Communications Technology

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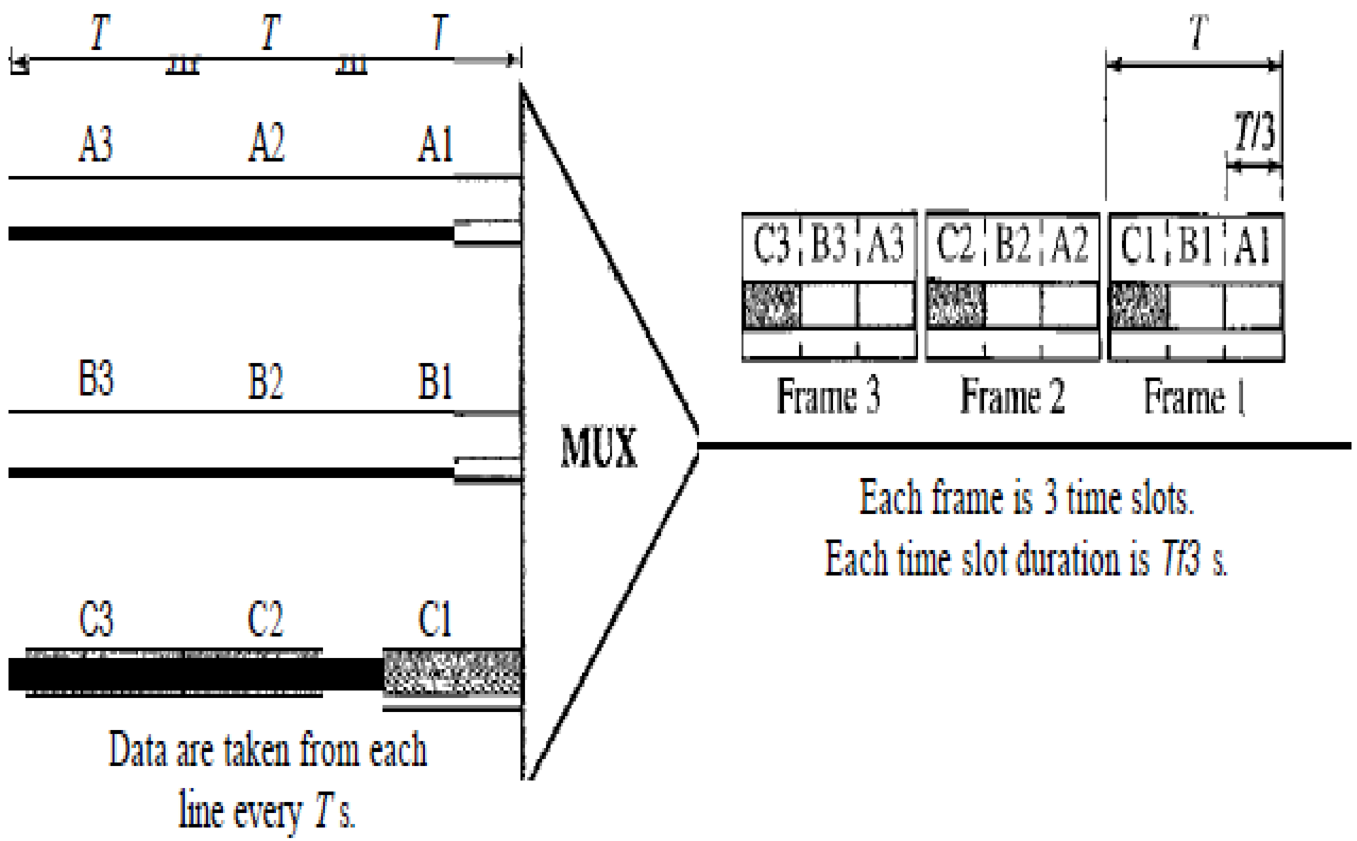
Chapter 1

Introduction

Synchronous Time-Division Multiplexing

Synchronous time-division multiplexing



Input unit duration = T

Output unit duration = T/n, (n input connection)

Frame duration= Input unit duration (T)

Frame rate= Input rate

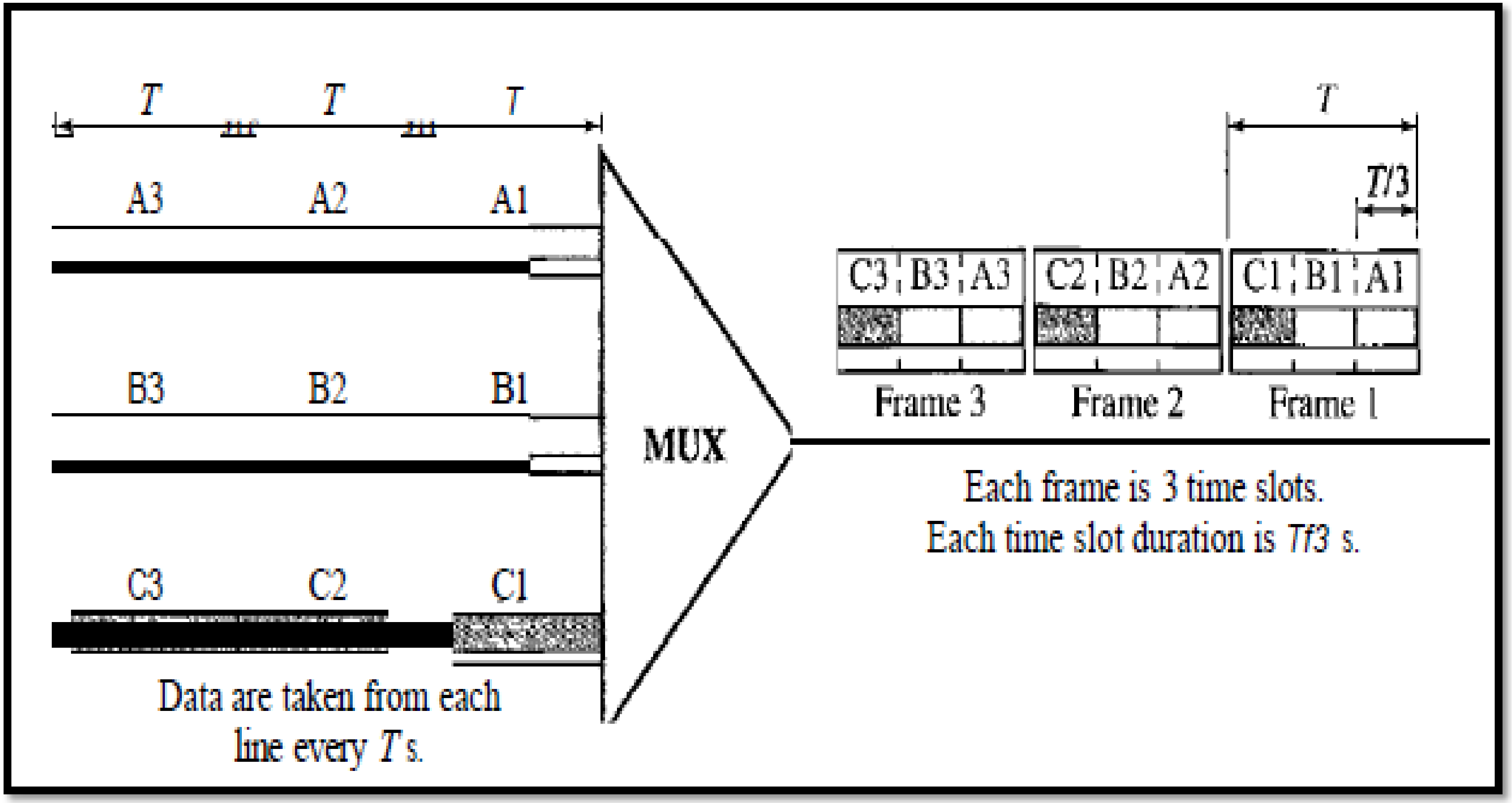
Date rate= 1/ unit duration

Unit Duration = 1/ date rate

Bit rate= Output rate = Frame rate x Frame size

Example 1

The data rate for each input connection is 1 kbps. Number of connection is 3. 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?



T
T
T
A3
A2
A1
B3
B2
B1
C3
C2
C1
Data are taken from each
line every T s.
MUX
T
T/3
C3 B3 A3
C2 B2 A2
C1 B1 A1
Frame 3
Frame 2
Frame 1
Each frame is 3 time slots.
Each time slot duration is T/3 s.

V

Input unit duration $= 1/$ input data rate

$= 1/\ 10^3 = 10^{-3}$ s $=$ 1 ms

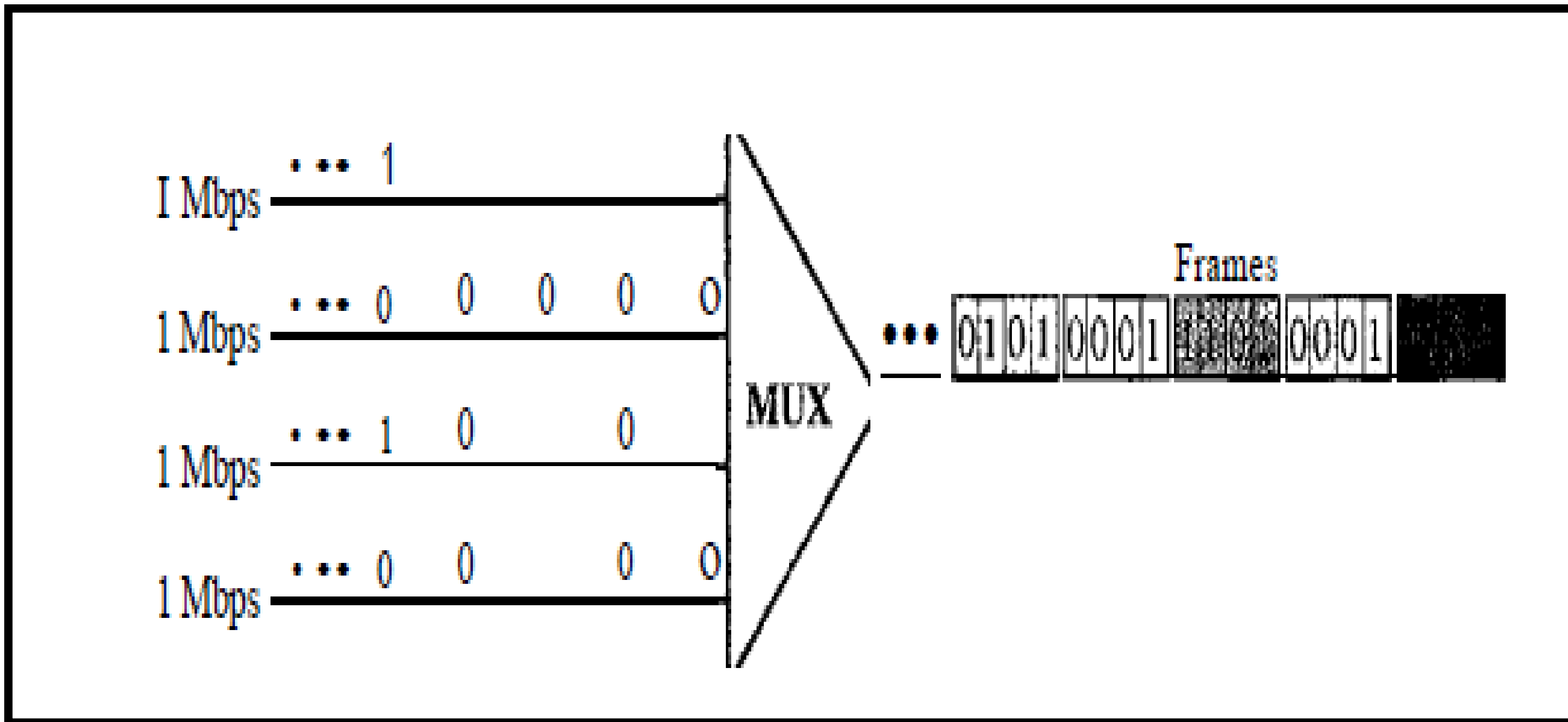
Output unit duration $= T/n = 1/3$ ms

Frame duration $= T =$ 1 ms

∧

Example 2

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.


1 Mbps
1 Mbps
1 Mbps
1 Mbps
MUX
Frames
0101
0001
0001

Input unit duration = 1/ input data rate

=1Mbps=1/ 10^6 = 10^{-6} s = 1 µs

Output unit duration = T/n = 1/4 µs

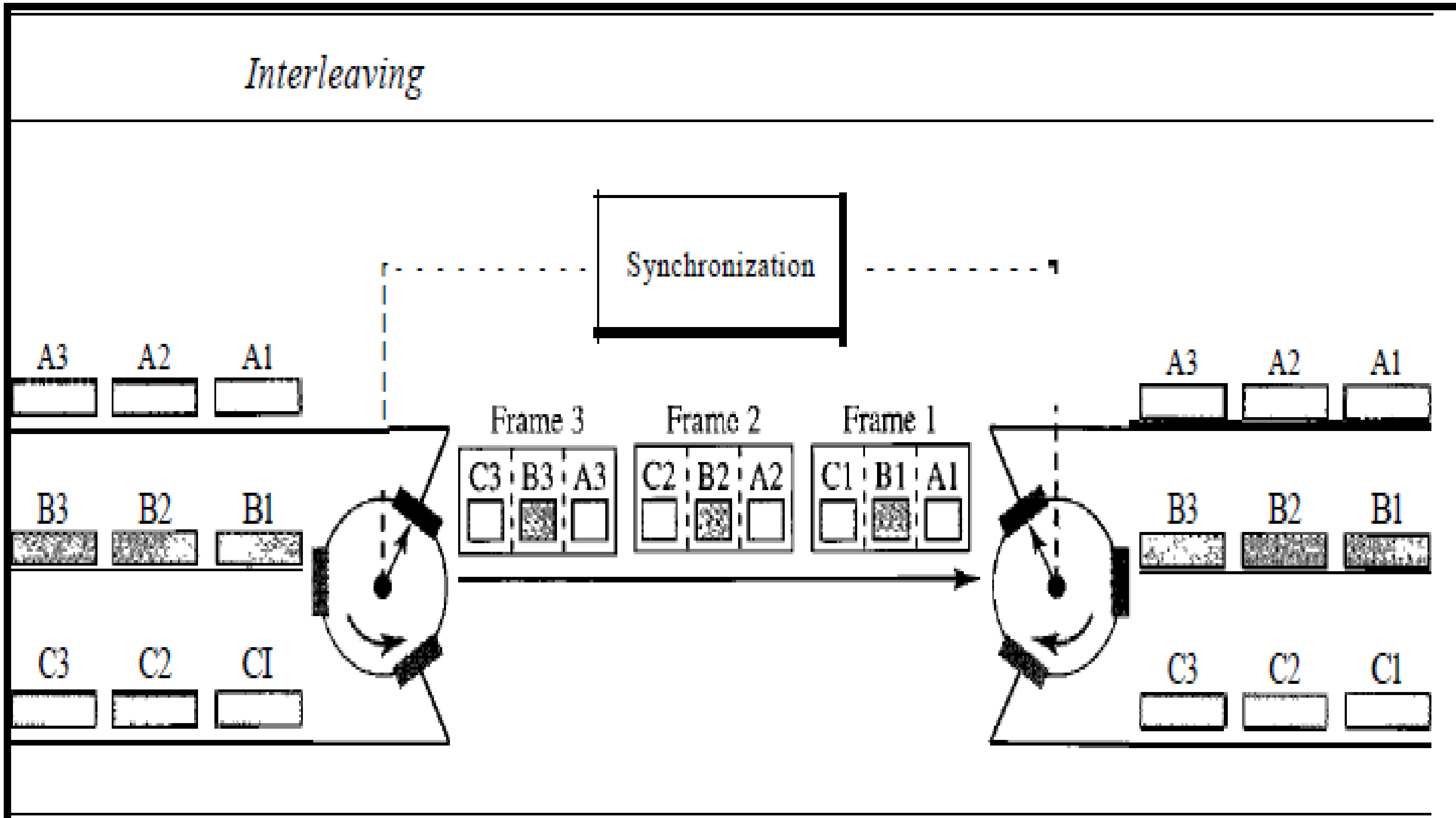
Output date rate = 1/ output unit duration

= 4Mbps

Frame rate = input rate = 1 Mbps

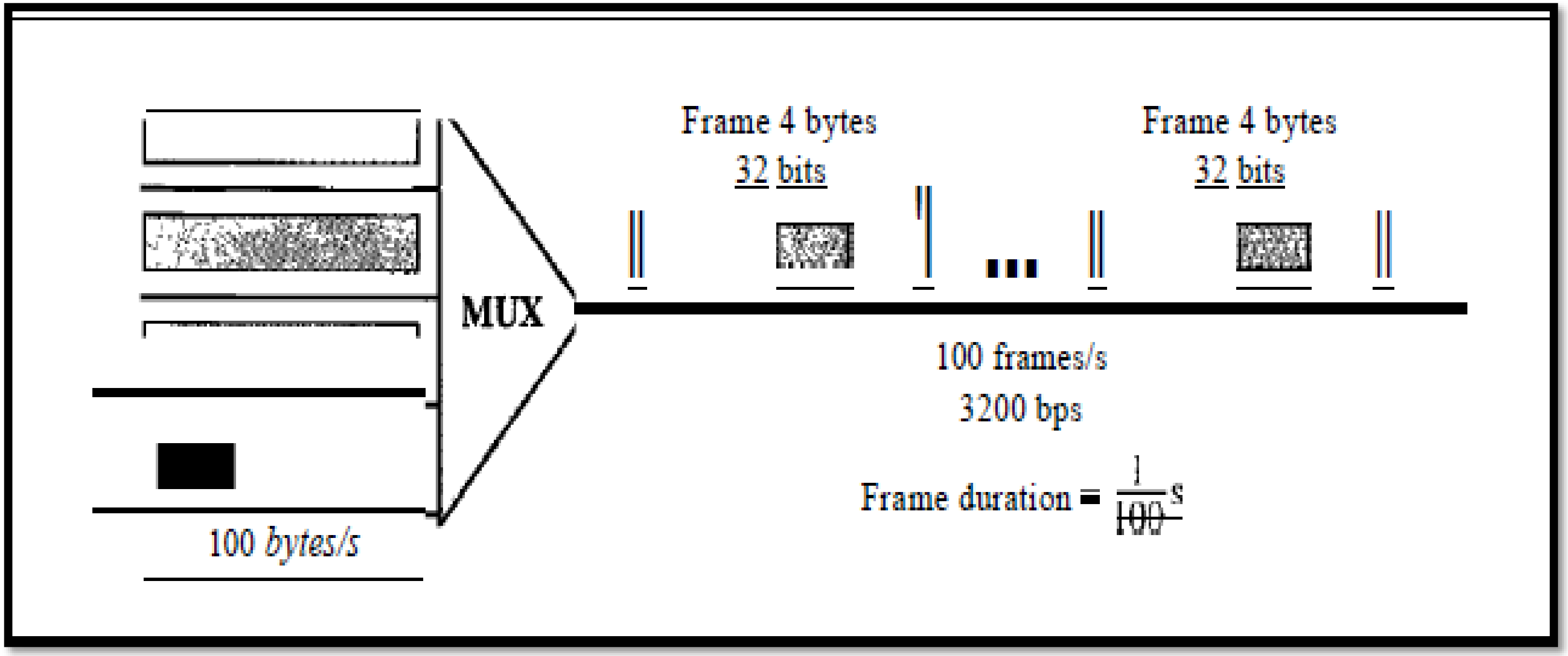
TDM can be visualized as two fast-rotating switches, one on the multiplexing side and the other on the demultiplexing side. The switches are synchronized and rotate at the same speed, but in opposite directions. On the multiplexing side, as the switch opens in front of a connection, that connection has 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. We assume that no switching is involved and that the data from the first connection at the multiplexer site go to the first connection at the demultiplexer.


Interleaving
Synchronization
A3
A2
A1
B3
B2
B1
C3
C2
CI
Frame 3
Frame 2
Frame 1
C3
B3
A3
C2
B2
A2
C1
B1
A1
A3
A2
A1
B3
B2
B1
C3
C2
C1

Example 3

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.



MUX
Frame 4 bytes
32 bits
Frame 4 bytes
32 bits
100 frames/s
3200 bps
Frame duration = 1/100 s
100 bytes/s

Each frame carries 1 byte from each channel; **the size of each frame**, therefore, is 4 bytes, or 32 bits.

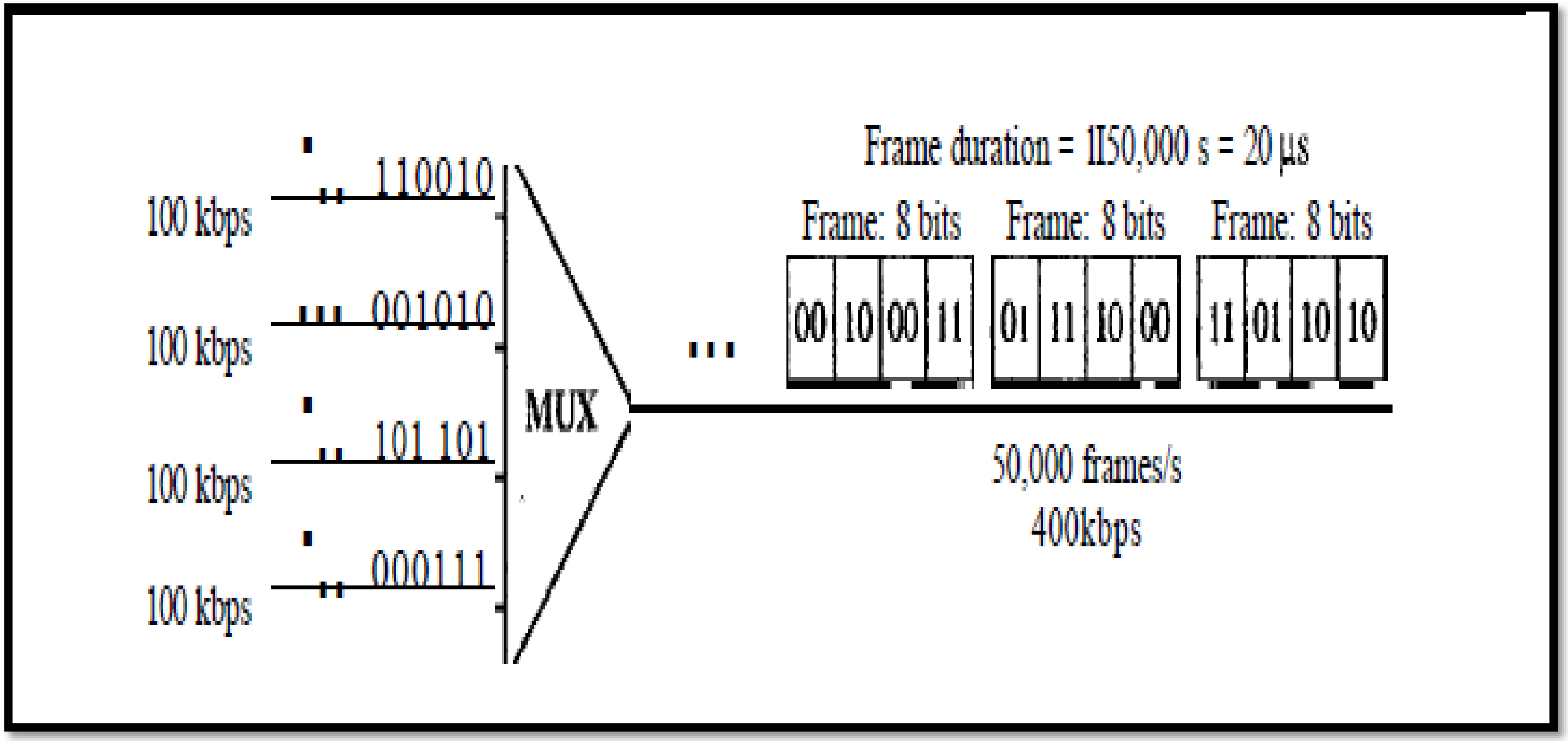
Because each channel is sending 100 bytes/s and a frame carries 1 byte from each channel, **the frame rate** must be 100 frames per second.

The **duration of a frame** is therefore 1/100 s.

The link is carrying 100 frames per second, and since each frame contains 32 bits, **the bit rate** is 100 x 32, or 3200 bps. This is actually 4 times the bit rate of each channel, which is 100 x 8 =800 bps.

Example 4

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?



Frame duration = 1/50,000 s = 20 µs
100 kbps
110010
100 kbps
001010
100 kbps
101 101
100 kbps
000111
MUX
...
Frame: 8 bits
Frame: 8 bits
Frame: 8 bits
00
10
00
11
01
11
10
00
11
01
10
10
50,000 frames/s
400kbps

The output for four arbitrary inputs. The link carries 50,000 frames per second since each frame contains 2 bits per channel.

The frame duration is therefore 1/50,000 s or 20 μs.

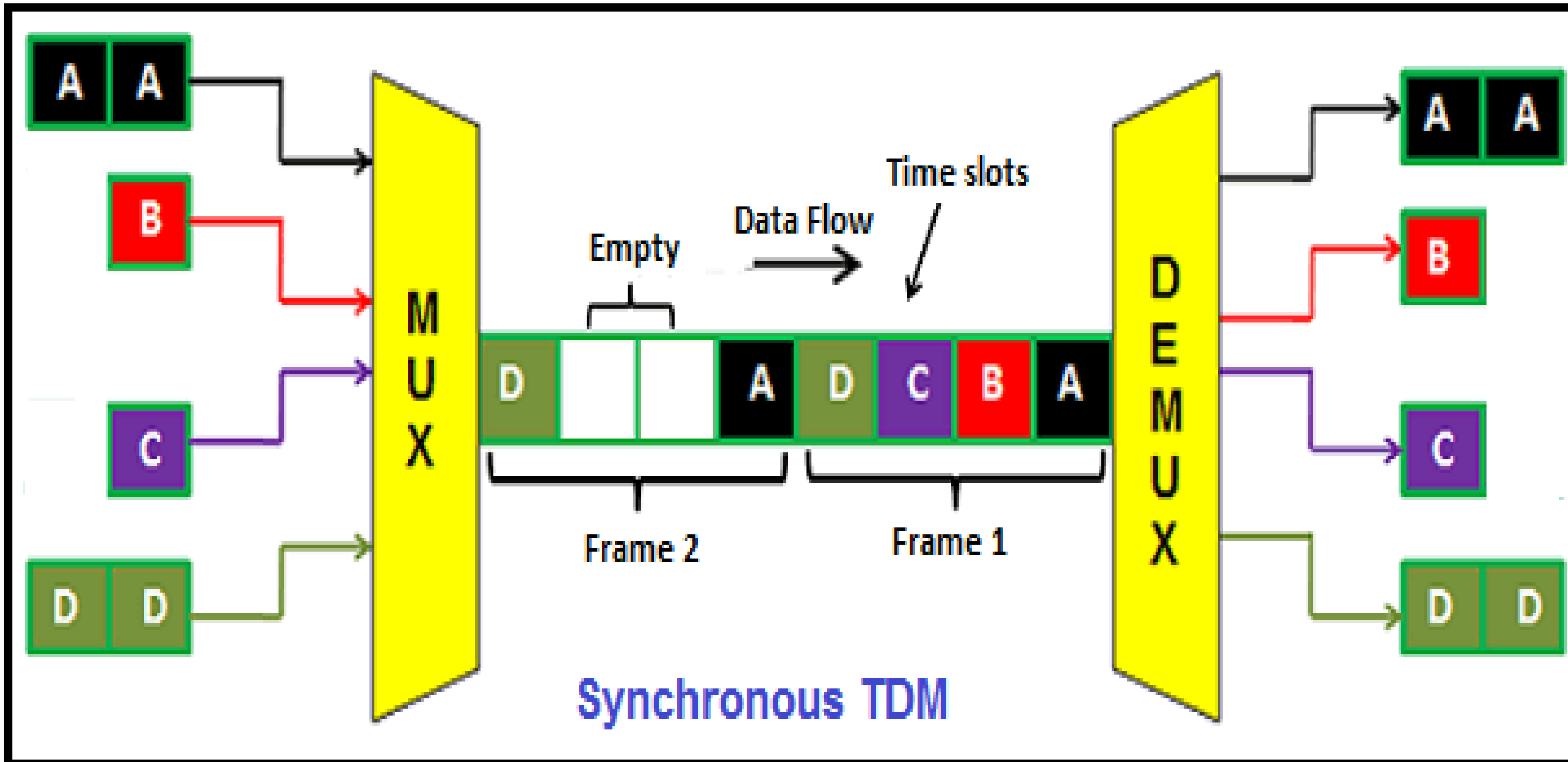
The frame rate is 50,000 frames per second, and each frame carries 8 bits;

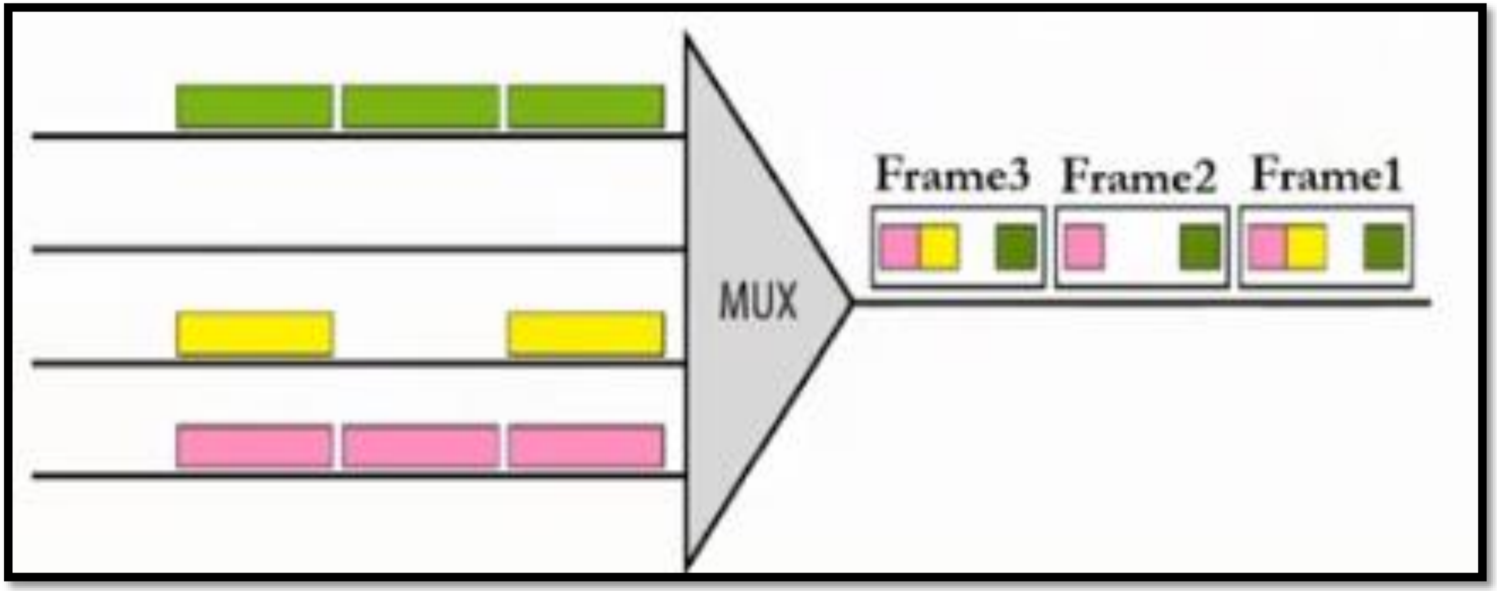
the bit rate is 50,000 x 8 =400,000 bits or 400 kbps.

The bit duration is 1/400,000 s, or 2.5 μs.

Note that the frame duration is 8 times the bit duration because each frame is carrying 8 bits.

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. The first output frame has three slots filled, the second frame has two slots filled, and the third frame has three slots filled. No frame is full. Statistical TDM can improve the efficiency by removing the empty slots from the frame.

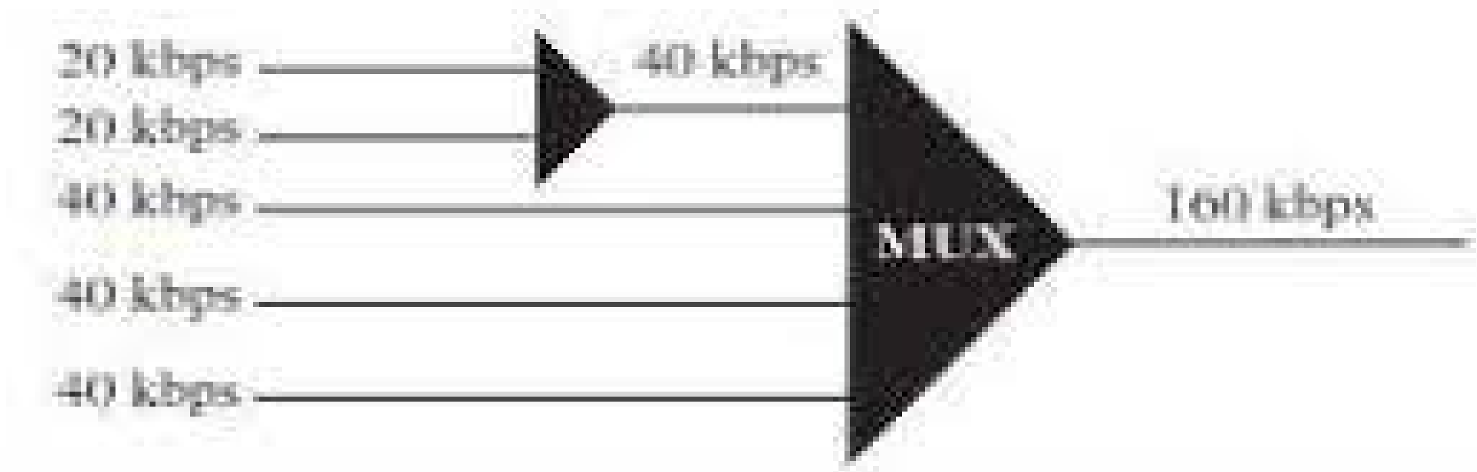

A A
B
C
D D
MUX
Empty
Data Flow
Time slots
D A D C B A
Frame 2
Frame 1
DEMUX
A A
B
C
D D
Synchronous TDM


MUX
Frame3
Frame2
Frame1

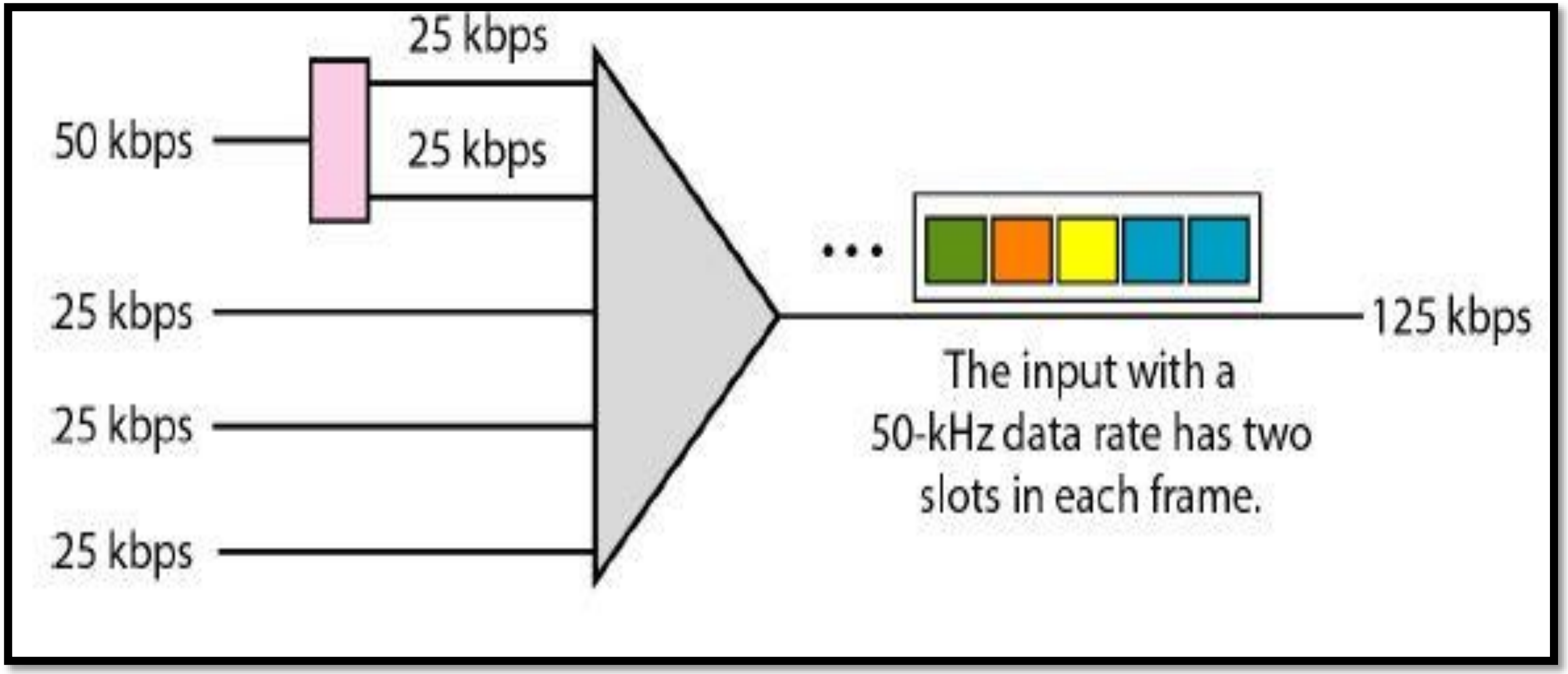
Data Rate Management: One problem with TDM is how to handle a disparity in the input data rates. In all our discussion so far, we assumed that the data rates of all input lines were the same. However, if data rates are not the same, three strategies, or a combination of them, can be used. We call these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

1- Multilevel Multiplexing: Multilevel multiplexing is a technique used when the data rate of an input line is a multiple of others. For example, 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.

Multilevel multiplexing

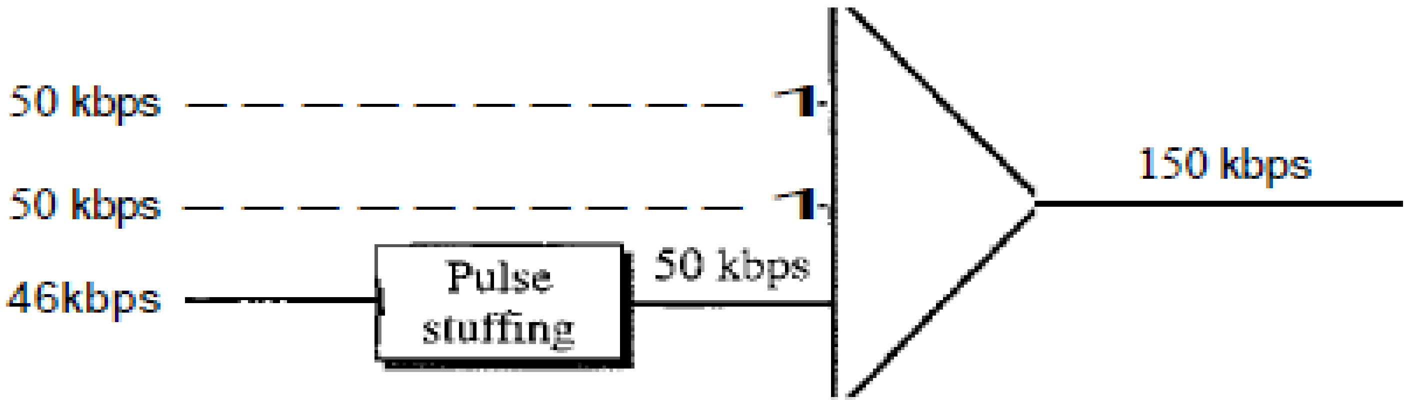


2- Multiple-Slot Allocation Sometimes it is more efficient to allot more than one slot in a frame to a single input line. For example, we might have an input line that has a data rate that is a multiple of another input. The input line with a 50-kbps data rate can be given two slots in the output. We insert a serial-to-parallel converter in the line to make two inputs out of one.


25 kbps
50 kbps
25 kbps
25 kbps
25 kbps
25 kbps
• • •
125 kbps
The input with a
50-kHz data rate has two
slots in each frame.

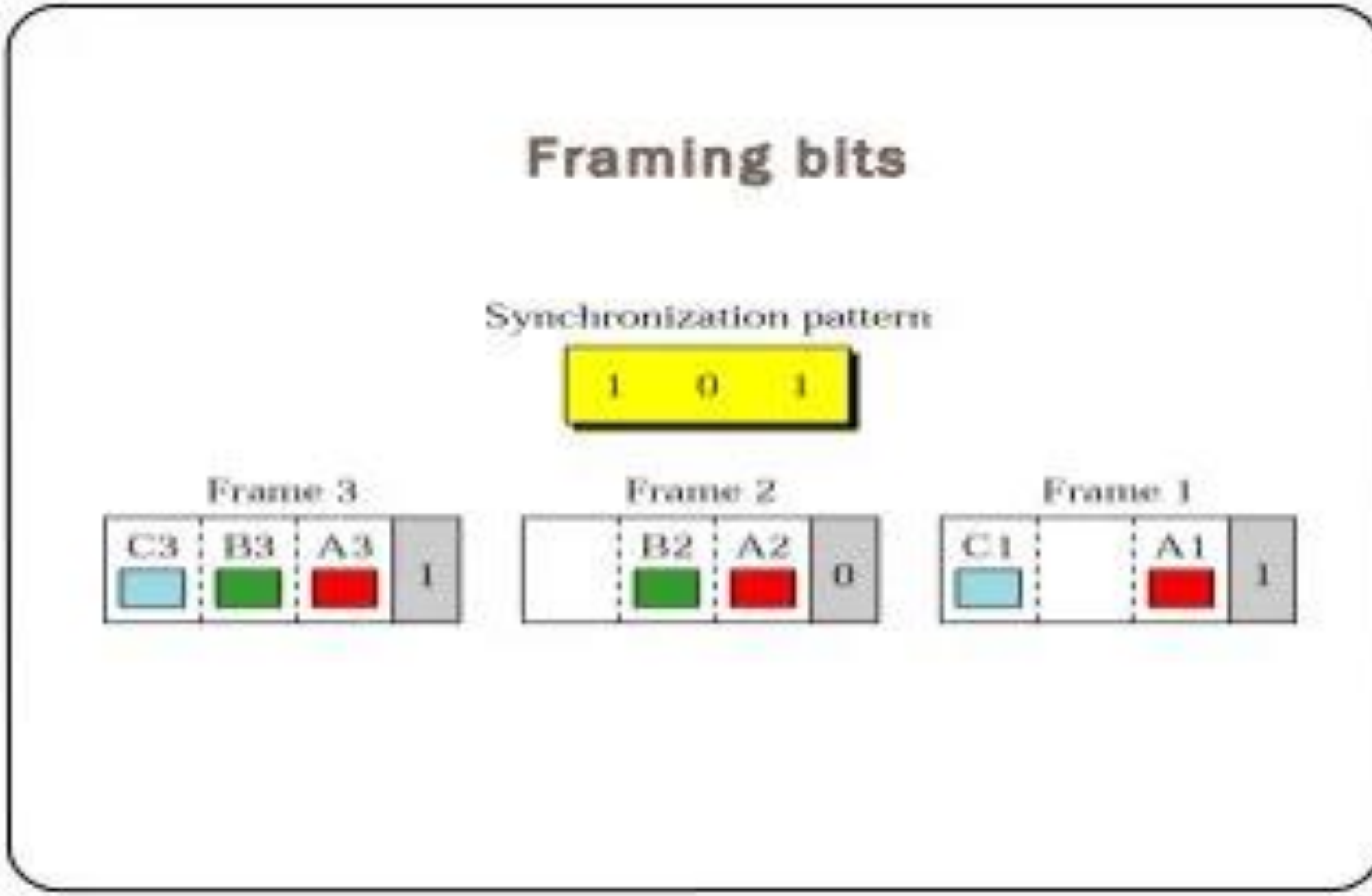
3- Pulse Stuffing: Sometimes the bit rates of sources are not multiple integers of each other. Therefore, neither of the above two techniques can be applied. One solution is to make the highest input data rate the dominant data rate and then add dummy bits to the input lines with lower rates. This will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

Pulse stuffing



Frame Synchronizing: The implementation of TDM is not as simple as that of FDM. 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.


Framing bits
Synchronization pattern
1 0 1
Frame 3
C3
B3
A3
1
Frame 2
B2
A2
0
Frame 1
C1
A1
1

Example 5

We have four sources, each creating 250 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.

We can answer the questions as follows:

a. The **data rate of each source** is 250 x 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 x 8 + 1 =33 bits.

f. The link sends 250 frames per second, and each frame contains 33 bits. This means that the **data rate of the link** is 250 x 33, or 8250 bps.

Note that the bit rate of the link is greater than the combined bit rates of the four channels. If we add the bit rates of four channels, we get 8000 bps. Because 250 frames are traveling per second and each contains 1 extra bit for synchronizing, we need to add 250 to the sum to get 8250 bps.

Example 6

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?

We can allocate one slot to the first channel and two slots to the second channel.

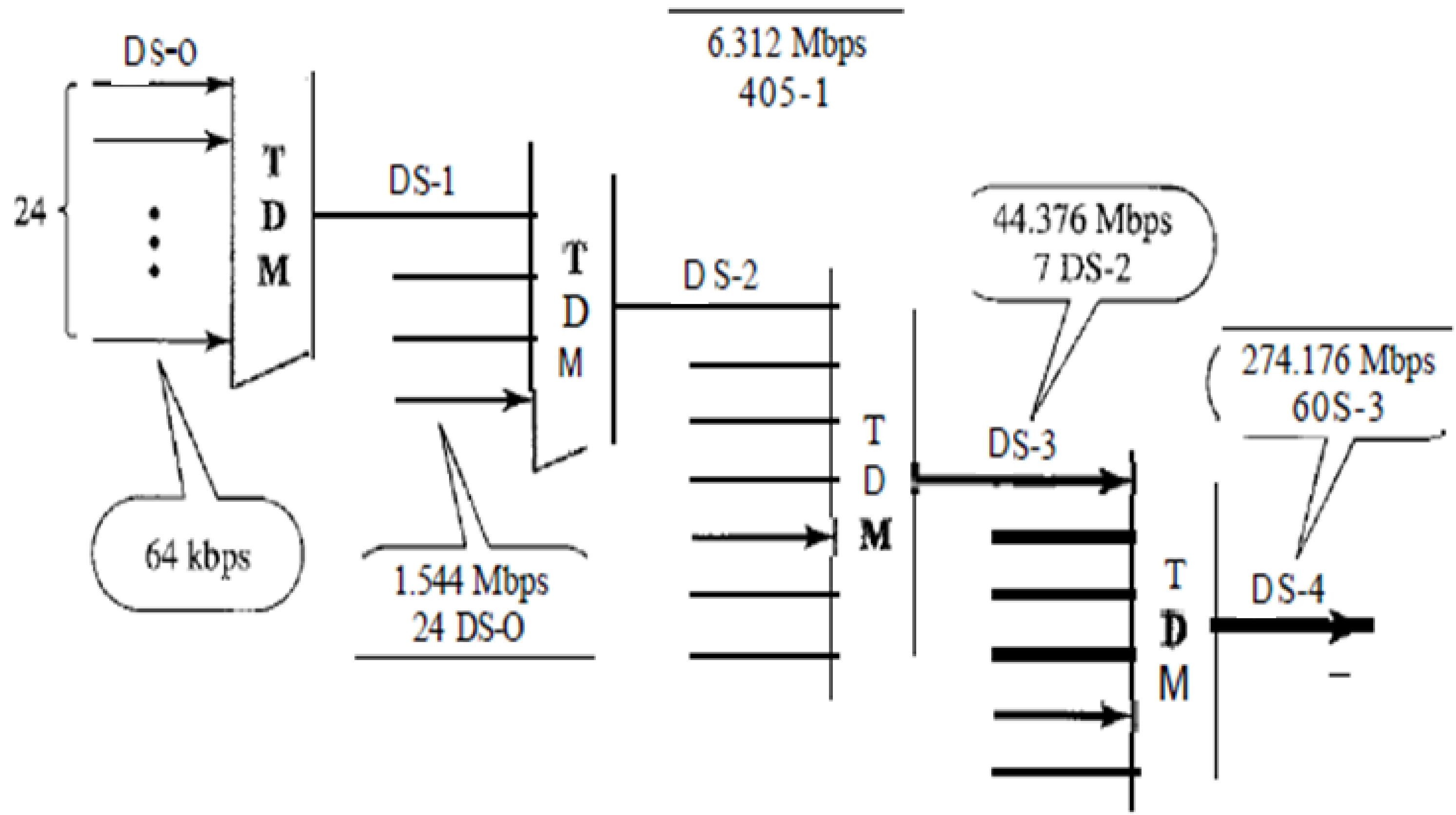
Each frame carries 3 bits. The **frame rate** is 100,000 frames per second because it carries 1 bit from the first channel.

The **frame duration** is 1/100,000 s, or 10 ms.

The **bit rate** is 100,000 frames/s x 3 bits per frame, or 300 kbps. Note that because each frame carries 1 bit from the first channel, the bit rate for the first channel is preserved. The bit rate for the second channel is also preserved because each frame carries 2 bits from the second channel.

Digital Signal Service: Telephone companies implement TDM through a hierarchy of digital signals, called digital signal **(DS)** service or digital hierarchy. The data rates supported by each level.

Digital hierarchy



- **A DS-0** 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-0 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-0 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-0 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-0, 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.

DS and T line rates

Sen/ice	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

The T-l line is used to implement DS-l; T-2 is used to implement DS-2; and so on. **DS-0 is not actually offered as a service**, but it has been defined as **a basis for reference purposes**.