Bandwidth Utilization (Part 2)

Course Code: **COE 3201** Course Title: **Data Communication**

Dept. of Computer Engineering
Faculty of Engineering

Lecture No:	**10**	**Week No:**	**11**	**Semester:**	
Lecturer:					

Lecture Outline

1. Interleaving
2. Data rate management
3. Digital Hierarchy
4. T-lines & E-Lines

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.

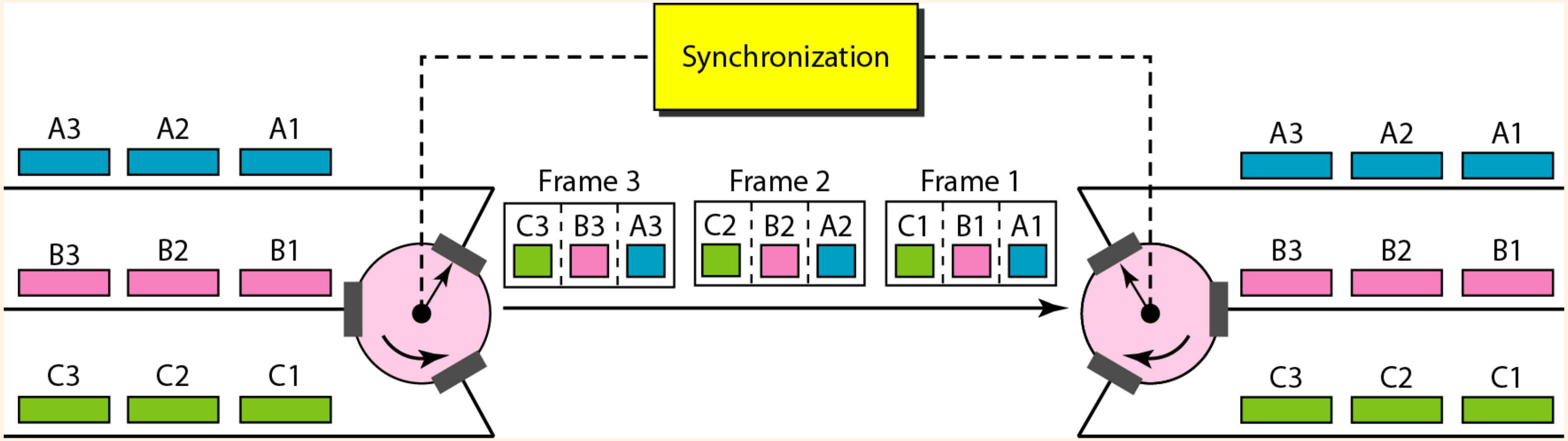


Fig. 17: Interleaving

TDM

- <u>Example 8: </u>**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.***

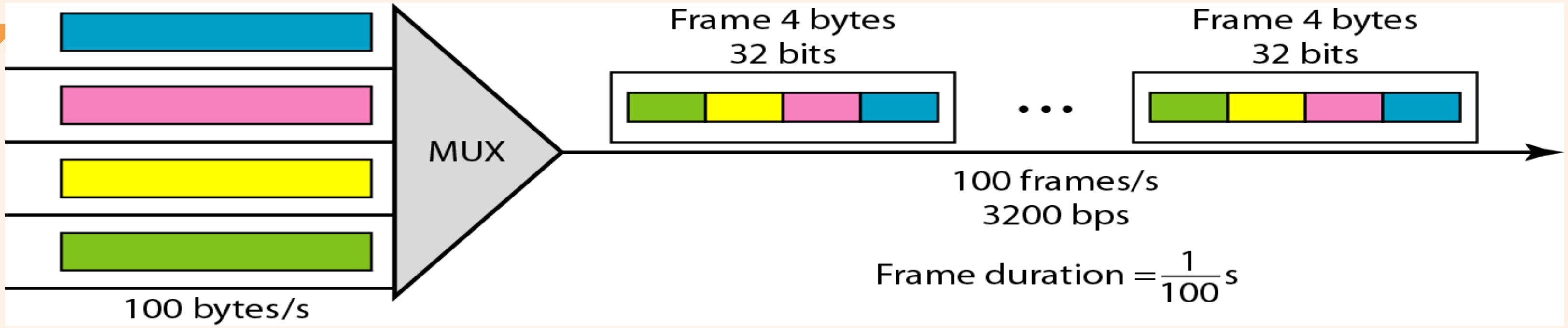


Fig. 18: Example 8.

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.***

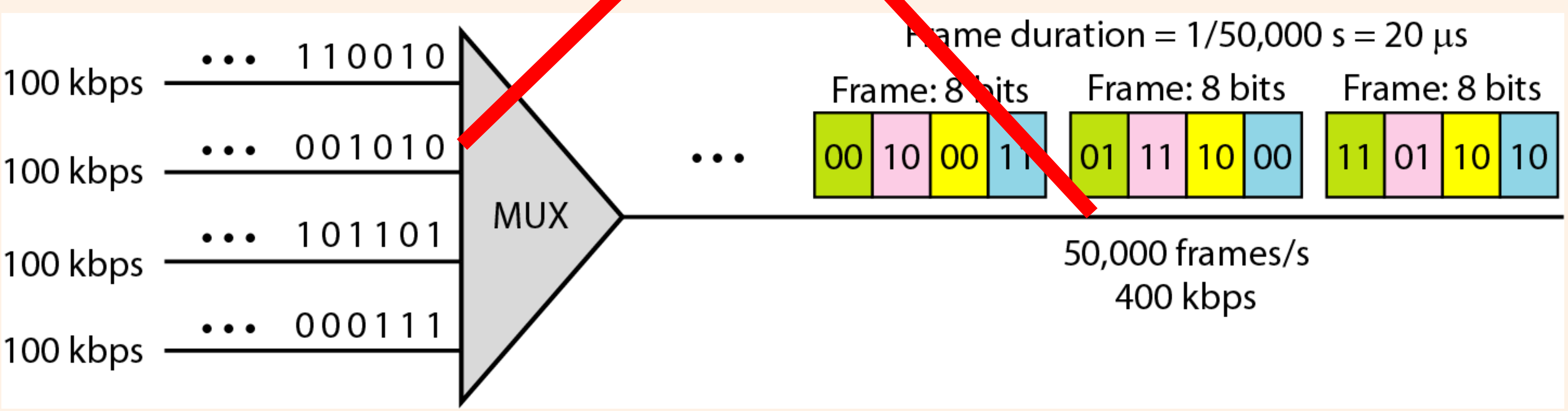
TDM

Example 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.

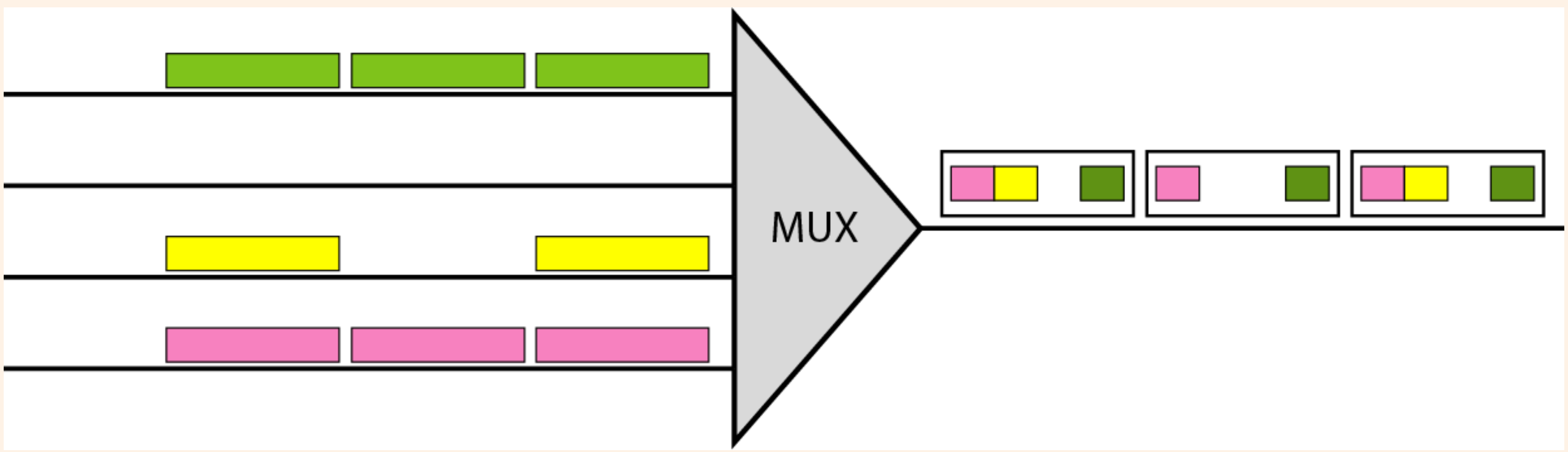


Fig. 20: Empty Slots.

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

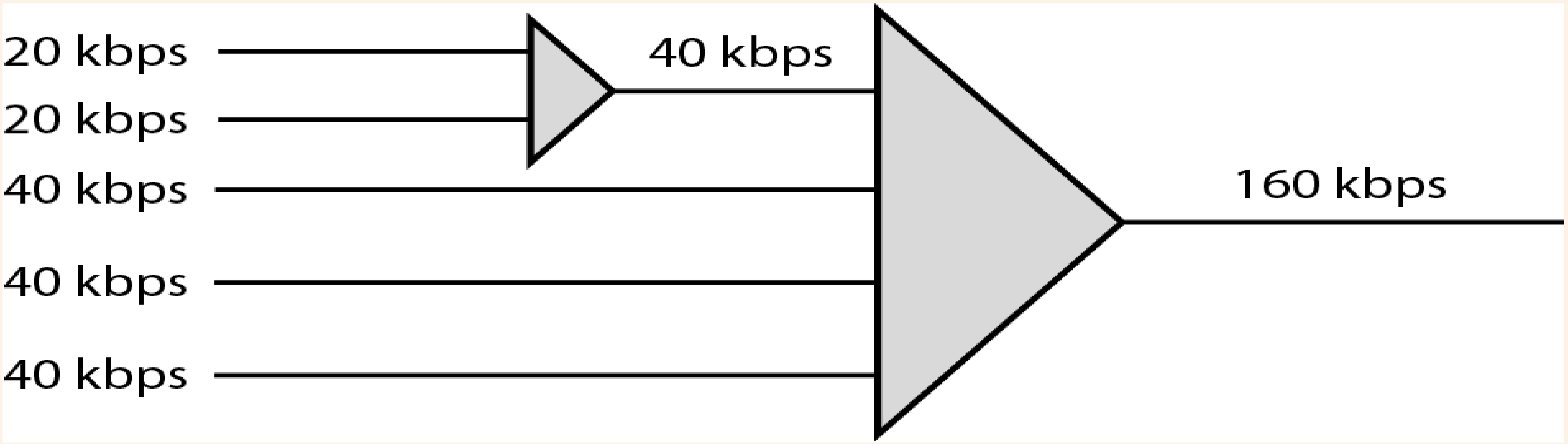


Fig. 21: Multilevel Multiplexing.

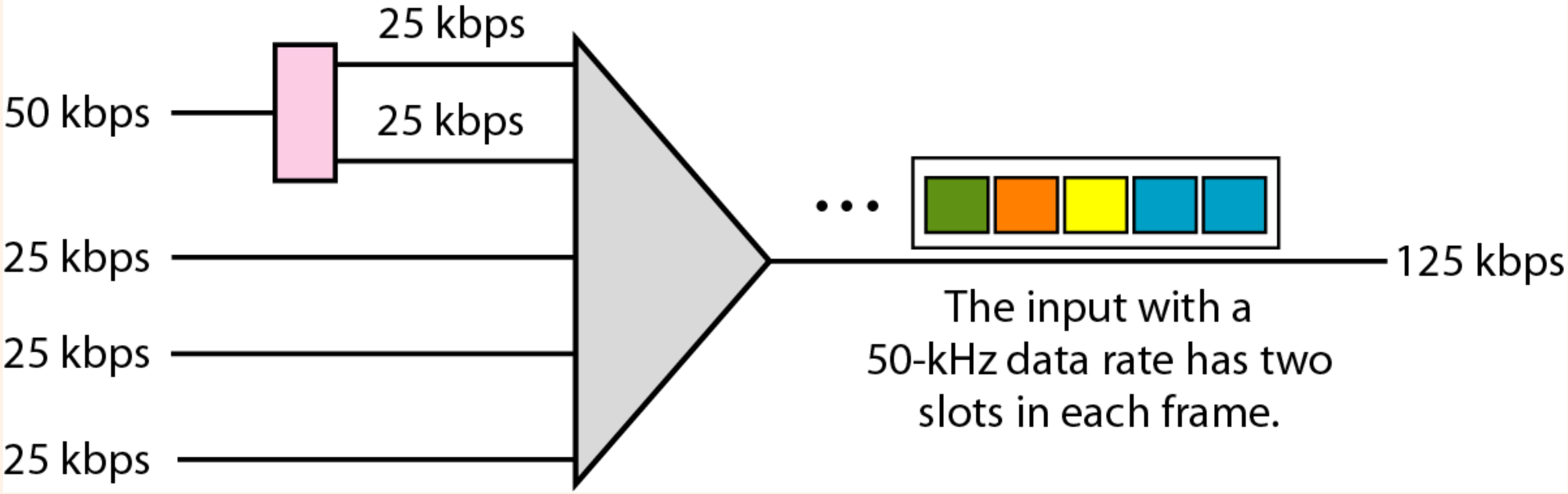


Fig. 22: Multislot Multiplexing.

Data Rate Management

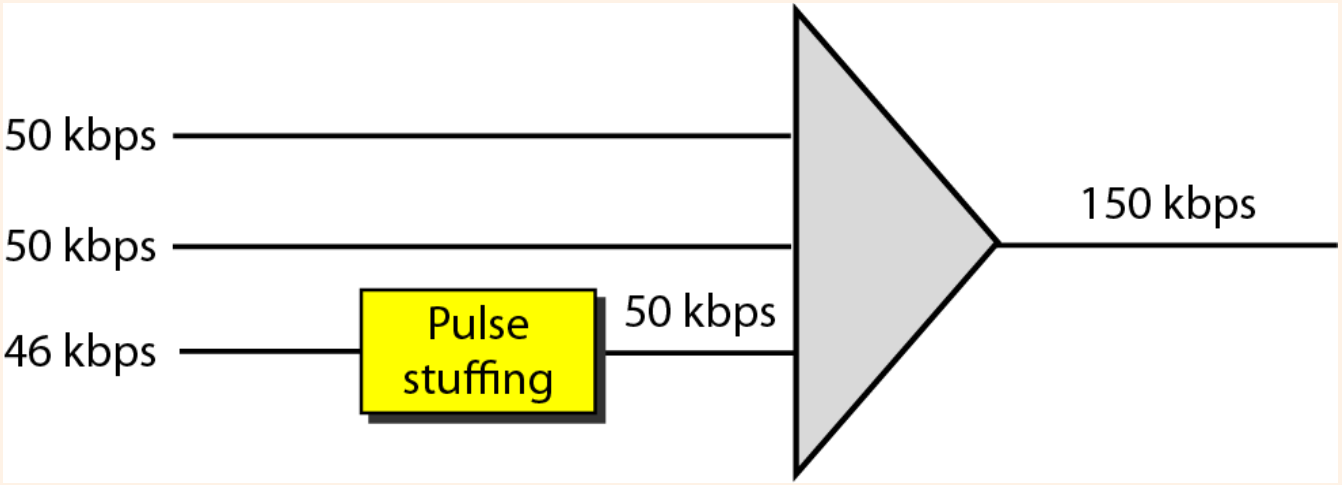


Fig. 23: Pulse stuffing

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.***

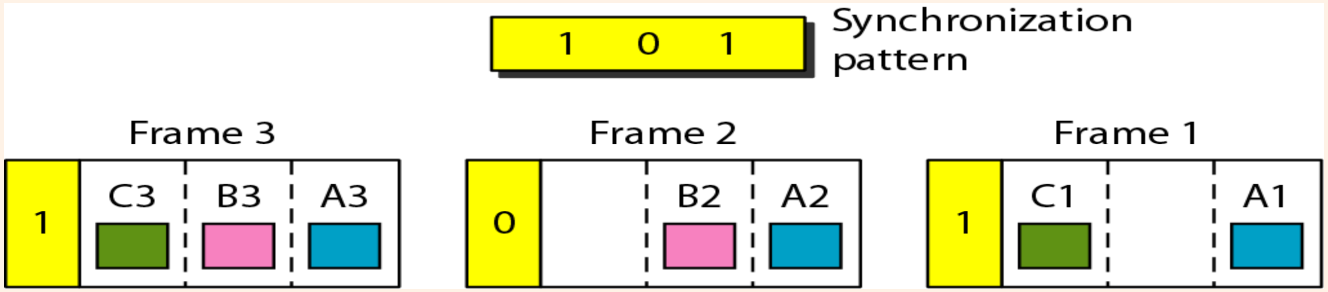


Fig. 24: Multislot Multiplexing.

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.

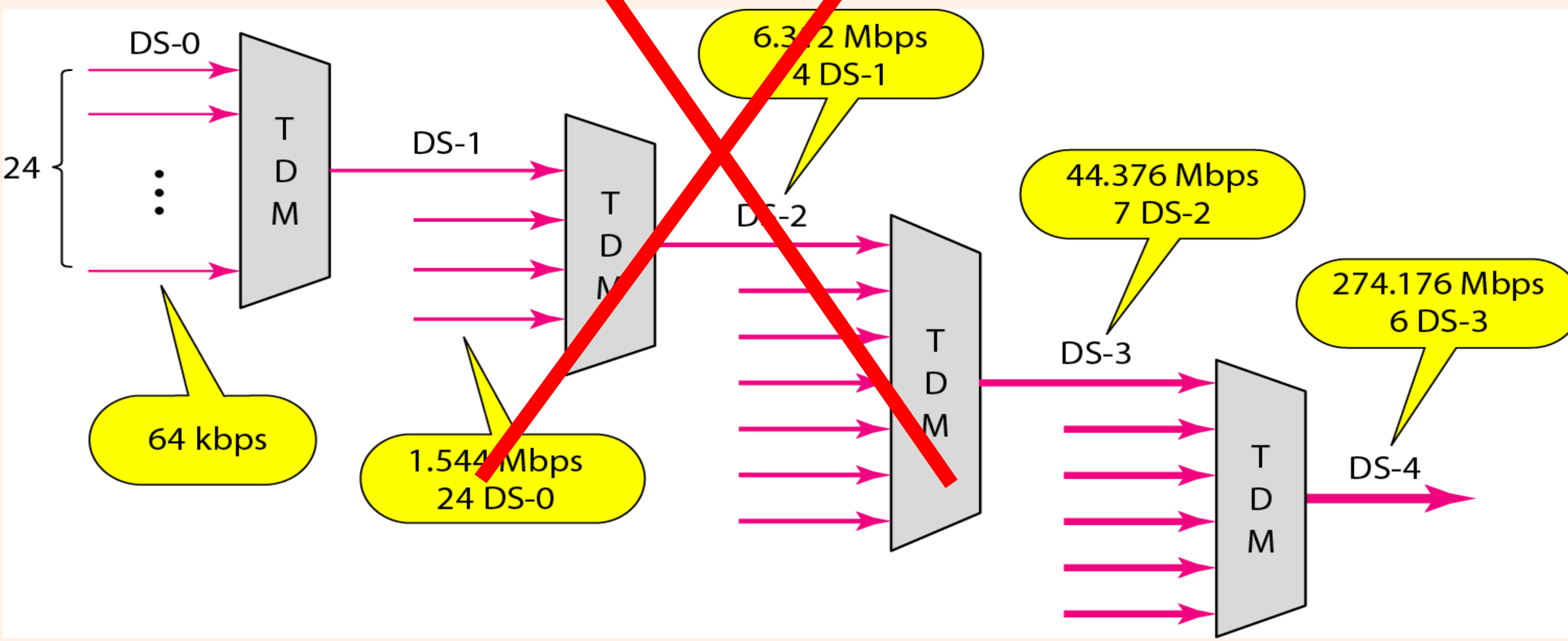


Fig. 25: Digital Hierarchy.

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.**

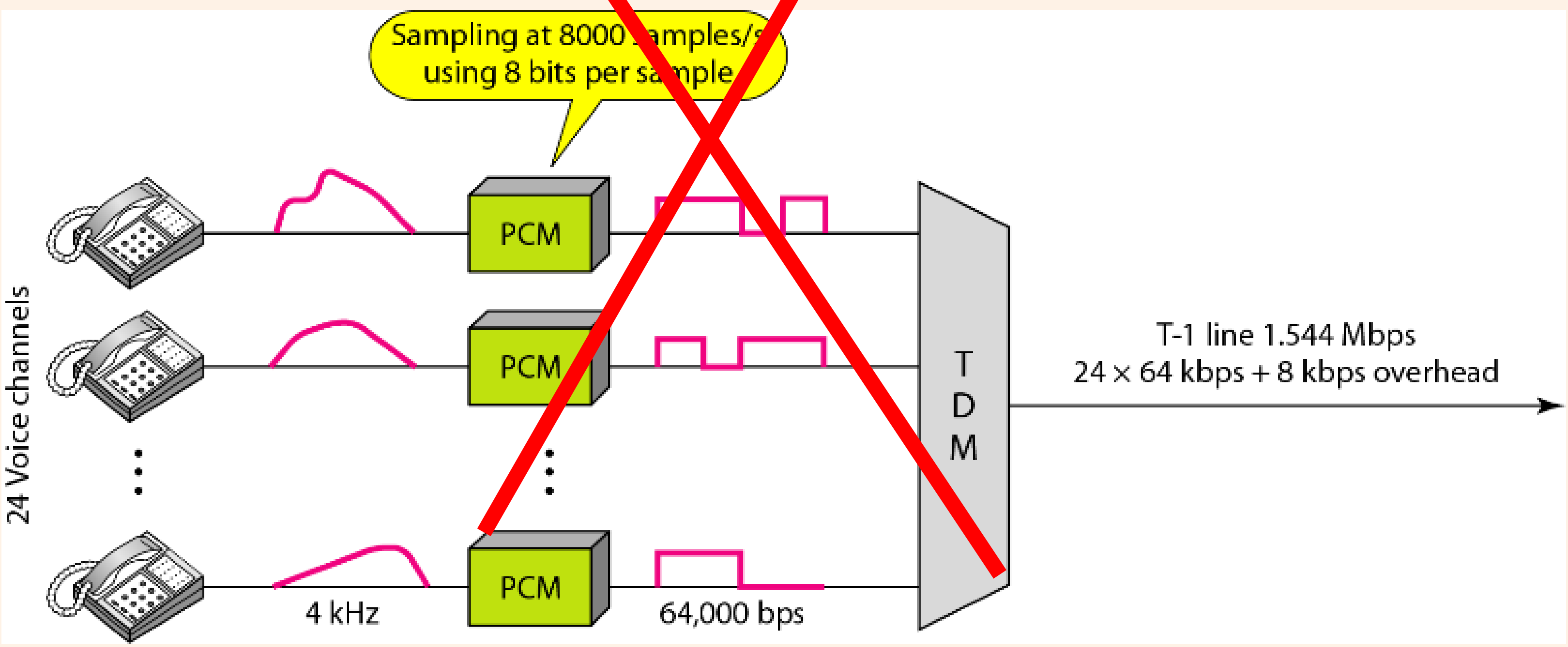


Fig. 26: T-1 line for multiplexing telephone lines.

T-1 frame structure

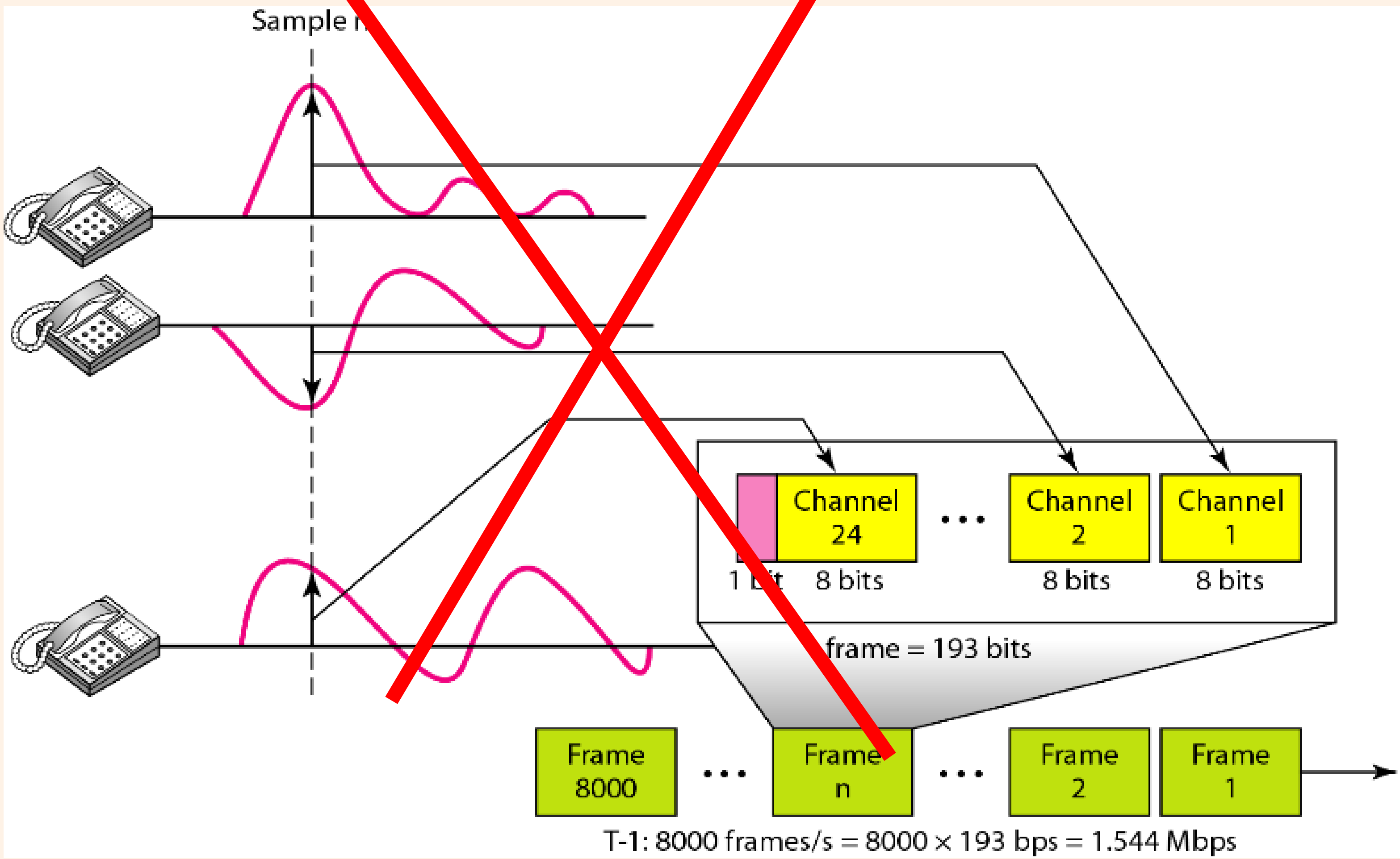


Fig. 27: T-1 Frame Structure.

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

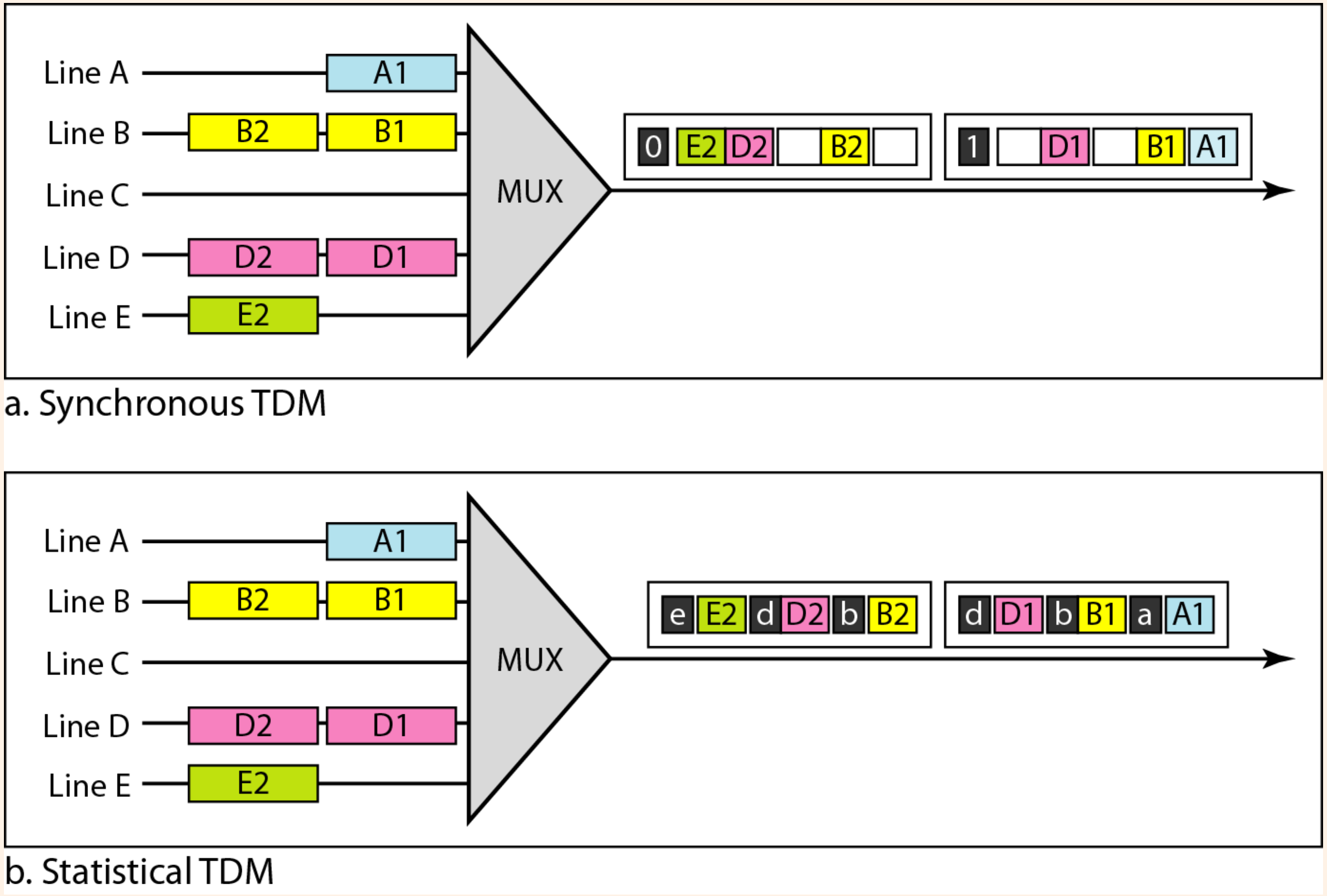


Fig. 28: TDM slot comparison.