Computer Networks (CSC305)

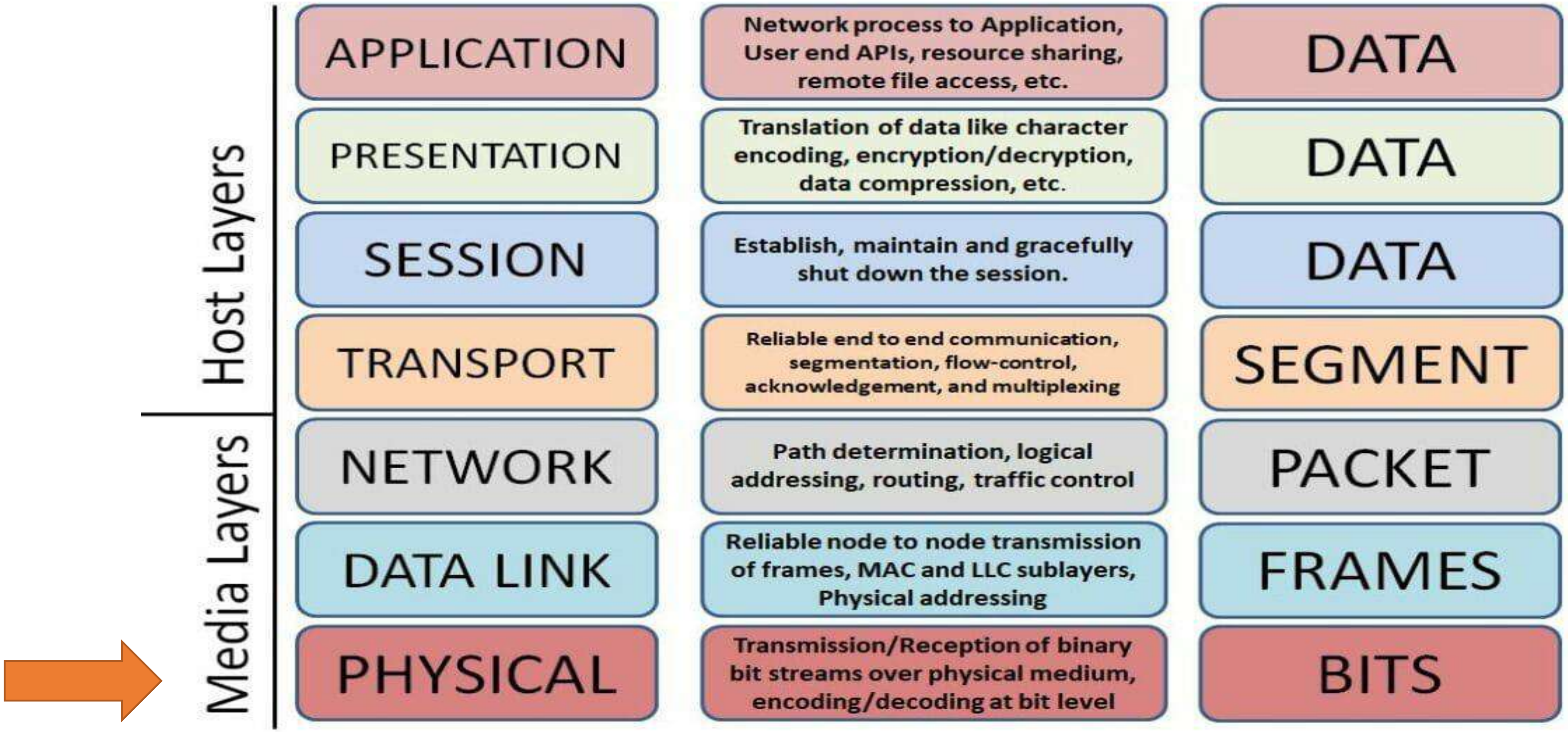
Course Outline:

√Overview of Data Communication and Networking

√Physical Layer

- Data Link Layer
    - Logical Link Control (LLC)
    - Medium Access Control (MAC)
- Network Layer
- Transport Layer
- Application Layer

OSI Reference Model



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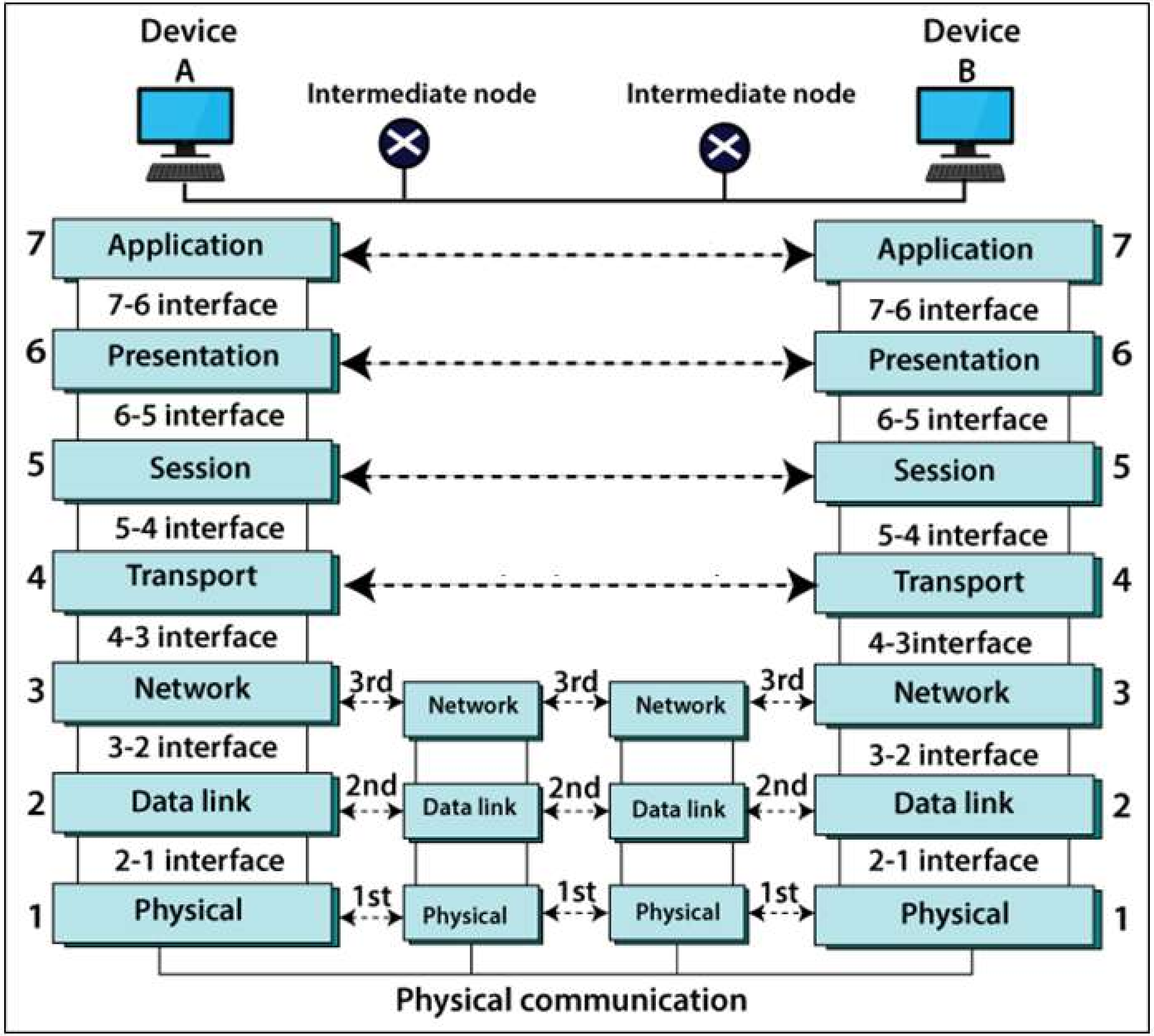


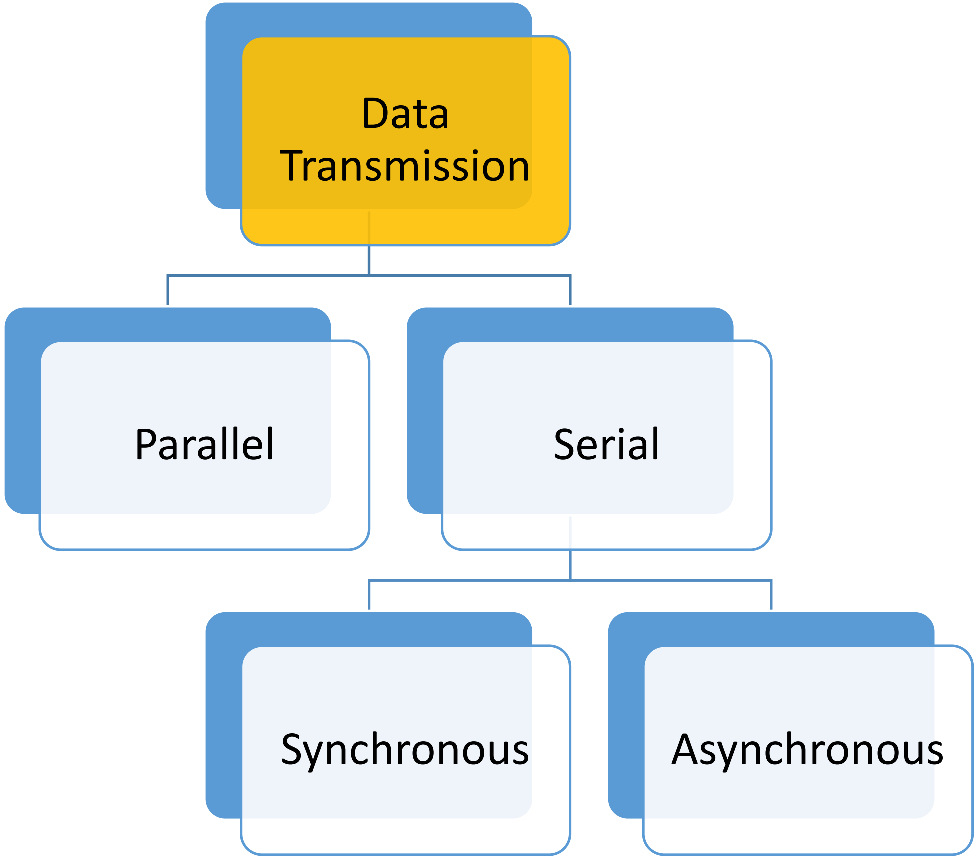
Physical Layer

- Connection Types / Line Configuration
  - Point-to-Point
  - Multipoint
- Physical Topology
  - Bus
  - Ring
  - Star
  - Mesh
  - Cellular
- Signalling
  - Analog
  - Digital
- **Bit Synchronization**
  - **Synchronous**
  - **Asynchronous**

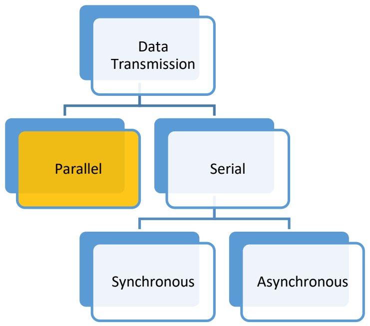
- Multiplexing
  - Time-Division Multiplexing (TDM)
  - Frequency-Division Multiplexing (FDM)
  - Wave-Division Multiplexing (WDM)
- Spread Spectrum
  - Frequency Hopping Spread Spectrum
  - Direct Sequence Spread Spectrum
- Switching
  - Circuit Switching
  - Message Switching
  - Packet Switching
- Transmission Media
  - Guided Media
  - Unguided Media

Physical Layer | Bit Synchronization

The transmission of binary data across a link can be accomplished in the following modes:

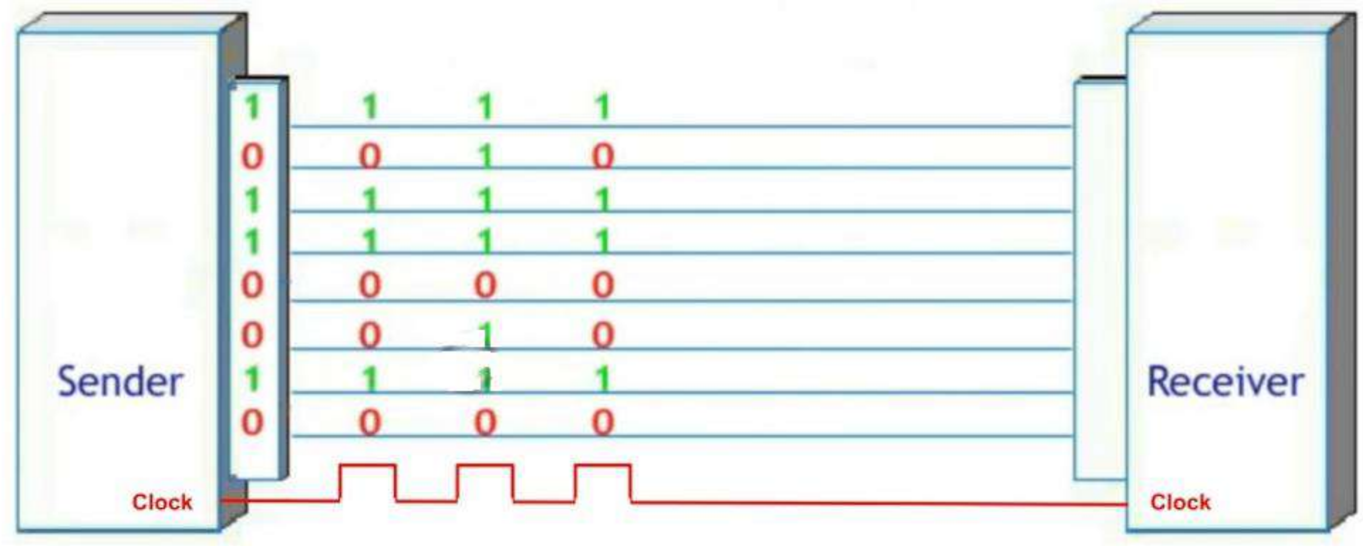


Physical Layer | Bit Synchronization



Parallel Transmission

Multiple bits are sent with each clock pulse.



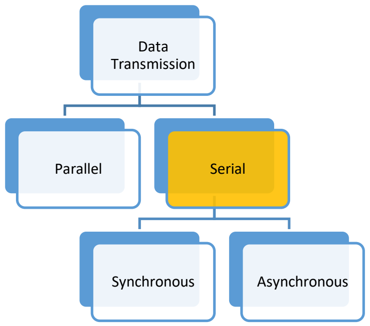
Mechanism for parallel transmission is a conceptually simple one: **Use 'n' wires to send 'n' bits at one time.**

Advantage: Speed

Disadvantage: Cost

Usually limited to **Short Duration.**

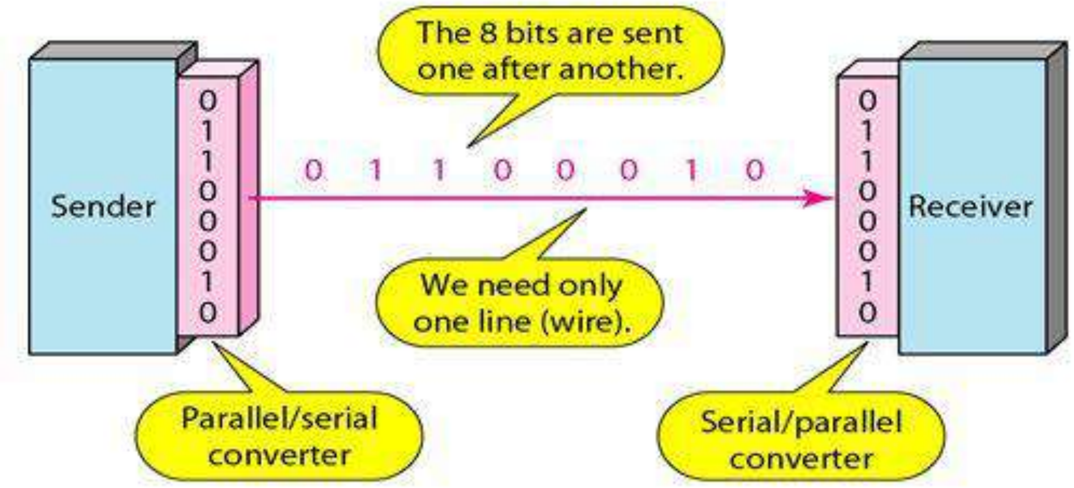
Physical Layer | Bit Synchronization



Serial Transmission

One bit follows another.

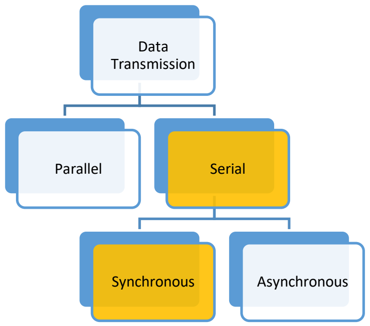
Need only one communication channel.



Communication within devices is parallel, conversion devices are required at the interface **between the sender and the line (**parallel-to-serial**) and between the line and the receiver (**serial-to-parallel**).**

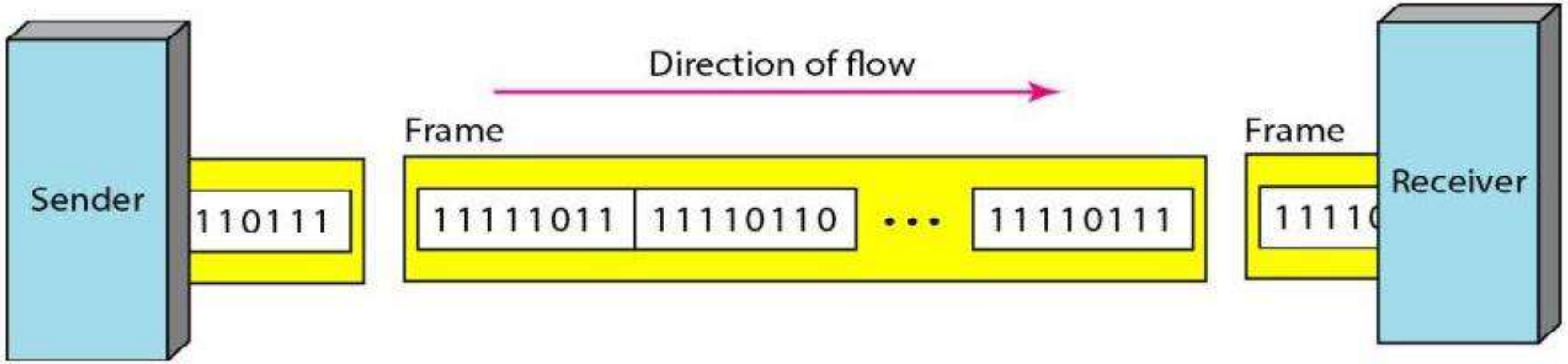
Advantage: Reduced Cost in comparison with parallel transmission.

Physical Layer | Bit Synchronization



Serial Transmission | Synchronous Transmission

The bit stream is combined into a longer ‘frames’, which may contain multiple bytes.



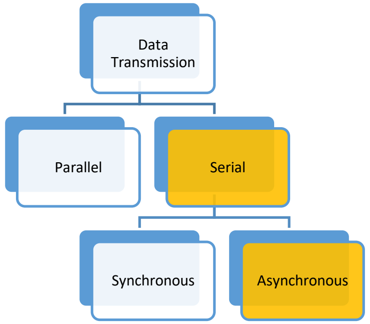
The data are transmitted as **an unbroken string of 1s and 0s**, and the receiver separates that string into the bytes, or characters, it needs to reconstruct the information.

If the sender wishes to send data **in separate bursts**, the gaps between bursts must be filled with a special sequence of 0s and 1s that means **idle**.

Advantage – Speed

More useful for **High-Speed Applications**.

Physical Layer | Bit Synchronization

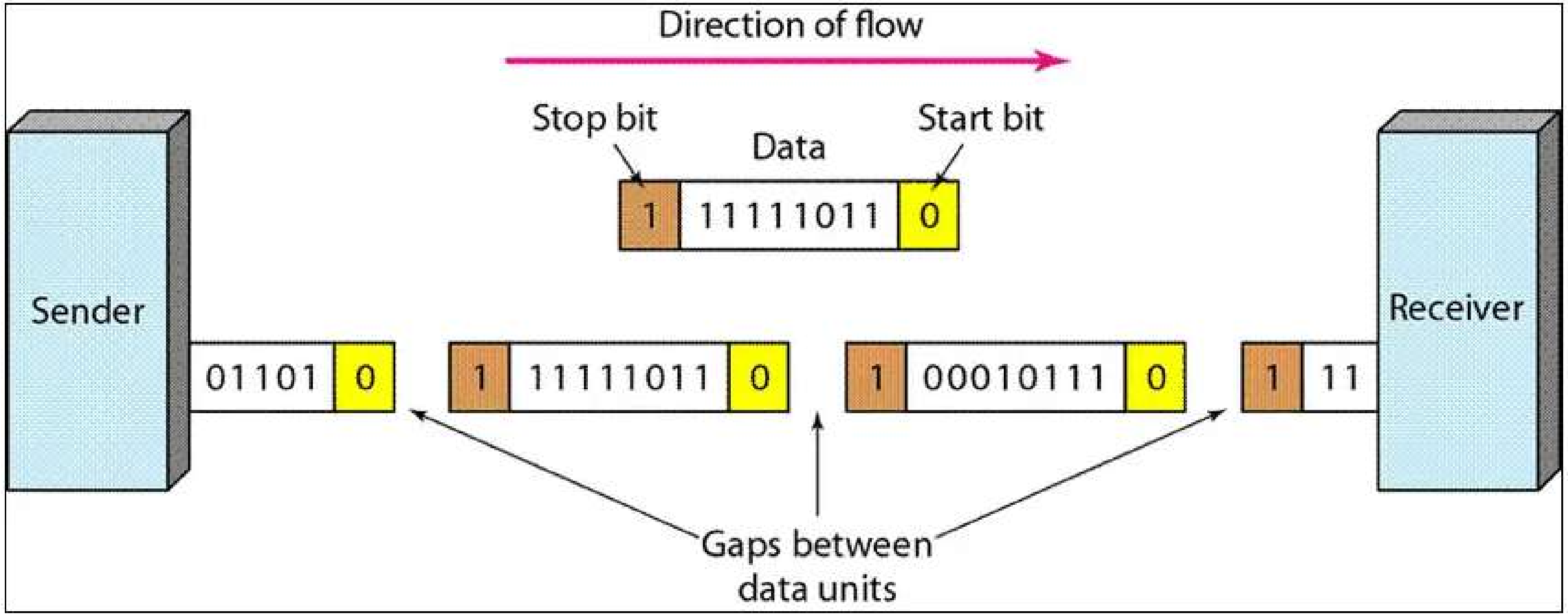


Serial Transmission | Asynchronous Transmission

Timing of the signal is unimportant.

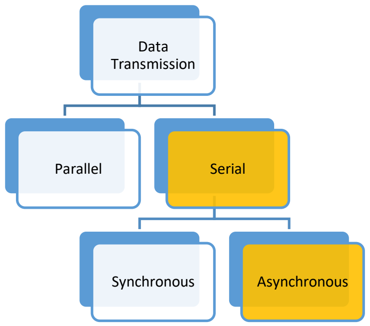
Information is received and translated **by agreed-upon patterns**.

Patterns are based on **grouping the bit stream into bytes**. Each group, usually eight bits, is sent along the link as a unit.



The transmission of each byte may then be followed by a gap of varying duration.

Physical Layer | Bit Synchronization

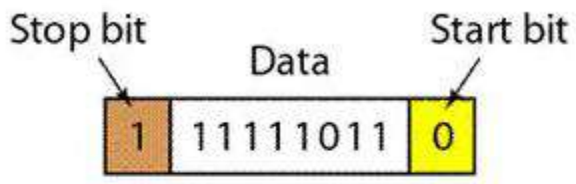


The sending system handles each group independently relaying it to the link whenever ready, without regard to a timer.

To alert the receiver to the arrival of a new group:

- **An extra bit is added to the beginning of each byte**. **This bit is usually a 0**, is called the **START BIT**.

- To let the receiver know that **the byte is finished**, one or more additional bits are appended to the end of the byte. These bits, **usually 1s**, are called **STOP BIT(s)**.



Each byte is increased in size to atleast 10 bits.

“**Asynchronous at the byte level**” but the bits are still synchronized (their duration are the same).

Cheaper and effective – Good for **low-speed communication**.

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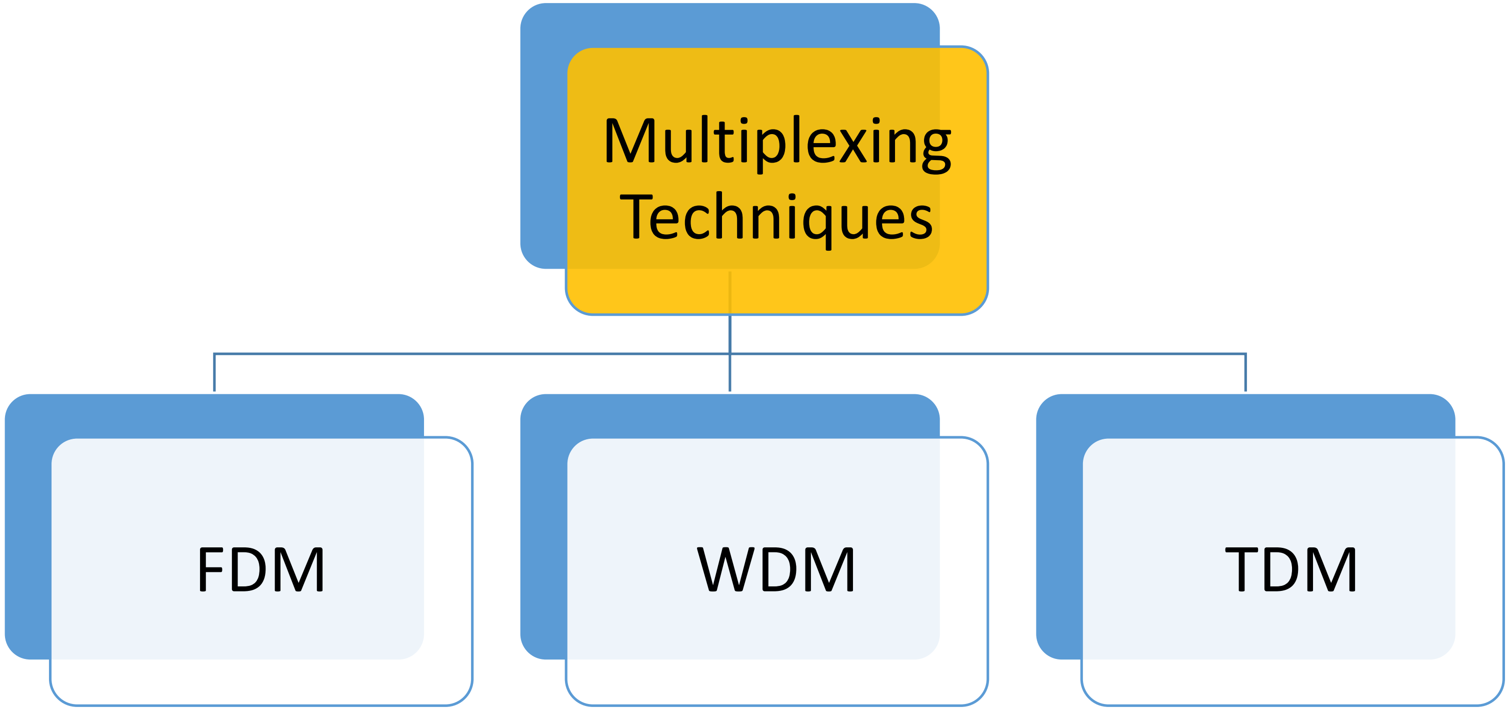
Physical Layer | Multiplexing

Two communicating stations will <u>not utilize the **FULL CAPACITY OF A DATA LINK**</u>.

For efficiency, it should be possible **<u>to share that capacity</u>**. The generic term for such sharing is **MULTIPLEXING**.

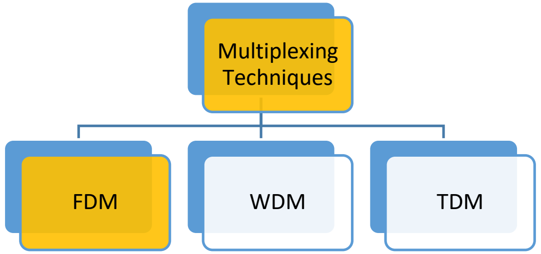


Frequency Division Multiplexing

Wavelength Division Multiplexing

Time Division Multiplexing

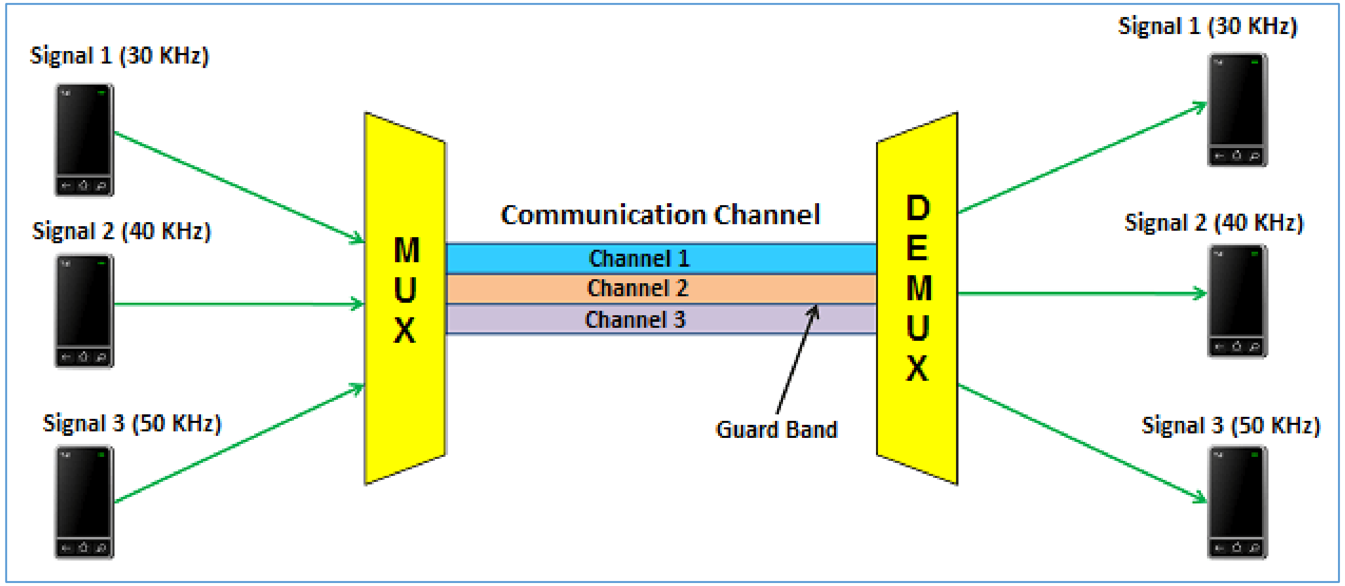
Physical Layer | Multiplexing



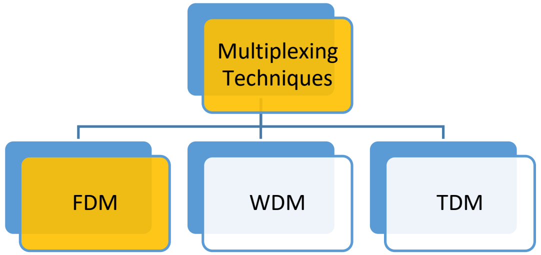
Frequency Division Multiplexing (FDM)

Useful bandwidth of the transmission medium exceeds the required bandwidth of signals to be transmitted.

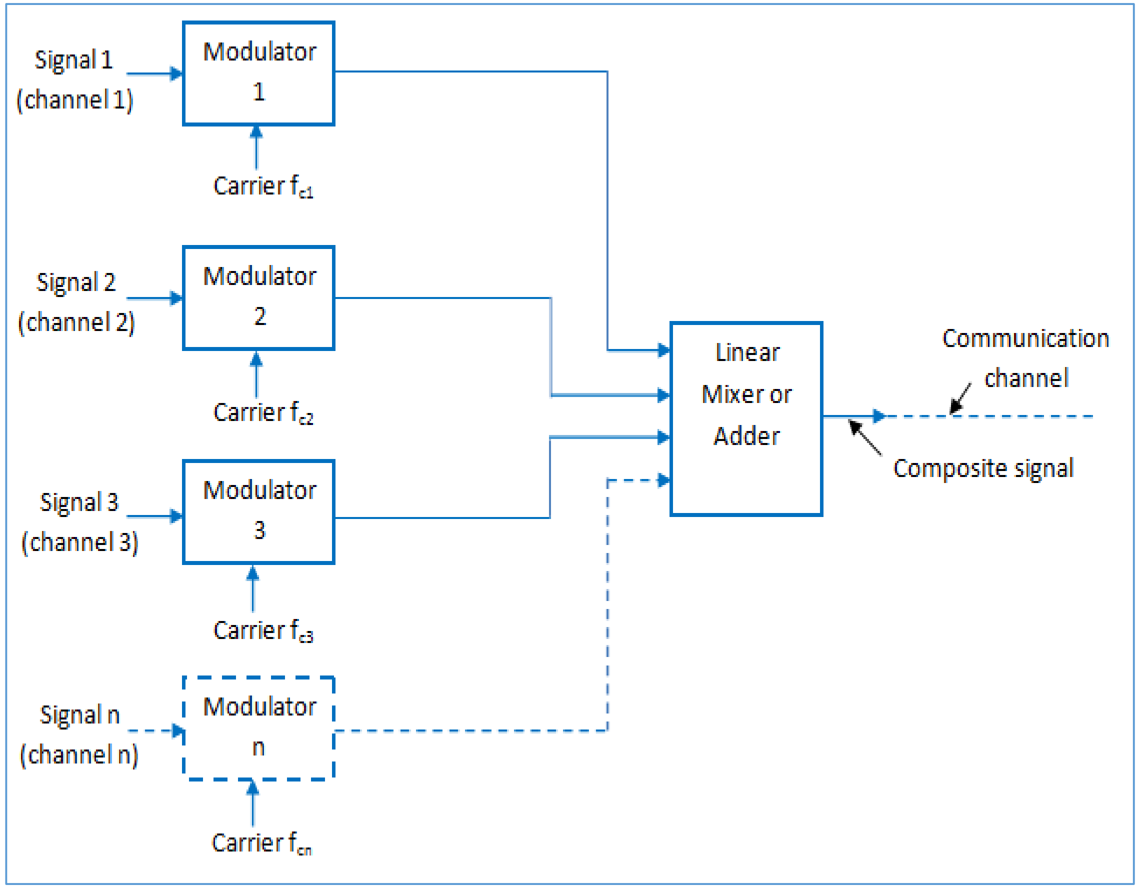
Number of signals can be carried simultaneously if each signal is modulated onto a different carrier frequency and the carrier frequencies are sufficiently separated that the bandwidths of the signals do not significantly overlap.



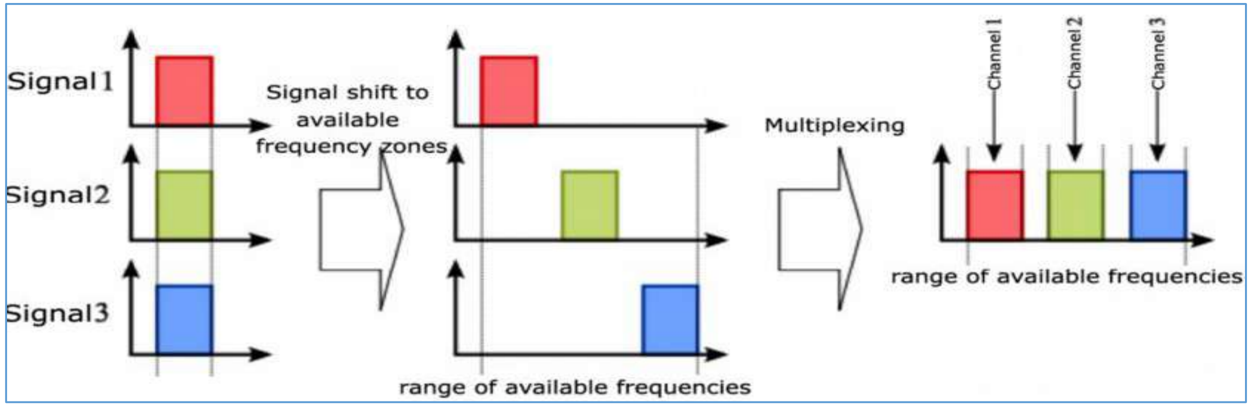
Physical Layer | Multiplexing



Frequency Division Multiplexing (FDM)



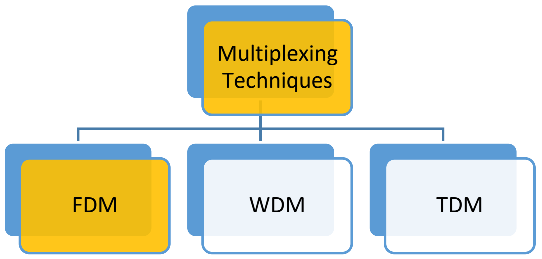
The modulated signals are **summed** to produce a composite baseband signal.



The channels are separated by **guard bands (unused portions of the spectrum) to prevent interference**.

The **composite signal** may then be shifted as a whole to another carrier frequency by an additional modulation step.

Physical Layer | Multiplexing



Frequency Division Multiplexing (FDM)

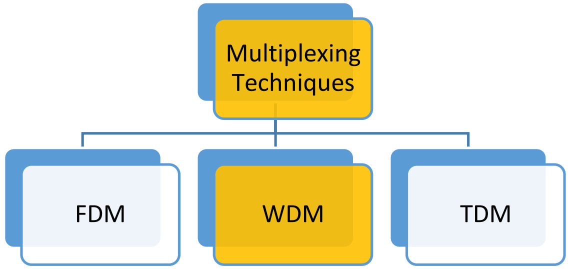
Advantages:

- **Efficient Use of Bandwidth:** Allows multiple signals to be transmitted over a single communication channel, which can lead to more efficient use of available bandwidth.
- **No Time Synchronization Required:** Does not require precise time synchronization between the transmitting and receiving devices, making it easier to implement.
- **Low Implementation Cost:** Relatively simple technique that does not require sophisticated hardware or software, making it less expensive to implement.

Disadvantages:

- **Limited Capacity:** FDM is limited in terms of the number of signals that can be transmitted over a single communication channel, which can be a disadvantage in applications where a large number of signals need to be transmitted.
- **Interference:** FDM can be susceptible to interference from other signals transmitted on nearby frequencies, which can degrade the quality of the transmitted signals.
- **Difficulty in Assigning Frequencies:** FDM requires careful assignment of frequencies to different signals to avoid interference, which can be a complex and time-consuming process.

Physical Layer | Multiplexing

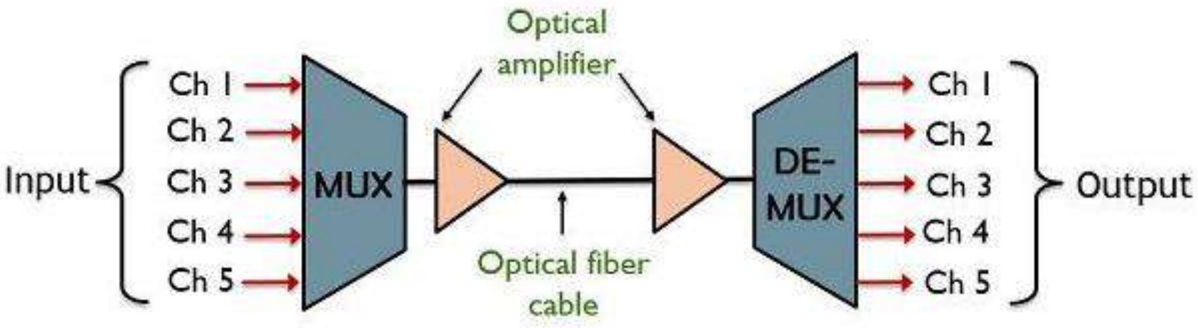


Wavelength Division Multiplexing (WDM)

The true potential of optical fibre is fully exploited **when multiple beams of light at different frequencies are transmitted on the same fibre**.

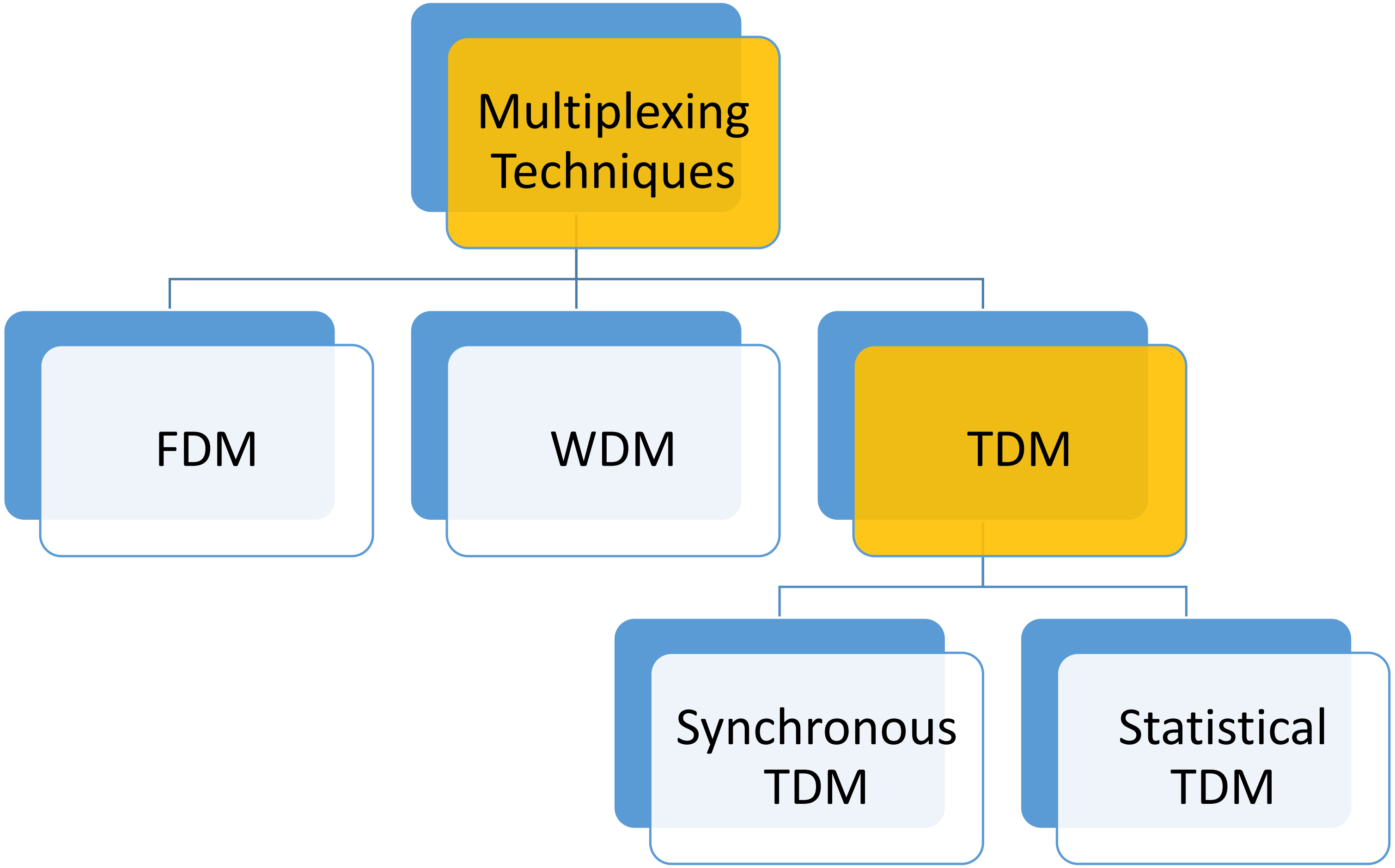
This is a form of FDM but commonly called **Wavelength Division Multiplexing (WDM)**.

A number of sources generate a laser beam at different wavelengths. These are sent to a multiplexer, which consolidates the sources for transmission over a single fibre line.

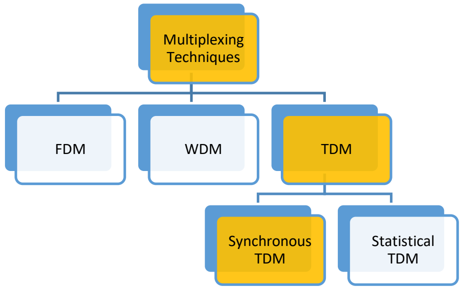


Physical Layer | Multiplexing

Time Division Multiplexing (TDM)



Physical Layer | Multiplexing



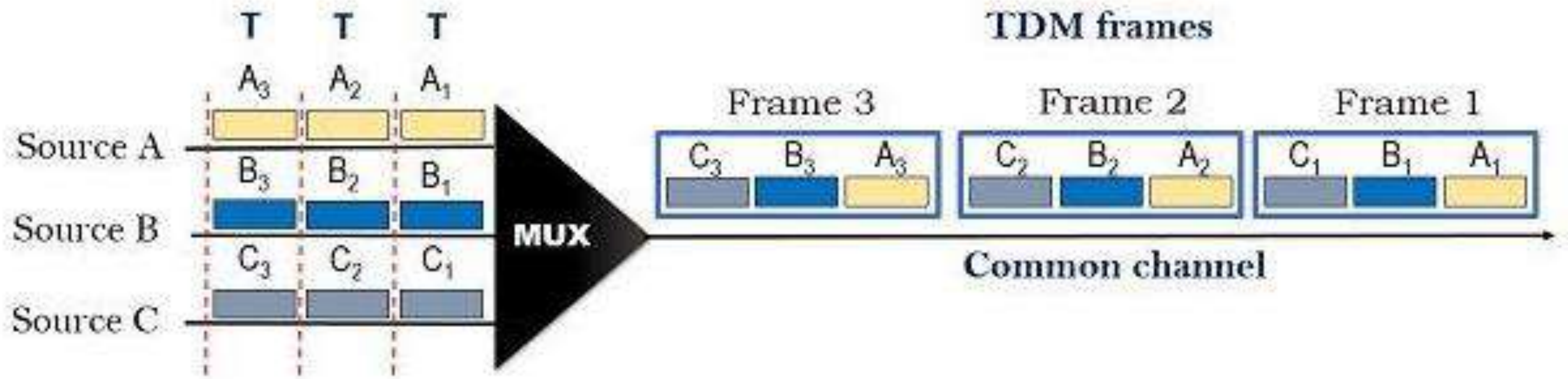
Time Division Multiplexing (TDM) | Synchronous

When the data transmission rate of media is greater than that of the source, and **each signal is allotted a definite amount of time**.

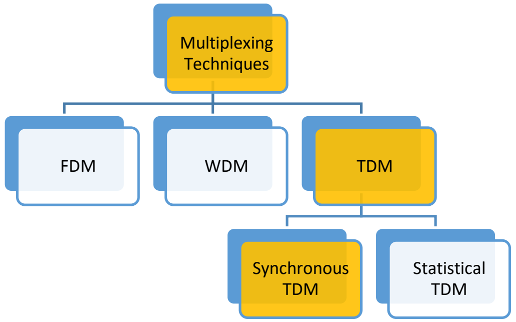
Time slots are so small that **all transmissions appear to be parallel**.

Multiple digital signals can be carried on **a single transmission path** by **interleaving portions of each signal in time**.

The interleaving can be at the *bit level* or *in blocks of bytes* or *larger quantities*.

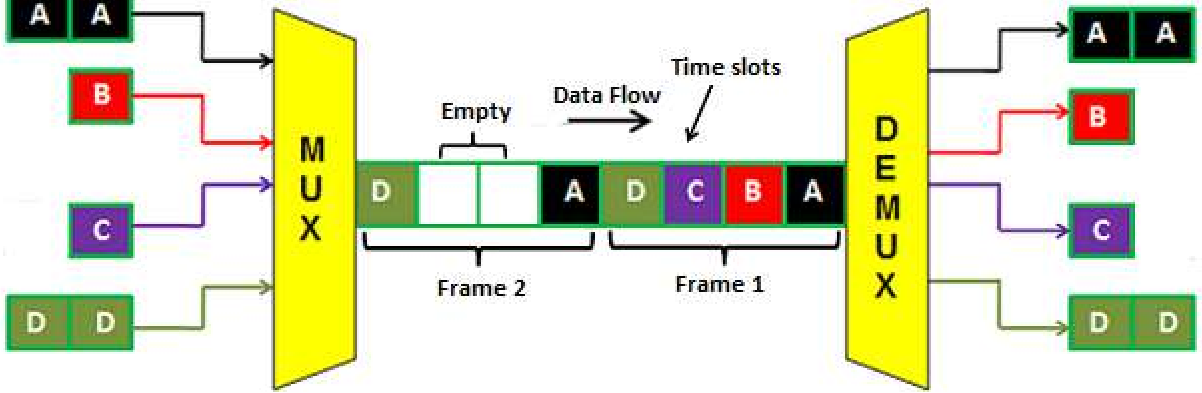


Physical Layer | Multiplexing



Time Division Multiplexing (TDM) | Synchronous

The time slot may be empty or occupied.

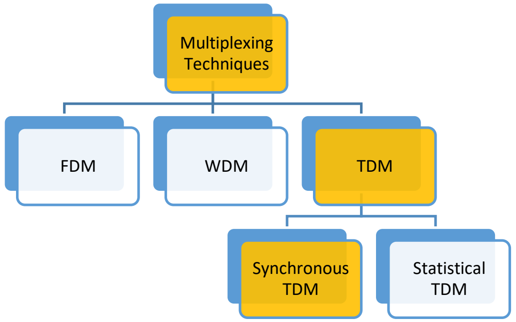


The data are organized into frames. **Each frame contains a cycle of time slots.**

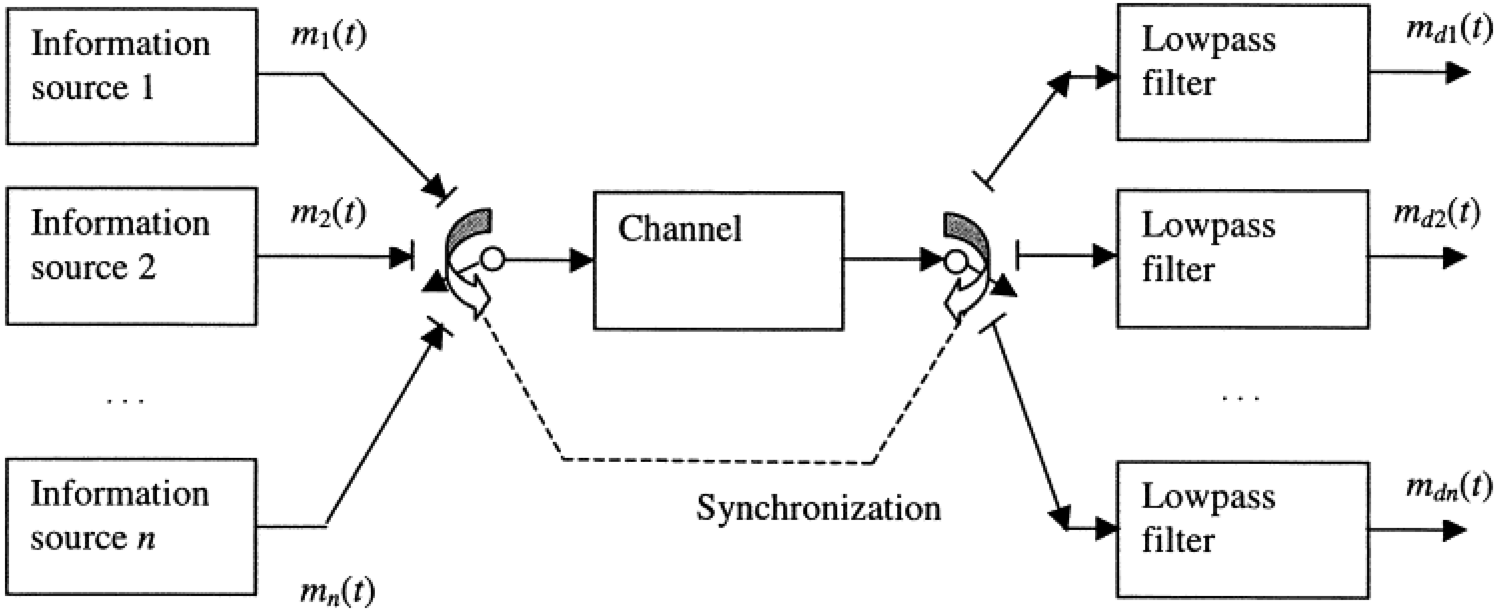
The sequence of slots dedicated to one source, from frame to frame, is called a **CHANNEL**. The slot length equals the transmitter buffer length, typically a bit or a byte (character).

Called **synchronous** because the time slots are pre-assigned to sources and fixed. The time slots for each source are transmitted whether or not the source has data to send.

Physical Layer | Multiplexing



Time Division Multiplexing (TDM) | Synchronous

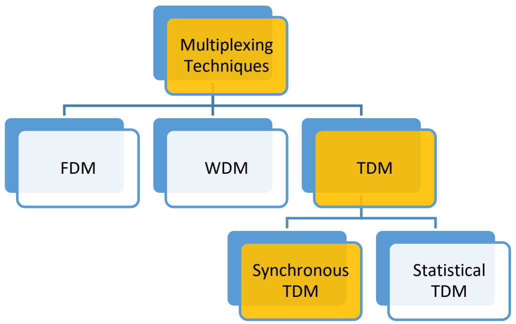


The data rate of composite signal **must be at least equal to the sum of the data rates of the $m_i(t)$**.

The incoming information from each source **are briefly buffered**. Each buffer is typically *one bit or one character in length*.

The buffers are scanned sequentially to form a composite digital data stream. The scan operation is sufficiently rapid so that *each buffer is emptied before more data can arrive*.

Physical Layer | Multiplexing

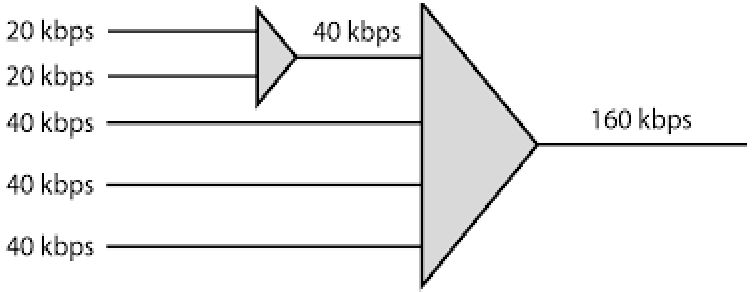


Time Division Multiplexing (TDM) | Synchronous

To handle a **disparity in the input data rates**:

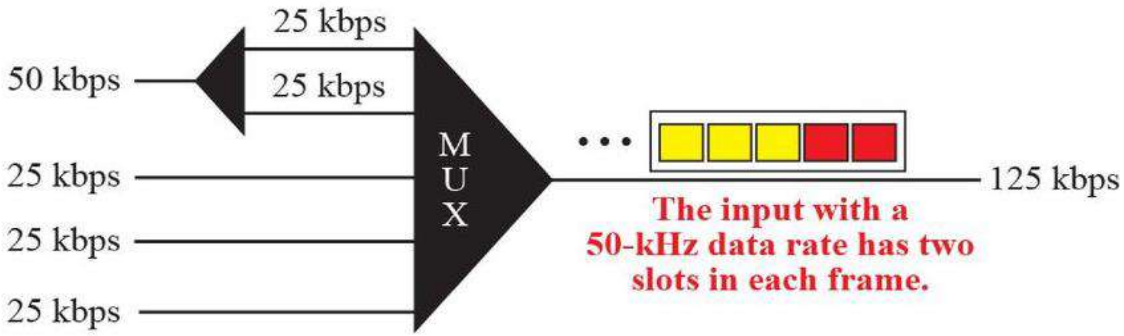
Multi-level TDM

Used when the **data rate of an input line is a multiple of others**.



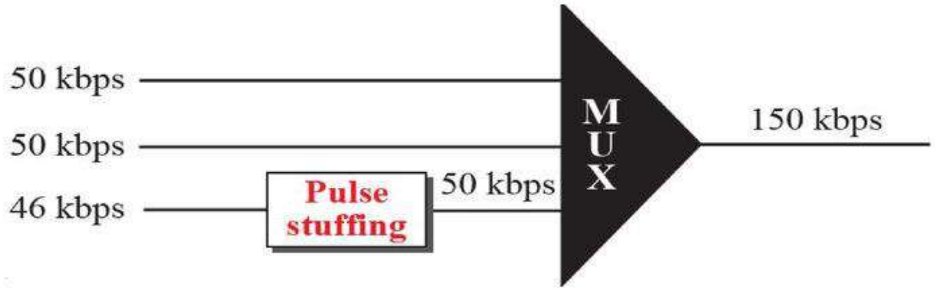
Multi-slot TDM

Used to **demultiplex a higher data rate input** to provide more outputs with a lower data rate.

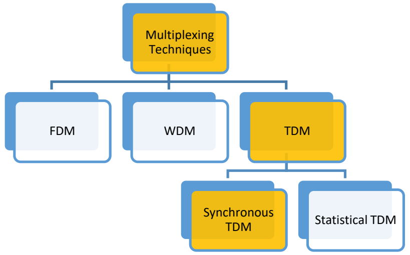


Pulse-stuffed TDM

Strategy of adding extra bits to the input in purpose **to equal the data rate of pulse-stuffed input with other inputs**.



Physical Layer | Multiplexing



Time Division Multiplexing (TDM) | Synchronous

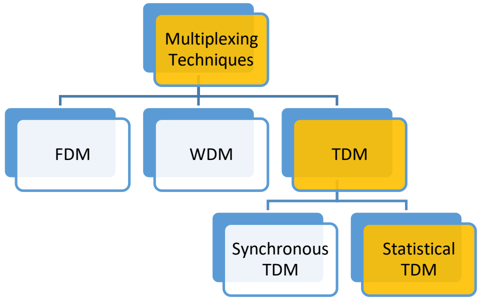
Advantages:

- **High Capacity:** Support a large number of signals over a single communication channel, making it ideal for applications where many signals need to be transmitted.
- **Simple Implementation:** Relatively simple technique that is easy to implement, making it a cost-effective solution for many applications.
- **Precise Time Synchronization:** Requires precise time synchronization between the transmitting and receiving devices, which can help ensure accurate transmission of signals.

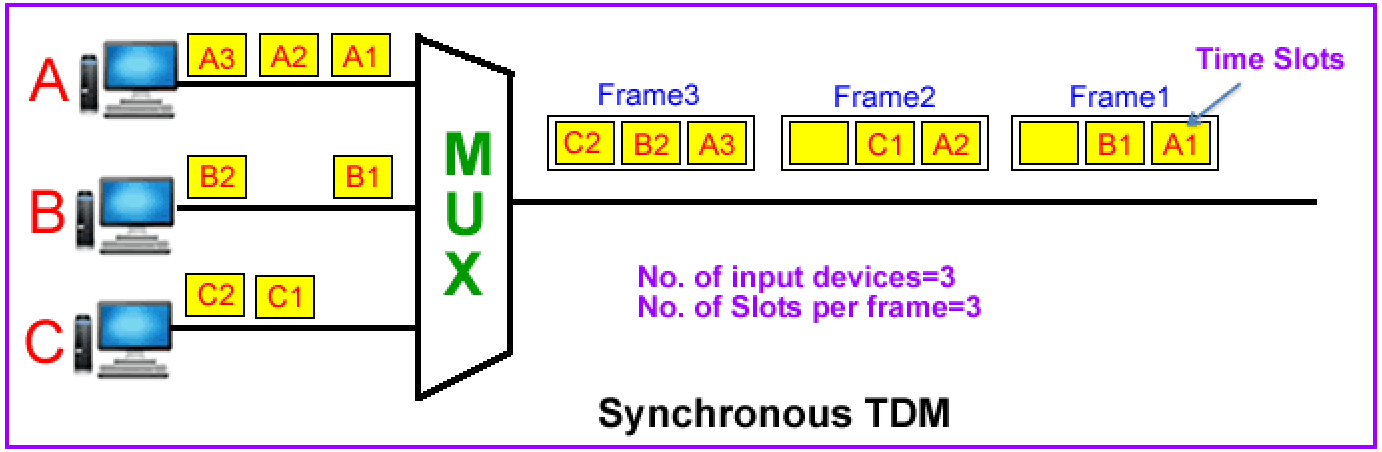
Disadvantages:

- **Inefficient Use of Bandwidth:** TDM may not make optimal use of available bandwidth, as time slots may be left unused if there are no signals to transmit during a particular time slot.
- **High Implementation Cost:** TDM requires sophisticated hardware or software to ensure precise time synchronization between the transmitting and receiving devices, making it more expensive to implement than FDM.
- **Vulnerable to Timing Jitter:** TDM can be vulnerable to timing jitter, which can occur when the timing of the transmitting and receiving devices drifts out of sync, leading to errors in the transmission of signals.

Physical Layer | Multiplexing



Time Division Multiplexing (TDM) | Statistical



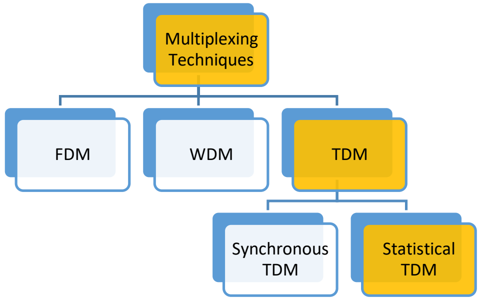
Dynamically allocating time slots on demand.

Multiplexer has a number of I/O lines on one side and a higher-speed multiplexed line on the other.

The *data rate on the multiplexed line* is **less than the sum of the data rates of the attached devices**.

Statistical TDM / Asynchronous TDM / Intelligent TDM

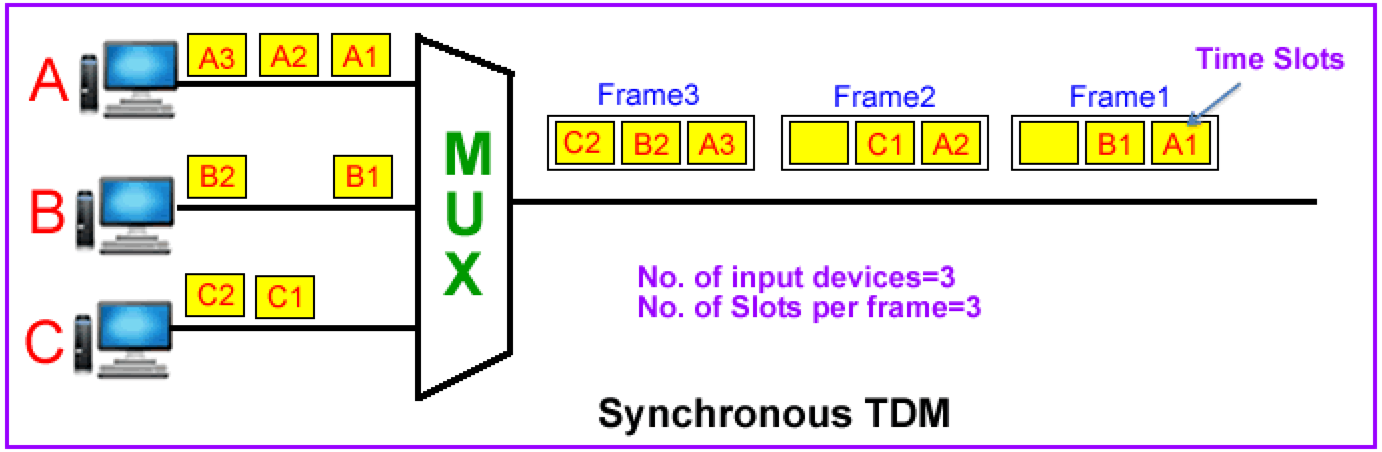
Physical Layer | Multiplexing



Time Division Multiplexing (TDM) | Statistical

How does the demultiplexer know which slot belongs to which output line?

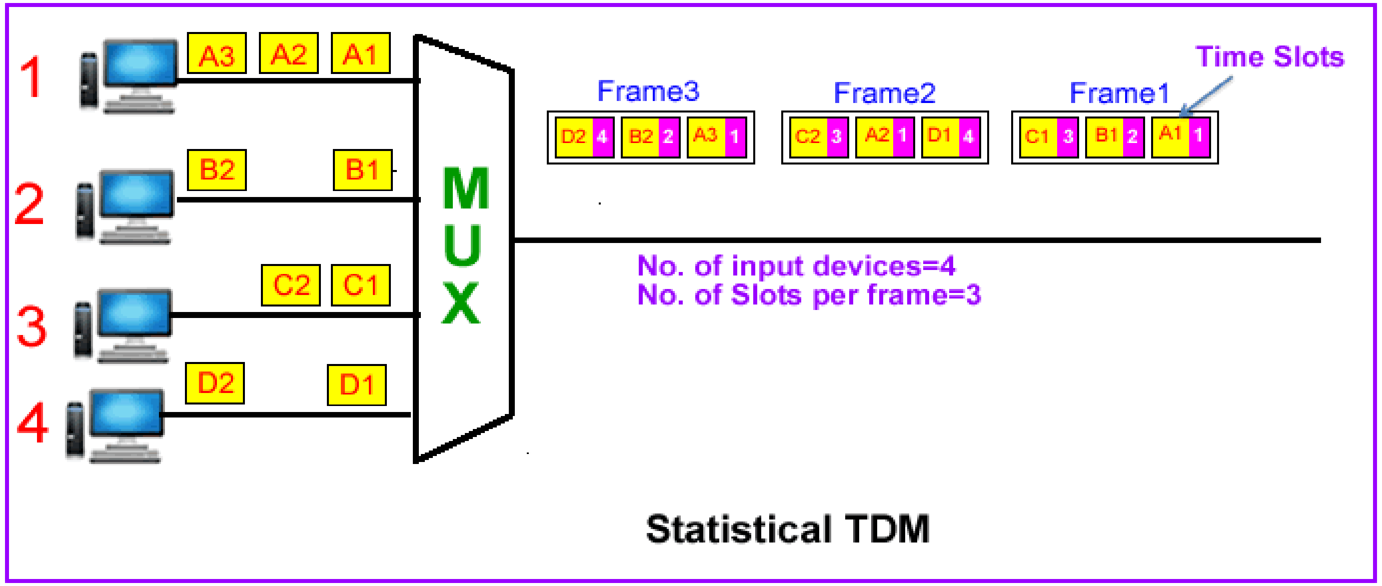
- Must carry an ADDRESS of source.
- This increases overhead and limits its potential efficiency.



It can accommodate traffic of varying data rates by varying the length of the time slots.

- ***Control bits*** *should be appended to the beginning of each time slot* ***to indicate the length of the coming data portion***.

Stations transmitting at a faster data rate can be given **a longer slot**.



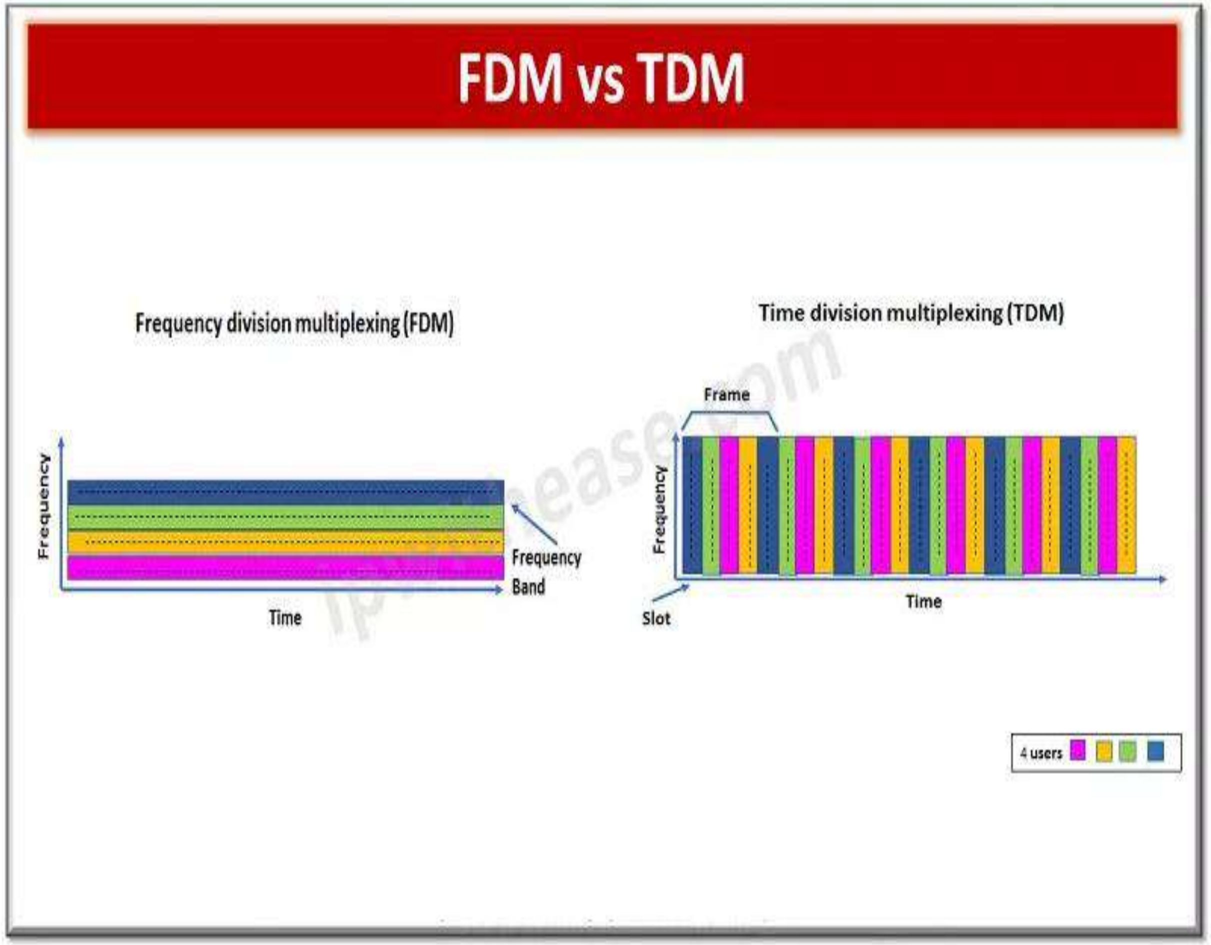
Physical Layer | Multiplexing

Multiplexing Techniques

- FDM
- WDM
- TDM

Multiplexing

Radio, Television broadcasting and Cable Television.



Scheduling, Data Transmission, and Resource Allocation. It is also widely used in networking protocols to ensure that all devices are given equal access and that data is sent in a timely manner.

<u>In FDM</u> all the signals operate at the same time with different frequencies, but **<u>in TDM</u>**, **all the signals operate with the same frequency at different times.**

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Physical Layer | Spread Spectrum

Multiplexing combines signals from several sources to achieve bandwidth efficiency; the available bandwidth of a link is divided between the sources.

Spread spectrum (SS) also combine signals from different sources to fit into a larger bandwidth.

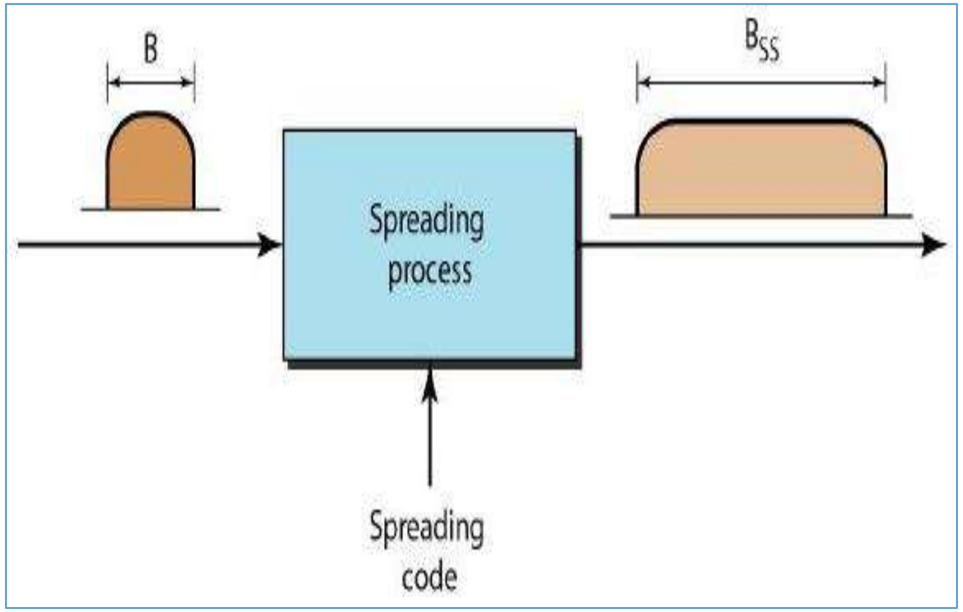
Spread spectrum is **designed to be used in wireless applications** (LANs and WANs).

In wireless applications, all stations use air as the medium for communication. Stations must be able to share this medium *without interception by an eavesdropper* and *without being subject to jamming from a malicious intruder*.

To achieve these goals, spread spectrum techniques **add redundancy**; they *spread the original spectrum needed for each station*.

The spread spectrum **expands the required bandwidth** *for each station*.

The expanded bandwidth allows the source to wrap its message in a protective envelope for a more secure transmission.



Physical Layer | Spread Spectrum

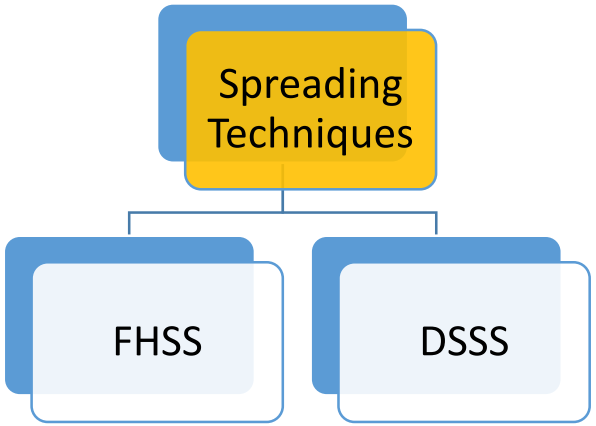
Spread spectrum achieves its goals through two principles:

1. The bandwidth allocated to each station needs to be, by far, larger than what is needed. **This allows redundancy**.

2. The expanding of the original bandwidth B to B_{ss} must be done **by a process** that is independent of the original signal. In other words, the **spreading process** occurs after the signal is created by the source.

The **spreading process** uses a **spreading code** and *spreads the bandwidth*.

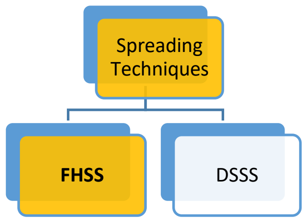
The **spreading code** is **a series of numbers that look random, but are actually a pattern**.



Frequency Hopping Spread Spectrum

Direct Sequence Spread Spectrum

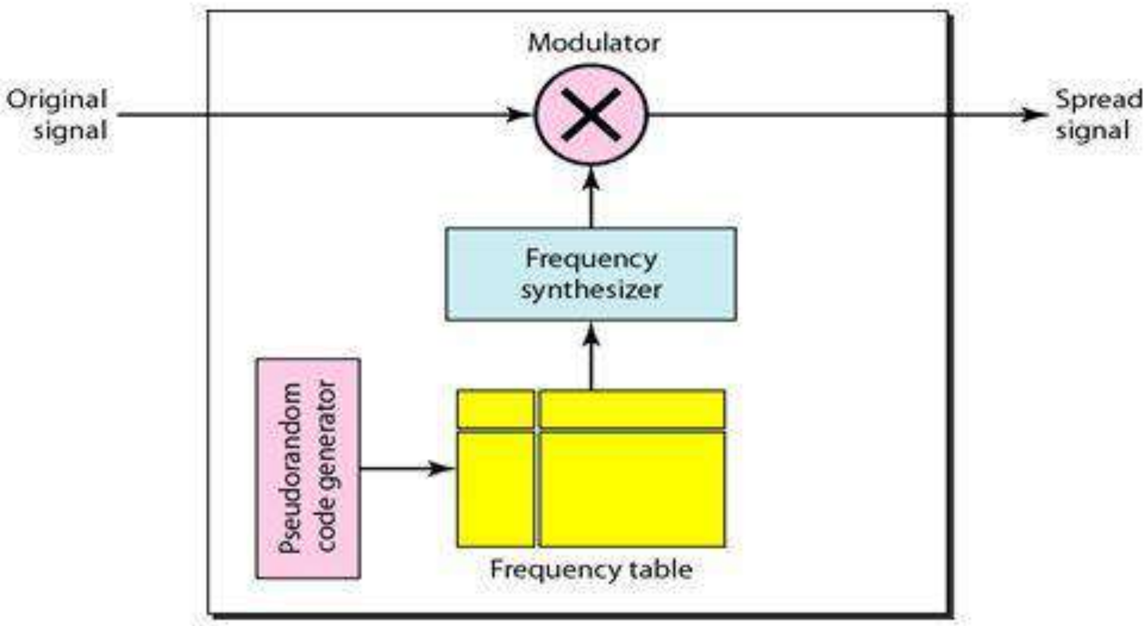
Physical Layer | Spread Spectrum



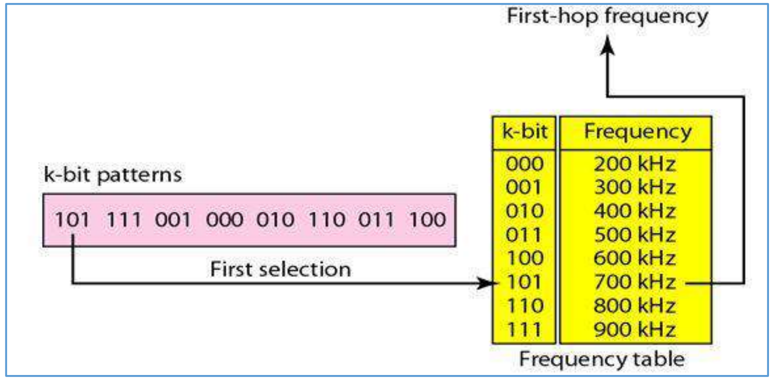
Frequency Hopping Spread Spectrum (FHSS)

The signal is broadcast over a seemingly random series of radio frequencies, **hopping from frequency to frequency at fixed intervals**.

A receiver, hopping between frequencies in synchronization with the transmitter, picks up the message.

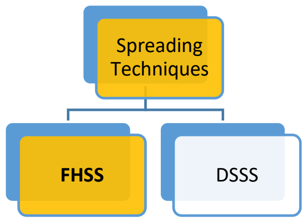


A pseudorandom code generator, called **pseudorandom noise (PN)**, creates **a k-bit pattern** for every hopping period T_h.



The frequency table uses the pattern to find the **frequency to be used** for this hopping period and passes it to the frequency synthesizer.

Physical Layer | Spread Spectrum

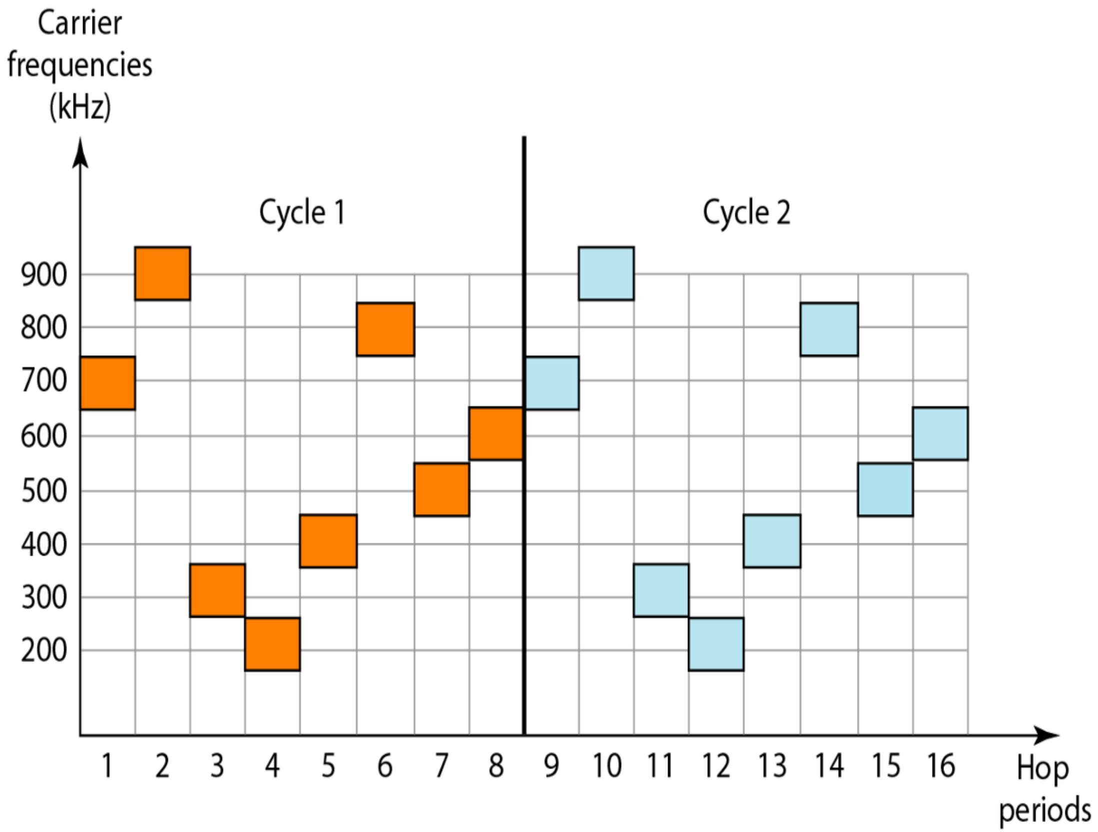


The **frequency synthesizer** creates a carrier signal of that frequency, and the **source signal modulates the carrier signal**.

The FHSS technique uses **M different carrier frequencies that are modulated by the source signal**.

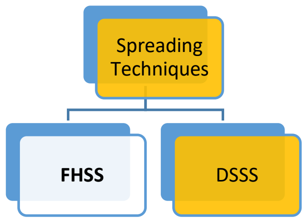
At one moment, the signal modulates one carrier frequency; **at the next moment**, the signal modulates another carrier frequency.

Both transmitter and receiver use the same code to tune into a sequence of channels in synchronization.



Pattern of channel usage is called the **hopping sequence**, the time spend on a channel with a certain frequency is called the **dwell time**.

Physical Layer | Spread Spectrum



Direct Sequence Spread Spectrum (DSSS)

Each bit in the original signal is **represented by multiple bits** in the transmitted signal, using **a spreading code**.

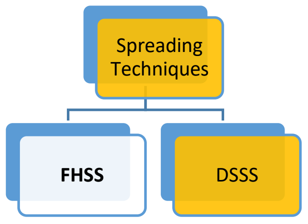
Each bit is assigned a code of n bits, called **chips**, where the chip rate is n times that of the data bit.

The **spreading code** spreads the signal across a wider frequency band in direct proportion to the number of bits used i.e., **a 10-bit spreading code spreads the signal across a frequency band that is 10 times greater than a 1-bit spreading code**.

Each station is assigned **a unique m-bit code**. This code is called the **Code Division Multiple Access (CDMA) chip sequence**.

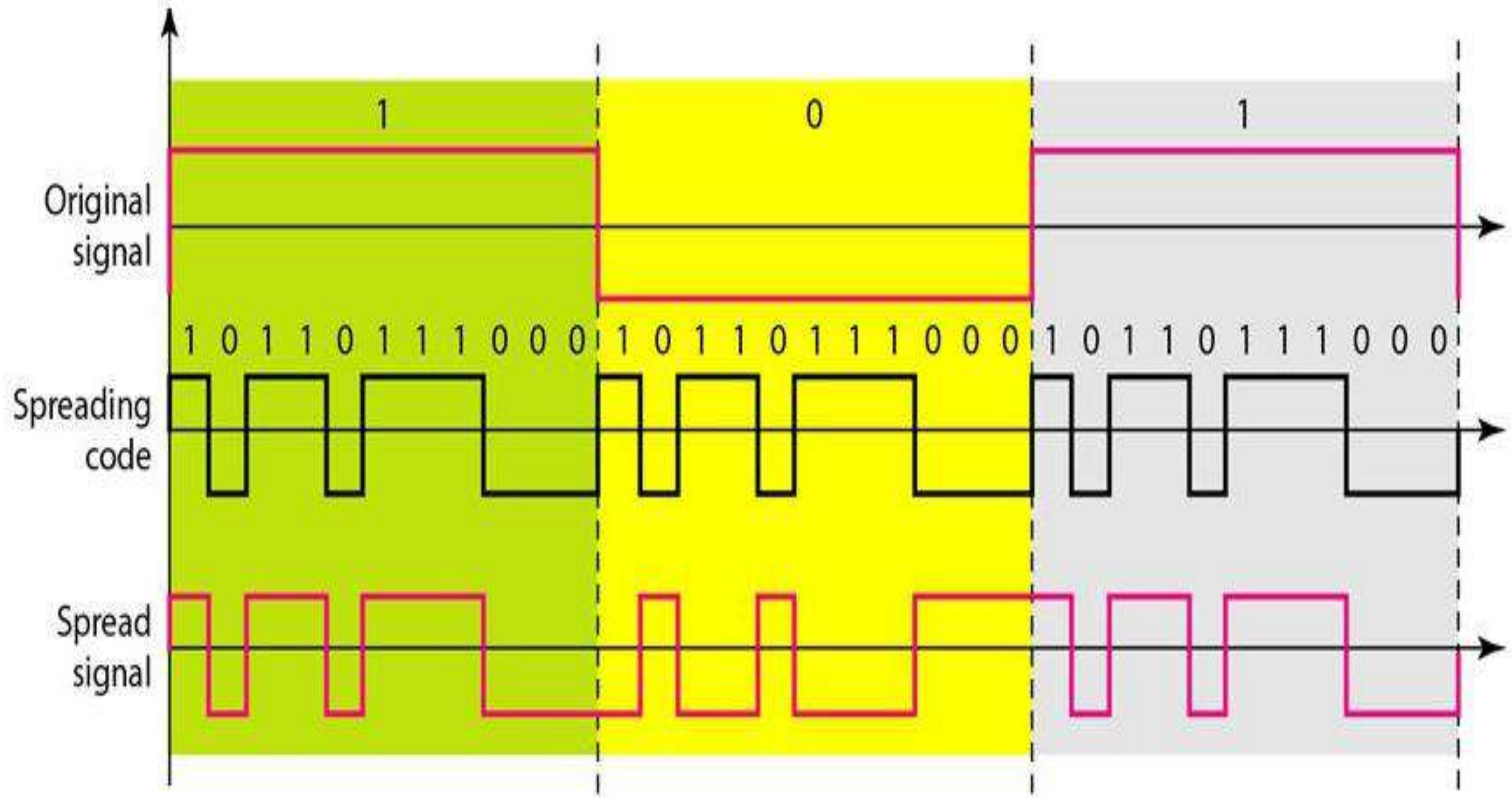
To transmit a 1-bit, the transmitting station **sends its chip sequence**, whereas to send 0, it sends the **complement chip sequence**.

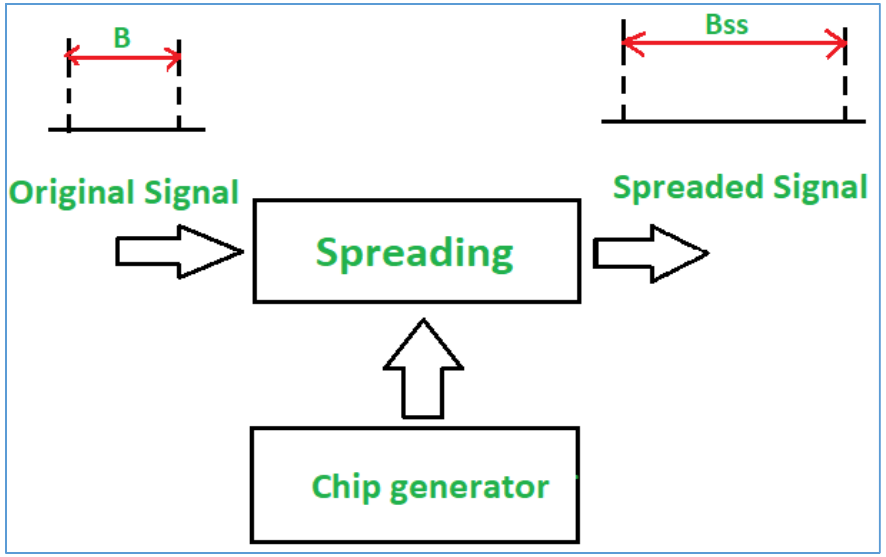
Physical Layer | Spread Spectrum



If the station 'A' is assigned the 11 bits **chip sequence** 10110111000, so

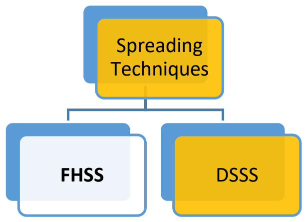
- Bit 1 will be transmitted as **10110111000** &
- Bit 0 as **01001000111**





The required bandwidth for the spread signal is **11 times larger than the bandwidth of the original signal**.

Physical Layer | Spread Spectrum



Example:

There are four stations A, B, C & D with their **chip sequences**:

- A: 00011011
- B: 00101110
- C: 01011100
- D: 01000010

Using bipolar notations (bit 0 as -1 and bit 1 as +1):

- A: -1 -1 -1 +1 +1 -1 +1 +1
- B: -1 -1 +1 -1 +1 +1 +1 -1
- C: -1 +1 -1 +1 +1 +1 -1 -1
- D: -1 +1 -1 -1 -1 -1 +1 -1

Assume that there are six cases of four stations transmitting at the same time:

CASE I: Only Station 'C' is transmitting (Bit 1)

_ _ 1 _	**C**	**S1 = (-1 +1 -1 +1 +1 +1 -1 -1)**

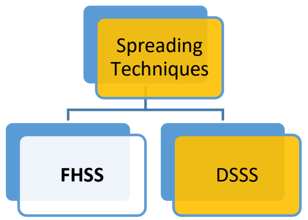
CASE II: Only Station 'B' & 'C' is transmitting (Bit 1)

_ 1 1 _	**B+C**	**S2 = (-2 0 0 0 +2 +2 0 -2)**

CASE III: Station 'A' is transmitting (Bit 1) and station 'B' transmit '0'

1 0 _ _	**A+B`**	**S3 = (0 0 -2 +2 0 -2 0 +2)**

Physical Layer | Spread Spectrum



A: -1 -1 -1 +1 +1 -1 +1 +1
B: -1 -1 +1 -1 +1 +1 +1 -1
C: -1 +1 -1 +1 +1 +1 -1 -1
D: -1 +1 -1 -1 -1 -1 +1 -1

CASE IV: Station 'A' & 'C' is transmitting (Bit 1) and station 'B' transmits (Bit 0)

1 0 1 _	**A+B`+C**	**S4 = (-1 +1 -3 +3 -1 -1 -1 +1)**

CASE V: All four Stations transmits (Bit 1)

1 1 1 1	**A+B+C+D**	**S5 = (-4 0 -2 0 +2 0 +2 -2)**

CASE VI: Station 'A', 'B' & 'D' is transmitting (Bit 1) and station 'C' transmits (Bit 0)

1 1 0 1	**A+B+C`+D**	**S6 = (-1 -2 0 -2 0 -2 +4 0)**

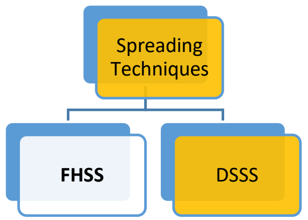
Let us assume that we are interested in recovering the bit sequence of station 'C'.

DSSS does the recovery **by computing the normalized inner product** of the **received chip sequence** (the linear sum of all the stations that transmitted) and the **chip sequence of the station whose bit stream it is trying to recover**.

If the received chip sequence is S (S1 to S6), we computer the normalized inner product (S . C) i.e.,

S1 . C = (-1 +1 -1 +1 +1 +1 -1 -1) . (-1 +1 -1 +1 +1 +1 -1 -1) = (+1+1+1+1+1+1+1+1)/8 = 1

Physical Layer | Spread Spectrum



If the received chip sequence is S (S1 to S6), we computer the normalized inner product (S . C) i.e.,

S1 . C = (-1 +1 -1 +1 +1 +1 -1 -1) . (-1 +1 -1 +1 +1 +1 -1 -1) = (+1+1+1+1+1+1+1+1)/8 = 1

S2 . C = (-2 0 0 0 +2 +2 0 -2) . (-1 +1 -1 +1 +1 +1 -1 -1) = (+2+0+0+0+2+2+0+2)/8 = 1

S3 . C = (0 0 -2 +2 0 -2 0 +2) . (-1 +1 -1 +1 +1 +1 -1 -1) = (+0+0+2+2+0-2+0-2)/8 = 0

S4 . C = (-1 +1 -3 +3 -1 -1 -1 +1) . (-1 +1 -1 +1 +1 +1 -1 -1) = (+1+1+3+3+1-1+1-1)/8 = 1

S5 . C = (-4 0 -2 0 +2 0 +2 -2) . (-1 +1 -1 +1 +1 +1 -1 -1) = (+4+0+2+0+2+0-2+2)/8 = 1

S6 . C = (-1 -2 0 -2 0 -2 +4 0) . (-1 +1 -1 +1 +1 +1 -1 -1) = (+2-2+0-2+0-2-4+0)/8 = -1

From each of the six sums ‘S1’ through ‘S6’, we calculate the bit by summing the pairwise products of the received ‘S’ and the ‘C’ vector and then take 1/8 of the result.

S3 . C = 0; means that in third case **station ‘C’ did not transmit.**

S6 . C = -1; means that in sixth case **station ‘C’ transmitted a 0 bit.**

Physical Layer

- Connection Types / Line Configuration
  - Point-to-Point
  - Multipoint
- Physical Topology
  - Bus
  - Ring
  - Star
  - Mesh
  - Cellular
- Signalling
  - Analog
  - Digital
- Bit Synchronization
  - Synchronous
  - Asynchronous

- Multiplexing
  - Time-Division Multiplexing (TDM)
  - Frequency-Division Multiplexing (FDM)
  - Wave-Division Multiplexing (WDM)
- Spread Spectrum
  - Frequency Hopping Spread Spectrum
  - Direct Sequence Spread Spectrum
- **Switching**
  - **Circuit Switching**
  - **Message Switching**
  - **Packet Switching**
- Transmission Media
  - Guided Media
  - Unguided Media

Physical Layer | Switching

Options for connecting multiple devices:

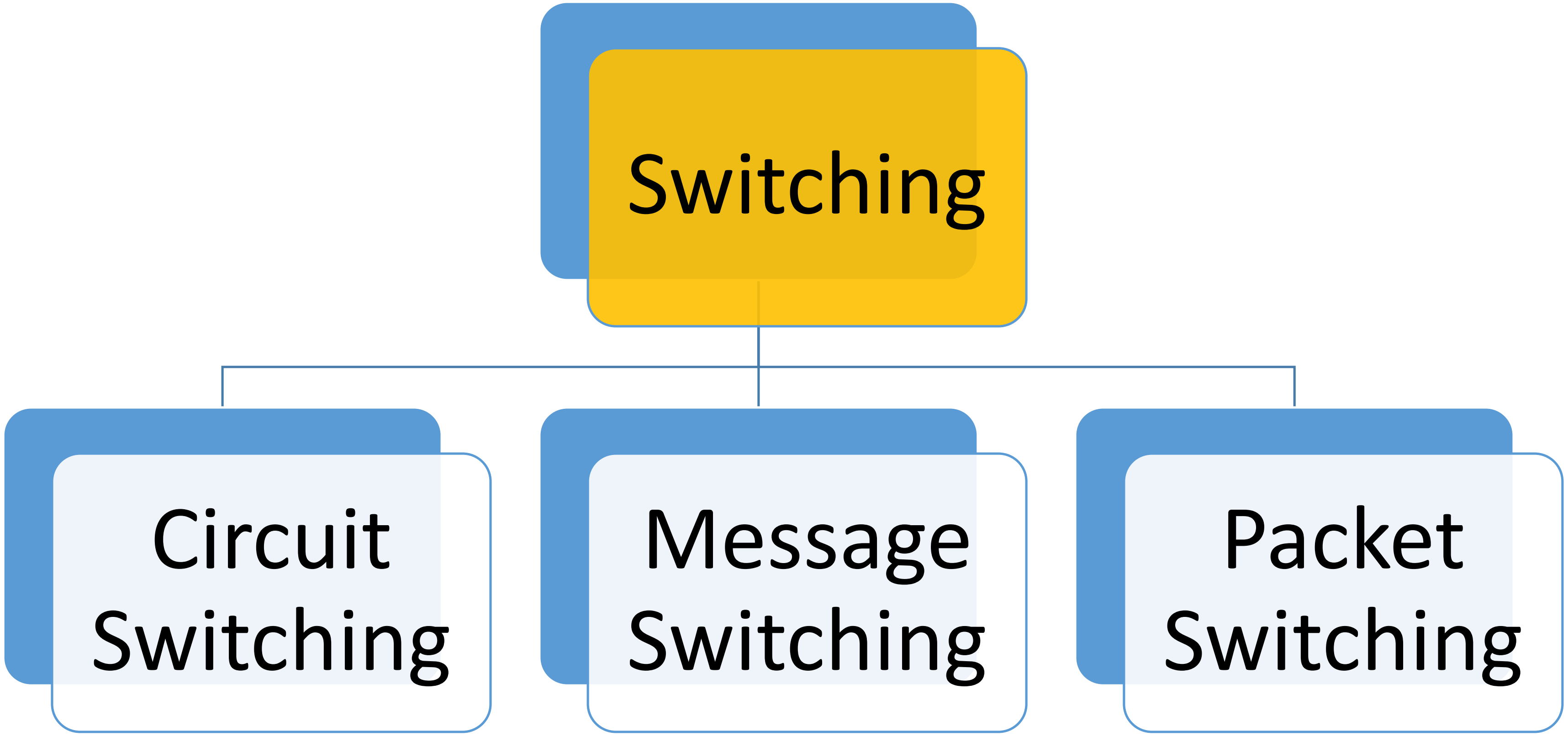
- **Point-to-Point Connection**
  - *Impractical and wasteful when applied to very large networks*.
- **Multi-point Connection**
  - *Ruled out because the distances between devices and the total number of devices increase beyond the capacities of the media and equipment.*

Better solution is SWITCHING.

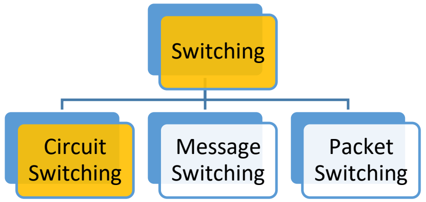
Switched network consists of **a series of inter-linked nodes**, called **switches**.

Switches are **hardware and/or software devices** capable of creating ***temporary connections*** *between two or more devices linked to the switch but not to each other*.

Physical Layer | Switching

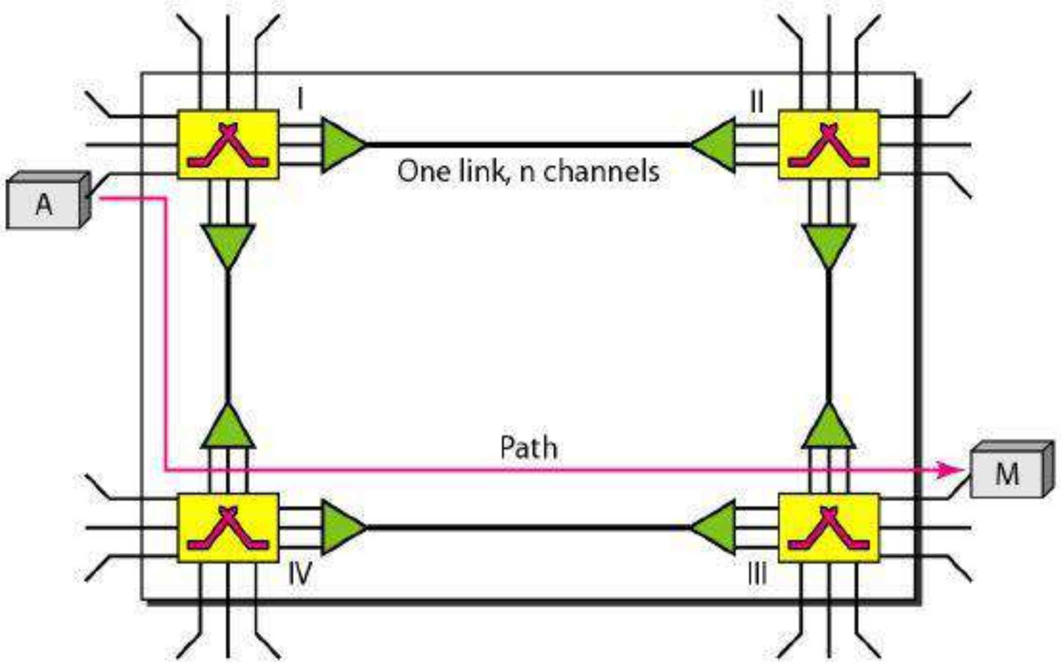


Physical Layer | Switching



Circuit Switching

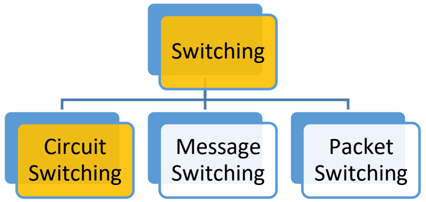
A circuit-switched network is made of a set of switches connected by physical links, in which each link is divided into ‘n’ channels (*using TDM or FDM*).



Set-up end-to-end path (Dedicated Path) *before any data can be sent*.

Completely transparent – the sender and receiver can use any bit rate, format, or framing method they want to.

Physical Layer | Switching



Circuit Switching

The actual communication in a circuit-switched network requires **three phases**:

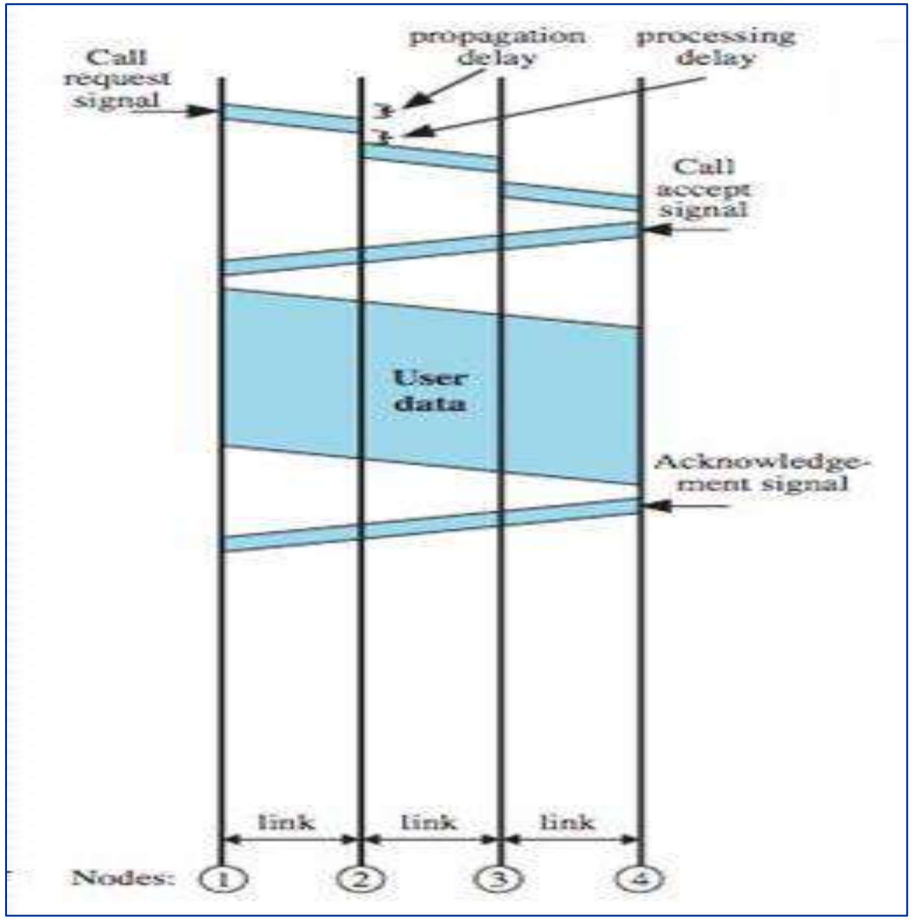
- **Setup Phase**
- **Data-Transfer Phase**
- **Teardown Phase**

The resources need to be reserved during the setup phase; the resources remain dedicated for the entire duration of data transfer until the teardown phase.

It reserves the required bandwidth in advance, any unused bandwidth on an allocated circuit is just wasted.

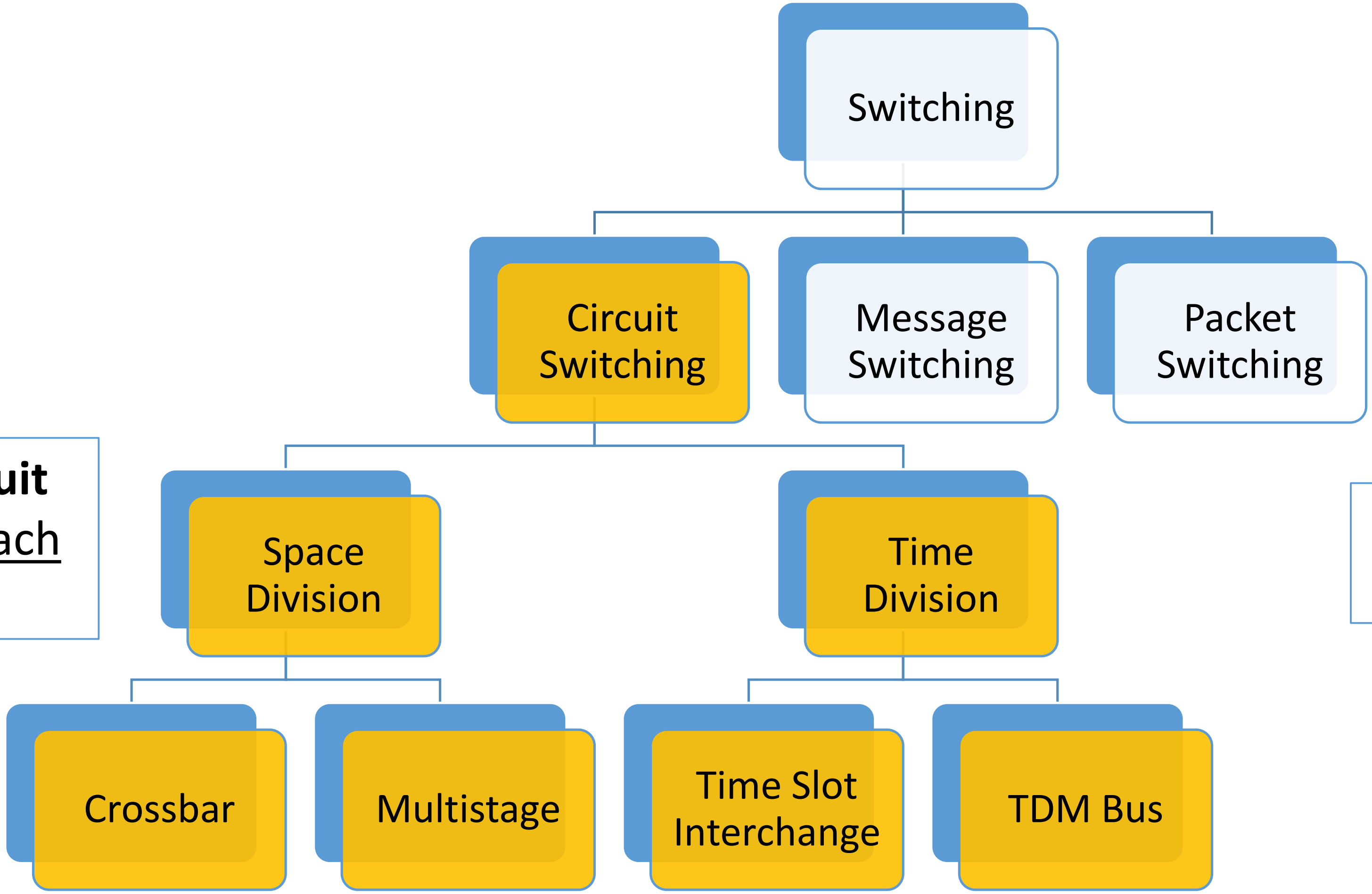
The delay in this type of network is minimal.

Total delay is due to the time needed to **create the connection**, **transfer data**, and **disconnect the circuit**.



Physical Layer | Switching

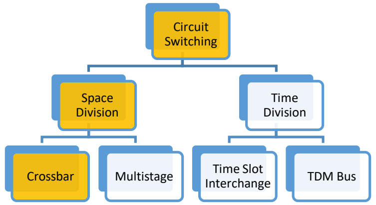
Circuit Switching



The paths in the circuit are separated from each other spatially.

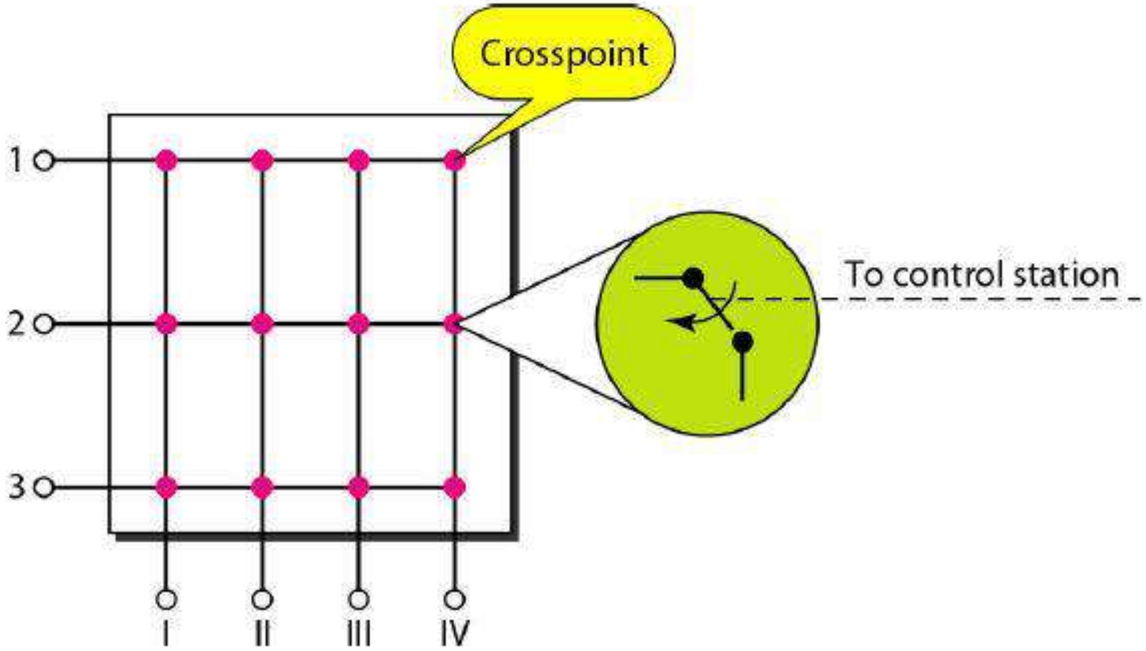
Uses TDM to achieve switching.

Physical Layer | Switching



Circuit Switching | Crossbar Switches

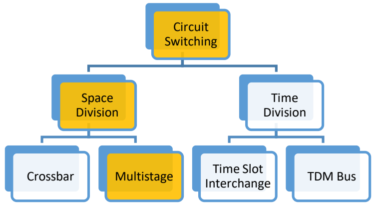
Connects 'n' inputs to 'm' outputs in a grid, using **electronic micro-switches (transistors) at each cross-point**.



Number of cross-points required to connect **1000 inputs to 1000 outputs** requires a crossbar with **10,00,000 cross-points** - **IMPRACTICAL (**Huge Size**)**

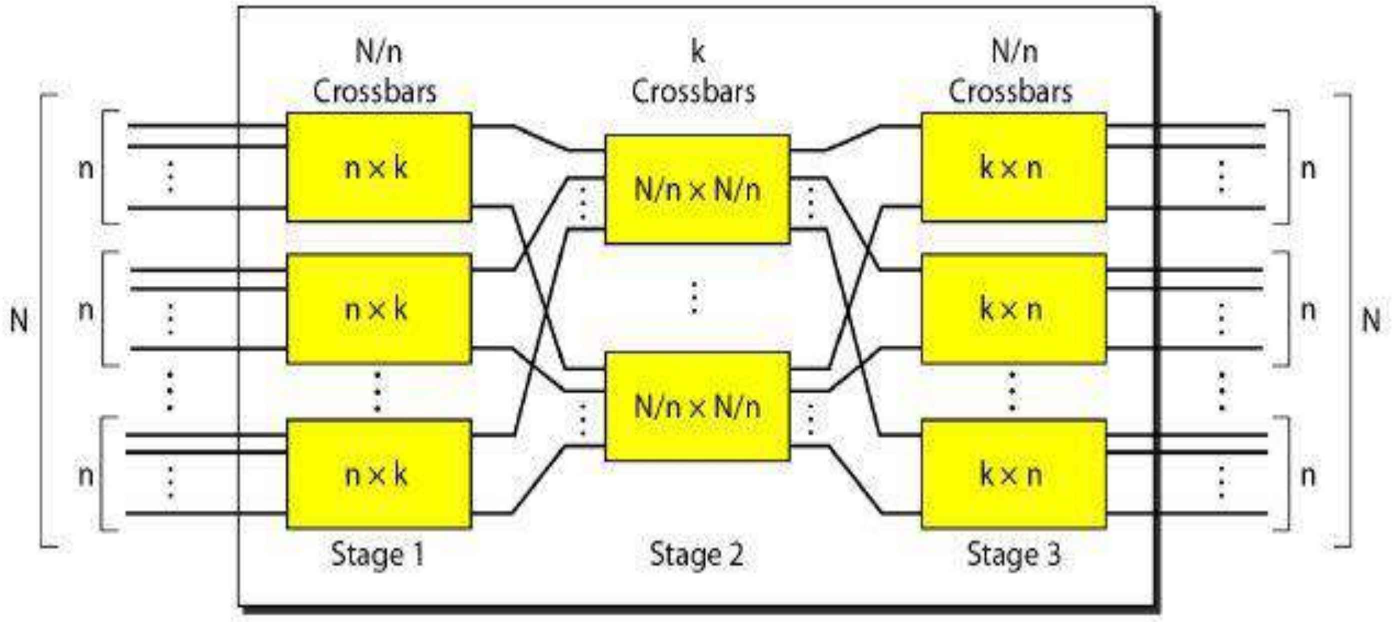
Solution – **Multistage Switches (**requires less number of cross-points**)**

Physical Layer | Switching



Circuit Switching | Multistage Switches

Requires less number of cross-points.



Number of cross-points:

$$\frac{N}{n}(n \times k) + k\left(\frac{N}{n} x \frac{N}{n}\right) + \frac{N}{n}(k \times n)$$

$$\boxed{\mathbf{2kN + k\left(\frac{N}{n}\right)^2}}$$

Problem – **Blocking (**during heavy traffic**)**

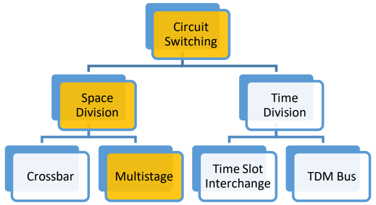
Refers to times when one input cannot be connected to an output because **there is no path available between them**.

Clos proposed the following condition of non-blocking in multistage switches:

Clos criterion: $\boldsymbol{n = (N/_2)^{1/2}}$ $\boldsymbol{and\ k \geq (2n-1)}$

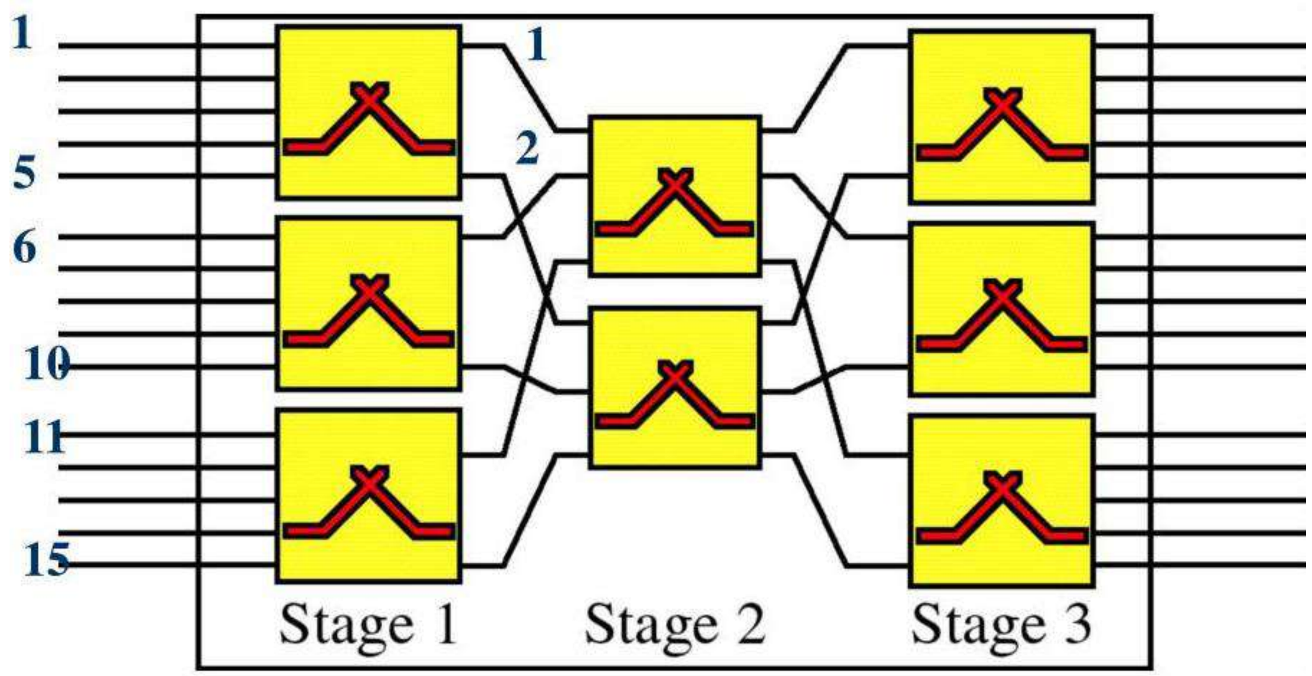
Total number of cross-points: $\boldsymbol{\geq 4N\left[(2N)^{1/2} - 1\right]}$

Physical Layer | Switching



Circuit Switching | Multistage Switches

15-by-15 Switch



Crossbar switch (single-stage) requires 15x15 = 225 cross-points.

Number of cross-points in this **3-stage switch**:

Stage 1: 3 x (5x2) = 30 cross-points.

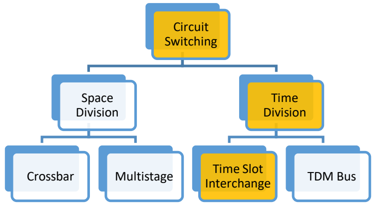
Stage 2: 2 x (3x3) = 18 cross-points.

Stage 3: 3 x (5x2) = 30 cross-points.

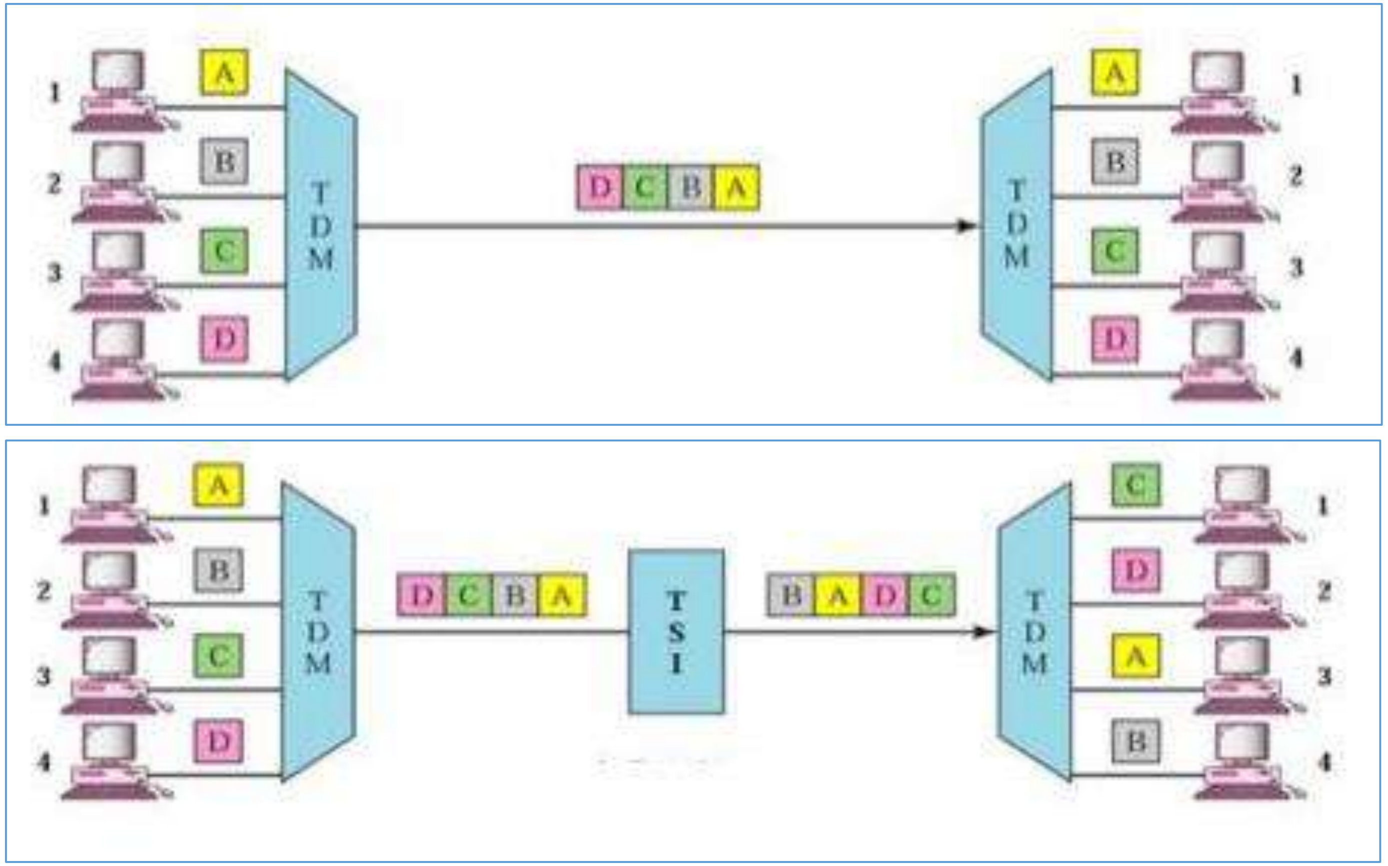
TOTAL = 78 cross-points.

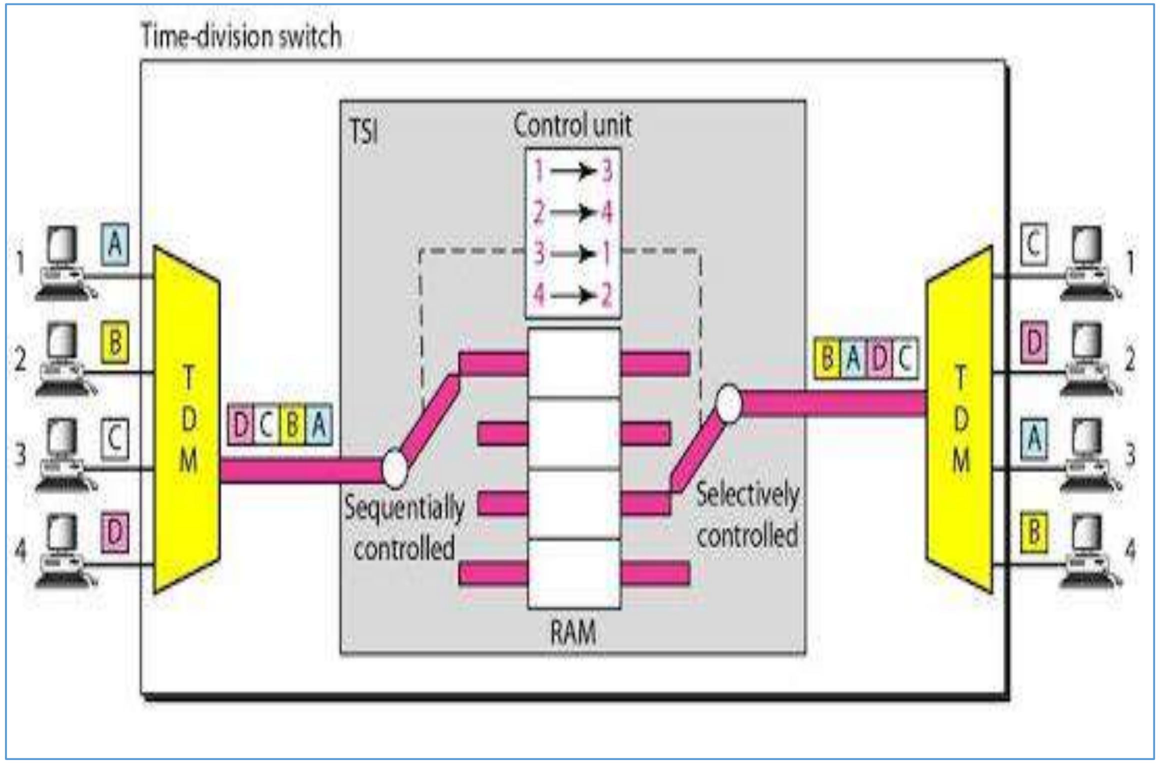
In large systems (10,000 input & output) – **the number of stages can be increased to cut down the number of cross-points required**. **But possible blocking increases as well**.

Physical Layer | Switching



Circuit Switching | Time Slot Interchange (TSI)

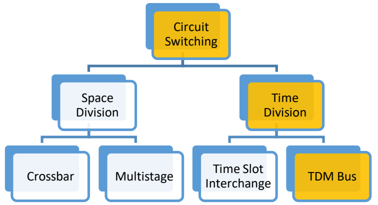




TSI changes the ordering of the slots based on the desired connections.

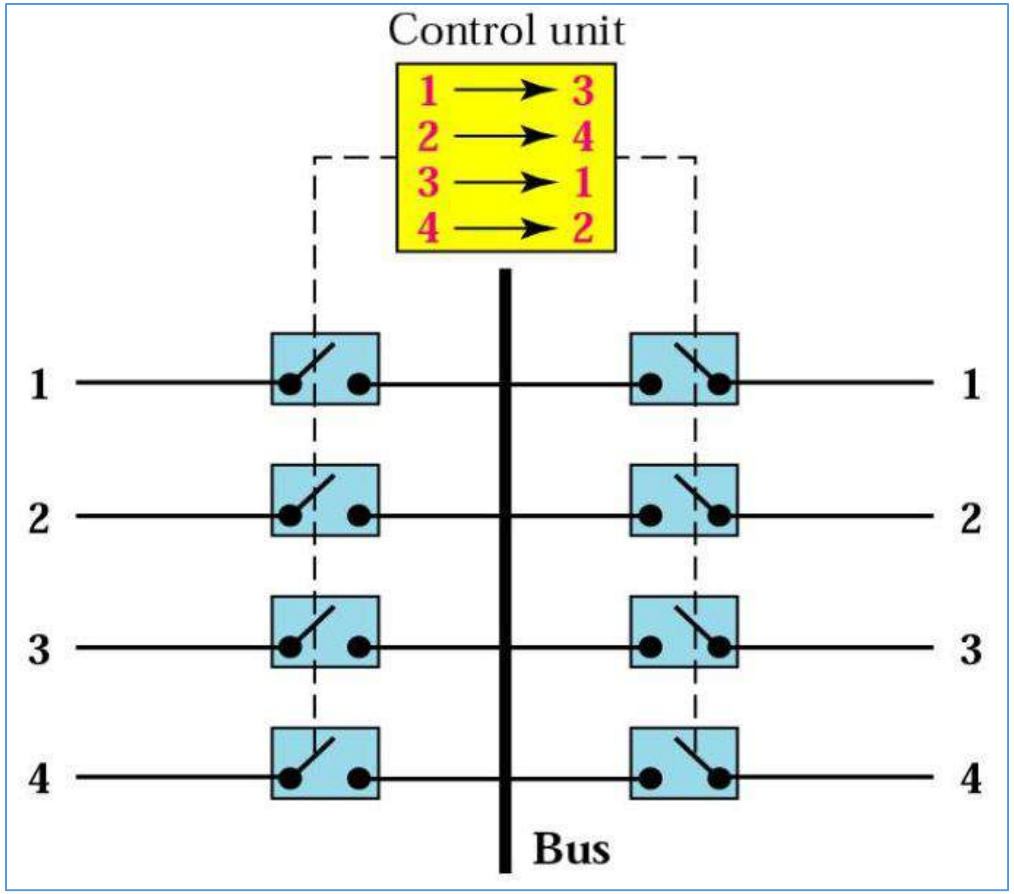
Consists of RAM with several memory location (*size of memory is same as that of time slot* **and** *number of location is same as the number of inputs*).

Physical Layer | Switching

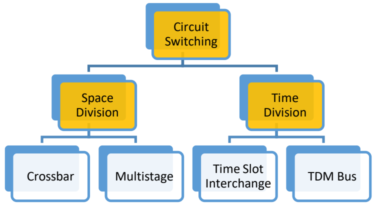


Circuit Switching | TDM Bus

Data or information arriving from an input line is **put onto specific timeslots** on a high-speed bus, where **a recipient would listen to the bus and pick out only the signals for a certain timeslot**.



Physical Layer | Switching



Circuit Switching | Comparison

Space Division Switching

Advantage : Instantaneous

Disadvantage : Number of cross-point requirements.

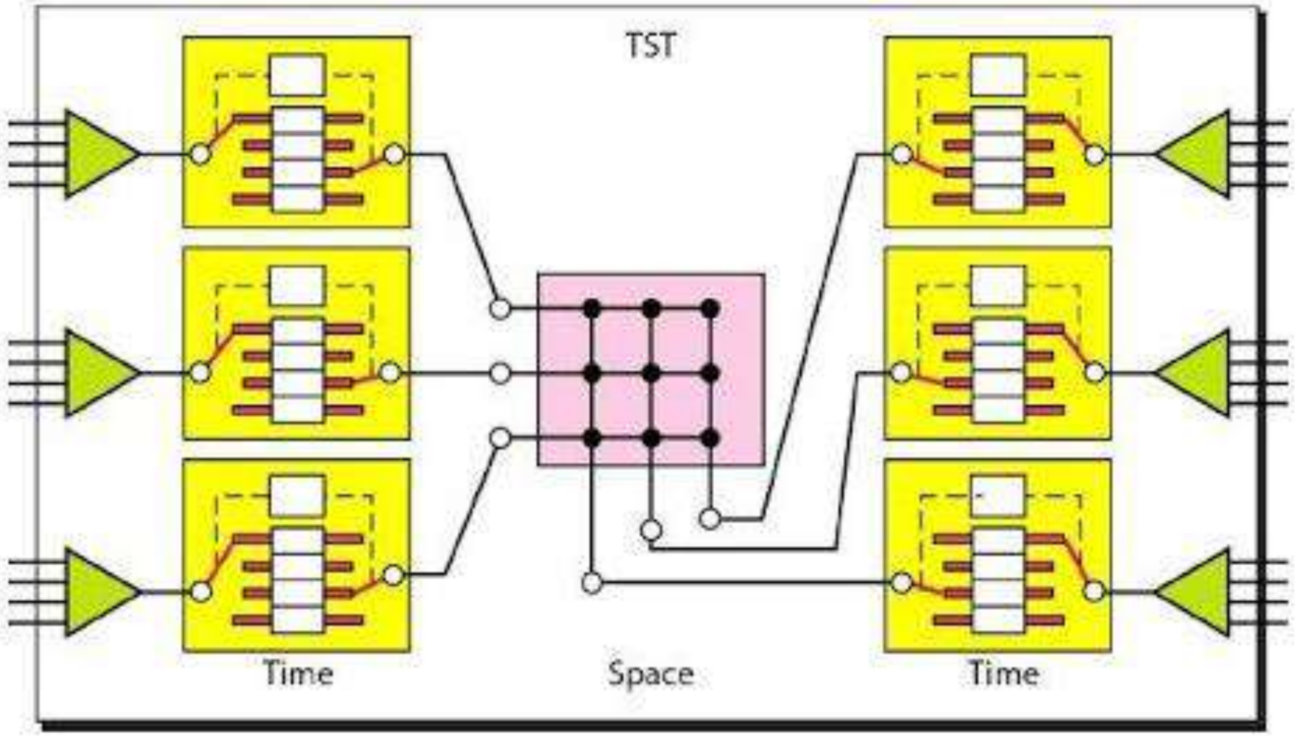
Time Division Switching

Advantage : No cross-points.

Disadvantage : Delay in Switching

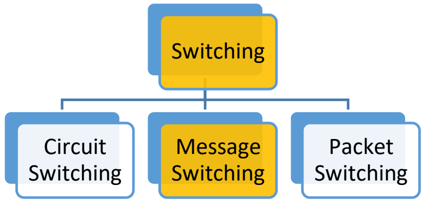
3 TSIs – the *average delay is one-third* of what would result from using one TSI to handle all 12 inputs.

Space division switch *allow connectivity between all possible input and output pairs*.



Time-Space-Time (TST) Switching

Physical Layer | Switching



Message Switching

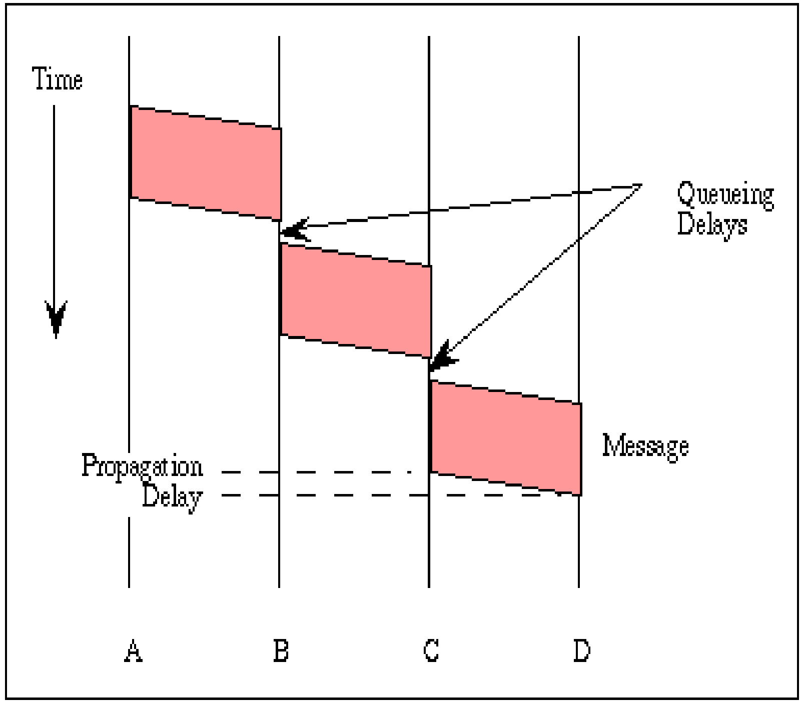
Follows Store-and-forward mechanism.

A node **receives a message**, **store it** **until the appropriate route is free**, then **sends it along**.

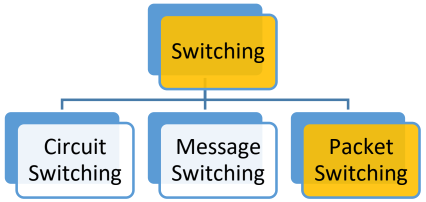
No physical path is established **in advance** between sender and receiver.

Each block is received **in its entirely**, inspected for errors, and then **re-transmitted**.

No limit on block size.



Physical Layer | Switching



Packet Switching

Circuit switching was designed for **voice communication** i.e., it is less well suited to data and other non-voice transmission. It is inflexible.

In packet-switched network, **data are transmitted in discrete units** of *potentially variable length blocks* called **packets**.

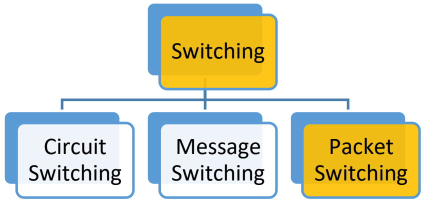
The maximum length of the packet is **established by the network**.

Longer transmissions are **broken up into multiple packets**. Each packet contains not only data but also a header with control information.

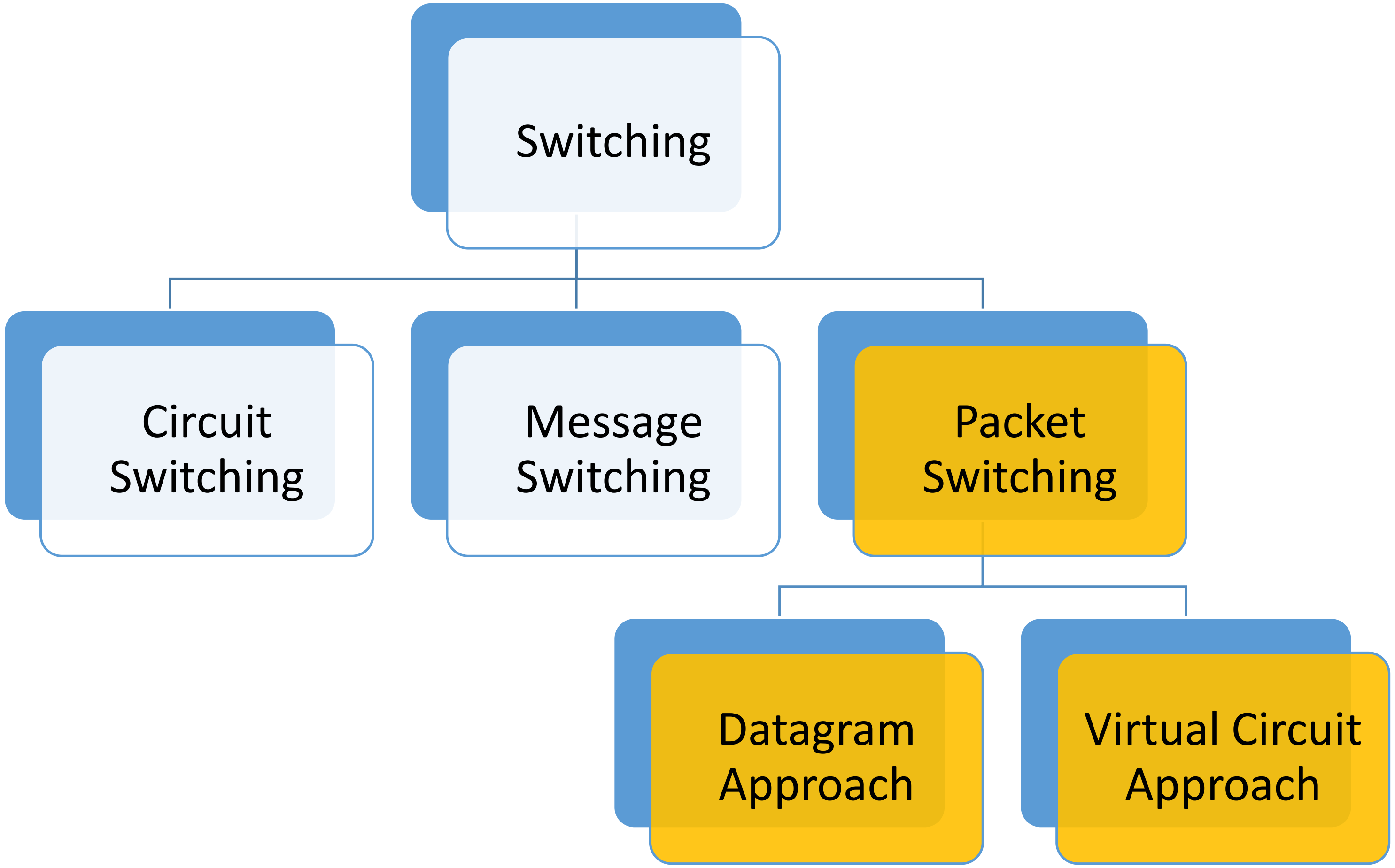
The packets are sent over the network **node-to-node**. At each node, *the packet is stored briefly then routed according to the information in its header*.

In a packet-switched network, **there is no resource reservation**; **resources are allocated on demand**.

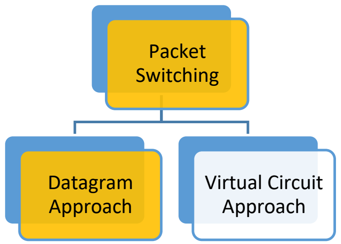
Physical Layer | Switching



Packet Switching



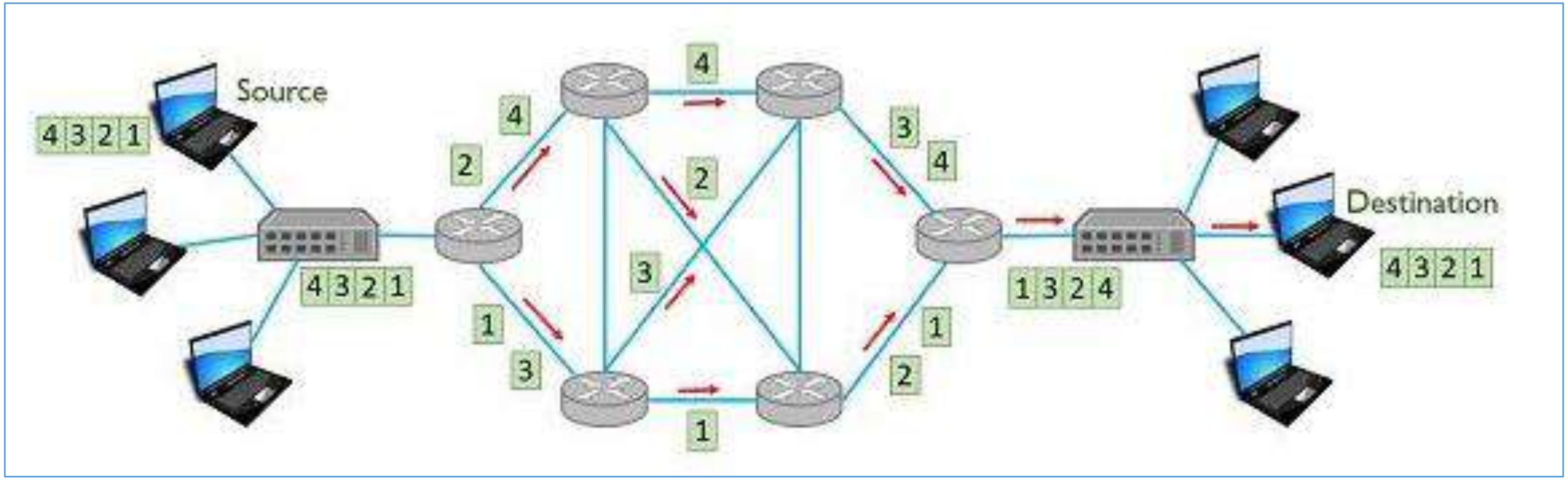
Physical Layer | Switching



Packet Switching | Datagram Approach

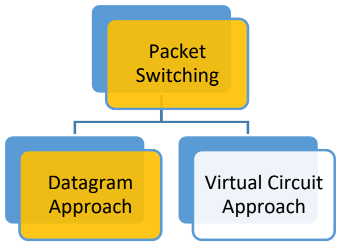
Each packet is **treated independently of all others**. Even if a packet is part of a multi-packet transmission, the network treats it as though it existed alone.

Packets in this approach are referred to a **DATAGRAMS**.



The datagrams may arrive at their destination out of order and may also be lost or dropped because of *different delay or a lack of resources*.

Physical Layer | Switching



Packet Switching | Datagram Approach

In most protocols, it is the **responsibility of an upper-layer protocol** to reorder the datagrams or ask for lost datagrams before passing them on to the application.

The datagram networks are sometimes referred to as **connectionless networks**. The term connectionless here means that the switch does not keep information about the connection state.

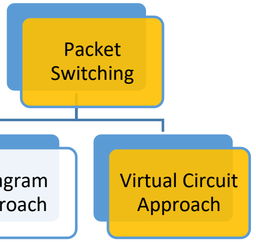
Each switch maintains **a routing table** which is based on the destination address. *The routing tables are dynamic and are updated periodically*.

Every packet in a datagram network carries **a header** that contains, among other information, the destination address of the packet. *It remains the same during the entire journey of the packet*.

The resources are allocated only when there are packets to be transferred.

The packet travels through two switches. There are **three transmission times**, **three propagation delays**, **two waiting times** and **processing time in each switch**.

Physical Layer | Switching



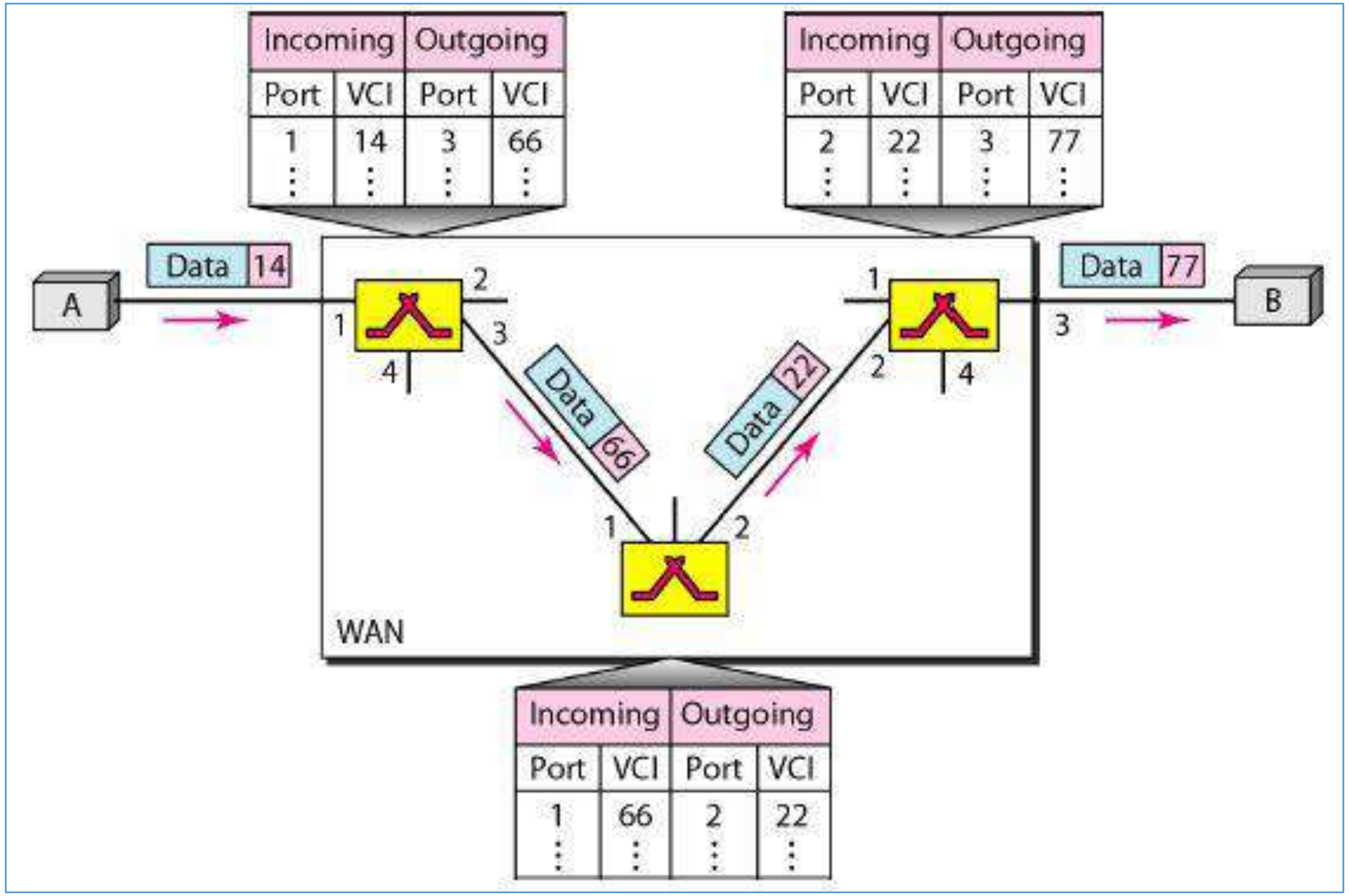
Packet Switching | Virtual Circuit Approach

A virtual-circuit network is a **cross between** a circuit-switched network and a datagram network.

Two-types of addressing are involved: **Global** & **Local (Virtual-Circuit Identifier)**.

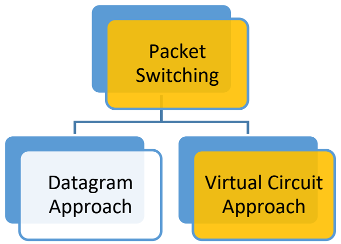
A **VCI** is a small number that has only switch scope; it is used by a frame between two switches.

A source and destination need to go through three phases: **Setup, Data Transfer, and Teardown**.

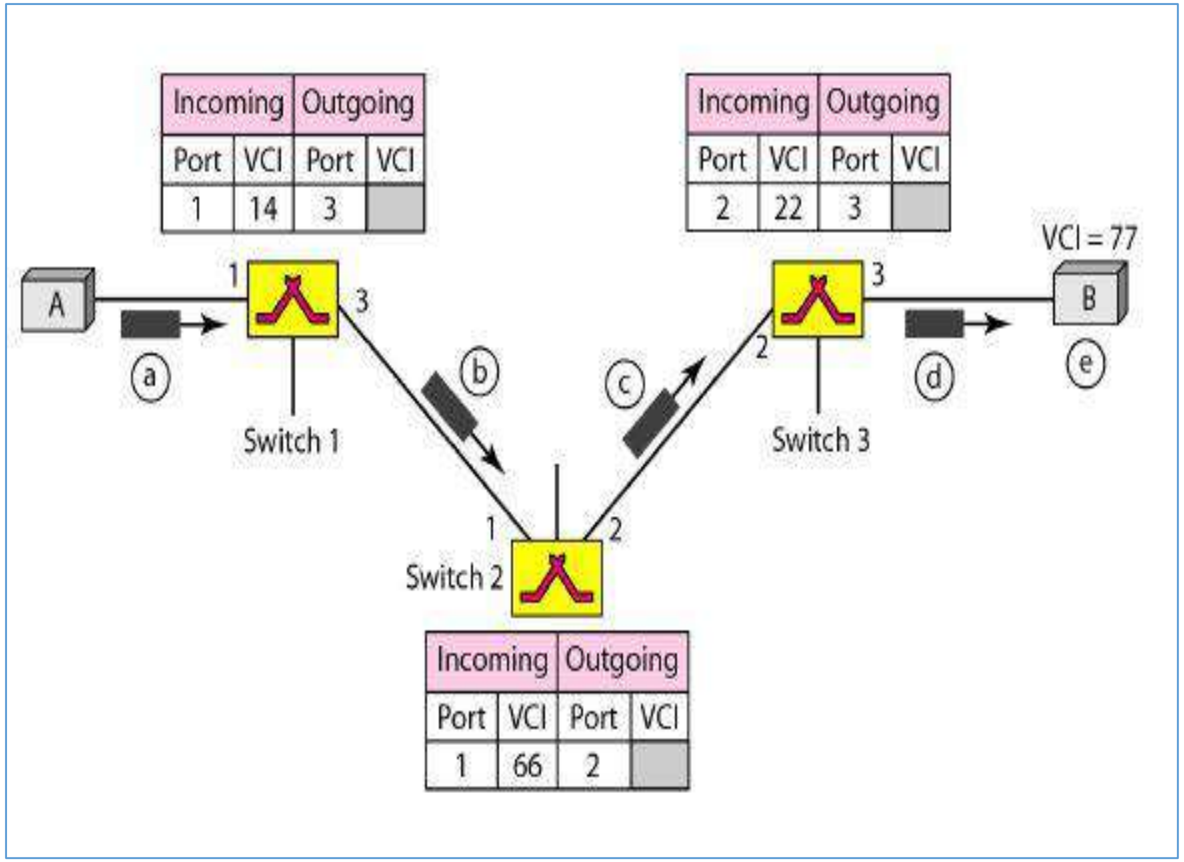


Data Transfer

Physical Layer | Switching



Packet Switching | Virtual Circuit Approach



Setup Request

The source and destination use their **global addresses** to help switches make <u>switching table entries</u> for the connection.

a. Source ‘A’ sends a **setup frame** to switch 1.

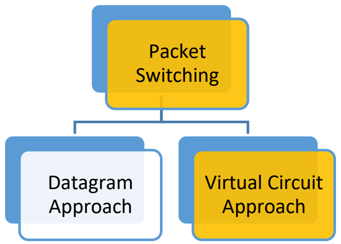
b. Three entries Port 1, **Available VCI** i.e., 14 and outgoing port 3.

c. Same as ‘b’ at switch 2.

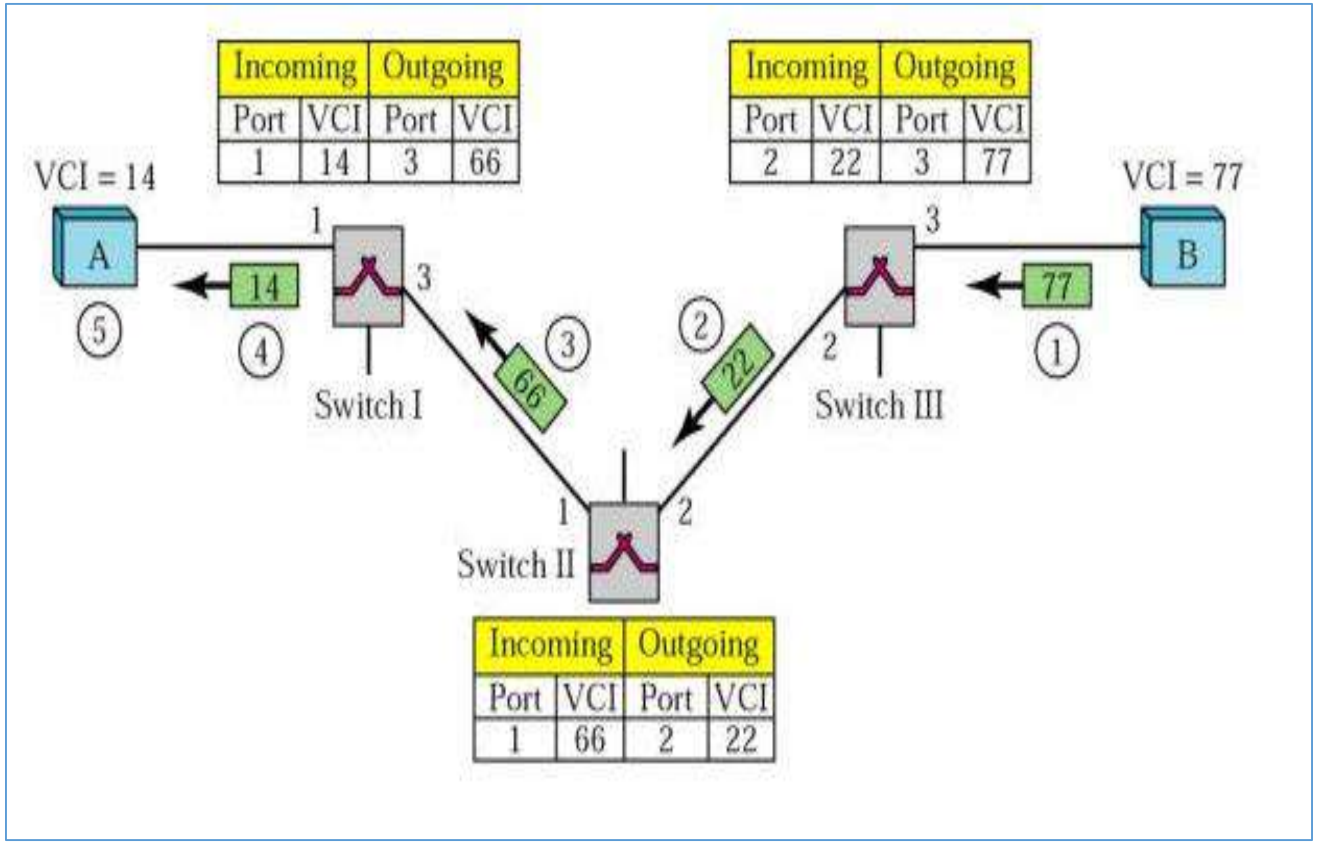
d. Same as ‘b’ at switch 3.

e. Destination ‘B’ receives the setup frame, and **<u>if it is ready to receive frames from ‘A’</u>**, it **<u>assigns a VCI</u>** to the incoming frames that come from ‘A’, in this case it is 77. <u>This VCI lets the destination know that the frames come from ‘A’, and not from other sources</u>.

Physical Layer | Switching



Packet Switching | Virtual Circuit Approach



Acknowledgement

1. The destination sends an ACK to switch 3. The ACK carries the global source and destination addresses so the switch knows which entry in the table is to be completed. The frame also carries VCI 77.

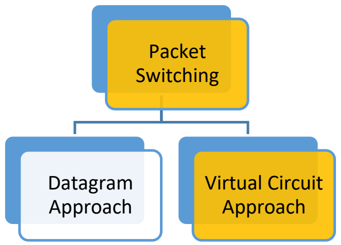
2. Switch III sends an ACK to Switch II that contains its incoming VCI in the table.

3. Switch II sends an ACK to Switch I that contains its incoming VCI in the table.

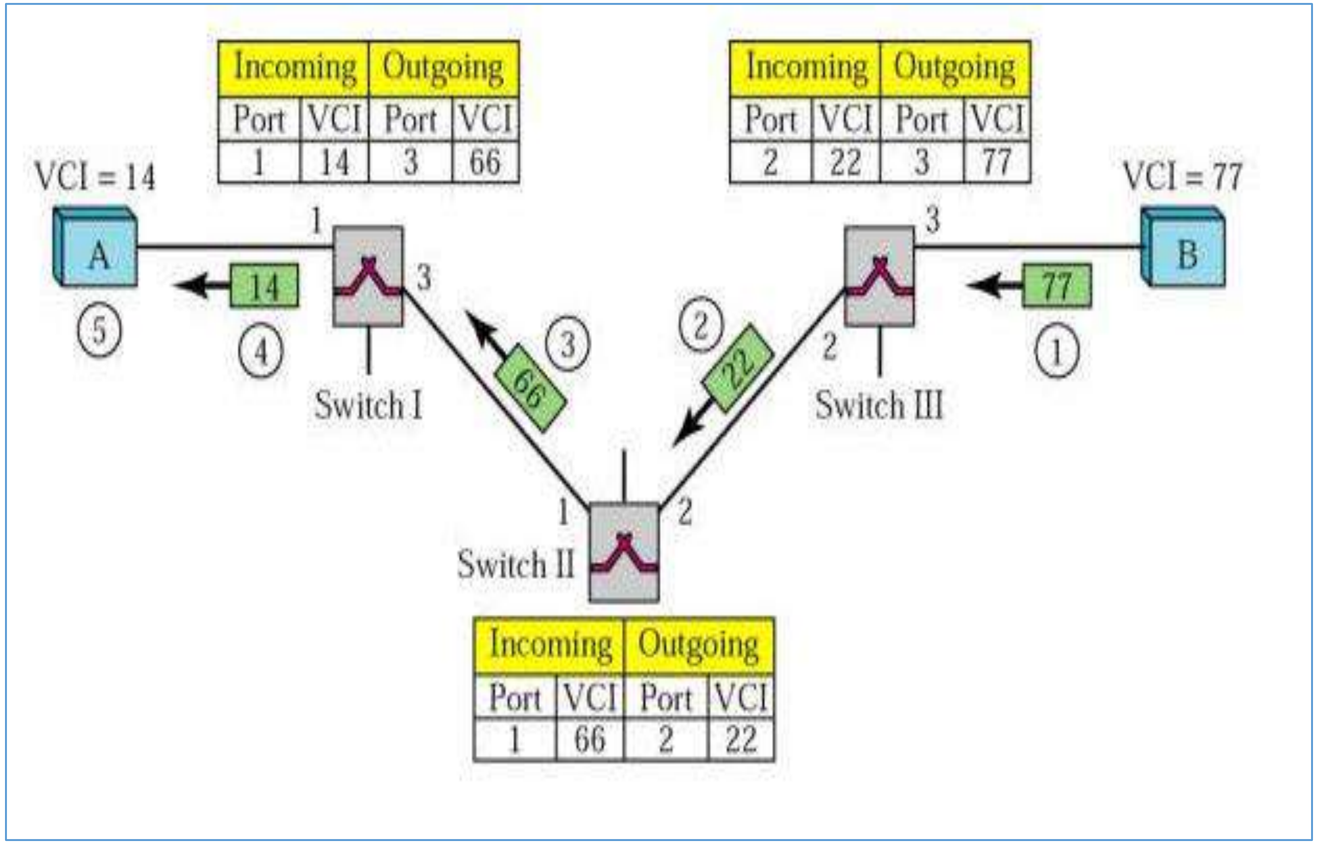
4. Switch I sends an ACK to Source A that contains its incoming VCI in the table.

5. The source uses this as the outgoing VCI for the data frames to be sent to destination B.

Physical Layer | Switching



Packet Switching | Virtual Circuit Approach

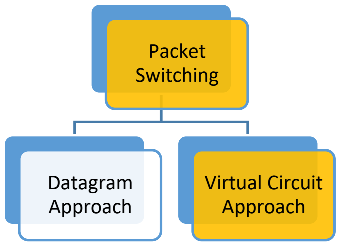


Acknowledgement

In the teardown phase, the source and destination inform the switches to delete the corresponding entry.

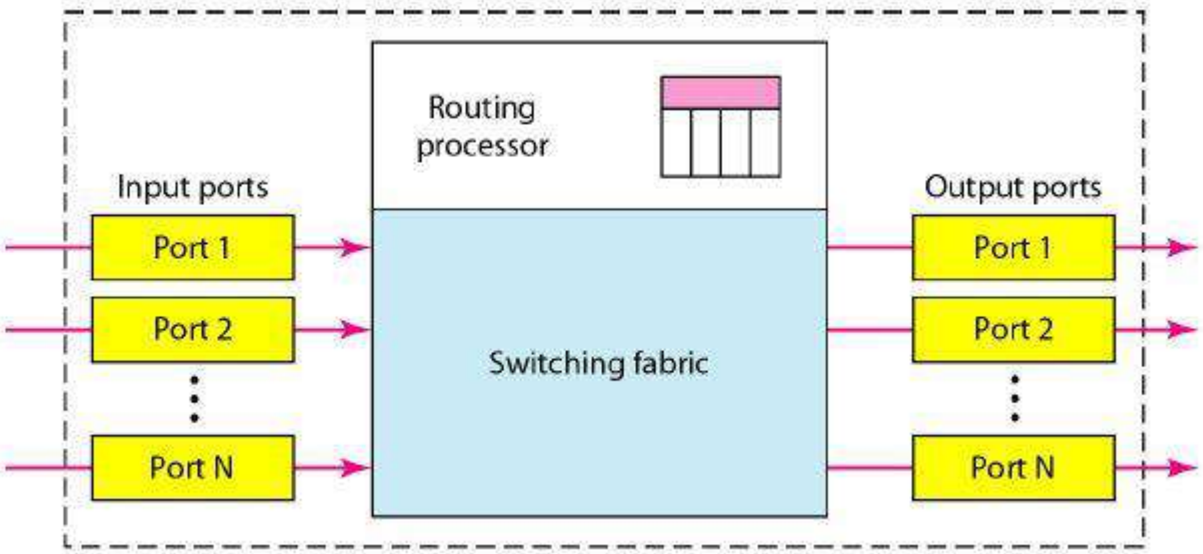
- Source A, after sending all frames to B, sends a special frame called a teardown request.
- Destination B responds with a teardown confirmation.
- All switches delete the corresponding entry from their tables.

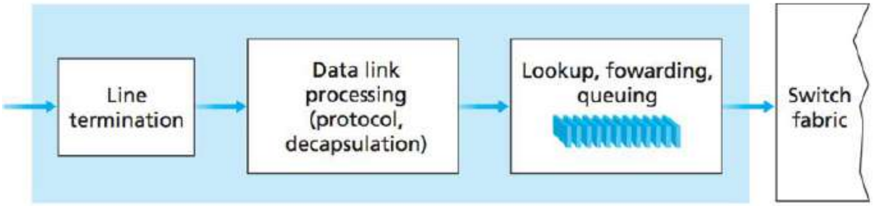
Physical Layer | Switching



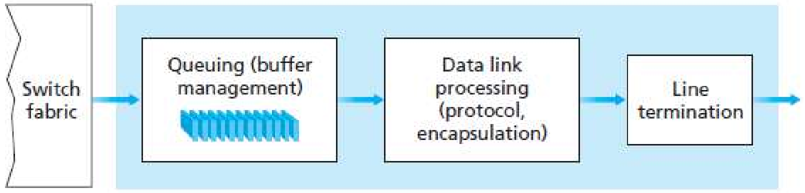
Packet Switching | Virtual Circuit Approach

Switch Structure



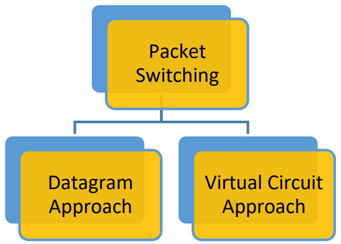


Input Port



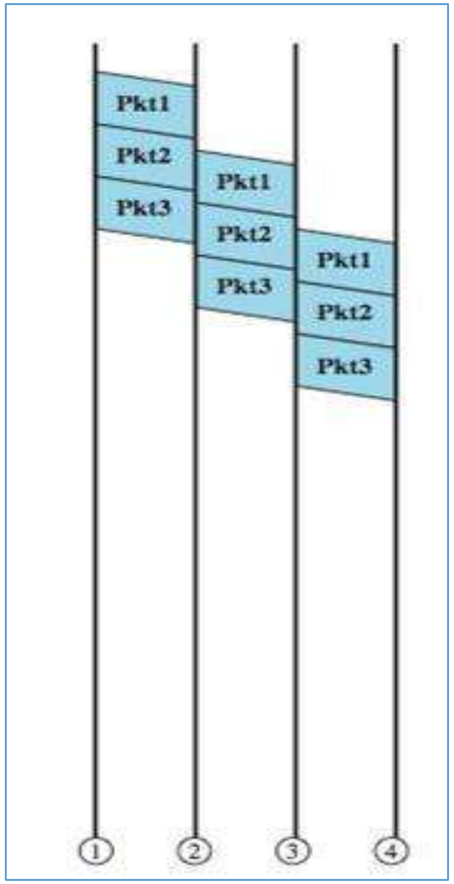
Output Port

Physical Layer | Switching

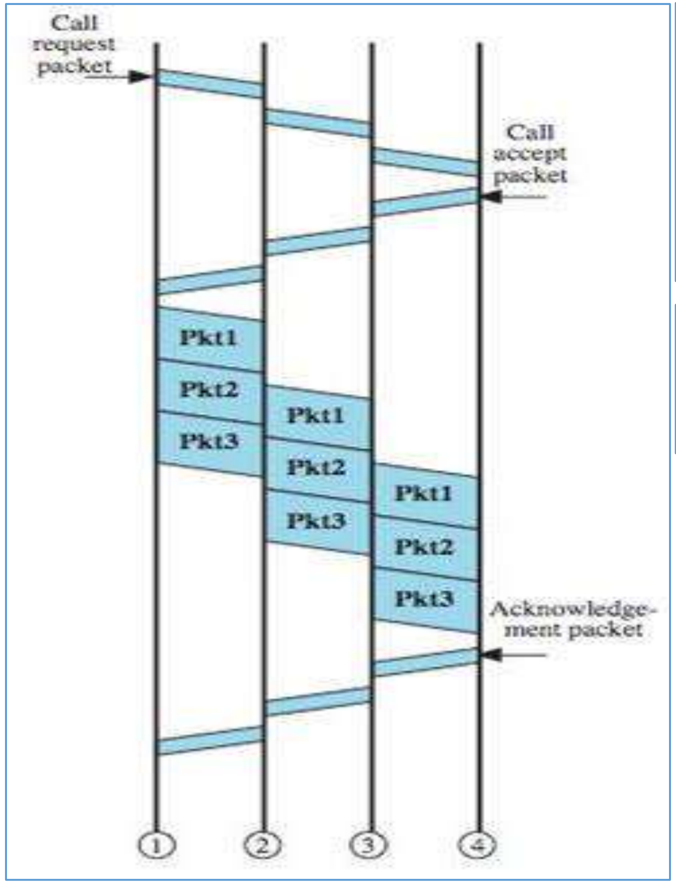


Packet Switching | Datagram Approach vs Virtual Circuit Approach

Each packet is treated independently from all others.



Datagram Approach

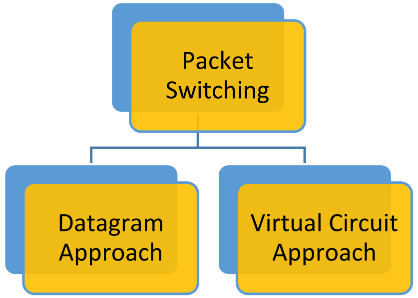


Virtual Circuit Approach

Relationship between all packets belonging to a message or session is preserved.

Single Route is chosen during each session.

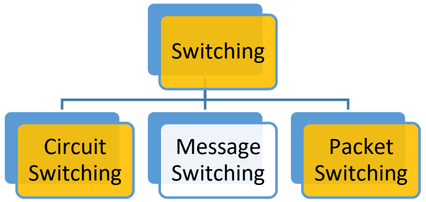
Physical Layer | Switching



Packet Switching | Datagram Approach vs Virtual Circuit Approach

Items	Datagram Approach	Virtual Circuit Approach
Circuit Setup	Not Needed	Required
Addressing	Each packet contains the full Source and Destination Address.	Each packet contains a short virtual circuit number.
State Information	Routers do not hold state information about connections	Each virtual circuit requires router table space per connection.
Routing	Each packet is routed independently	Each packet follows same path.
Effects of router failure	None	All virtual circuit that passed through are terminated.
Quality of Service (QoS)	Difficult	Easy if enough resources can be allocated in advance for each virtual circuit.
Congestion Control	Difficult	Easy if enough resources can be allocated in advance for each virtual circuit.

Physical Layer | Switching



Circuit Switching Vs Packet Switching

Items	Circuit Switching	Packet Switching (Datagram Approach)
Circuit Setup	Required	Not Required
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
Time of possible congestion	During setup	On every packet
Potentially wasted Bandwidth	Yes	No
Store-and-forward Transmission	No	Yes
Transparency	Yes	No
Charging	Per minute	Per packet

Physical Layer

- Connection Types / Line Configuration
  - Point-to-Point
  - Multipoint
- Physical Topology
  - Bus
  - Ring
  - Star
  - Mesh
  - Cellular
- Signalling
  - Analog
  - Digital
- Bit Synchronization
  - Synchronous
  - Asynchronous

- Multiplexing
  - Time-Division Multiplexing (TDM)
  - Frequency-Division Multiplexing (FDM)
  - Wave-Division Multiplexing (WDM)
- Spread Spectrum
  - Frequency Hopping Spread Spectrum
  - Direct Sequence Spread Spectrum
- Switching
  - Circuit Switching
  - Message Switching
  - Packet Switching
- **Transmission Media**
  - **Guided Media**
  - **Unguided Media**

Physical Layer | Transmission Media

The **physical path** through which the electrical voltages and electromagnetics waves travel is called "**Transmission Media**".

Transmission Media

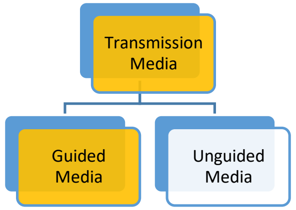
Provides a physical connection from one device to another.

Guided Media

Unguided Media

Signals are broadcast through air (or, in a few cases, water).

Physical Layer | Transmission Media

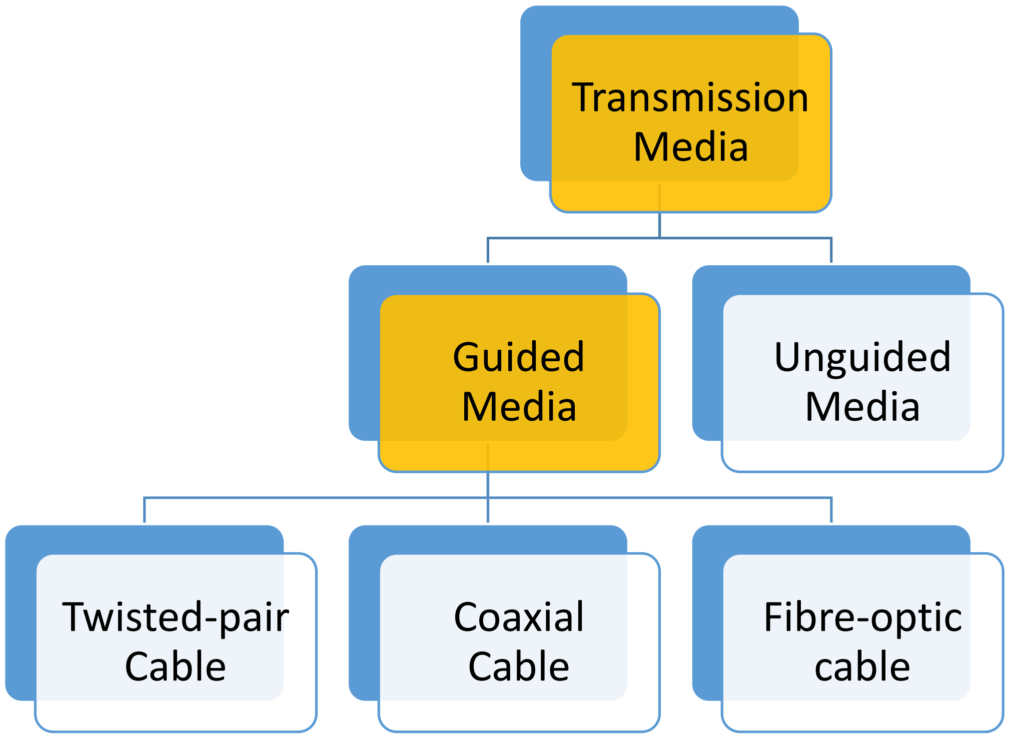


Guided Media

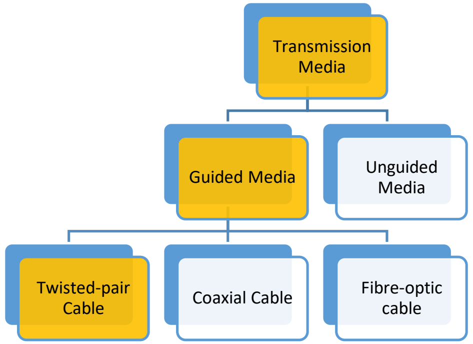
Provides a **physical connection from one device to another**.

Cable media or guided media **provide a conductor for the electromagnetic signal**.

A signal travelling along any of these media is directed and contained by the physical limits of the medium.



Physical Layer | Transmission Media



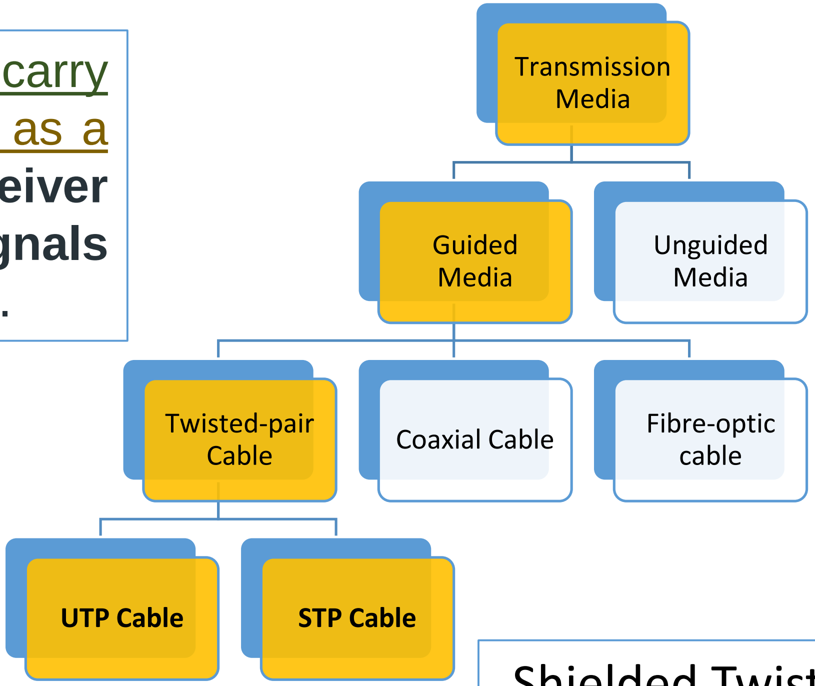
Guided Media | Twisted-Pair Cable

Twisted pairs are formed by two insulated 22 to 26 gauge copper wires that are **twisted about each other**.

When one or more twisted pairs are combined within a common jacket, they form a **twisted pair cable**.

Twisting the copper wires reduces crosstalk and signal emissions.

One of the conductors is used to carry the signal and the other is used as a ground reference only. **The receiver uses the difference of signals between these two conductors**.

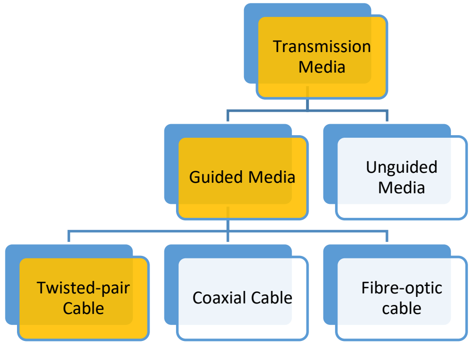


The **noise or crosstalk** in the two parallel conductors is high but this is greatly reduced in twisted pair cables due to the twisting characteristic. In the first twist, one conductor is near to noise source and the other is far from the source but in the next twist the reverse happens and the resultant noise is very less and hence the balance in signal quality is maintained and the receiver receives very less or no noise.

Unshielded Twisted Pair cable

Shielded Twisted Pair cable

Physical Layer | Transmission Media



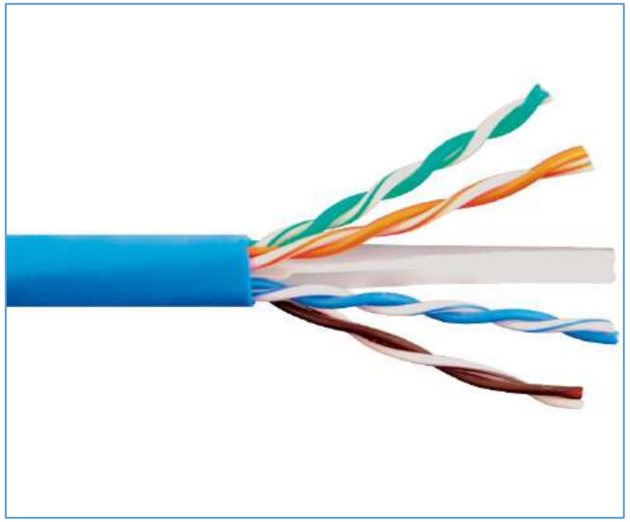
Guided Media | Twisted-Pair Cable

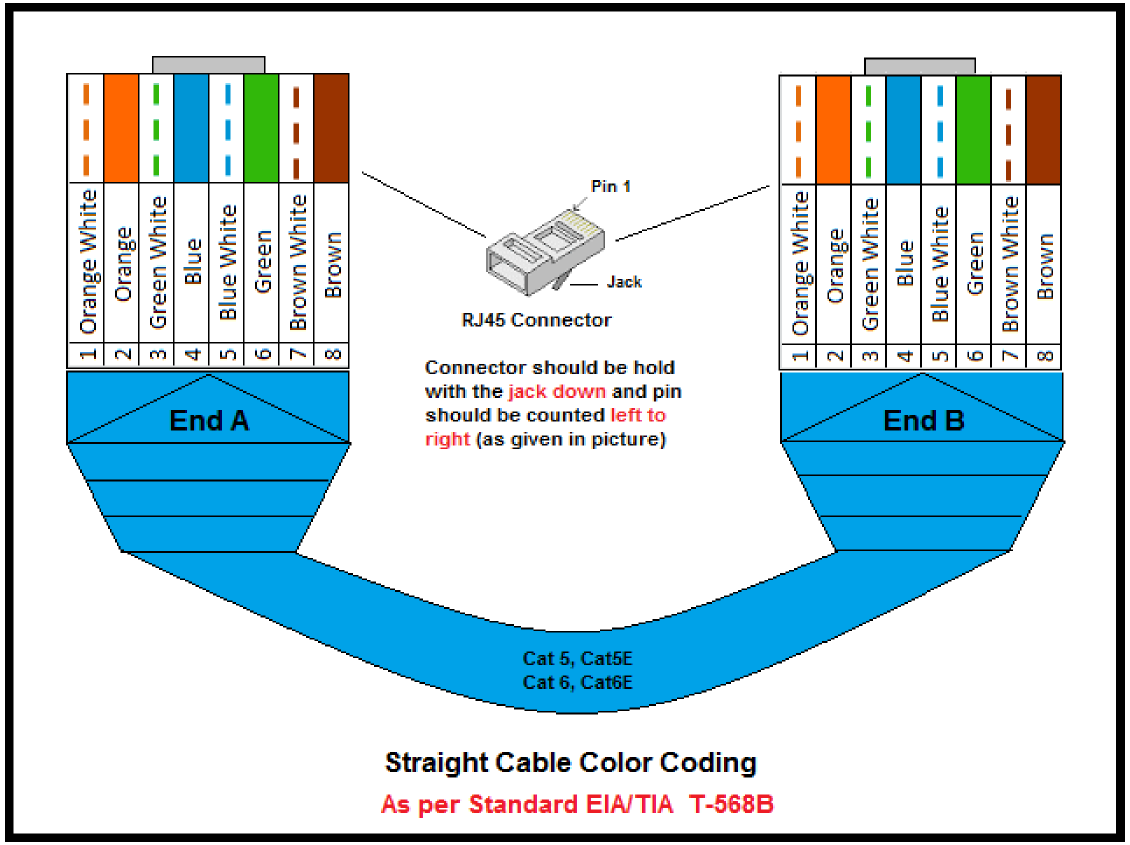
Unshielded Twisted Pair (UTP) Cable

Most common type of telecommunication medium in use today.

Its **frequency range** is suitable for transmitting both data and voice.

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

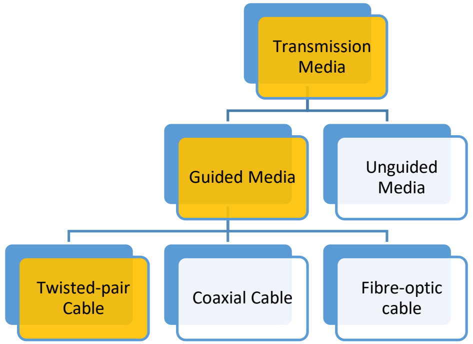




Advantages:

Cheap, Flexible and easy to install.

Physical Layer | Transmission Media

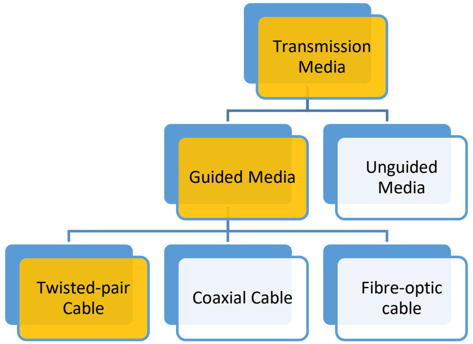


Guided Media | Twisted-Pair Cable | UTP

The Electronic Industries Association (EIA) has developed standards to grade UTP cable by quality.

Category	Maximum Speed	Max. Length	Frequency	SHIELDING	Application
CAT 1	Up to 1Mbps(Carry only Voice)	--	1MHz	Unshielded	Old telephone cabling
CAT 2	Up to 4Mbps	--	4MHz	Unshielded	Token Ring Network
CAT 3	Up to 10Mbps	100m	16MHz	Unshielded	Token Ring & 10BASE-T Network
CAT 4	Up to 16Mbps	100m	20MHz	Unshielded	Token Ring Network
CAT 5	Up to 100Mbps	100m	100MHz	Unshielded	Ethernet, Fast ethernet and Token Ring
CAT 5e	Up to 1Gbps	100m	100MHz	Unshielded or Shielded	Ethernet, Fast ethernet & Gigabit ethernet
CAT 6	Up to 10Gbps	100m	250MHz	Unshielded or Shielded	Ethernet, Fast ethernet, Gigabit ethernet & 10G Ethernet(37 - 55 meter)
CAT 6a	Up to 10Gbps	100m	500MHz	Shielded	Ethernet, Fast ethernet, Gigabit ethernet & 10G Ethernet(37 - 55 meter)
CAT 7	Up to 10Gbps	100m	600MHz	Shielded	Ethernet, Fast ethernet, Gigabit ethernet & 10G Ethernet(100 meter)
CAT 8	Up to 40Gbps	100m	2000MHz	Shielded	Ethernet, Fast ethernet, Gigabit ethernet & 25G-40G Ethernet(30 meter)

Physical Layer | Transmission Media



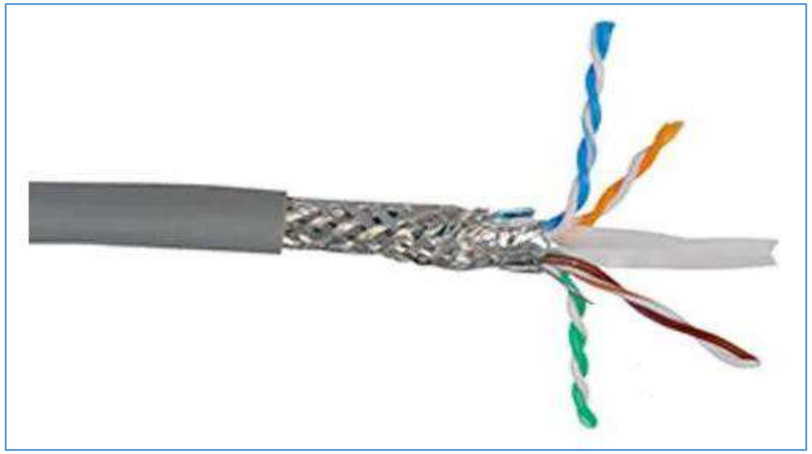
Guided Media | Twisted-Pair Cable

Shielded Twisted Pair (STP) Cable

STP cable has a **metal foil or braided-mesh covering that encases each pair of insulated conductors**.

The **metal casing** prevents the penetration of electromagnetic noise. Also eliminate crosstalk.

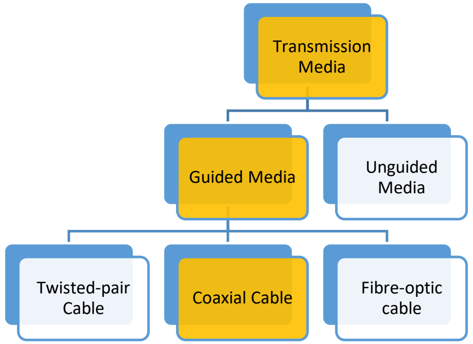
This covering provides **strength to the overall structure of the cable**.



The shielding ensures that the induced signal can be returned to the source via ground and only circulate around the shield **without affecting the main propagating signal**.

Used for **long-distance communication and transmission** and are installed underground.

Physical Layer | Transmission Media

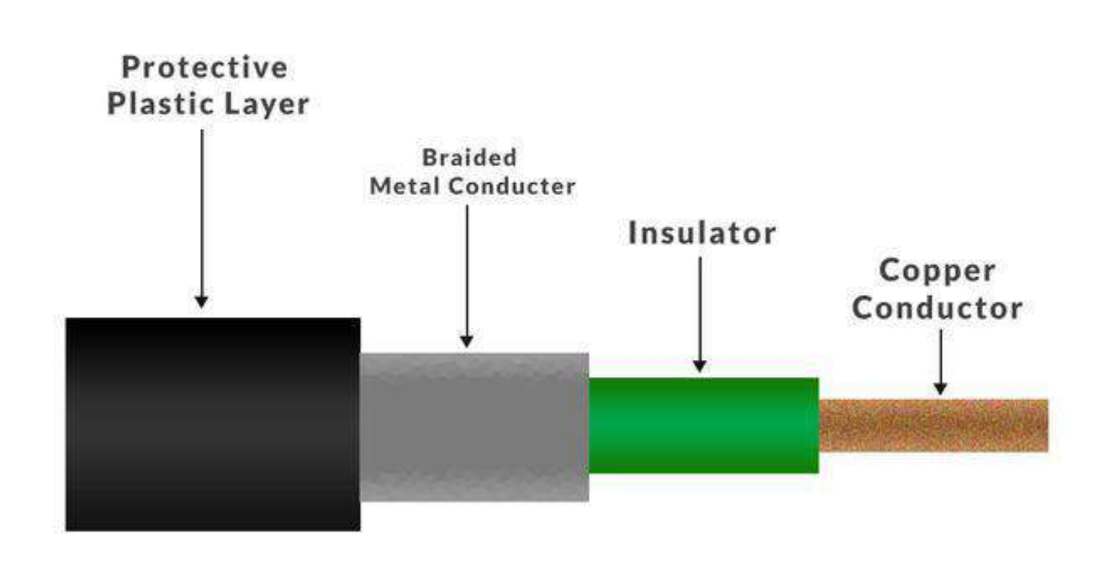


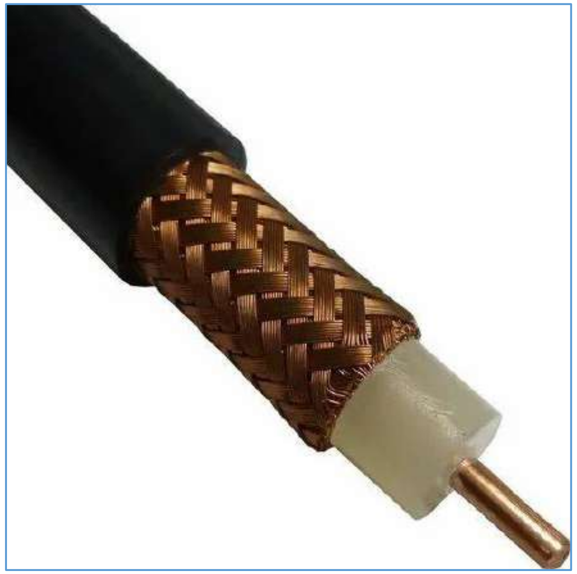
Guided Media | Co-axial Cable

Carries signals of **higher frequency ranges** than twisted-pair cable.

Cable has a **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 (also usually copper).

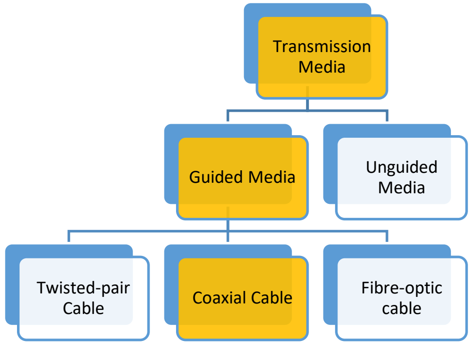
The outer metallic wrapping serves both as **a shield against noise** and as **the second conductor**, which completes the circuit.





Bayonet Network Connector (BNC)

Physical Layer | Transmission Media



Guided Media | Co-axial Cable

Applications of Coaxial cable:

The coaxial cables are used in Ethernet LANs and also used in MANs.

1. **Television:** Coaxial cable used for television would be 75 Ohm and **RG-6 coaxial cable**.

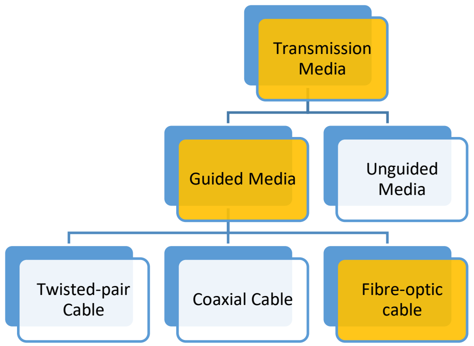
2. **Internet:** Coaxial cables are also used for carrying internet signals, **RG-6 cables** are used for this.

3. **CCTV:** The coaxial cables are also used in CCTV systems and both **RG-59 and RG-6 cables** can be used.

4. **Video:** The coaxial cables are also used in video Transmission the **RG-6** is used for better digital signals and **RG-59** for lossless transmission of video signals.

5. **HDTV**: The HDTV uses **RG-11** as it provides more space for signals to transfer.

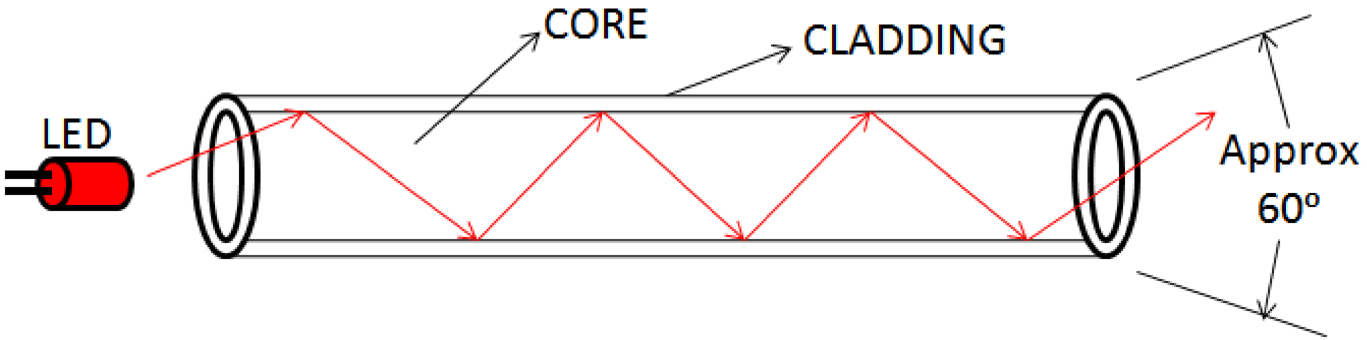
Physical Layer | Transmission Media



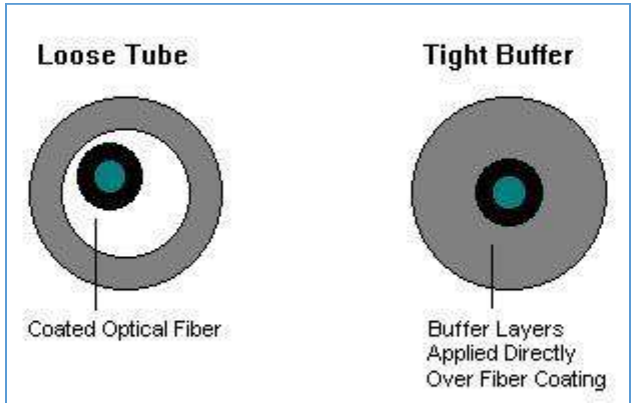
Guided Media | Fibre-Optic Cable

Made of a light-conducting glass or plastic core surrounded by more glass, called **cladding**, and a tough outer sheath.

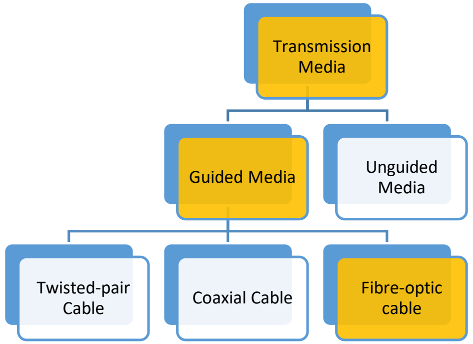
The centre core provides the light path while the cladding is composed of varying layers of reflective glass. **The glass cladding is designed to reflect light back into the core**.



The core and cladding strand is surrounded by a **tight** or **loose sheath**.

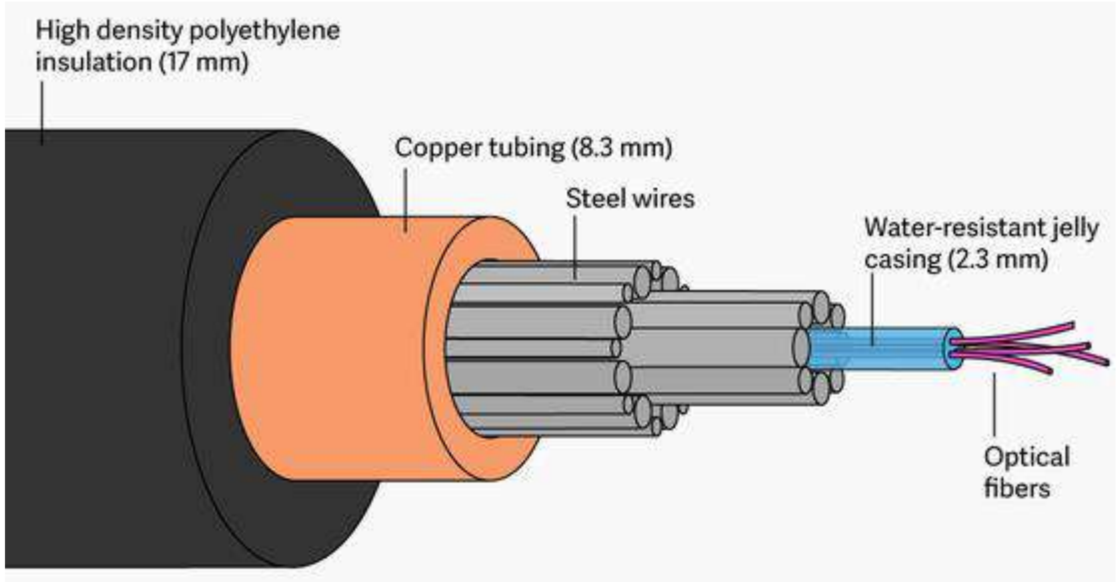


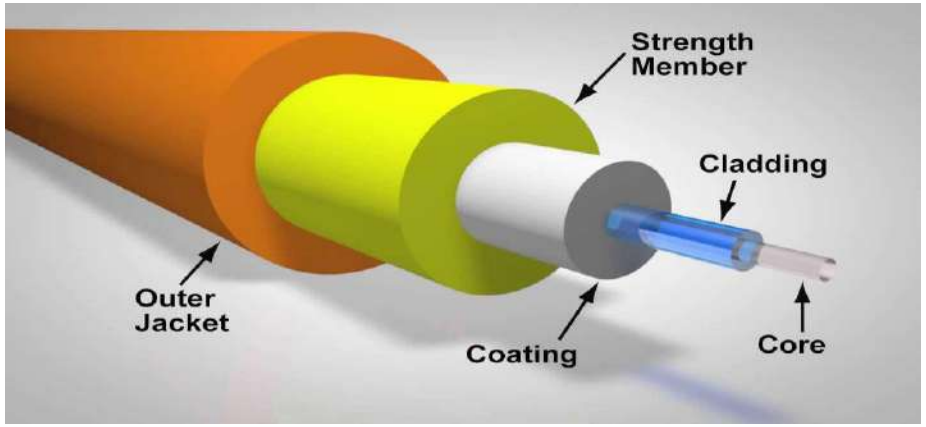
Physical Layer | Transmission Media



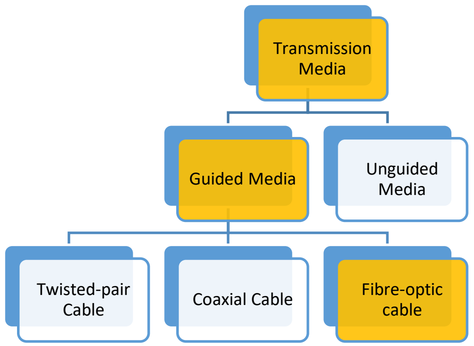
Guided Media | Fibre-Optic Cable

The sheath provides **the necessary cable strength** to protect the fibre from excessive temperature changes, bending, stretching or breaking.



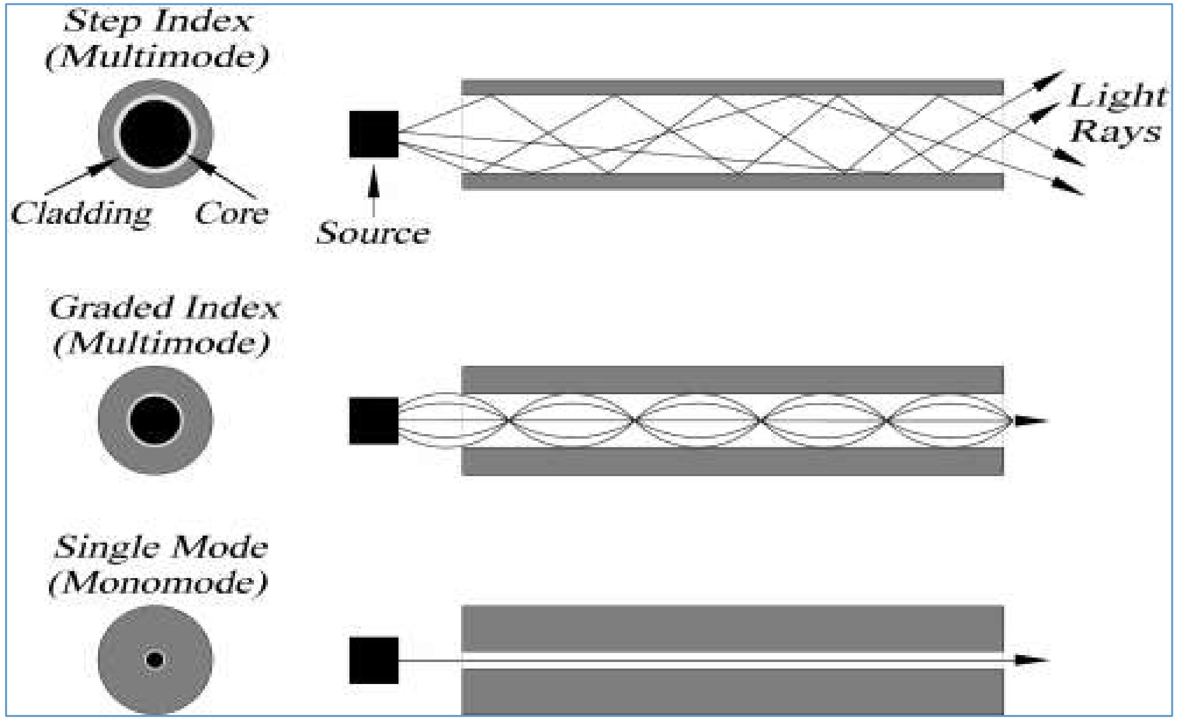


Physical Layer | Transmission Media



Guided Media | Fibre-Optic Cable

Optical fibres may be **Multi-mode** or **single-mode** in nature.

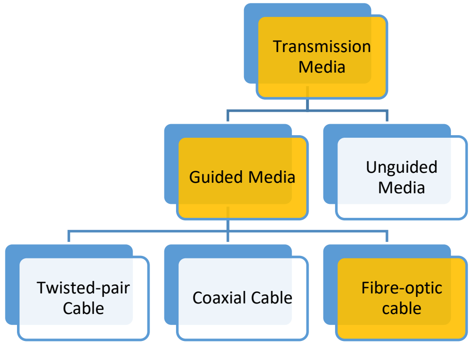


Allow various paths.

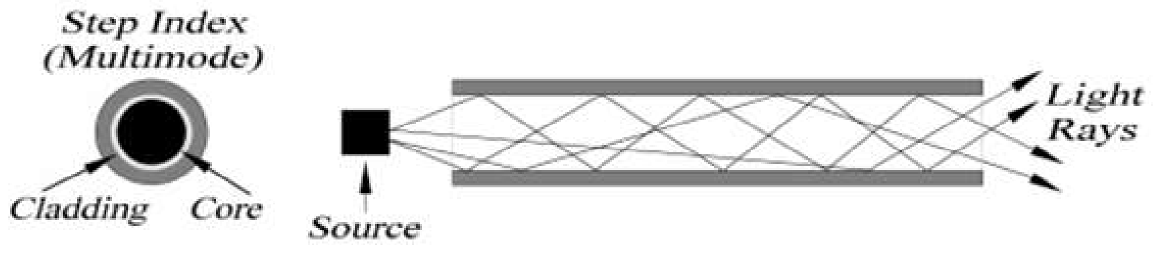
Allow various paths.

Allow only one light path.

Physical Layer | Transmission Media



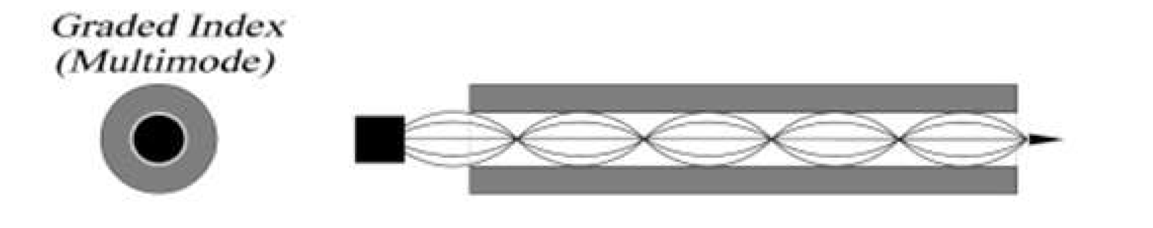
Guided Media | Fibre-Optic Cable



Density of the core remains constant from the centre to the edge.

A beam of light moves through this in a straight line until it reaches the interface of the core and cladding.

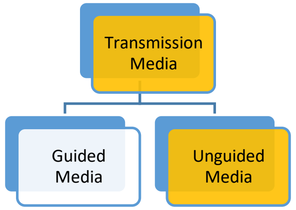
At the interface, there is an abrupt change to a lower density that alters the angle of the beam's motion.



Decreases the distortion of the signal through the cable.

The density of the core is highest at the centre of the core and decreases gradually to its lowest at the edge.

Physical Layer | Transmission Media



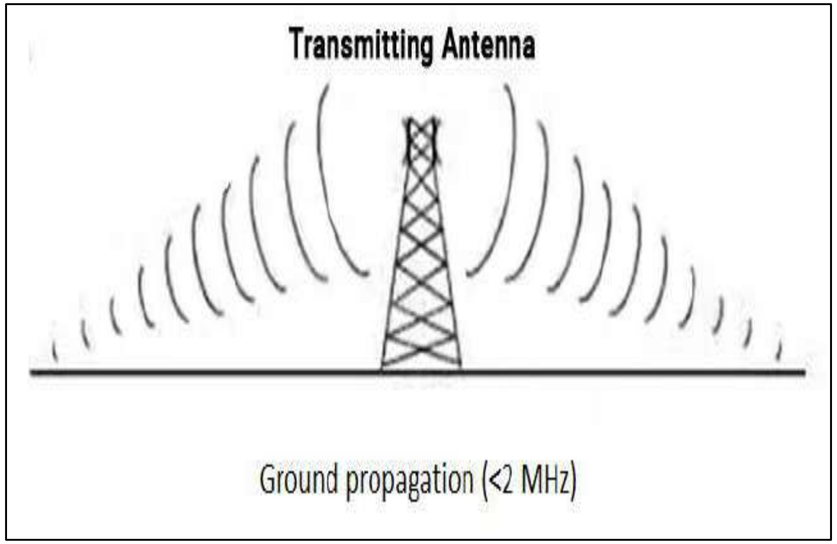
Unguided Media

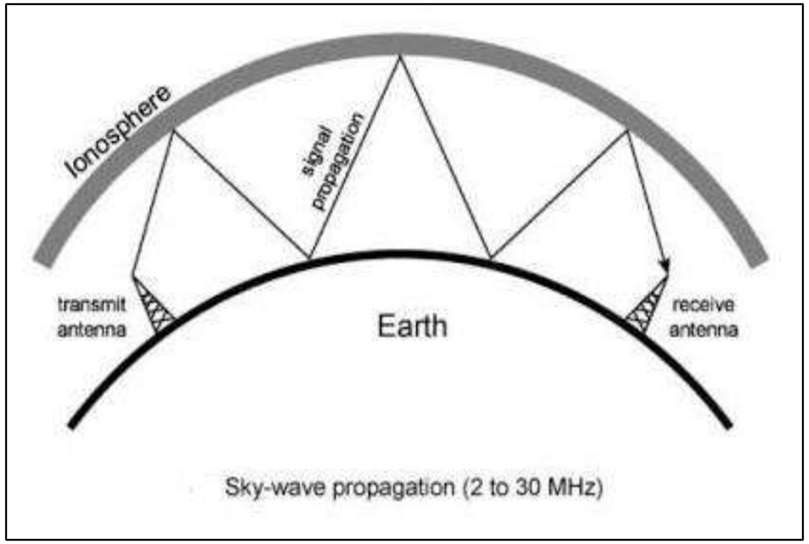
Also called **Wireless Communication**.

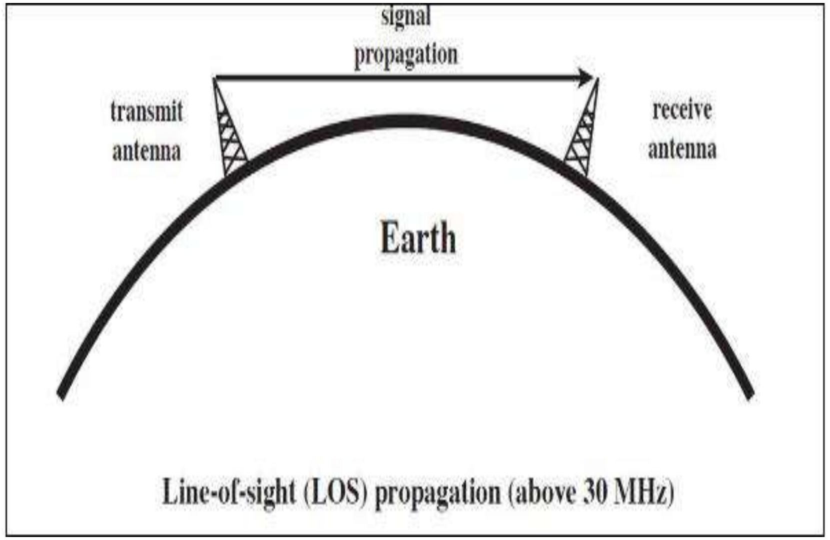
Transport electromagnetic waves without using a physical conductor.

Signals are **broadcast through air** and thus are available to anyone who has device capable of receiving them.

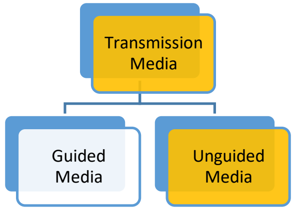
Unguided signals can travel from the source to the destination in several ways:







Physical Layer | Transmission Media



Unguided Media

Wireless transmission can be through **Radio Waves**, **Microwaves** **or** **Infrared**.

Radio Waves (3 KHz to 1 GHz):

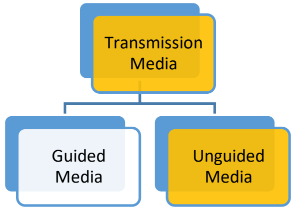
Very Low Frequency (VLF)	3-30 kHz	Ground propagation	Long-range Radio Navigation.
Low Frequency (LF)	30-300 kHz	Ground Propagation	Radio beacons and navigational locators.
Middle Frequency (MF)	300 kHz - 3 MHz	Sky Propagation	AM Radio
High Frequency (HF)	3 – 30 MHz	Sky Propagation	Ship, Aircraft, Citizens band (CB)
Very High Frequency (VHF)	30 – 300 MHz	Sky & LoS Propagation	VHF TV, FM Radio

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**.

The radio waves transmitted by one antenna are susceptible to interference by another antenna that may send signals using the *same frequency or band*.

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*.

Physical Layer | Transmission Media



Unguided Media

Microwaves (1 to 300 GHz):

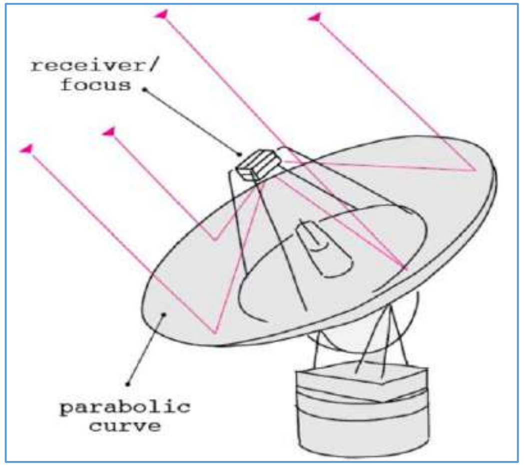
Ultra High Frequency (UHF)	300 MHz – 3 GHz	LoS Propagation	UHF TV, Cellular Phones, Paging, Satellite
Super-high Frequency (SF)	3 – 30 GHz	LoS Propagation	Satellite
Extremely High Frequency (EHF)	30 – 300 GHz	LoS Propagation	Radar, Satellite

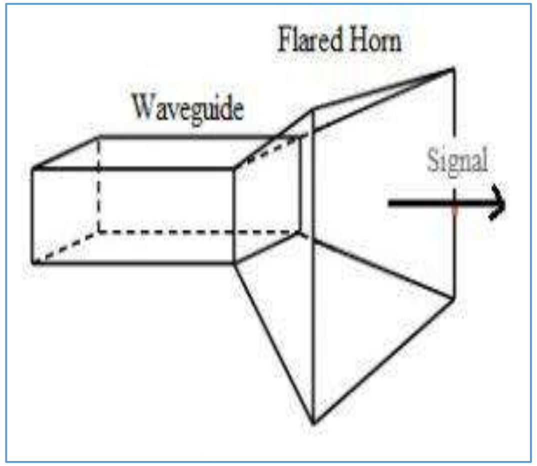
Microwaves are unidirectional. When an antenna transmits microwaves, they can be **narrowly focused**.

The sending and receiving antennas **need to be aligned**.

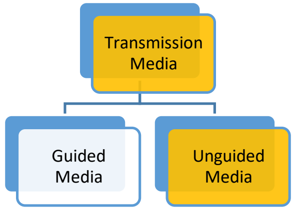
Microwaves need unidirectional antennas:

- **Parabolic Dish Antenna**
- **Horn Antenna**





Physical Layer | Transmission Media

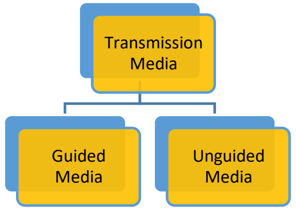


Unguided Media

Infrared (300 GHz to 400 THz):

- Used for short-range communication.
- Cannot penetrate walls. Prevents interference between one system and another.
- 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) has established standards for using these signals for communication between devices such as keyboards, microphones, PCs and printers.

Physical Layer | Transmission Media



Comparison

Medium	Cost	Bandwidth/data Rate	Attenuation	EMI	Security
UTP	Low	3MHz/4Mbps	High (2-10 KM)	High	Low
Coaxial Cable	Moderate	350MHz/500Mbps	Moderate (1-10 KM)	Moderate	Low
Optical Fibre	High	2GHz/2Gbps	Low (10-100KM)	Low	High
Radio	Moderate	1-10 Mbps	Low-high	High	Low
Microwave	High	1Mbps – 10Gbps	Variable	High	Moderate
Satellite	High	1Mbps – 10Gbps	Variable	High	Moderate
Infrared	Low	2400bps – 4Mbps	Low	Low	High