UNIT-IV

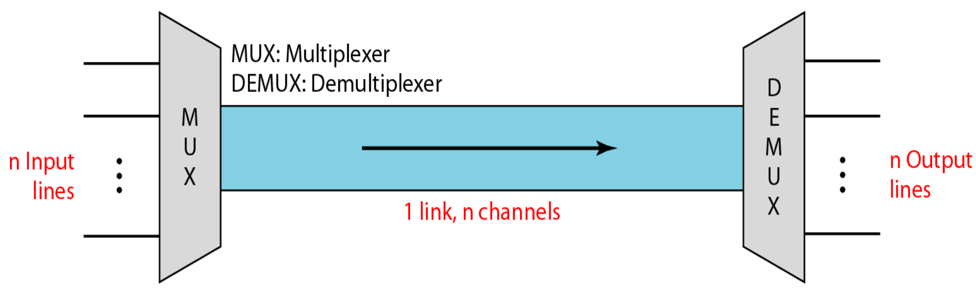
OVERVIEW OF PHYSICAL LAYER SWITCHING & MULTIPLEXING

Syllabus: **Physical layer and overview of PL Switching: Multiplexing**: frequency division multiplexing, wave length division multiplexing, synchronous time division multiplexing, statistical time division multiplexing, **introduction to switching**: Circuit Switched Networks, Datagram Networks, Virtual Circuit Networks.

MULTIPLEXING:

- **Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link.**

In a multiplexed system, ***n*** lines **share the bandwidth of one link**. Following Figure shows the basic format of a multiplexed system. The lines on the left direct their transmission streams to a **multiplexer (MUX)**, which combines them into a single stream (many-to one). At the receiving end, that stream is fed into a



demultiplexer (DEMUX), which separates the stream back into its component transmissions (one-to-many) and directs them to their corresponding lines.

Figure: ***Dividing a link into channels***

MULTIPLEXING TECHNQUIES:

There are **three** basic multiplexing techniques: **frequency-division multiplexing**, **wavelength-division multiplexing**, and **time-division multiplexing**. The first two are techniques designed for analog signals, the third, for digital signals.

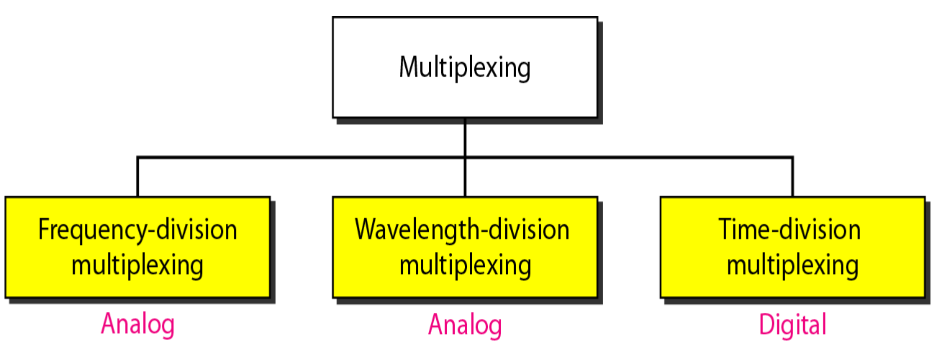


Figure: ***Categories of multiplexing***

Frequency-division multiplexing (FDM):

- Frequency-division multiplexing (FDM) is an analog technique that can be applied when the bandwidth of a link is greater than the combined bandwidths of the signals to be transmitted.
- In FDM, signals generated by each sending device modulate different carrier frequencies.
- These modulated signals are then combined into a single composite signal that can be transported by the link.
- Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal.

- These bandwidth ranges are the channels through which the various signals travel.
- Channels can be separated by strips of unused bandwidth-**guard bands**-to prevent signals from overlapping.
- In addition, carrier frequencies must not interfere with the original data frequencies.

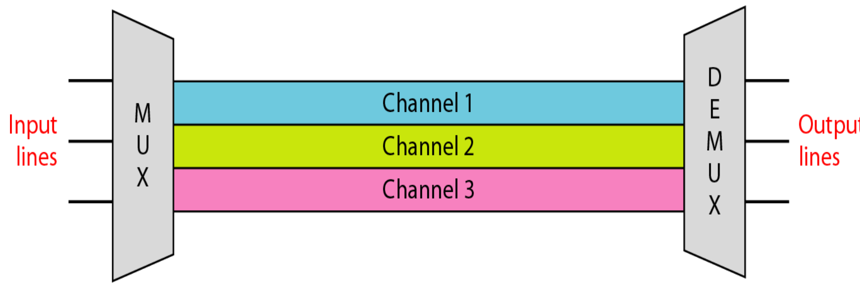


Figure: *Frequency-division multiplexing*

Above Figure gives a conceptual view of FDM. In this illustration, the transmission path is divided into three parts, each representing a channel that carries one transmission.

Multiplexing Process:

Following Figure is a conceptual illustration of the multiplexing process. Each source generates a signal of a similar frequency range. Inside the multiplexer, these similar signals modulates different carrier frequencies *(*f1,f2*,* and f3*).* The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it.

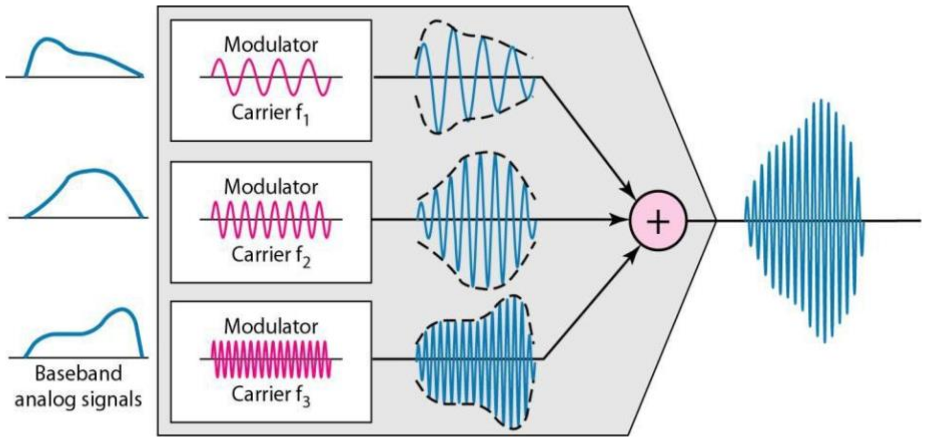


Figure: ***FDM process***

Demultiplexing Process:

The demultiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals. The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines. Following Figure is a conceptual illustration of demultiplexing process.

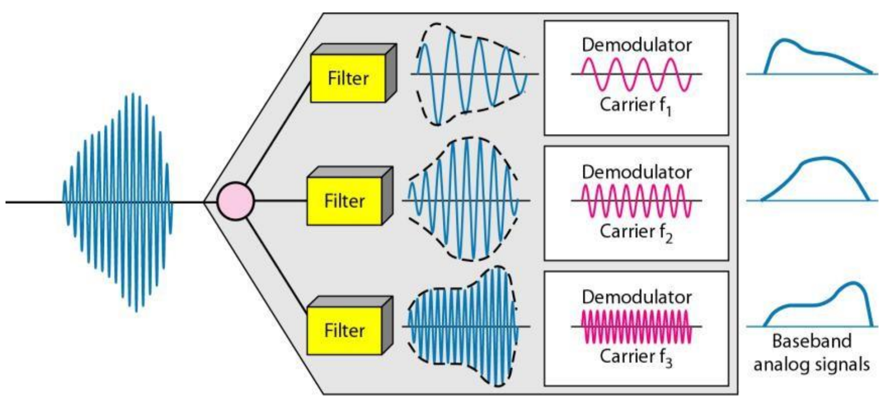


Figure: ***FDM demultiplexing example***

The Analog Carrier System:

To maximize the efficiency of their infrastructure, telephone companies have traditionally multiplexed signals from lower-bandwidth lines onto higher-bandwidth lines. In this way, many switched or leased lines can be combined into fewer but bigger channels. For analog lines, FDM is used.

One of these hierarchical systems used by AT&T is made up of groups, supergroups, master groups, and jumbo groups (see Following Figure).

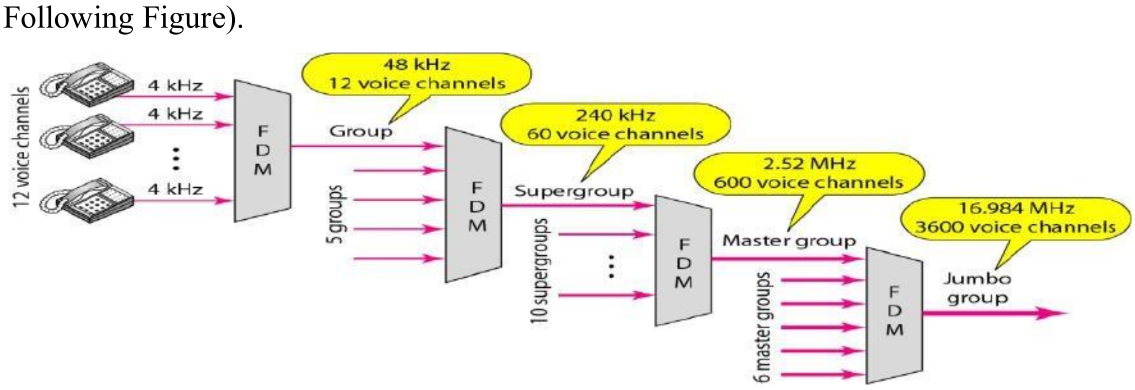


Figure: Analog hierarchy

Applications of FDM:

A very common application of FDM is AM and FM radio broadcasting.

Wavelength-Division Multiplexing:

- Wavelength-division multiplexing (WDM) is designed to use the high-data-rate capability of fiber-optic cable.
- Multiplexing allows us to combine several lines into one.
- WDM is conceptually the same as FDM, except that the multiplexing and demultiplexing involve optical signals transmitted through fiber-optic channels. The idea is the same: We are combining different signals of different frequencies. The difference is that the frequencies are very high.

Following Figure gives a conceptual view of a WDM multiplexer and demultiplexer. Very narrow bands of light from different sources are combined to make a wider band of light. At the receiver, the signals are separated by the demultiplexer.

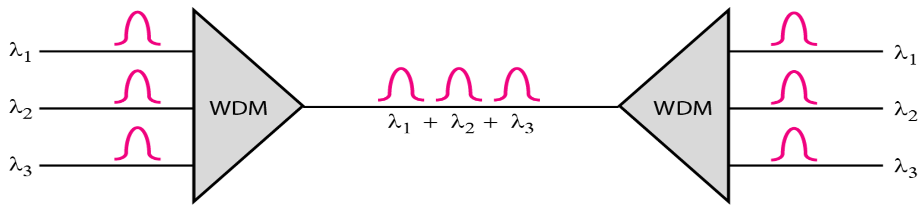


Figure: *Wavelength-division multiplexing*

- Although WDM technology is very complex, the basic idea is very simple. We want to combine multiple light sources into one single light at the multiplexer and do the reverse at the demultiplexer.
- The combining and splitting of light sources are easily handled by a prism. Recall from basic physics that a prism bends a beam of light based on the angle of incidence and the frequency.
- Using this technique, a multiplexer can be made to combine several input beams of light, each containing a narrow band of frequencies, into one output beam of a wider band of frequencies. A demultiplexer can also be made to reverse the process. Following Figure shows the concept.

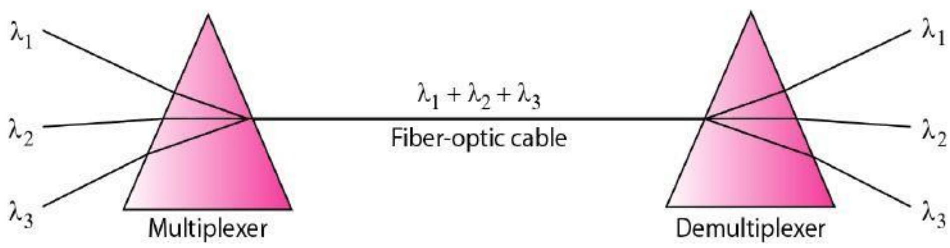


Figure: *Prisms in wavelength-division multiplexing and demultiplexing*

One application of WDM is the SONET network in which multiple optical fiber lines are multiplexed and demultiplexed.

Time-Division Multiplexing

- Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a **link**.
- Instead of sharing a portion of the bandwidth as in FDM, time is shared.
- Each connection occupies a portion of time in the link.

In the figure, portions of signals 1, 2, 3, and 4 occupy the link sequentially.

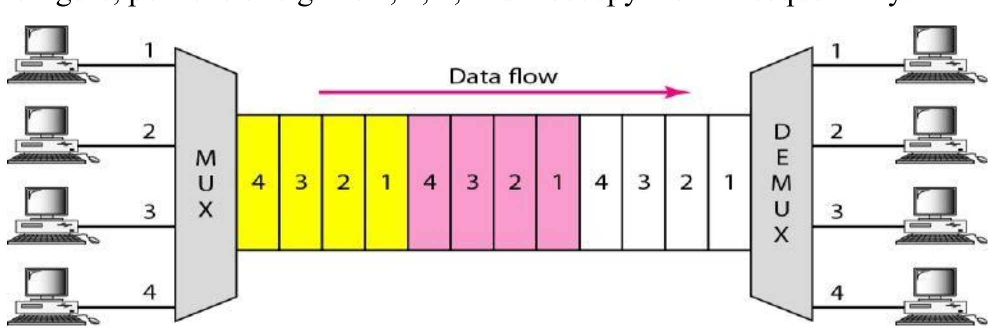


Figure: Time division multiplexing

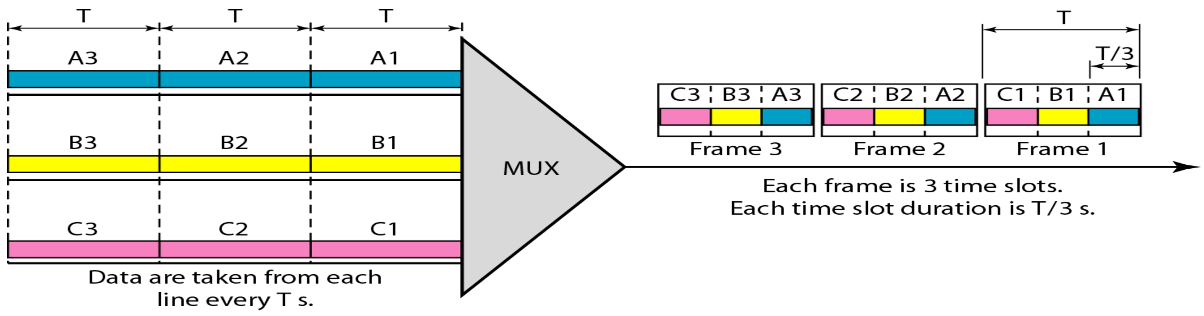
- TDM into two different schemes: **synchronous and statistical**.

Synchronous TDM: In synchronous TDM, each input connection has an allotment in the output even if it is not sending data.

Time Slots and Frames:

- In synchronous TDM, the data flow of each input connection is divided into units, where each input occupies one input time slot.

- A unit can be 1 bit, one character, or one block of data.
- Each input unit becomes one output unit and occupies one output time slot.
- However, the duration of an output time slot is *n* times shorter than the duration of an input time slot.
- If an input time slot is *T* s, the output time slot is ***T/n*** s, where *n* is the number of connections.



Following Figure shows an example of synchronous TDM where *n* is 3.

- In synchronous TDM, a round of data units from each input connection is collected into a **frame**.
- If we have n connections, a frame is divided into n time slots and one slot is allocated for each unit, one for each input line.
- If the duration of the input unit is T, the duration of each slot is $\boldsymbol{T/n}$ and the duration of each frame is T
- The data rate of the output link must be n times the data rate of a connection to guarantee the flow of data.

In above Figure, the data rate of the link is 3 times the data rate of a connection; likewise, the duration of a unit on a connection is 3 times that of the time slot.

Interleaving:

- TDM can be visualized as two fast-rotating switches, one on the multiplexing side and the other on the demultiplexing side.
- The switches are synchronized and rotate at the same speed, but in opposite directions.
- On the multiplexing side, as the switch opens in front of a connection, that connection has the opportunity to send a unit onto the path. This process is called **interleaving.**
- On the demultiplexing side, as the switch opens in front of a connection, that connection has the opportunity to receive a unit from the path.

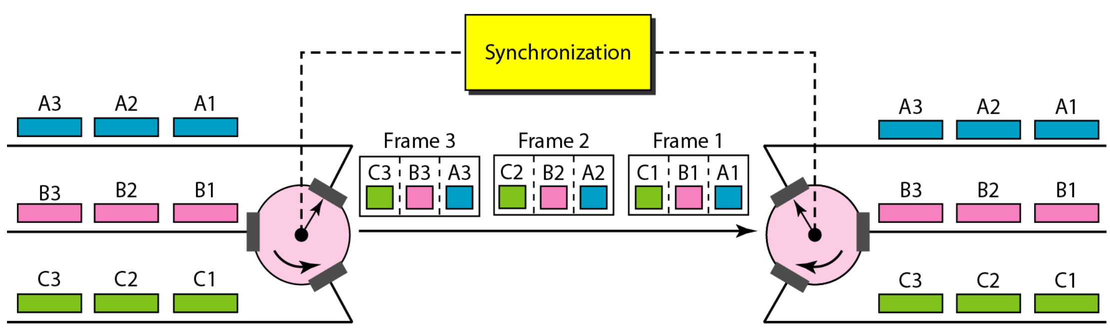


Figure: ***Interleaving***

Empty Slots

Synchronous TDM is not as efficient as it could be. If a source does not have data to send, the corresponding slot in the output frame is empty. Following Figure shows a case in which one of the input lines has no data to send and one slot in another input line has discontinuous data.

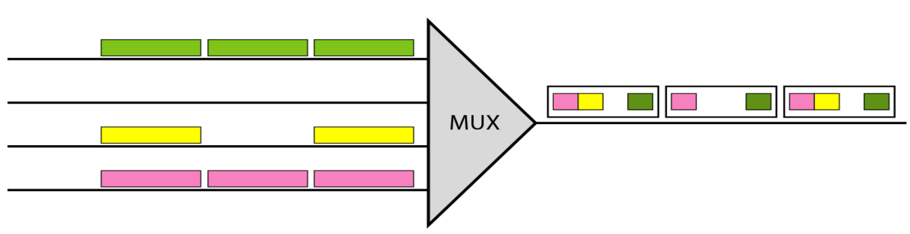


Figure: empty slots

Data Rate Management:

One problem with TDM is how to handle a disparity in the input data rates. We assumed that the data rates of all input lines were the same. However, if data rates are not the same, three strategies, or a combination of them, can be used. We call these three strategies **multilevel multiplexing, multiple-slot allocation,** and **pulse stuffing.**

Multilevel Multiplexing Multilevel multiplexing is a technique used when the data rate of an input line is a multiple of others. For example, in Following Figure, we have two inputs of 20 kbps and three inputs of 40 kbps. The first two input lines can be multiplexed together to provide a data rate equal to the last three. A second level of multiplexing can create an output of 160 kbps.

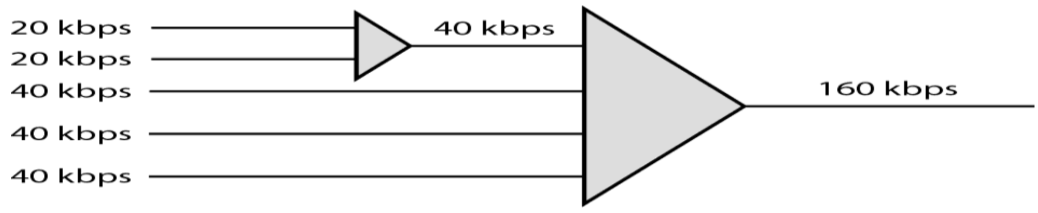
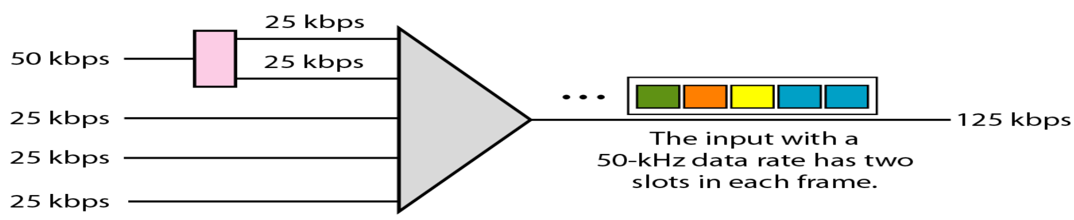


Figure: ***Multilevel multiplexing***

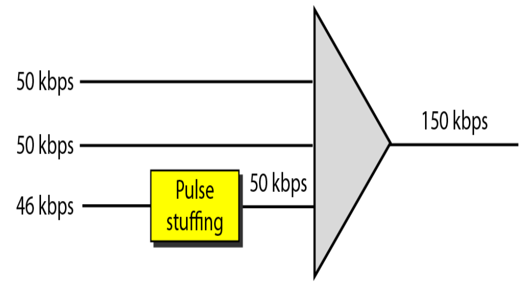
<u>Multiple-Slot Allocation</u>: Sometimes it is more efficient to allot more than one slot in a frame to a single input line. For example, we might have an input line that has a data rate that is a multiple of another input. In



Following Figure, the input line with a 50-kbps data rate can be given two slots in the output. We insert a serial-to-parallel converter in the line to make two inputs out of one.

Figure: Multiple-slot multiplexing

Pulse Stuffing: Sometimes the bit rates of sources are not multiple integers of each other. Therefore, neither of the above two techniques can be applied. One solution is to make the highest input data rate the dominant data rate and then add dummy bits to the input lines with lower rates. This will increase their rates. This technique is called **pulse stuffing, bit padding, or bit stuffing**. The idea is shown in Following Figure. The input with a data rate of 46 is pulse-stuffed to increase the rate to 50 kbps. Now multiplexing can take place.



Frame Synchronizing:

The implementation of TDM is not as simple as that of FDM. If the multiplexer and the demultiplexer are not synchronized, a bit belonging to one channel may be received by the wrong channel. For this reason, one or more synchronization bits are usually added to the beginning of each frame. These bits, called **framing bits**, follow a pattern, frame to frame, that allows the demultiplexer to synchronize with the incoming stream so that it can separate the time slots accurately. In most cases, this synchronization information consists of 1 bit per frame, alternating between 0 and 1, as shown in Following Figure.

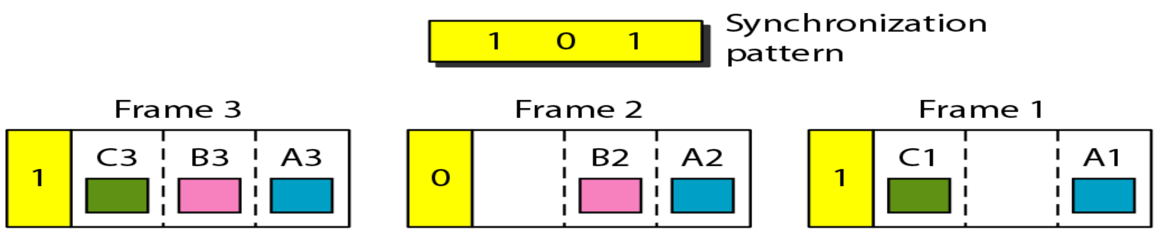


Figure: Framing bits

Digital Signal Service:

Telephone companies implement TDM through a hierarchy of digital signals, called **digital signal (DS)** service or digital hierarchy. Following Figure shows the data rates supported by each level.

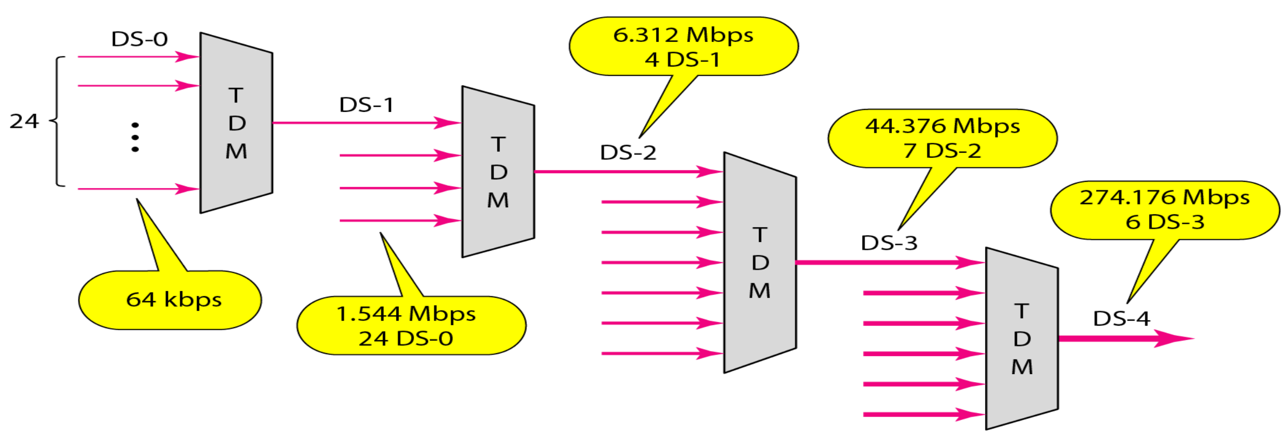


Figure: *Digital hierarchy*

- A **DS-O** service is a single digital channel of 64 kbps.
- **DS-1** is a 1.544-Mbps service; 1.544 Mbps is 24 times 64 kbps plus 8 kbps of overhead. It can be used as a single service for 1.544-Mbps transmissions, or it can be used to multiplex 24 DS-O channels or to carry any other combination desired by the user that can fit within its 1.544-Mbps capacity.
- **DS-2** is a 6.312-Mbps service; 6.312 Mbps is 96 times 64 kbps plus 168 kbps of overhead. It can be used as a single service for 6.312-Mbps transmissions; or it can be used to multiplex 4 DS-l channels, 96 DS-O channels, or a combination of these service types.
- **DS-3** is a 44.376-Mbps service; 44.376 Mbps is 672 times 64 kbps plus 1.368 Mbps of overhead. It can be used as a single service for 44.376-Mbps transmissions; or it can be used to multiplex 7 DS-2 channels, 28 DS-l channels, 672 DS-O channels, or a combination of these service types.
- **DS-4** is a 274. 176-Mbps service; 274.176 is 4032 times 64 kbps plus 16.128 Mbps of overhead. It can

be used to multiplex 6 DS-3 channels, 42 DS-2 channels, 168 DS-l channels, 4032 DS-O channels, or a combination of these service types.

T Lines:

DS-O, DS-l, and so on are the names of services. To implement those services, the telephone companies use **T lines** (T-l to T-4). These are lines with capacities precisely matched to the data rates of the DS-l to DS-4 services. So far only T-l and T-3 lines are commercially available.

Service	*Line*	*Rate (Mbps)*	*Voice Channels*
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

Table: ***DS and T line rates***

T Lines for Analog Transmission:

T lines are digital lines designed for the transmission of digital data, audio, or video. However, they also can be used for analog transmission (regular telephone connections), provided the analog signals are first sampled, then time-division multiplexed.

24 voice channels can be multiplexed onto one T-1 line

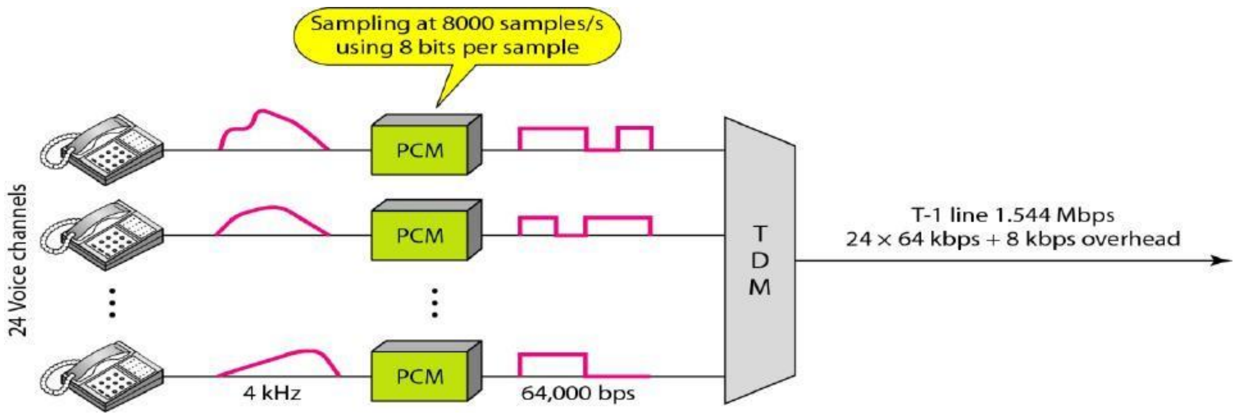


Figure: ***T-1 line for multiplexing telephone lines***

E Lines:

Europeans use a version of T lines called E lines. The two systems are conceptually identical,

Line	Rate (Mbps)	Voice Channels
E-1	2.048	30
E-2	8.448	120
E-3	34.368	480
E-4	139.264	1920

but their capacities differ. Following Table shows the E lines and their capacities.

Table : ***E line rates***

Statistical Time-Division Multiplexing:

- In statistical time-division multiplexing, slots are dynamically allocated to improve bandwidth efficiency.
- Only when an input line has a slot's worth of data to send is it given a slot in the output frame.
- In statistical multiplexing, the number of slots in each frame is less than the number of input lines.
- The multiplexer checks each input line in round robin fashion; it allocates a slot for an input line if the line has data to send; otherwise, it skips the line and checks the next line.

Following Figure shows a synchronous and a statistical TDM example. In the former, some slots are empty because the corresponding line does not have data to send. In the latter, however, no slot is left empty as long as there are data to be sent by any input line.

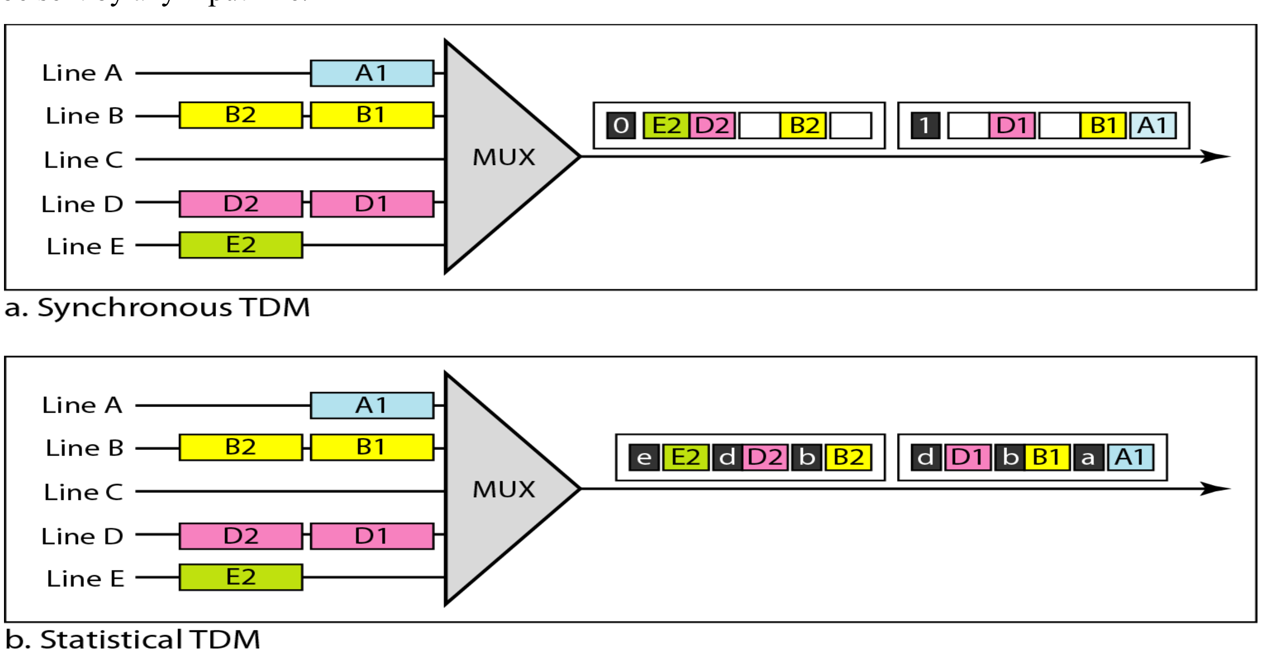


Figure :TDM Slot comparsion

Addressing:

- Above Figure also shows a major difference between slots in synchronous TDM and statistical TDM.
- An output slot in synchronous TDM is totally occupied by data; in statistical TDM, a slot needs to carry data as well as the address of the destination.
- In synchronous TDM, there is no need for addressing; synchronization and preassigned relationships between the inputs and outputs serve as an address.
- In statistical multiplexing, there is no fixed relationship between the inputs and outputs because there are no preassigned or reserved slots. We need to include the address of the receiver inside each slot to show where it is to be delivered. The addressing in its simplest form can be *n* bits to define *N* different output lines with $n=\log_2 N$. For example, for eight different output lines, we need a 3-bit address.

<u>Slot Size:</u>

Since a slot carries both data and an address in statistical TDM, the ratio of the data size to address size must be reasonable to make transmission efficient. For example, it would be inefficient to send 1 bit per slot as data when the address is 3 bits. This would mean an overhead of 300 percent. In statistical TDM, a block of data is usually many bytes while the address is just a few bytes.

<u>No Synchronization Bit:</u>

There is another difference between synchronous and statistical TDM, but this time it is at the frame level. The frames in statistical TDM need not be synchronized, so we do not need synchronization bits.

<u>Bandwidth:</u>

In statistical TDM, the capacity of the link is normally less than the sum of the capacities of each channel. The designers of statistical TDM define the capacity of the link based on the statistics of the load for each channel. If on average only *x* percent of the input slots are filled, the capacity of the link reflects this. Of course, during peak times, some slots need to wait.

1. Synchronous Time-Division Multiplexing (STDM)

Synchronous TDM divides the communication channel into fixed time slots assigned to each user in a repetitive cycle. Even if a user has no data to send, their slot remains reserved. It ensures predictable timing but can waste bandwidth due to idle slots.

2. Statistical Time-Division Multiplexing (Statistical TDM)

Statistical TDM dynamically allocates time slots to users that have data to transmit, improving bandwidth efficiency. Each data packet includes an address identifying its source. It is more flexible than synchronous TDM but may introduce variable delay.

3. Asymmetric Digital Subscriber Line (ADSL)

ADSL is a broadband technology that transmits high-speed Internet data over standard telephone lines. It provides higher download speeds than upload speeds, using different frequency bands for voice and data. It enables simultaneous phone and Internet use.

4. xDSL (Digital Subscriber Line Family)

xDSL is a group of technologies, including ADSL, SDSL, and VDSL, that deliver high-speed Internet over copper telephone lines. Each type offers different speed and distance capabilities. It uses existing telephone infrastructure for broadband access.