Bandwidth Utilization

Course Code: COE 3201

Course Title: Data Communication

Dept. of Computer Engineering
Faculty of Engineering

Lecture No:	**8**	**Week No:**	**9**	**Semester:**	**Spring 23-24**
Lecturer:	Dr Amirul Islam				

Lecture Outline

- Wavelength-division multiplexing (WDM)
- Time-division multiplexing (TDM)
- Synchronous TDM
- Interleaving
- Data rate management
- Digital Hierarchy
- T-lines & E-Lines

Wavelength-division multiplexing (WDM)

- Wavelength-division multiplexing (WDM) is designed to use the high-data-rate capability of fiber-optic cable.
- The optical fiber data rate is higher than the data rate of metallic transmission cable but using a fiber-optic cable for a single line wastes the available bandwidth.
- WDM 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.
- Figure 6.10 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.

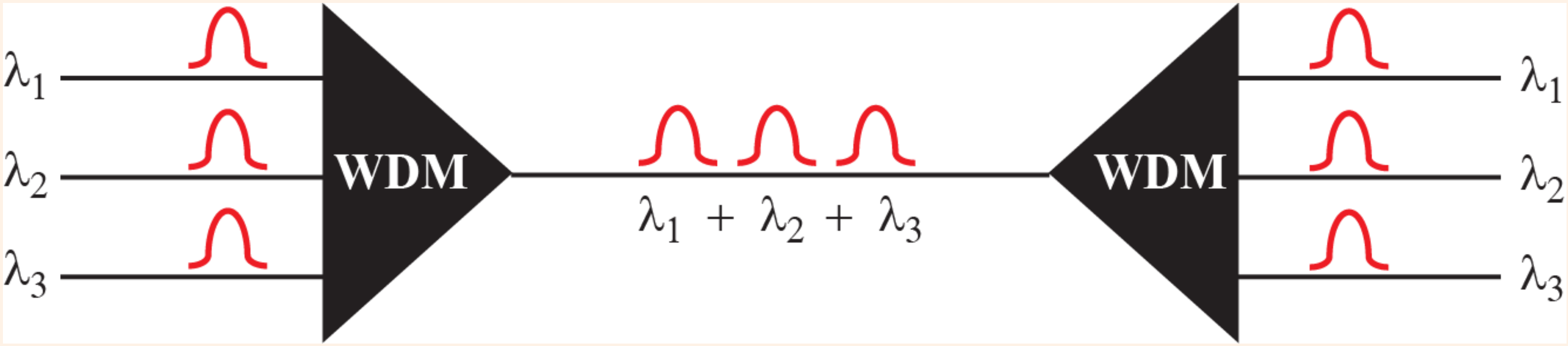


Figure 6.10: Wavelength-division multiplexing

- 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.

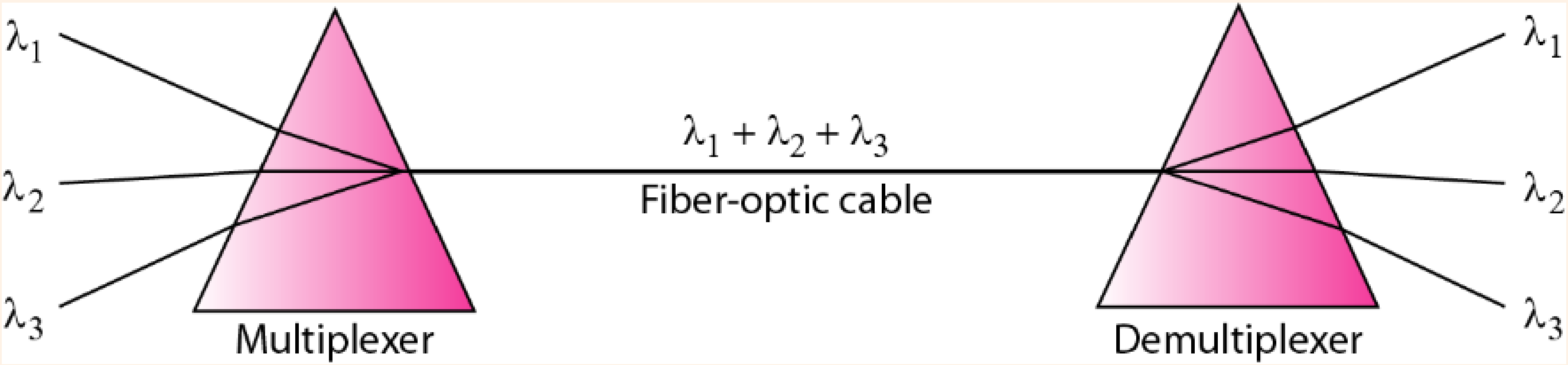


Figure 6.11: Prisms in wave-length division multiplexing

Time-division Multiplexing (TDM)

- 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.
- Figure 6.12 gives a conceptual view of TDM.
- Note that the same link is used as in FDM; here, however, the link is shown sectioned by time rather than by frequency.

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

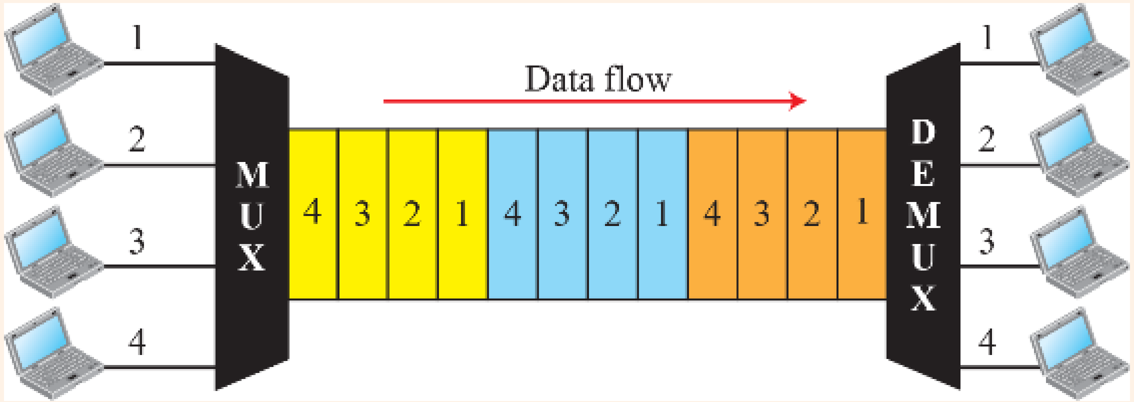


Figure 6.12: TDM

Synchronous TDM

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

Synchronous TDM

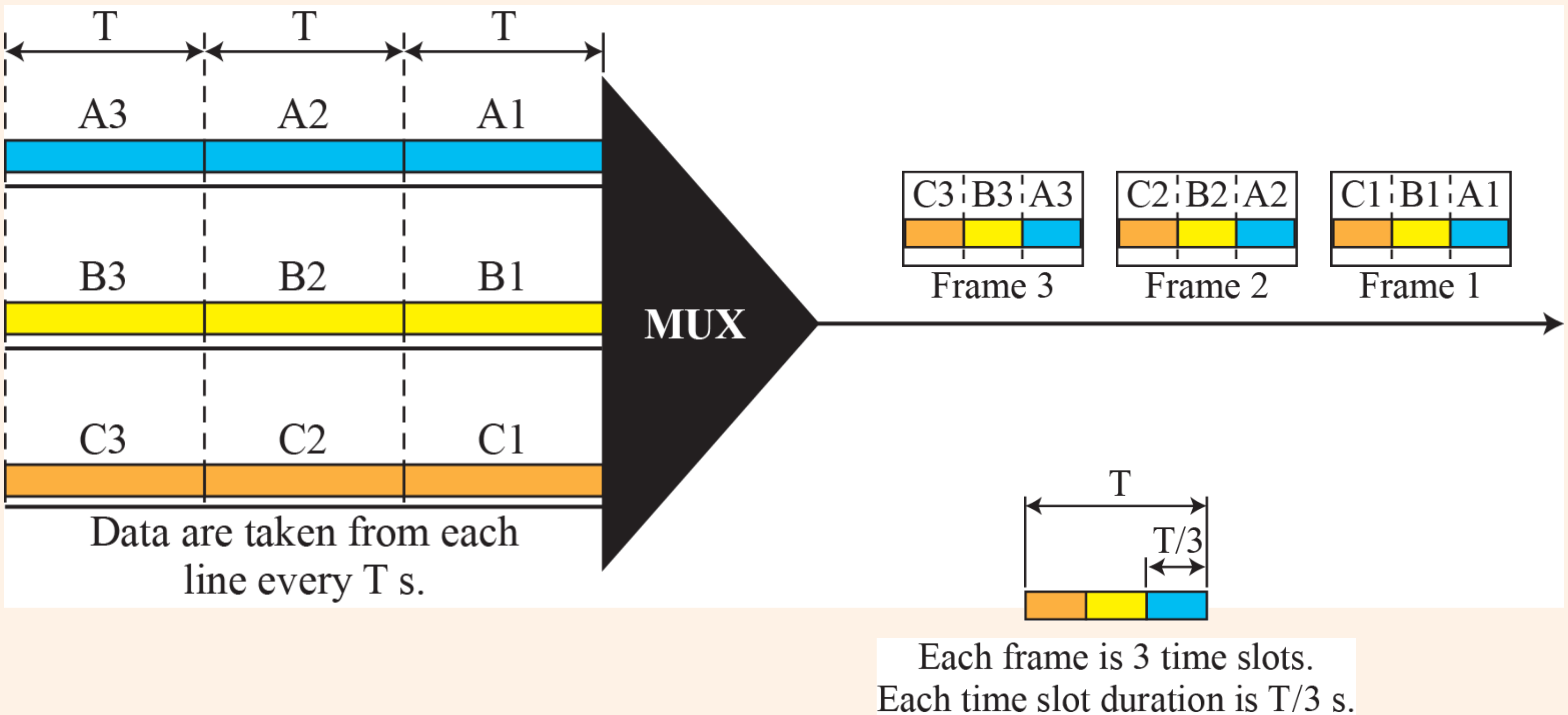


Figure 6.13: Synchronous time-division multiplexing

Example 6.5: In Figure 6.13, the data rate for each input connection is 1 kbps. If 1 bit at a time is multiplexed (a unit is 1 bit), what is the duration of a. each input slot, b. each output slot, and c. each frame?

Solution: We can answer the questions as follows:

a. The data rate of each input connection is 1 kbps. This means that the bit duration is 1/1000 s or 1 ms. The duration of the input time slot is 1 ms (same as bit duration).

b. The duration of each output time slot is one-third of the input time slot. This means that the duration of the output time slot is 1/3 ms.

c. Each frame carries three output time slots. So the duration of a frame is 3 × (1/3) ms, or 1 ms. The duration of a frame is the same as the duration of an input unit.

Example 6.6: Figure 6.14 shows synchronous TDM with a data stream for each input and one data stream for the output. The unit of data is 1 bit. Find (a) the input bit duration, (b) the output bit duration, (c) the output bit rate, and (d) the output frame rate.

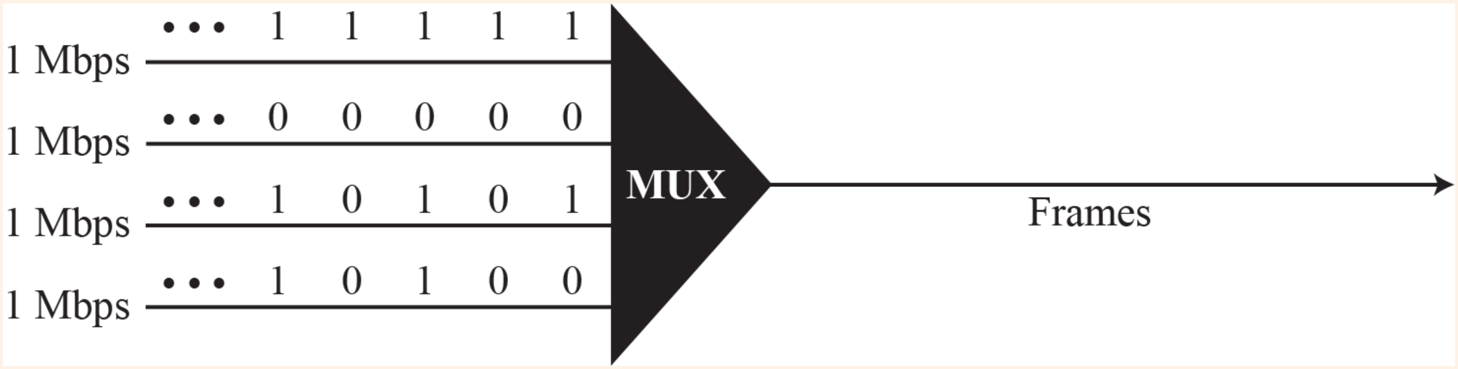


Figure 6.14: Example 6.6

Synchronous TDM

Solution

We can answer the questions as follows:

1. The input bit duration is the inverse of the bit rate: 1/1 Mbps = 1 μs.
2. The output bit duration is one-fourth of the input bit duration, or 1/4 μs.
3. The output bit rate is the inverse of the output bit duration, or 1/(1/4) μs or 4 Mbps. This can also be deduced from the fact that the output rate is 4 times as fast as any input rate; so the output rate = 4×1 Mbps = 4 Mbps.
4. The frame rate is always the same as any input rate. So the frame rate is 1,000,000 frames per second. Because we are sending 4 bits in each frame, we can verify the result of the previous question by multiplying the frame rate by the number of bits per frame.

Example 6.7: Four 1-kbps connections are multiplexed together. A unit is 1 bit. Find (1) the duration of 1 bit before multiplexing, (2) the transmission rate of the link, (3) the duration of a time slot, and (4) the duration of a frame.

Solution

We can answer the questions as follows:

1. The duration of 1 bit before multiplexing is 1/1 kbps, or 0.001 s (1 ms).
2. The rate of the link is 4 times the rate of a connection, or 4 kbps.
3. The duration of each time slot is one-fourth of the duration of each bit before multiplexing, or 1/4 ms or 250 μs. Note that we can also calculate this from the data rate of the link, 4 kbps. The bit duration is the inverse of the data rate, or 1/4 kbps or 250 μs.
4. The duration of a frame is always the same as the duration of a unit before multiplexing, or 1 ms. We can also calculate this in another way. Each frame in this case has four time slots. So the duration of a frame is 4 times 250 μs, or 1 ms.

Interleaving

The **process** of taking a **group of bits** from **each input line** for multiplexing is called ***interleaving.***

Interleaving is the process of **multiplexing.**

In **TDM, synchronization** between the **sender** and **receiver** is very important.

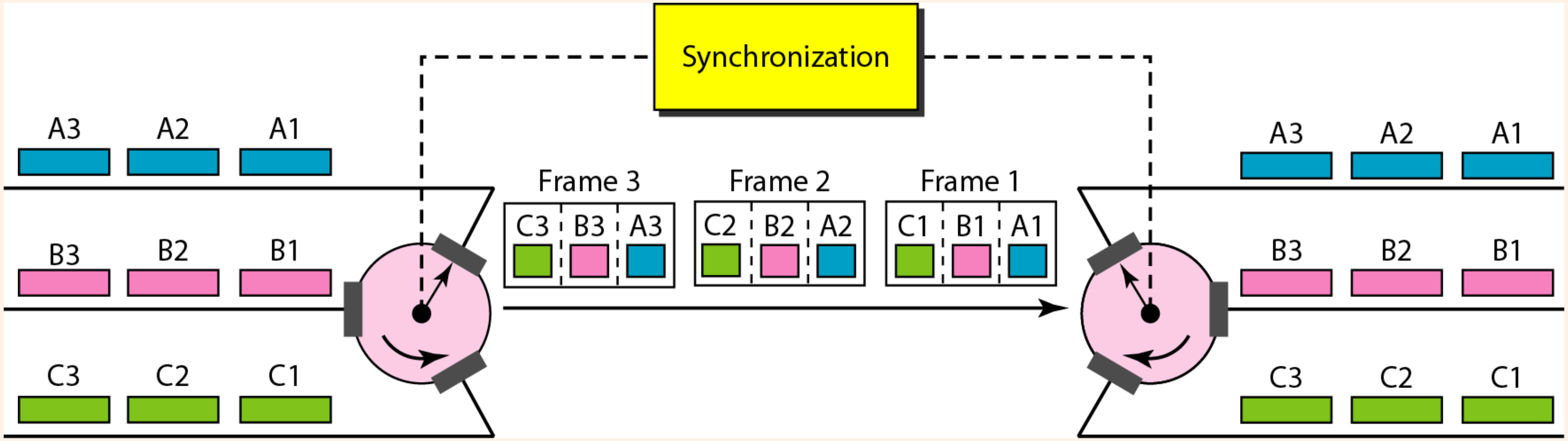
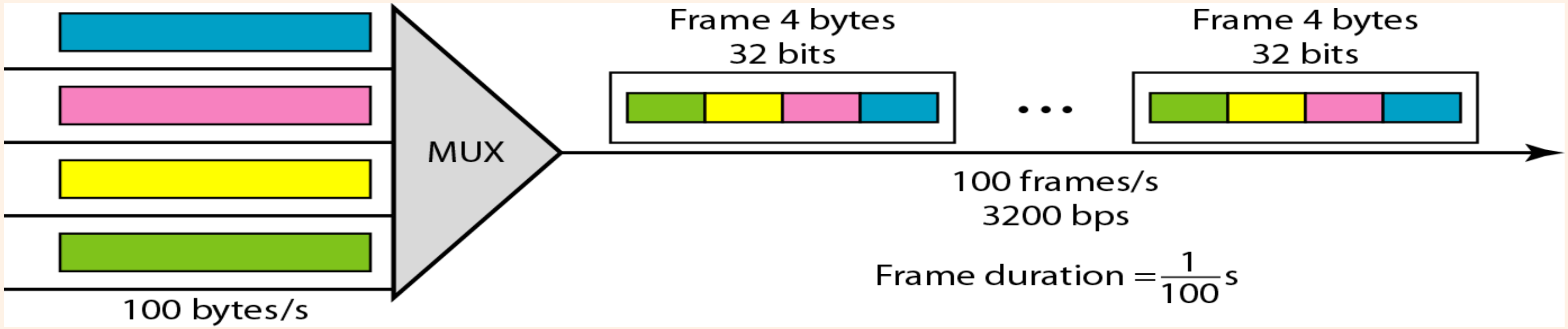


Fig. 17: Interleaving

TDM

Example 6.8: **Four channels** are **multiplexed** using **TDM.** If **each channel** sends ***100 bytes /s*** and we multiplex ***1 byte per channel,*** show the ***frame traveling on the link, the size of the frame, the duration of a frame, the frame rate, and the bit rate for the link.***

Solution:



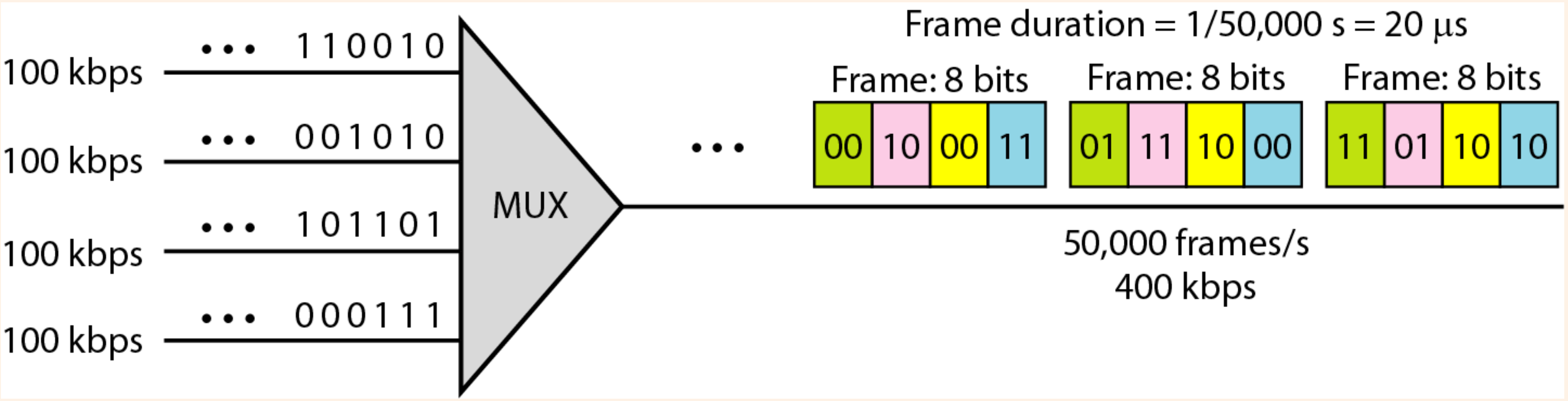
The multiplexer is shown in ***Figure 18.*** **Each frame** carries ***1 byte*** from each channel; the size of each frame, therefore, is ***4 bytes, or 32 bits.*** Because each channel is sending ***100 bytes/s*** and a frame carries ***1 byte*** from each channel, the frame rate must be ***100 frames per second.*** The bit rate is ***100 × 32, or 3200 bps.***

Example 6.9:

A multiplexer combines **four *100-kbps* channels** using a time slot of ***2 bits.*** Show ***the output with four arbitrary inputs. What is the frame rate? What is the frame duration? What is the bit rate? What is the bit duration?***

Solution:

Figure 19 shows the output ***(4x100kbps)*** for **four arbitrary inputs.** The link carries ***400K/(2x4)=50,000*** frames per second **[2x4=8bit]** . The frame duration is therefore ***1/50,000 s*** or ***20 μs.*** The **bit duration** on the output link is ***1/400,000 s, or 2.5 μs.***



Empty Slot

- Sometimes an input link may **have no data to transmit.**
- When that happens, **one or more slots** on the output link will go **unused.**
- That is **wastage** of **bandwidth.**
- **Statistical TDM** can improve the efficiency.

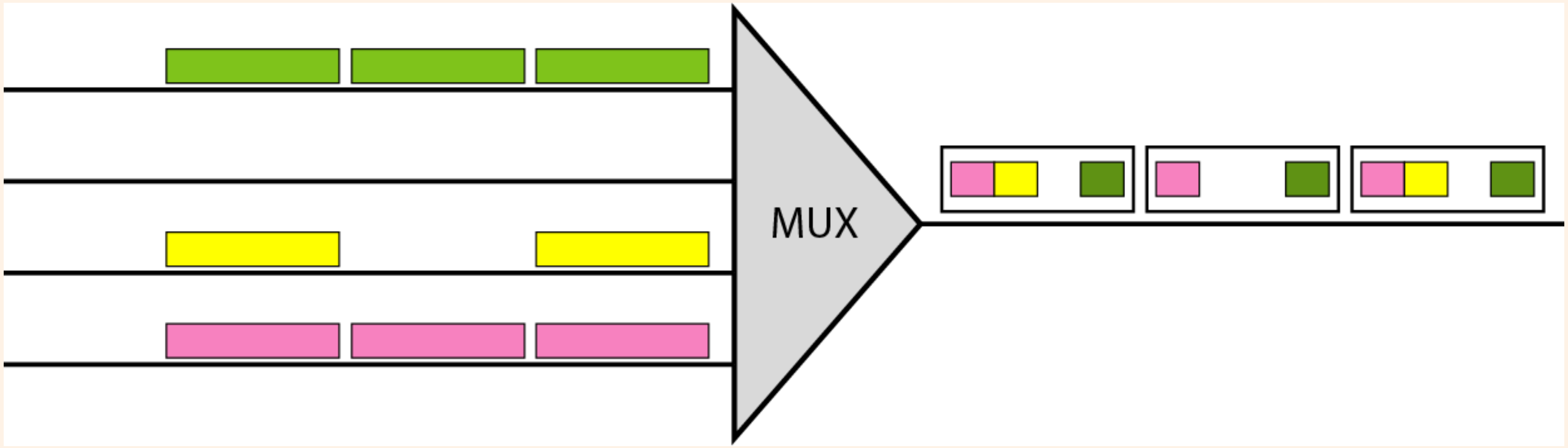


Fig. 20: Empty Slots.

Data Rate Management

- **Data Rate Management:**

Not all input links maybe have the **same data rate.**

Some links maybe **slower.** There maybe several different input link speeds.

There are **three strategies** that can be used to overcome the data rate mismatch: ***multilevel, multislot and pulse stuffing.***

- **Data rate matching:**

Multilevel: used when the **data rate of the input links** are **multiples** of **each other.**

Multislot: used when there is a **GCD(Greatest Common Divisor)** between the data rates. The **higher bit rate channels** are **allocated** more slots per frame, and the **output frame rate** is a multiple of each input link.

Pulse Stuffing: used when there is **no GCD between the links.** The **slowest** speed link will be **brought up to the speed** of the other links by **bit insertion,** this is called **pulse stuffing.**

Data Rate Management

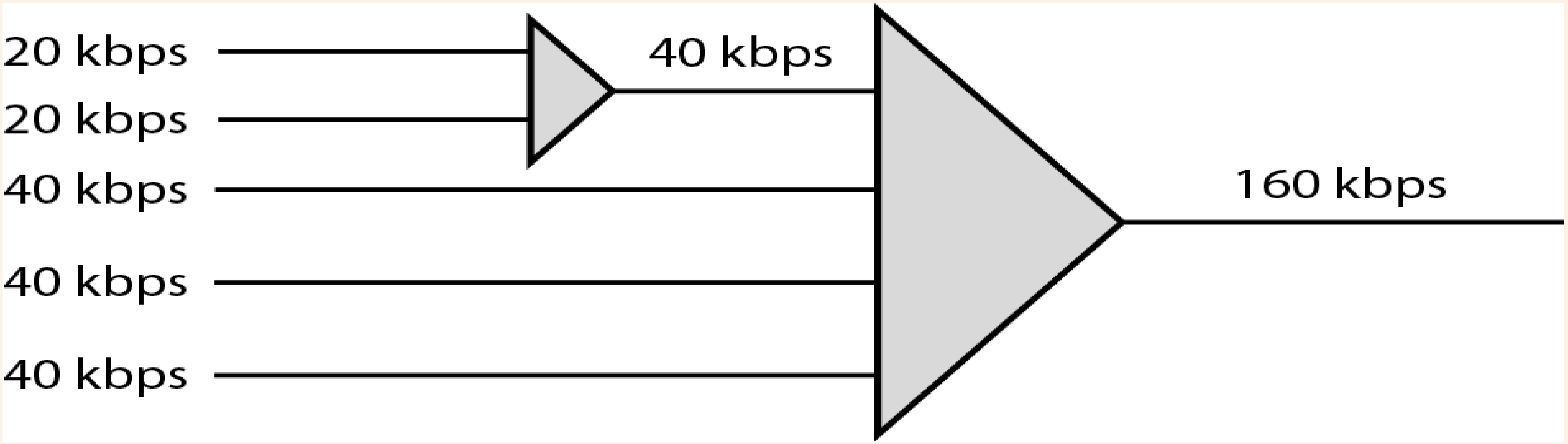


Fig. 21: Multilevel Multiplexing.

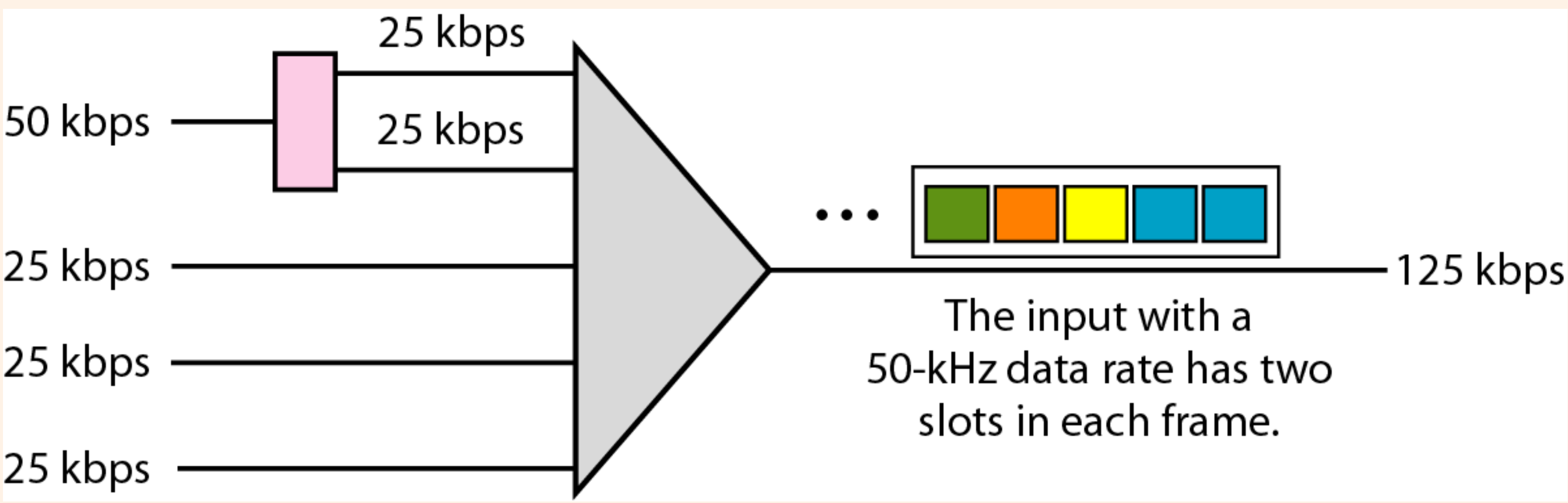


Fig. 22: Multislot Multiplexing.

Data Rate Management

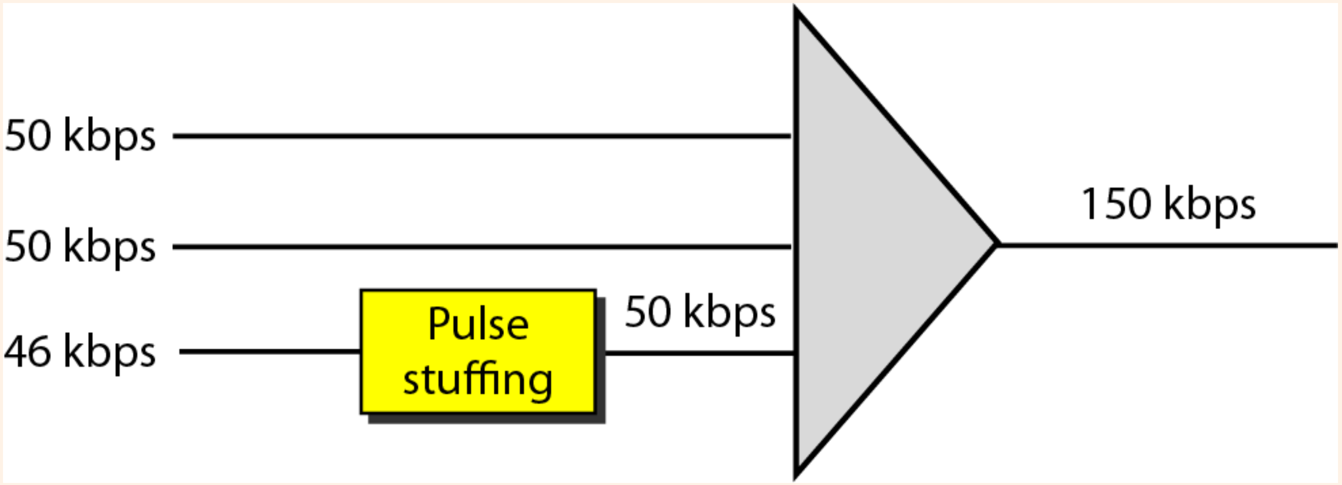


Fig. 23: Multislot Multiplexing

Frame Synchronization

- **Synchronization** between the **multiplexer** and **demultiplexer** is a major issue.
- 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 ***Figure 24.***

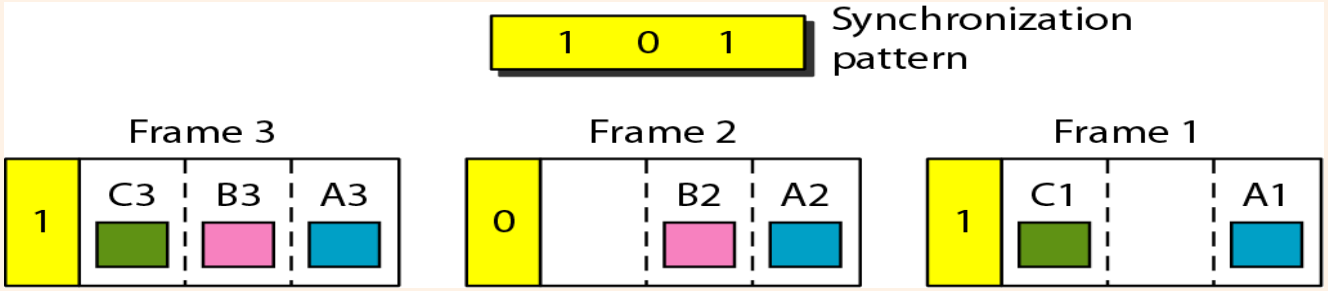


Fig. 24: Multislot Multiplexing.

Mathematical Problem

Example 10:

We have **four sources,** each creating **250** ***8-bit*** characters per second. If the **interleaved** unit is a **character** and ***1*** **synchronizing bit** is **added** to each frame, find **(a) the data rate of each source, (b) the duration of each character in each source, (c) the frame rate, (d) the duration of each frame, (e) the number of bits in each frame, and (f) the data rate of the link.**

Solution:

a. The **data rate** of each source is ***250 × 8 = 2000 bps = 2 kbps.***

b. Each source sends ***250 characters per second;*** therefore, the **duration** of a character is ***1/250 s, or 4 ms.***

c. Each **frame** has **one character** from each source, which means the link needs to send ***250 frames per second*** to keep the transmission rate of each source.

d. The **duration** of each frame is ***1/250 s, or 4 ms.*** Note that the **duration** of each frame is the **same** as the duration of **each character** coming from each source.

e. Each frame **carries** ***4 characters*** and ***1 extra synchronizing bit.*** This means that each frame is ***4 × 8 + 1 = 33 bits.***

Mathematical Problem

Example 11:

Two channels, one with a **bit rate** of ***100 kbps*** and another with a ***bit rate*** of ***200 kbps,*** are to be multiplexed. **How this can be achieved? What is the frame rate? What is the frame duration? What is the bit rate of the link?**

Solution:

We can **allocate** one slot to the **first channel** and **two slots** to the **second channel.** Each frame carries ***3 bits.*** The **frame rate** is ***100,000 frames per second*** because it carries ***1 bit*** from the first channel. The ***bit rate*** is ***100,000 frames/s × 3 bits per frame, or 300 kbps.***

Digital Hierarchy

Digital hierarchy:

Telephone companies implement TDM through a hierarchy of digital signals, called digital signal (DS) service or digital hierarchy. ***Figure 25*** shows the data rates supported by each level.

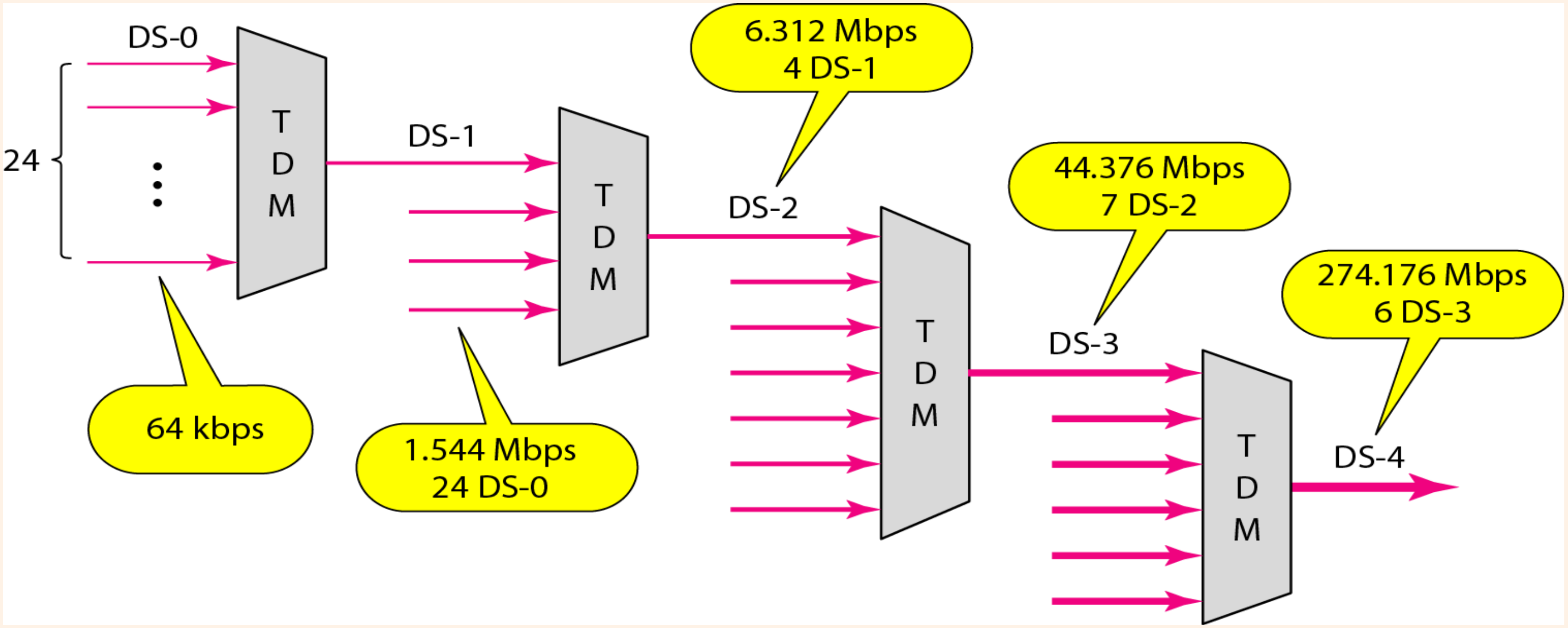


Fig. 25: Digital Hierarchy.

Digital Hierarchy

T Lines:

DS-0, DS-1, and so on are the ***names of services.*** To implement those services, the telephone companies use ***T lines (T-1 to T-4).*** These are lines with capacities precisely matched to the data rates of the ***DS-1* to *DS-4*** services (see ***Table 1***). So far only ***T-1 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 1

Digital Hierarchy

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.**

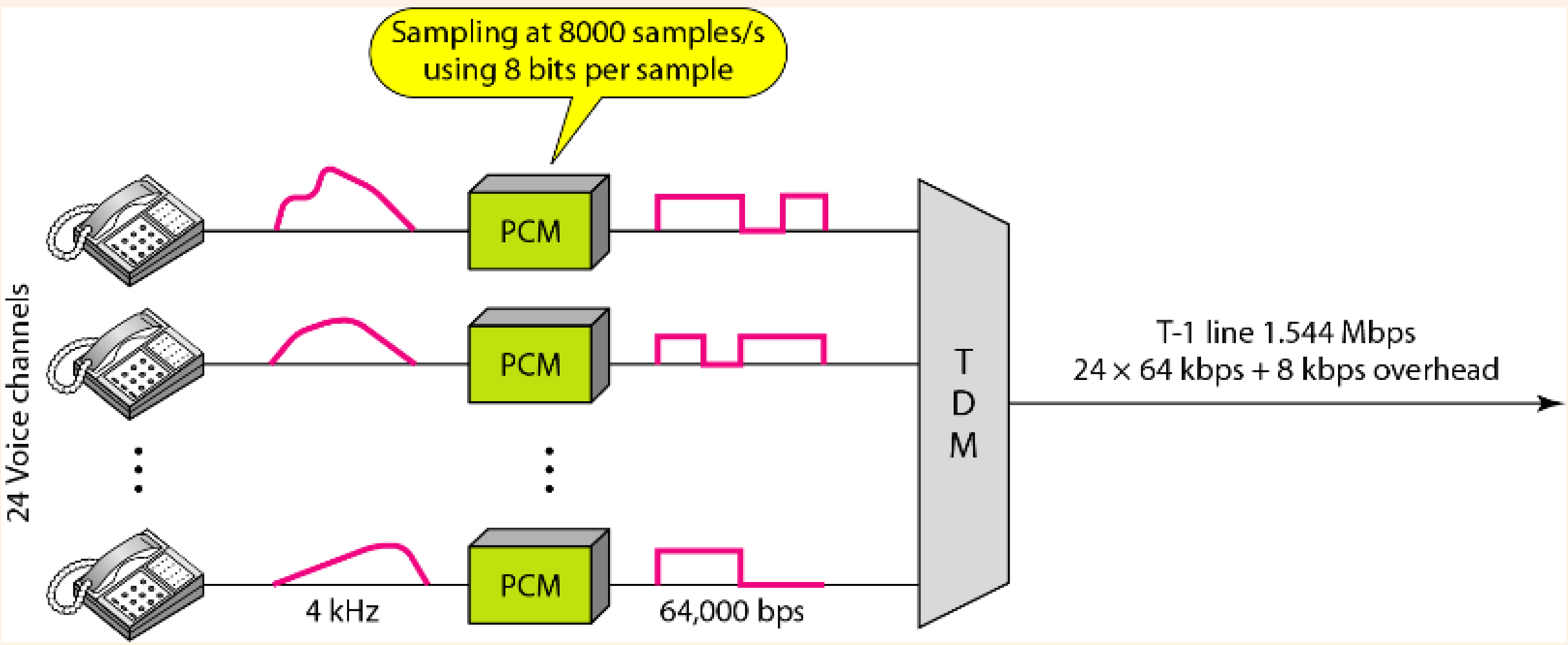


Fig. 26: T-1 line for multiplexing telephone lines.

T-1 frame structure

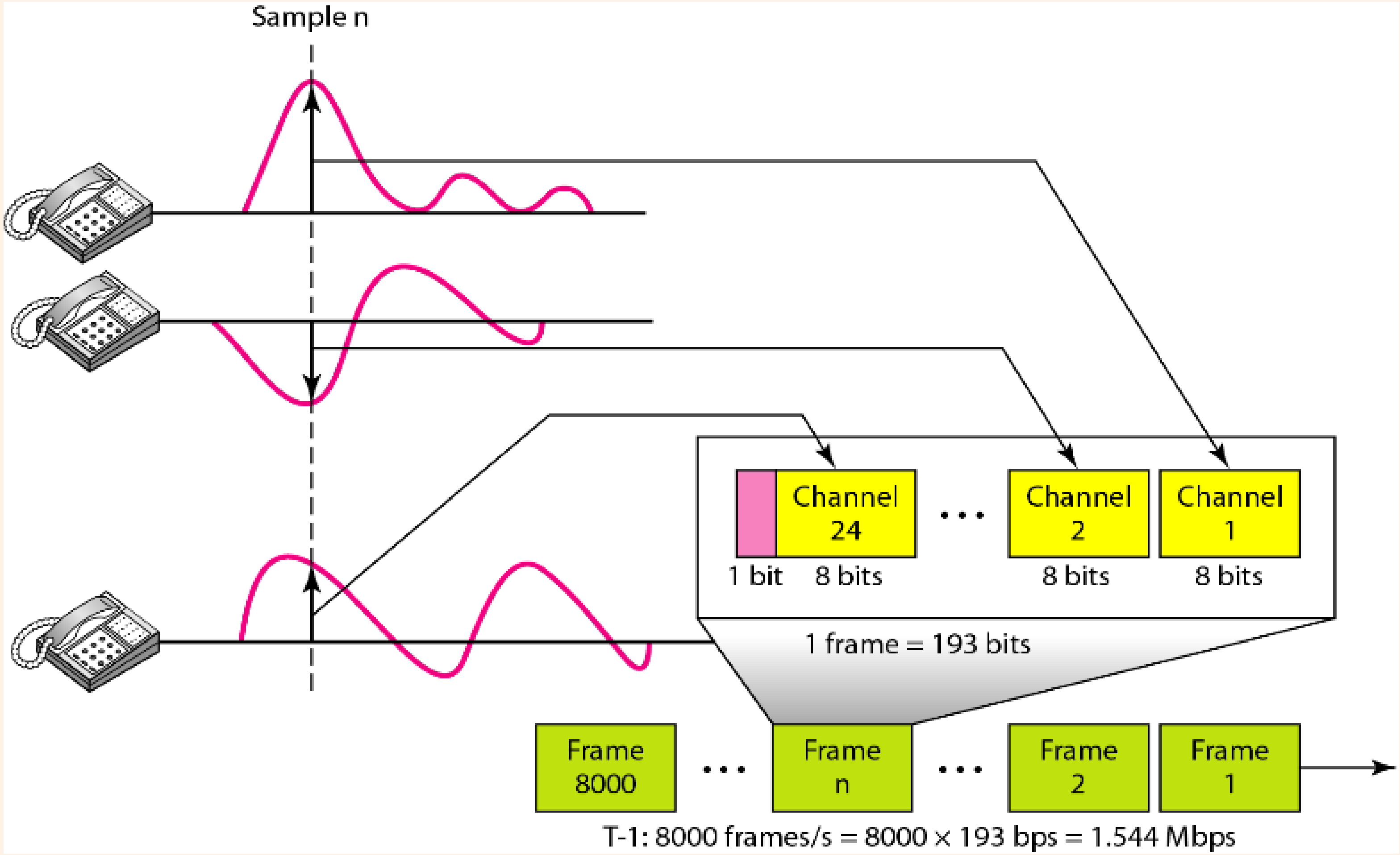


Fig. 27: T-1 Frame Structure.

E line rates

E line rates:

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

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

Table 2

Statistical Time-Division Multiplexing

In **synchronous TDM,** each input has a **reserved** slot in the **output frame.** This can be **inefficient** if **some input lines** have **no data** to send.

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, then it is 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.**

1. The **multiplexer checks** each input line in **round robin fashion;**
2. it **allocates** a slot for an input line if the **line has data to send;** otherwise,
3. it **skips** the **line** and **checks** the **next line.**

Statistical Time-Division Multiplexing

Addressing:

Figure 28 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 pre assigned relationships between the inputs and outputs serve as an address. If the multiplexer and the demultiplexer are synchronized, this is guaranteed.

In **statistical multiplexing,** there is **no fixed relationship** between the inputs and outputs because there are **no pre-assigned or reserved slots.**

We **need** to **include** the **address** of the receiver **inside** each slot to show **where** it is to be **delivered.**

TDM slot comparison

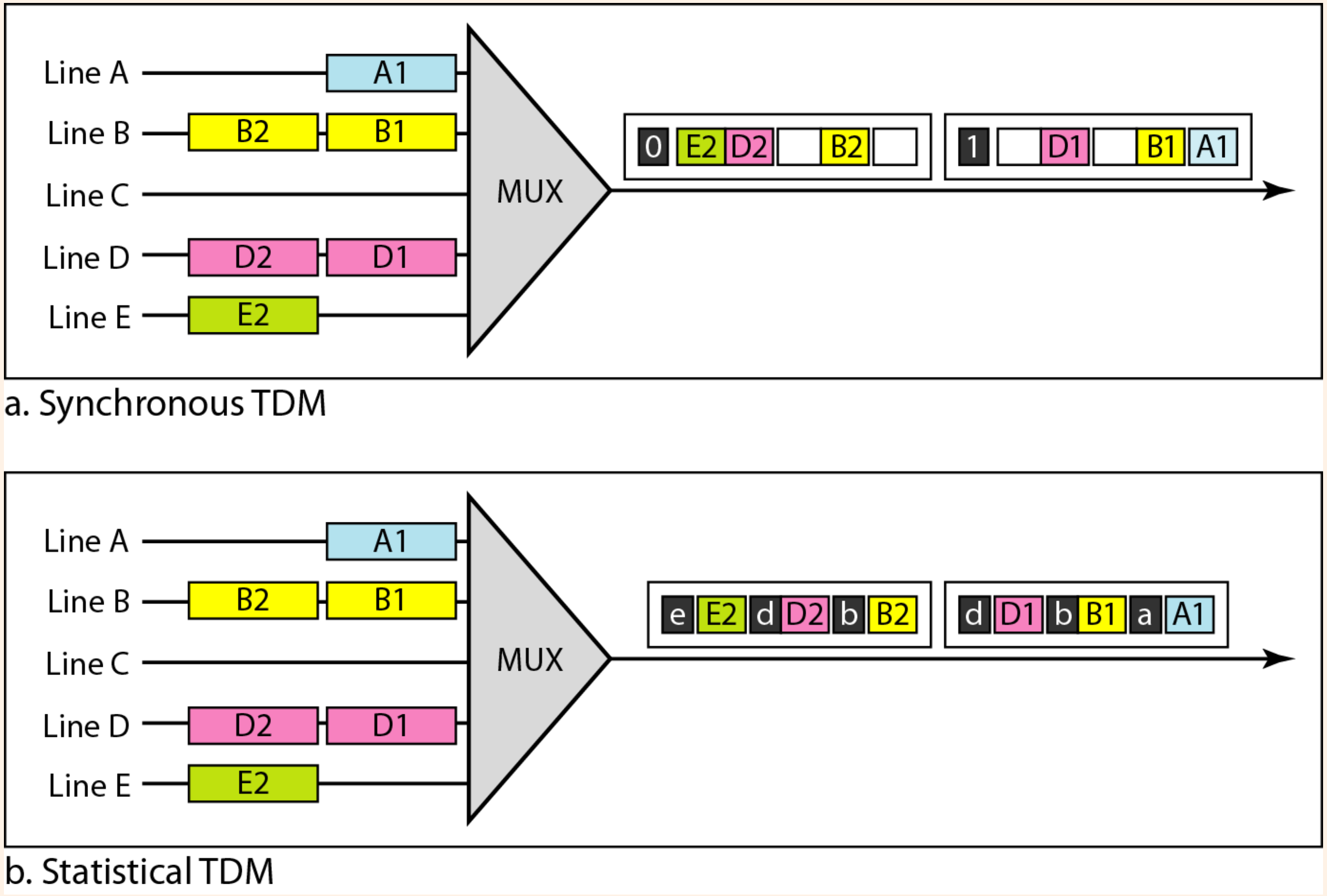


Fig. 28: TDM slot comparison.

References

1. Prakash C. Gupta, “Data communications”, Prentice Hall India Pvt.
2. William Stallings, "Data and Computer Communications”, Pearson
3. Forouzan, B. A. "Data Communication and Networking. Tata McGraw." (2005).