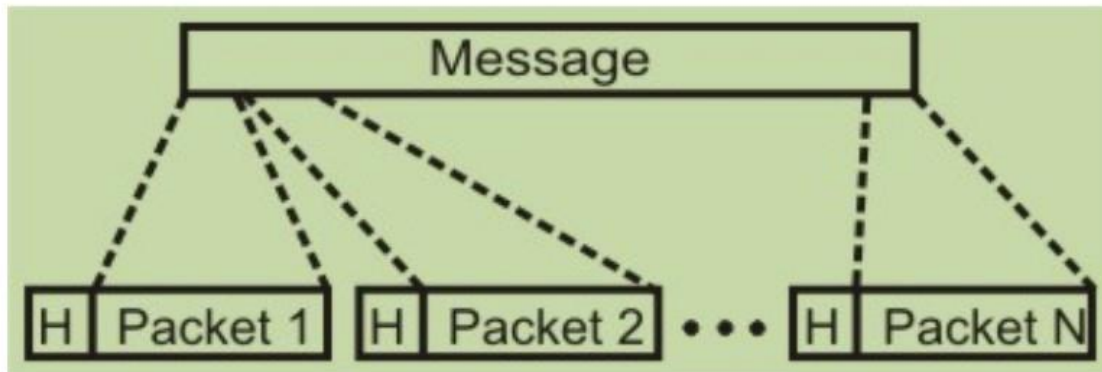

Circuit switching telecommunication networks was originally designed to handle voice traffic, and the majority of the traffic on these networks continues to be voice. A key characteristic of the circuit switching is that resources within the network are dedicated to a particular call. For voice communication the resulting circuit will enjoy the high percentage of utilization because most of the time one party or the other is talking. However, as the circuit-switching network began to be used increasingly for data connections, two shortcomings became apparent:

I. In a typical user host data connection (e.g., personal computer user logged on to a database server), much of the time the line is idle. Thus, with data connections, a circuit-switching approach is inefficient.

II. In a circuit-switching network, the connection provides for transmission at constant data rate. Thus, each of the two devices that are connected must transmit and receive at the same data rate as the other; this limits the utility of the network in interconnecting a variety of host computers and terminals.

Packet Switching:

Messages are divided into subsets of equal length called packets. In packet switching approach, data are transmitted in short packets (few Kbytes). A long message is broken up into a series of packets as shown in Figure. Every packet contains some control information in its header, which is required for routing and other purposes.


Main difference between Packet switching and Circuit Switching is that the communication lines are not dedicated to passing messages from the source to the destination. In Packet Switching, different messages (and even different packets) can pass through different routes, and when there is a "dead time" in the communication between the source and the destination, the lines can be used by other sources.

There are two basic approaches commonly used to packet Switching: virtual circuit packet switching and datagram packet switching. In virtual-circuit packet switching a virtual circuit is made before actual data is transmitted, but it is different from circuit switching in a sense that in circuit switching the call accept signal comes only from the final destination to the source while in case of virtual-packet switching this call accept signal is transmitted between each adjacent intermediate node as shown in Fig. Other features of virtual circuit packet switching are discussed in the following subsection.

Virtual Circuit:

An initial setup phase is used to set up a route between the intermediate nodes for all the packets passed during the session between the two end nodes. In each intermediate node, an entry is registered in a table to indicate the route for the connection that has been set up. Thus, packets passed through this route, can have short headers, containing only a virtual circuit identifier (VCI), and not their destination. Each intermediate node passes the packets according to the information that was stored in it, in the setup phase. In this way, packets arrive at the destination in the correct sequence, and it is guaranteed that essentially there will not be errors. This approach is slower than Circuit Switching, since different virtual circuits may compete over the same resources, and an initial setup phase is needed to initiate the circuit. As in Circuit Switching, if an intermediate node fails, all virtual circuits that pass through it are lost. The most common forms of Virtual Circuit networks are X.25 and Frame Relay, which are commonly used for public data networks (PDN).

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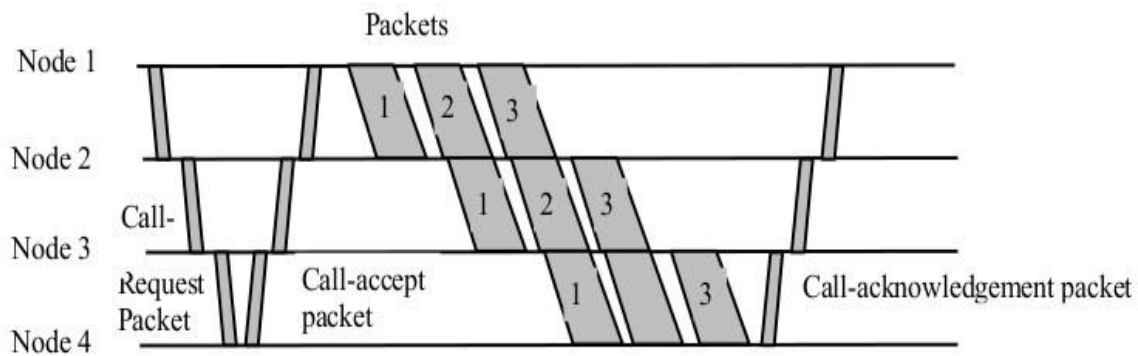
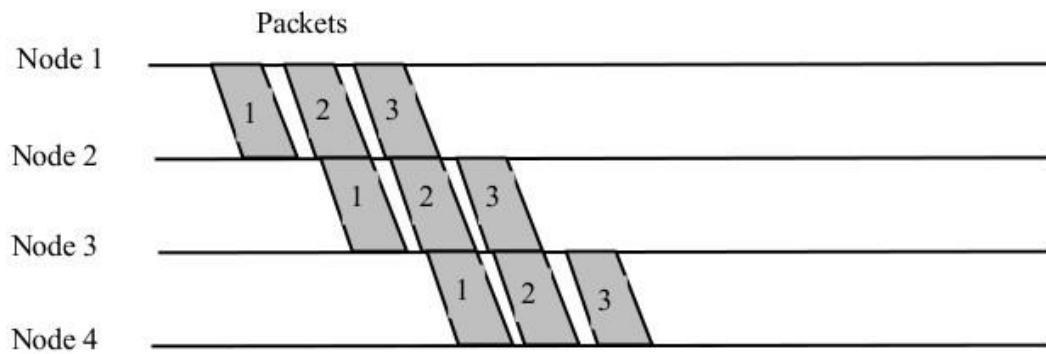*Virtual circuit packet switching techniques*
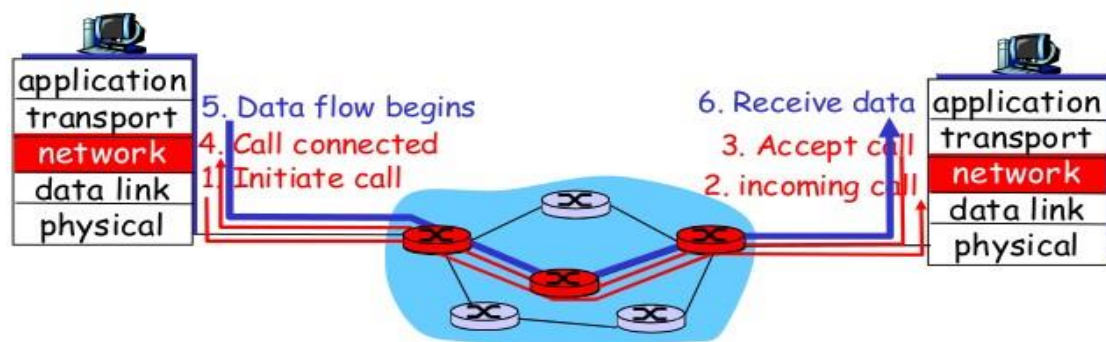
Virtual Circuit

Datagram:

This approach uses a different, more dynamic scheme, to determine the route through the network links. Each packet is treated as an independent entity, and its header contains full information about the destination of the packet. The intermediate nodes examine the header of the packet, and decide to which node to send the packet so that it will reach its destination.
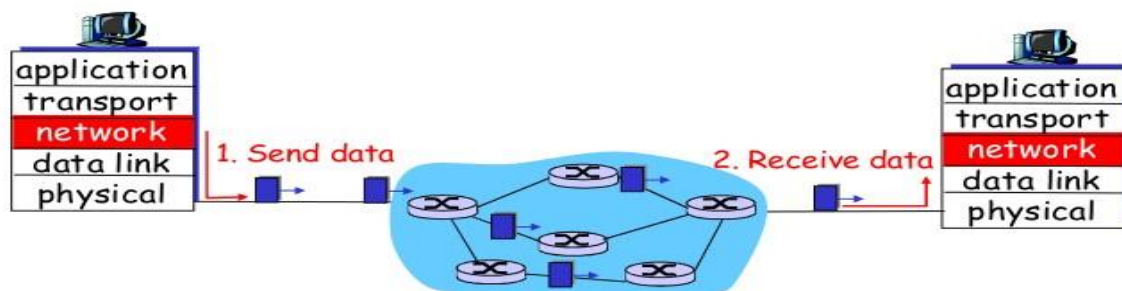
In this method, the packets don't follow a pre-established route, and the intermediate nodes (the routers) don't have pre-defined knowledge of the routes that the packets should be passed through. Packets can follow different routes to the destination, and delivery is not guaranteed. Due to the nature of this method, the packets can reach the destination in a different order than they were sent, thus they must be sorted at the destination to form the original message. This approach is time consuming since every router has to decide where to send each packet. The main implementation of Datagram Switching network is the Internet, which uses the IP network protocol.

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Datagram packet switching

Datagram Packet Switching Vs Virtual-circuit Packet Switching:

S.No	Datagram Packet Switching	Virtual-Circuit Packet Switching
1	Two packets of the same user pair can travel along different routes.	All packets of the same virtual circuit travel along the same path.
2	The packets can arrive out of sequence.	Packet sequencing is guaranteed.
3	Packets contain full source and destination address.	Packets contain short VC Id. (VCI).
4	Each host occupies routine table entries.	Each VC occupies routing table entries.
5	Requires no connection setup.	Requires VC setup. First packet has large delay.
6	Also called Connection less	Also called connection oriented.
7	Examples: X.25 and Frame Relay	Eg. Internet which uses IP Network protocol.

Virtual Circuit:

Virtual Circuits is a connection between two network devices appearing like a direct and dedicated connection but it but is actually a group of logic circuit resources from which specific circuits are allocated as needed to meet traffic requirements in a packet switched network. In this case, the two network devices can communicate as though they have a dedicated physical connection. Examples of networks with virtual circuit capabilities include X.25 connections, Frame Relay and ATM networks.

Virtual circuits can be either permanent, called Permanent virtual Circuits (PVC), or temporary, called Switched Virtual Circuits (SVCs).

A Permanent Virtual Circuit (PVC) is a virtual circuit that is permanently available to the user. A PVC is defined in advance by a network manager. A PVC is used on a circuit that includes routers that must maintain a constant connection in order to transfer routing information in a dynamic network environment. Carriers assign PVCs to customers to reduce overhead and improve performance on their networks.

A switched virtual circuit (SVC) is a virtual circuit in which a connection session is set up dynamically between individual nodes temporarily only for the duration of a session. Once a communication session is complete, the virtual circuit is disabled.

X.25:

A packet-switching protocol for wide area network (WAN) connectivity that uses a public data network (PDN) that parallels the voice network of the Public Switched Telephone Network (PSTN). The current X.25 standard supports synchronous, full-duplex communication at speeds up to 2 Mbps over two pairs of wires, but most implementations are 64-Kbps connections via a standard DS0 link.

X.25 defines a telephone network for data communications. To begin communication, one computer calls another to request a communication session. The called computer can accept or refuse the connection. If the call is accepted, the two systems can begin full-duplex information transfer. Either side can terminate the connection at any time.

The X.25 specification defines a point-to-point interaction between data terminal equipment (DTE) and data communication equipment (DCE). DTEs (terminals and hosts in the user's facilities) connect to DCEs (modems, packet switches, and other ports into the PDN, generally located in the carrier's facilities), which connect to packet switching exchanges (PSEs, or simply switches) and other DCEs inside a PSN and, ultimately, to another DTE. The relationship between the entities in an X.25 network is shown in Figure.
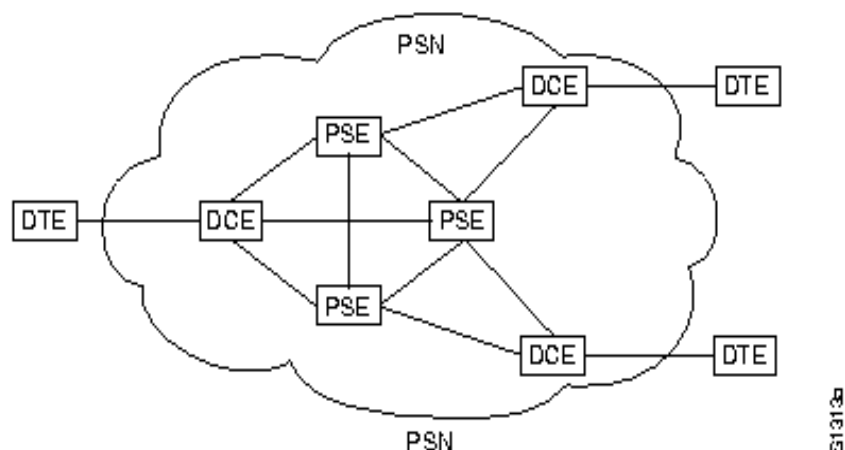
Because X.25 was designed when analog telephone transmission over copper wire was the norm, X.25 packets have a relatively large overhead of error-correction information, resulting in comparatively low overall bandwidth. Newer WAN technologies such as frame relay, Integrated Services Digital Network (ISDN), and T-carrier services are now generally preferred over X.25. However, X.25 networks still have applications in areas such as credit card verification, automatic teller machine transactions, and other dedicated business and financial uses.

How It Works

The X.25 standard corresponds in functionality to the first three layers of the Open Systems Interconnection (OSI) reference model for networking. Specifically, X.25 defines the following:

- The physical layer interface for connecting data terminal equipment (DTE), such as computers and terminals at the customer premises, with the data communications equipment (DCE), such as X.25 packet switches at the X.25 carrier's facilities. The physical layer interface of X.25 is called X.21bis and was derived from the RS-232 interface for serial transmission.

- The data-link layer protocol called Link Access Procedure, Balanced (LAPB), which defines encapsulation (framing) and error-correction methods. LAPB also enables the DTE or the DCE to initiate or terminate a communication session or initiate data transfer. LAPB is derived from the High-level Data Link Control (HDLC) protocol.
- The network layer protocol called the Packet Layer Protocol (PLP), which defines how to address and deliver X.25 packets between end nodes and switches on an X.25 network using permanent virtual circuits (PVCs) or switched virtual circuits (SVCs). This layer is responsible for call setup and termination and for managing transfer of packets.

An X.25 network consists of a backbone of X.25 switches that are called packet switching exchanges (PSEs). These switches provide packet-switching services that connect DCEs at the local facilities of X.25 carriers. DTEs at customer premises connect to DCEs at X.25 carrier facilities by using a device called a packet assembler/disassembler (PAD). You can connect several DTEs to a single DCE by using the multiplexing methods inherent in the X.25 protocol. Similarly, a single X.25 end node can establish several virtual circuits simultaneously with remote nodes.

An end node (DTE) can initiate a communication session with another end node by dialing its X.121 address and establishing a virtual circuit that can be either permanent or switched, depending on the level of service required. Packets are routed through the X.25 backbone network by using the ID number of the virtual circuit established for the particular communication session. This ID number is called the logical channel identifier (LCI) and is a 12-bit address that identifies the virtual circuit. Packets are generally up to 128 bytes in size, although maximum packet sizes range from 64 to 4096 bytes, depending on the system.

Disadvantages of X.25

Prior to Frame Relay, some organizations were using a virtual-circuit switching network called X.25 that performed switching at the network layer. For example, the Internet, which needs wide-area networks to carry its packets from one place to another, used X.25. And X.25 is still being used by the Internet, but it is being replaced by other WANs. However, X.25 has several drawbacks:
- X.25 has a low 64-kbps data rate. By the 1990s, there was a need for higher- data-rate WANs.
- X.25 has extensive flow and error control at both the data link layer and the network layer. This was so because X.25 was designed in the 1970s, when the available transmission media were more prone to errors. Flow and error control at both layers create a large overhead and slow down transmissions. X.25 requires acknowledgments for both data link layer frames and network layer packets that are sent between nodes and between source and destination.
- Originally X.25 was designed for private lise, not for the Internet. X.25 has its own network layer. This means that the user's data are encapsulated in the network layer packets of X.25. The Internet, however, has its own network layer, which means if the Internet wants to use X.25, the Internet must deliver its network layer packet, called a datagram, to X.25 for encapsulation in the X.25 packet. This doubles the overhead.

Frame Relay:

Frame Relay is a high-performance WAN protocol that operates at the physical and Data Link layers of the OSI reference model. X.25 has several disadvantages so Frame Relay was invented. Frame Relay is a wide-area network with the following features:

I. Frame Relay operates at a higher speed (1.544 Mbps and recently 44.376 Mbps). This means that it can easily be used instead of a mesh of T-I or T-3 lines.

II. Frame Relay operates in just the physical and data link layers. This means it can easily be used as a backbone network to provide services to protocols that already have a network layer protocol, such as the Internet.

III. Frame Relay allows bursty data.

IV. Frame Relay allows a frame size of 9000 bytes, which can accommodate all local-area network frame sizes.

V. Frame Relay is less expensive than other traditional WANs.

VI. Frame Relay has error detection at the data link layer only. There is no flow control or error control. There is not even a retransmission policy if a frame is damaged; it is silently dropped. Frame Relay was designed in this way to provide fast transmission capability for more reliable media and for those protocols that have flow and error control at the higher layers.

Frame Relay Operation:

When carriers use Frame Relay to interconnect LANs, a router on each LAN is the DTE. A serial connection, such as a T1/E1 leased line, connects the router to the Frame Relay switch of the carrier at the nearest point-of-presence (POP) for the carrier. The Frame Relay switch is a DCE device. Network switches move frames from one DTE across the network and deliver frames to other DTEs by way of DCEs.
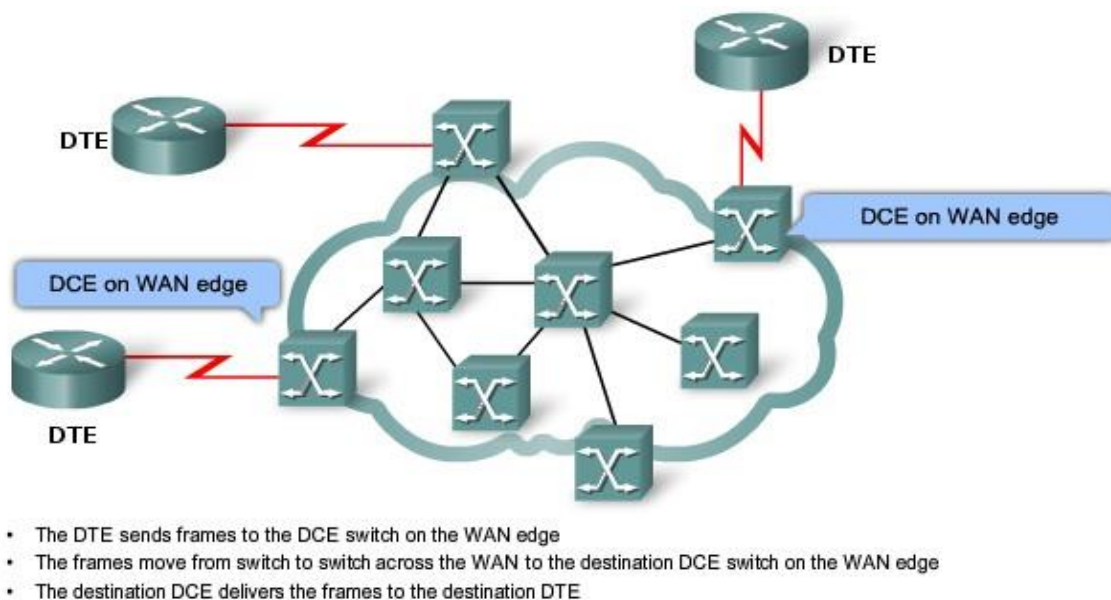

- The DTE sends frames to the DCE switch on the WAN edge
- The frames move from switch to switch across the WAN to the destination DCE switch on the WAN edge
- The destination DCE delivers the frames to the destination DTE

Figure: Frame Relay Operation

Virtual Circuits

The connection through a Frame Relay network between two DTEs is called a virtual circuit (VC). The circuits are virtual because there is no direct electrical connection from end to end. The connection is logical, and data moves from end to end, without a direct electrical circuit.

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With VCs, Frame Relay shares the bandwidth among multiple users and any single site can communicate with any other single site without using multiple dedicated physical lines.

There are two ways to establish VCs:
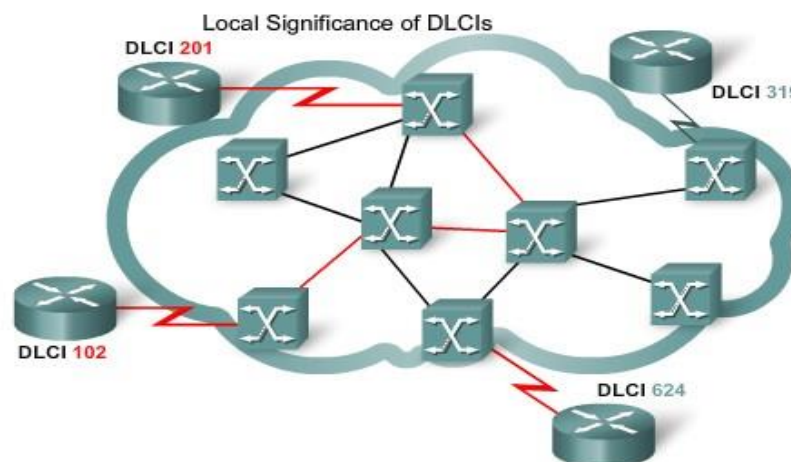**Permanent Virtual Circuit (PVC):**
A source and a destination may choose to have a permanent virtual circuit (PVC). In this case, the connection setup is simple. The corresponding table entry is recorded for all switches by the administrator (remotely and electronically, of course). An outgoing DLCI is given to the source, and an incoming DLCI is given to the destination. PVC connections have two drawbacks. First, they are costly because two parties pay for the connection all the time even when it is not in use. Second, a connection is created from one source to one single destination. If a source needs connections with several destinations, it needs a PVC for each connection PVCs, permanent virtual circuits, are preconfigured by the carrier, and after they are set up, only operate in DATA TRANSFER and IDLE modes. Note that some publications refer to PVCs as private Vcs.

Switched Virtual-circuit (SVC):
An alternate approach is the switched virtual circuit (SVC). The SVC creates a temporary, short connection that exists only when data are being transferred between source and destination. SVCs, switched virtual circuits, are established dynamically by sending signaling messages to the network (CALL SETUP, DATA TRANSFER, IDLE, CALL TERMINATION).

DLCI (Data link connection identifier):
Frame Relay is a virtual circuit network. A virtual circuit in Frame Relay is identified by a number called a data link connection identifier (DLCI). DLCI values typically are assigned by the Frame Relay service provider (for example, the telephone company). Usually, DLCIs 0 to 15 and 1008 to 1023 are reserved for special purposes. Therefore, service providers typically assign DLCIs in the range of 16 to 1007. Frame Relay DLCIs have local significance, which means that the values themselves are not unique in the Frame Relay WAN. A DLCI identifies a VC to the equipment at an endpoint. A DLCI has no significance beyond the single link. Two devices connected by a VC may use a different DLCI value to refer to the same connection.

DLCI values have local significance, which means that they are unique only to the physical channel on which they reside. Therefore, devices at opposite ends of a connection can use the same DLCI values to refer to different virtual circuits.

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Frame Relay Layers:
Frame Relay operates at the physical layer and the Data link layer.
Physical Layer
No specific protocol is defined for the physical layer in Frame Relay. Instead, it is left to the implementer to use whatever is available. Frame Relay supports any of the protocols recognized by ANSI.
Data Link Layer
At the data link layer, Frame Relay uses a simple protocol that does not support flow or error control. It only has an error detection mechanism. Figure blow shows the format of a Frame Relay frame. The address field defines the DLCI as well as some bits used to control congestion.
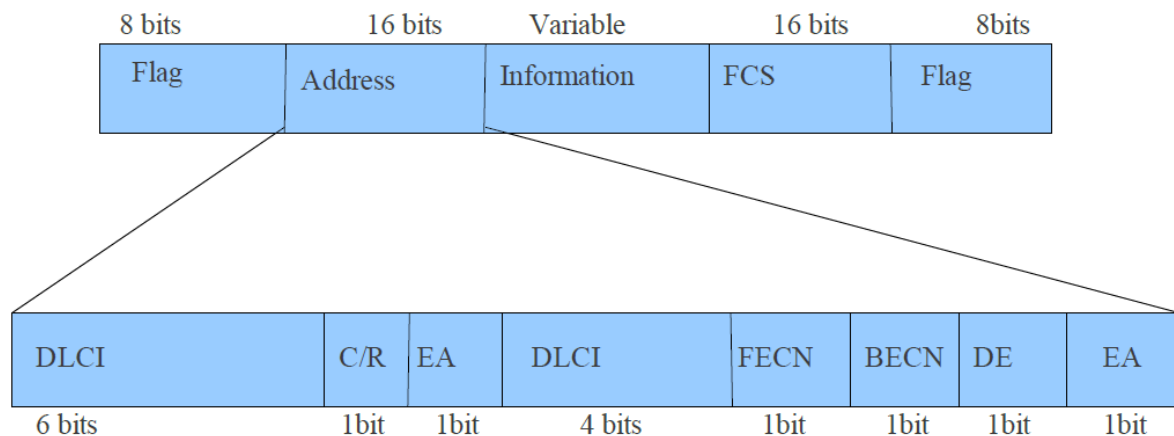
8 bits	16 bits	Variable	16 bits	8bits
Flag	Address	Information	FCS	Flag

DLCI	C/R	EA	DLCI	FECN	BECN	DE	EA
6 bits	1bit	1bit	4 bits	1bit	1bit	1bit	1bit

Figure Frame Relay Frame Format

C/R: Command/response
EA: Extended address
FECN: Forward explicit congestion notification
BECN: Backward explicit congestion notification
DE: Discard eligibility
DLCI: Data link connection identifier

Address (DLCI) field: The first 6 bits of the first byte makes up the first part of the DLCI. The second part of the DLCI uses the first 4 bits of the second byte. These bits are part of the10-bit data link connection identifier defined by the standard.
Command/response (CIR): The command/response (C/R) bit is provided to allow upper layers to identify a frame as either a command or a response. It is not used by the Frame Relay protocol.
Extended address (EA): The extended address (EA) bit indicates whether the current byte is the final byte of the address. An EA of 0 means that another address byte is to follow. An EA of 1 means that the current byte is the final one.
**Forward explicit congestion notification (FECN):** The forward explicit congestion notification (FECN) bit can be set by any switch to indicate that traffic is congested. This bit informs the destination that congestion has occurred. In this way, the destination knows that it should expect delay or a loss of packets.
Backward explicit congestion notification (BECN): The backward explicit congestion notification (BECN) bit is set (in frames that travel in the other direction) to indicate a congestion problem in the network. This bit informs the sender that congestion has occurred. In this way, the source knows it needs to slow down to prevent the loss of packets.

Discard eligibility (DE): The discard eligibility (DE) bit indicates the priority level of the frame. In emergency situations, switches may have to discard frames to relieve bottlenecks and keep the network from collapsing due to overload. When set (DE 1), this bit tells the network to discard this frame if there is congestion. This bit can be set either by the sender of the frames (user) or by any switch in the network.

FRADs

To handle frames arriving from other protocols, Frame Relay uses a device called a Frame Relay assembler/disassembler (FRAD). A FRAD assembles and disassembles frames coming from other protocols to allow them to be carried by Frame Relay frames. A FRAD can be implemented as a separate device or as part of a switch.
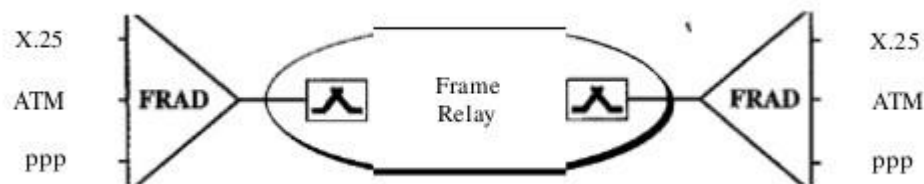
VOFR

Frame Relay networks offer an option called Voice Over Frame Relay (VOFR) that sends voice through the network. Voice is digitized using PCM and then compressed. The result is sent as data frames over the network. This feature allows the inexpensive sending of voice over long distances. However, note that the quality of voice is not as good as voice over a circuit-switched network such as the telephone network. Also, the varying delay mentioned earlier sometimes corrupts real-time voice.

Local Management Information (LMI)

Frame Relay was originally designed to provide PVC connections. There was not, therefore, a provision for controlling or managing interfaces. Local Management Information (LMI) is a protocol added recently to the Frame Relay protocol to provide more management features. In particular, LMI can provide:

- A keep-alive mechanism to check if data are flowing.
- A multicast mechanism to allow a local end system to send frames to more than one remote end system.
- A mechanism to allow an end system to check the status of a switch (e.g., to see if the switch is congested).

Asynchronous Transfer Mode (ATM)

Asynchronous transfer mode (ATM), also known as cell relay, is similar in concept to frame relay. Both frame relay and ATM take advantage of the reliability and fidelity of modern digital facilities to provide faster packet switching than X.25. ATM is even more streamlined than frame relay in its functionality, and can support data rates several orders of magnitude greater than frame relay.

The "asynchronous" in ATM means ATM devices do not send and receive information at fixed speeds or using a timer, but instead negotiate transmission speeds based on hardware and information flow reliability. The "transfer mode" in ATM refers to the

fixed-size cell structure used for packaging information.

ATM transfers information in fixed-size units called cells. Each cell consists of 53 octets, or bytes as shown in Figure.
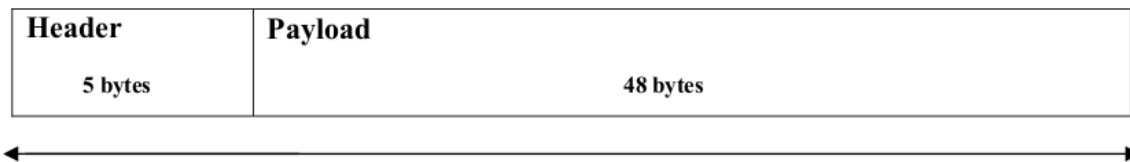
Header	Payload
5 bytes	48 bytes

Figure: ATM cell Format

- Transmits all information in fixed size blocks called cells.
- Cells are transmitted asynchronously.
- The network is connection oriented.
- Each cell is 53 bytes long – 5 bytes header and 48 bytes payload.
- Making an ATM call requires first sending a message to set up a connection. Subsequently all cells follow the same path to the destination.
- ATM was envisioned as the technology for providing B-ISDN services.
- It can handle both constant rate traffic and variable-length traffic. Thus, it can carry multiple types of traffic with end-to-end quality of service.
- ATM is independent of transmission medium. It doesn't prescribe any particular rule.
- They may be sent on a wire or Fiber by themselves or they may be also packaged inside the payload of the other carrier system.
- Delivery of the system is not guaranteed but the order is.

When the virtual circuit is established, what really happens is that a route is chosen from source to destination. All the switches along the way make table entries for the virtual circuit and have the opportunity to reserve resources for the new circuit. The cells are sent from one switch to the next (stored and forwarded) until they reach the destination. When a cell comes along, the switch inspects its header to find out which virtual circuit it belongs to.
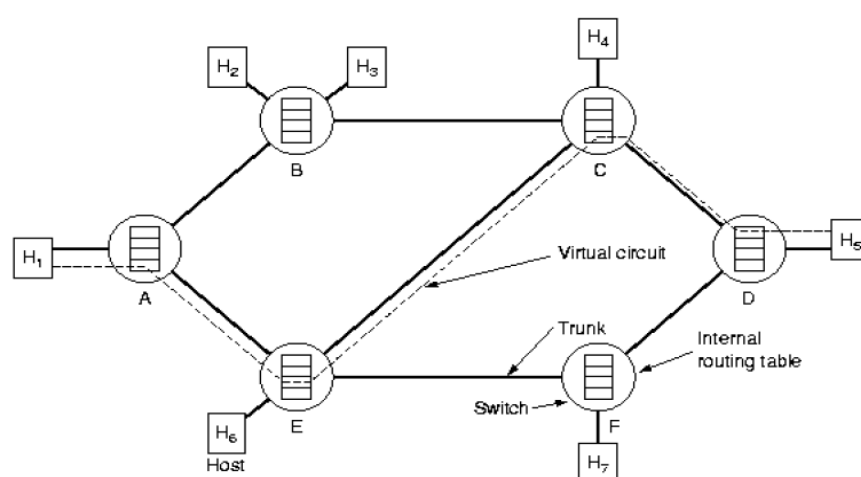

Figure: Cells travelling from Host 1 to Host 5

ATM Network Interfaces:

An ATM network consists of a set of ATM switches interconnected by point-to-point ATM links or interfaces. ATM switches support two primary types of interfaces: UNI and NNI as shown in Figure below. The UNI (User-Network Interface) connects ATM end systems (such as hosts and routers) to an ATM switch. The NNI (Network-Network Interface) connects two ATM switches. Depending on whether the switch is owned and located at the customer's premises or is publicly owned and operated by the telephone company, UNI and NNI can be further subdivided into public and private UNIs and NNIs. A private UNI connects an ATM endpoint and a private ATM switch. Its public counterpart connects an ATM endpoint or private switch to a public switch. A private NNI connects two ATM switches within the same private organization. A public one connects two ATM switches within the same public organization.
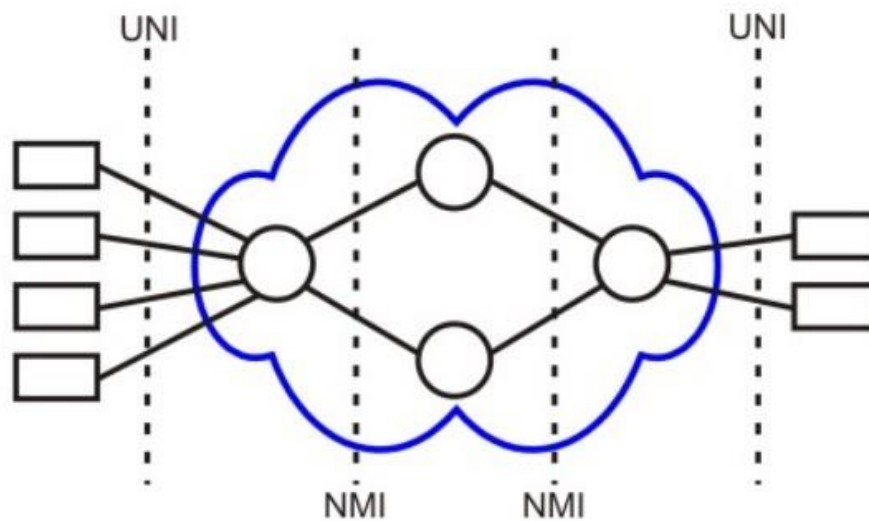
Figure: UNI and NNI interfaces of the ATM

ATM Virtual Connections

ATM operates as a channel-based transport layer; using Virtual circuits (VCs). This is encompassed in the concept of the Virtual Paths (VP) and Virtual Channels. Every ATM cell has an 8- or 12-bit Virtual Path Identifier (VPI) and 16-bit Virtual Channel Identifier (VCI) pair defined in its header. Together, these identify the virtual circuit used by the connection. The length of the VPI varies according to whether the cell is sent on the user-network interface (on the edge of the network), or if it is sent on the network-network interface (inside the network).

As these cells traverse an ATM network, switching takes place by changing the VPI/VCI values (label swapping). Although the VPI/VCI values are not necessarily consistent from one end of the connection to the other, the concept of a circuit is consistent (unlike IP, where any given packet could get to its destination by a different route than the others).

Another advantage of the use of virtual circuits comes with the ability to use them as a multiplexing layer, allowing different services (such as voice, Frame Relay, n* 64 channels, IP).

A virtual path connection (VPC) is a bundle of VCCs that have the same endpoints. Thus, all

of the cells flowing over all of the VCCs in a single VPC are switched together
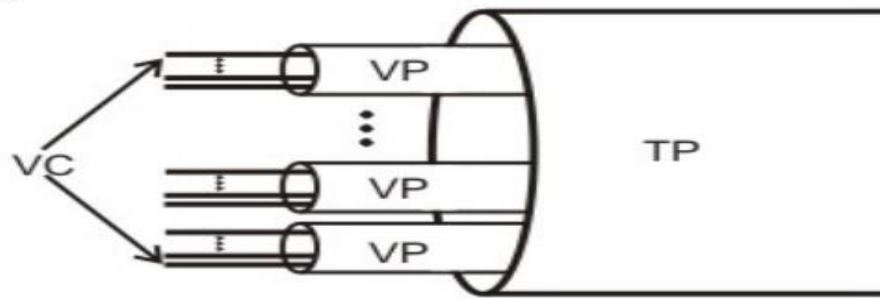
VC- Virtual Circuit
VP- Virtual Path
TP- Transmission Path

ATM Reference Model:
The protocol reference model makes reference to three separate planes:

User Plane: Provides for user information transfer, along with associated controls (e.g, flow control, error control).

Control Plane: Performs call control and connection control functions.

Management Plane: Includes plane management, which performs management functions related to a system as a whole and provides coordination between all the planes, and layer management, which performs management functions relating to resources and parameters residing in its protocol entities.
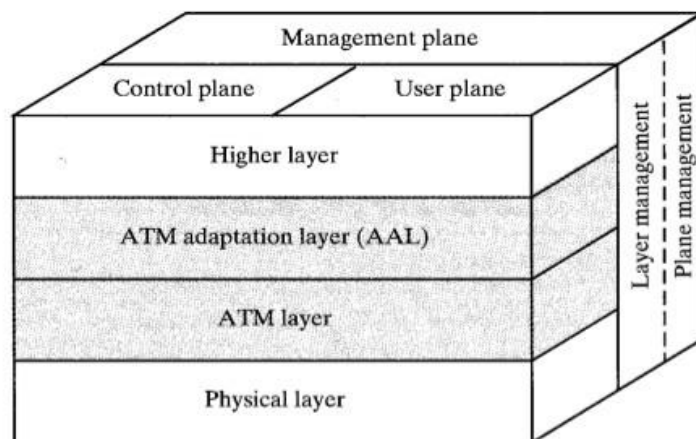
Physical layer: Analogous to the physical layer of the OSI reference model, the ATM physical layer manages the medium-dependent transmission.

ATM layer: Combined with the ATM adaptation layer, the ATM layer is roughly analogous to the data link layer of the OSI reference model. The ATM layer is responsible for the simultaneous sharing of virtual circuits over a physical link (cell multiplexing) and passing cells through the ATM network (cell relay). To do this, it uses the VPI and VCI information in the header of each ATM cell.

ATM adaptation layer (AAL): Combined with the ATM layer, the AAL is roughly analogous to the data link layer of the OSI model. The AAL is responsible for isolating higher-layer protocols from the details of the ATM processes. The adaptation layer prepares user data for conversion into cells and segments the data into 48-byte cell payloads.

ATM Advantages:
- ATM supports voice, video and data allowing multimedia and mixed services over a single network.
- Provides the best multiple service support
- Supports delay close to that of dedicated services
- Supports the broadest range of burstiness, delay tolerance and loss performance through the implementation of multiple QoS classes
- Provides the capability to support both connection-oriented and connectionless traffic using AALs
- Able to use all common physical transmission paths (such as DS1, SONET).
- Cable can be twisted-pair, coaxial or fiber-optic
- Ability to connect LAN to WAN
- Legacy LAN emulation
- Efficient bandwidth use by statistical multiplexing
- Scalability
- Higher aggregate bandwidth
- High speed Mbps and possibly Gbps

ATM disadvantages
- Flexible to efficiency's expense, at present, for any one application it is usually possible to find a more optimized technology
- Cost, although it will decrease with time
- New customer premises hardware and software are required
- Competition from other technologies -100 Mbps FDDI, 100 Mbps Ethernet and fast Ethernet

Integrated Service Digital Network: (ISDN)

Integrated Services Digital Network (ISDN) is a network that provides end-to-end digital connectivity to support a wide range of services including voice and data services. ISDN allows multiple digital channels to operate simultaneously through the same regular phone wiring used for analog lines, but ISDN transmits a digital signal rather than analog. Latency is much lower on an ISDN line than on an analog line.
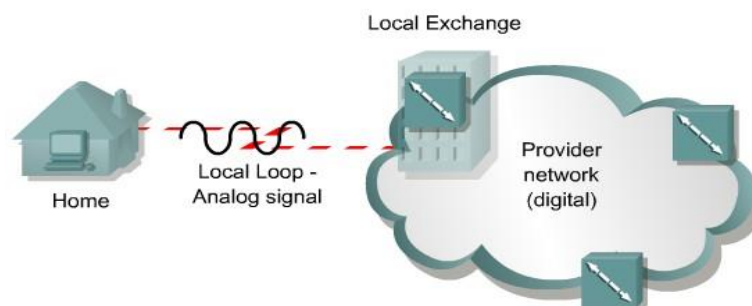
Figure: Analog communication without ISDN

The traditional PSTN was based on an analog connection between the customer premises and the local exchange, also called the local loop. The analog circuits introduce limitations on the bandwidth that can be obtained on the local loop. Circuit restrictions do not permit analog bandwidths greater than approximately 3000 Hz. ISDN technology permits the use of digital data on the local loop, providing better access speeds for the remote users.
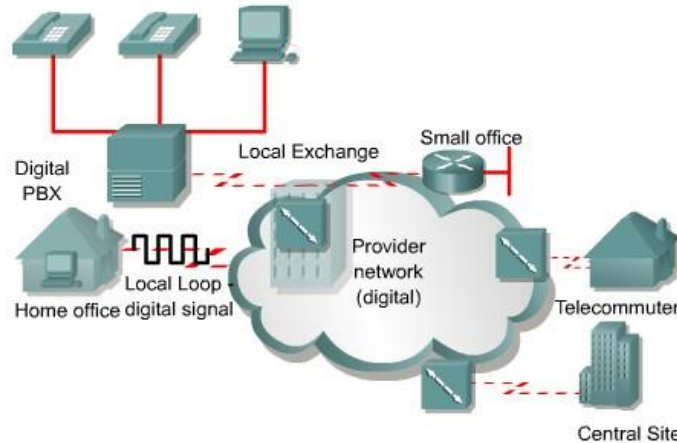

Figure: Digital communication with ISDN

ISDN standards define two main channel types, each with a different transmission rate.

The bearer channel or B channel: B channel is defined as a clear digital path of 64 kbps for voice or up to 64 Kbps of data. It is said to be clear because it can be used to transmit any type of digitized data in full-duplex mode. For example, a digitized voice call can be transmitted on a single B channel.

Delta channel or D channel: The D channel carries signaling messages, such as call setup and teardown, to control calls on B channels. Traffic over the D channel employs the Link Access Procedure on the D Channel (LAPD) protocol. LAPD is a data link layer protocol based on HDLC. There can either be 16 kbps for the Basic Rate Interface (BRI) or 64 kbps for the Primary Rate Interface (PRI). The D channel is used to carry control information for the B channel.
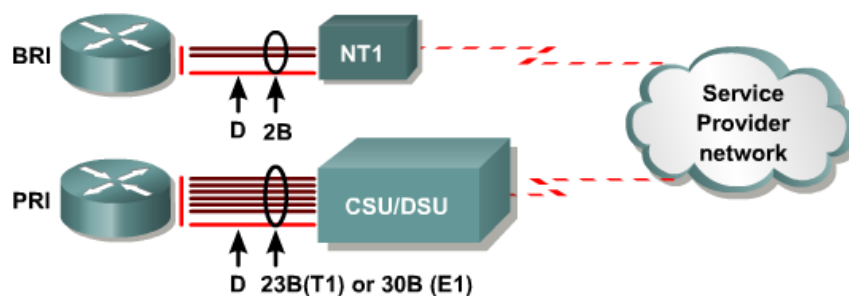
Channel	Capacity	Mostly Used for
B	64 kbps	Circuit-switched data (HDLC, PPP)
D	16/64 kbps	Signaling information (LAPD)

ISDN specifies two standard access methods, BRI and PRI. A single BRI or PRI interface provides a multiplexed bundle of B and D channels.

Basic Rate Interface (BRI)
The ISDN BRI structure consists of two B-channels at 64Kbps and one D-channel for control at 16Kbps. The B-channel can carry either voice or data while the D-channel is used for signaling and can be used for packet data.


The capacity of the BRI is therefore:
- two voice, two high-speed data or
- one voice and one high-speed data plus 16kbps packet data

BRI can carry a wide and flexible range of communications. A single BRI, for example, can carry two simultaneous voice or data conversations (to the same or different locations). The D-channel can also be used for packet communications to a third location, also simultaneously.

PRI (Primary Rate Interface)
In North America and Japan, PRI offers twenty-three 64 kbps B channels and one 64 kbps D channel. A PRI offers the same service as a T1 or DS1 connection. In Europe and much of the rest of the world, PRI offers 30 B channels and one D channel in order to offer the same level of service as an E1 circuit. PRI uses a Data Service Unit/Channel Service Unit (DSU/CSU) for T1/E1 connections.
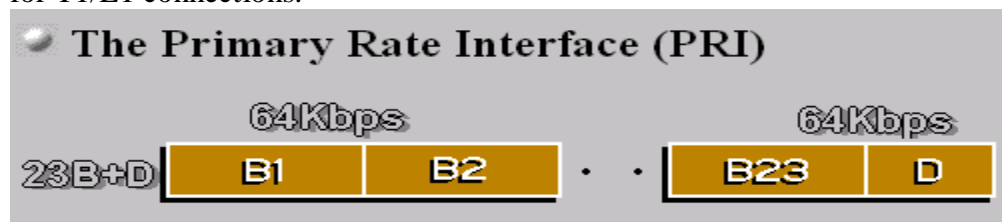
ISDN Reference Points
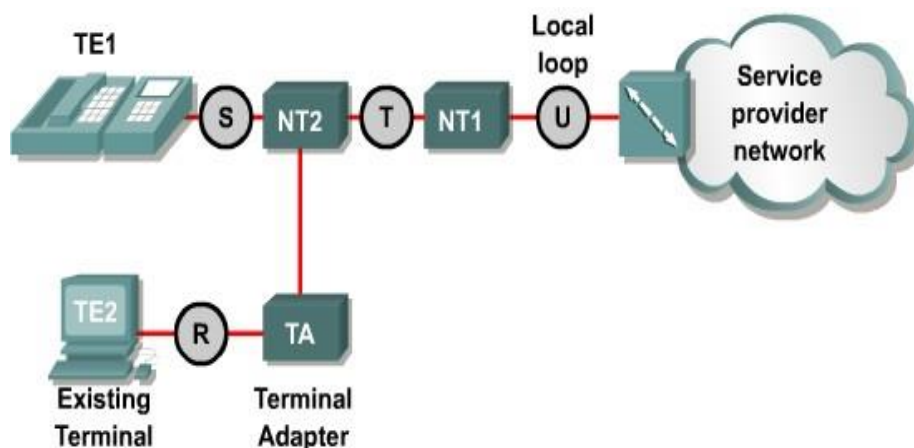
R: References the connection between a non-ISDN compatible device Terminal Equipment type 2 (TE2) and a Terminal Adapter (TA), for example an RS-232 serial interface.

S: References the points that connect into the customer switching device Network Termination type 2 (NT2) and enables calls between the various types of customer premises equipment.

T: Electrically identical to the S interface, it references the outbound connection from the NT2 to the ISDN network or Network Termination type 1 (NT1).

U: References the connection between the NT1 and the ISDN network owned by the telephone company.

Device	Device Type	Device Function
TE1	Terminal Equipment 1	Designates a device with a native ISDN interface, such as an ISDN router or ISDN telephone.
TE2	Terminal Equipment 2	Designates a non-ISDN device, such as a workstation or router, that requires a TA to connect to an ISDN service provider.
TA	Terminal Adapter	Converts EIA/TIA-232, V.35, and other signals into BRI signals.
NT2	Network Termination 2	The point at which all ISDN lines at a customer site are aggregated and switched using a customer switching device.
NT1	Network Termination 1	Controls the physical and electrical termination of the ISDN at the customer's premises. Converts the four-wire BRI signals into two-wire signals used by the ISDN digital line.

Public Switched Telephone Network (PSTN)

PSTN(Circuit Switch): PSTN is a circuit switched network is one where a dedicated connection (circuit or channel) must be set up between two nodes before they may communicate. For the duration of the communication, that connection may only be used by the same two nodes, and when the communication has ceased, the connection must be explicitly cancelled.

The basic digital circuit in the PSTN is a 64-kilobits-per-second channel, originally designed by Bell Labs, called a "DS0" or Digital Signal 0. To carry a typical phone call from a calling party to a called party, the audio sound is digitized at an 8 kHz sample rate using 8-bit pulse code modulation. The call is then transmitted from one end to another via telephone exchanges. The call is switched using a signaling protocol (SS7) between the telephone exchanges under an overall routing strategy.

PSTN, the Public Switched Telephone Network, is a circuit-switched network that is used primarily for voice communications worldwide, with more than 800 million subscribers. Originally a network of fixed-line analog telephone systems, the PSTN is now almost entirely digital and also includes mobile as well as fixed telephones. The basic digital circuit in the PSTN is a 64-kilobit-per-second channel, known as "DS0" or Digital Signal 0. DS0's are also known as timeslots because they are multiplexed together in a time-division fashion. To carry a typical phone call from a calling party to a called party, the audio sound is digitized at an 8 kHz sample rate using 8-bit pulse code modulation. Multiple DS0's can be multiplexed together on higher capacity circuits, such that 24 DS0's make a DS1 signal or T1 (the European equivalent is an E1, containing 32 64 kbit/s channels). For more than a hundred years, the PSTN was the only bearer network available for telephony. Today, the mobile

telephone over wireless access network, which is carried through the PSTN trunking network, is becoming increasingly popular. Other bearer networks for voice transmission include integrated service digital network (ISDN), Digital Subscriber Line (DSL), Asynchronous Transfer Mode (ATM), frame relay and the Internet VOIP.

T-1 & E-1 Circuit:

T-1 is a digital circuit that uses the DS-1 (Digital Signaling level 1) signaling format to transmit voice/data over the PSTN network at 1.544 Mbps. T-1 can carry up to 24 uncompressed digital channels of 64 Kbps (DS0) for voice or data.

E-1 is the European equivalent of the T-1, except E-1 carries information at the rate of 2.048 Mbps. E-1 is used to transmit 30 64Kbps digital channels (DS0) for voice or data calls, plus a 64Kbps channel for signaling, and a 64Kbps channel for framing and maintenance.

A T1/E1 circuit is a dedicated circuit and is always composed of two parts: the local loop and the carrier circuit.

A T1/E1 circuit is the first multiplexed level of the digital signaling multiplexing scheme. T1s use what is called a Stratum 3 clock to maintain what is called clocking on the line.