CHAPTER 6
Bandwidth Utilization

Review Questions

1. Describe the goals of multiplexing.

Ans: Multiplexing is a term used to refer to a process where multiple analog message signals or digital data streams are combined into one signal over a shared medium. The aim is to share an expensive resource. Multiplexing is provided by the Physical Layer of the OSI model, while multiple access also involves a media access control protocol, which is part of the Data Link Layer.

2. List three main multiplexing techniques mentioned in this chapter.

Ans: In chapter six, three multiplexing techniques mentioned. Such as:

i. Frequency-division multiplexing (FDM)
ii. Wavelength-division multiplexing (WDM)
iii. Time-division multiplexing (TDM)

3. Distinguish between a link and a channel in multiplexing.

Ans: In multiplexed system n-lines (channels) share bandwidth of one link. That means, link refers to the physical path and channel refers to the portion of a link that carries a transmission between a given pair of lines.

4. Which of the three multiplexing techniques is (are) used to combine analog signals? Which of the three multiplexing techniques is (are) used to combine digital signals?

Ans: The Wave division multiplexing and the Frequency division multiplexing are used to combine analog signals. The Time division multiplexing is used to combine digital signals.

5. Define the analog hierarchy used by telephone companies and list different levels of the hierarchy.

Ans: Telephone companies have multiplexing analog signal from low-bandwidth to high-bandwidth line. The analog hierarchy uses voice channels (4 KHz), groups (48 KHz), super-groups (240 KHz), master groups (2.4 MHz), and jumbo groups (15.12 MHz).

6. Define the digital hierarchy used by telephone companies and list different levels of the hierarchy.

Ans: Telephone companies have multiplexing digital signal from low rate data tohigh-bandwidth line. The digital hierarchy uses DS-0 (64 Kbps),DS-1 (1.544 Mbps), DS-2 (6.312 Mbps), DS-3 (44.376 Mbps) and DS-4 (274.176 Mbps).

7. Which of the three multiplexing techniques is common for fiber optic links? Explain the reason.

Ans: Wavelength-division multiplexing (WDM) is common for fiber optic links because it allows the multiplexing of signals with a very high frequency. Optic fiber data rate is higher than metallic transmission cable.

8. Distinguish between multilevel TDM, multiple slot TDM, and pulse-stuffed TDM.

Ans:

Multilevel TDM	Multiple slot TDM	Pulse-stuffed TDM
Multilevel TDM is used when the data rate of an input line is a multiple of others	Multi slot TMD is used when many slot in a frame produce 1 singleline.	Pulse-stuffed TMD is used when bit rate sort are not multiple. So we add dummy to make it the same.
make it lower	make it higher	make it equal

9. Distinguish between synchronous and statistical TDM.

Ans:

Parameter	Synchronous TDM	Statistical TDM
Working	In Synchronous TDM data flow of each input connection is divided into units and each input occupies one output time slot	In Statistical TDM slots are allotted dynamically. i.e. input line is given slots in output frame if and only if it has data to send.
No. of Slots	In Synchronous TDM number of slots in each frame are equal to number of input lines.	In Statistical TDM, Number of slots in each frame are less than the number of input lines.
Synchronization	Synchronization bits are used at the beginning of each frame.	No synchronization bits are used
Capacity	Max. Bandwidth utilization if all inputs have data to send.	The capacity of link is normally is less than the sum of the capacity of each channel.
Buffers	Buffering is not done, frame is sent after a particular interval of time whether someone has data to send or not.	Buffering is done and only those inputs are given slots in output frame whose buffer contains data to send.

10. Define spread spectrum and its goal. List the two spread spectrum techniques discussed in this chapter.

Ans: Spread spectrum is when multiplexing combined signal from several sourceachieve bandwidth efficiency. Spectrums are design to used in wireless application. Two spectrum techniques are FHSS and DDSS.

11. Define FHSS and explain how it achieves bandwidth spreading.

Ans: The frequency hopping spread spectrum (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 signalmodulates another carrier frequency.

12. Define DSSS and explain how it achieves bandwidth spreading.

Ans: The direct sequence spread spectrum (DSSS) technique expands the bandwidth of the original signal. It replaces each data bit within bits using a spreading code.

Exercises

13. Assume that a voice channel occupies a bandwidth of 4 kHz. We need to multiplex 10 voice channels with guard bands of 500 Hz using FDM. Calculate the required bandwidth.

Ans: Given, Channel Bandwidth = 4 KHz
Number of Channel = 10
Guard bands = 500 Hz = 0.5 KHz

To multiplex 10 voice channels, we need 9 guard bands.

.'. required bandwidth, B = 4×10 + 0.5×9 = 44.5 KHz

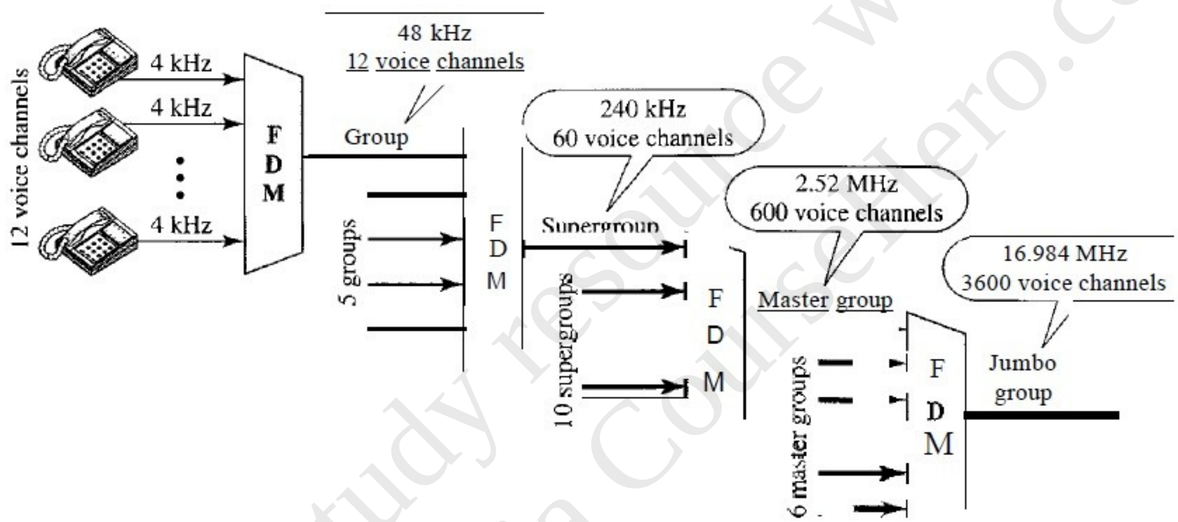
14. We need to transmit 100 digitized voice channels using a pass-band channel of 20 KHz. What should be the ratio of bits/Hz if we use no guard band?

Ans: Here, the bandwidth allocated to each voice channel, $B = \frac{20\,KHz}{100}$ = 200 Hz.

We know that, data rate of each digitized voice channel = 64 Kbps.

.'. Modulation technique uses the ratio is, $\frac{64\,K\,bps}{200} = \frac{64000}{200}$ = 320 bits/Hz

15. In the analog hierarchy of below Figure, find the overhead (extra bandwidth for guard band or control) in each hierarchy level (group, supergroup, master group, and jumbo group).



Ans:

a. Group level: Given, Number of channel =12 , Each channel Bandwidth = 4 KHz
Group Level Bandwidth = 48 KHz .'. overhead = 48 − (12 × 4) = 0 Hz.

b. Supergroup level: Given, Number of group =5 , Each group Bandwidth = 48 KHz
Supergroup Level Bandwidth = 240 KHz .'. overhead = 240 − (5 × 48) = 0 Hz.

c. Master group: Here,Number of supergroup =10 , Each supergroup Bandwidth = 240 KHz
Mastergroup Level Bandwidth = 2.52 MHz = 2520 KHz
.'. overhead = 2520 − (10 × 240) = 120 KHz.

d. Jumbo Group: Here,Number of mastergroup=6,Each mastergroup Bandwidth= 2.52 MHz
Mastergroup Level Bandwidth = 16.984 MHz
.'. overhead = 16.984 − (6 × 2.52) = 1.864 MHz

16. We need to use synchronous TDM and combine 20 digital sources, each of 100 Kbps. Each output slot carries 1 bit from each digital source, but one extra bit is added to each frame for synchronization. Answer the following questions:
a. What is the size of an output frame in bits?
b. What is the output frame rate?
c. What is the duration of an output frame?
d. What is the output data rate?
e. What is the efficiency of the system (ratio of useful bits to the total bits).

Ans:

a. Number of digital Source = 20 output slot carries = 1 bit Synchronizing extra bit = 1
.'. Frame size = 20 × 1 + 1 = 21 bits.
b. Each frame carries 1 bit from each source. Source bandwidth = 100 Kbps = 100000 bps
.'. Frame rate = 100000 frames/s.
c. Frame duration = $\frac{1}{Frame\ rate} = \frac{1}{100000} = 10^{-5}$ s = 10 μs
d. Data rate = frame rate × frame size = 100000 × 21 = 2.1 Mbps
e. In each frame 20 bits out of 21 are useful. .'. Efficiency = $\frac{20}{21} \times 100$ = 95%

17. Repeat Exercise 16 if each output slot carries 2 bits from each source.

Ans:

a. Number of digital Source = 20 output slot carries = 2 bit Synchronizing extra bit = 1
.'. Frame size = 20 × 2 + 1 = 41 bits.
b. Each frame carries 2 bit from each source. Source bandwidth = 100 Kbps = 100000 bps
.'. Frame rate = $\frac{100000}{2}$ = 50000 frames/s
c. Frame duration = $\frac{1}{Frame\ rate} = \frac{1}{50000} = 2 \times 10^{-5}$ s = 20 μs
d. Data rate = frame rate × frame size = 50000 × 41 = 2.05 Mbps
e. In each frame 40 bits out of 41 are useful. .'. Efficiency = $\frac{40}{41} \times 100$ = 97%

18. We have 14 sources, each creating 500 8-bit characters per second. Since only some of these sources are active at any moment, we use statistical TDM to combine these sources using character interleaving. Each frame carries 6 slots at a time, but we need to add four-bit addresses to each slot. Answer the following questions:
a. What is the size of an output frame in bits?
b. What is the output frame rate?
c. What is the duration of an output frame?
d. What is the output data rate?

Ans:

a. Given, per second = 8 bit, add more 4 bit Frame carries = 6 slots
.'. Frame size = 6 × (8 + 4) = 72 bits.

b. Here, number of slot = 6, that means 6 input lines.
   Each frame needs to carry 1character (8 bit) from each of these lines.
   ∴ The frame rate = $\frac{500}{1}$ = 500 frames/s.

c. Frame duration $\frac{1}{frame\,rate}$ = = $\frac{1}{500}$ = 2×10^{-3} s = 2 ms

d. Data rate = frame rate × frame size = 500 × 72 = 36 kbps.

19. Ten sources, six with a bit rate of 200 kbps and four with a bit rate of 400 kbps are to be combined using multilevel TDM with no synchronizing bits. Answer the following questions about the final stage of the multiplexing:
a. What is the size of a frame in bits?
b. What is the frame rate?
c. What is the duration of a frame?
d. What is the data rate?

Ans:

We combine six 200-kbps sources into three 400-kbps. Now we have seven 400-kbps channel.

a. Each output frame carries 1 bit from each of the seven 400-kbps line.
   ∴ Frame size = 7 × 1 = 7 bits.
b. Each frame carries 1 bit from each 400-kbps source.
   ∴ Frame rate = 400000 frames/s.
c. Frame duration = $\frac{1}{frame\,rate}$ = $\frac{1}{400000}$ = 2.5 μs.

d. Output data rate = frame rate × frame size = 400,000 × 7 = 2.8 Mbps..

20. Four channels, two with a bit rate of 200 kbps and two with a bit rate of 150 kbps, are to be multiplexed using multiple slot TDM with no synchronization bits. Answer the following questions:
a. What is the size of a frame in bits?
b. What is the frame rate?
c. What is the duration of a frame?
d. What is the data rate?

Ans:

a. From first two sources frame carries 4 bits
   From second two sources frame carries 3 bits.
   ∴ Frame size = 4 × 2 + 3 × 2 = 14 bits.
b. In first two sources, frame carries 4 bits from each 200-kbps
   In second two sources, frame carries 3 bits from each 150 kbps.
   ∴ Frame rate $\frac{200000}{4}$ = $\frac{150000}{3}$ = 50000 frames/s.

c. Frame duration = $\frac{1}{frame\,rate}$ = $\frac{1}{50000}$ = 20 μs.

d. Output data rate = frame rate × frame size = 50,000 × 14 = 700 kbps.

21. Two channels, one with a bit rate of 190 kbps and another with a bit rate of 180 kbps, are to be multiplexed using pulse stuffing TDM with no synchronization bits. Answer the following questions:
a. What is the size of a frame in bits?
b. What is the frame rate?
c. What is the duration of a frame?
d. What is the data rate?

Ans: Given, first source bit rate = 190 kbps
Second source bit rate = 180 kbps
Now, we add extra bits to the second source to make both rates = 190 kbps.

a. The frame carries 1 bit from each source. Frame size = 1 + 1 = 2 bits.
b. Each frame carries 1 bit from each 190-kbps source. Frame rate = 190000 frames/s.
c. Frame duration = $\frac{1}{frame\,rate} = \frac{1}{190000} = 5.3 \times 10^{-6}$ s = 5.3 μs
d. Output data rate = frame rate × frame size = 190000 × 2 = 380 kbps.

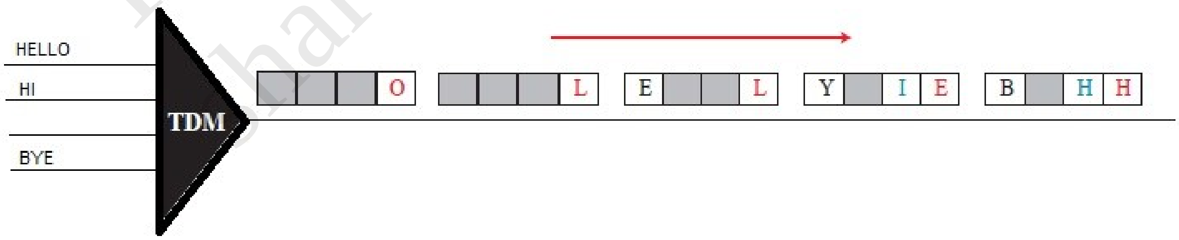
Here the output bit rate is greater than the sum of the input rates (370 kbps) because of extra bits added to the second source.

22. Answer the following questions about a T-1 line:
a. What is the duration of a frame?
b. What is the overhead (number of extra bits per second)?
Ans:

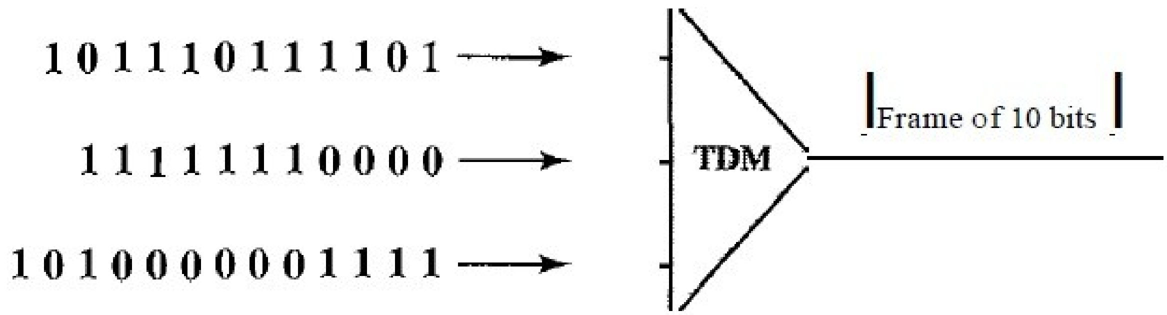
a. T-1 line sends 8000 frames/s. ∴ Frame duration = $\frac{1}{frame\,rate} = \frac{1}{8000}$ = 125 μs.

b. Each frame carries one extra bit. ∴ Overhead = 8000 × 1 = 8 kbps

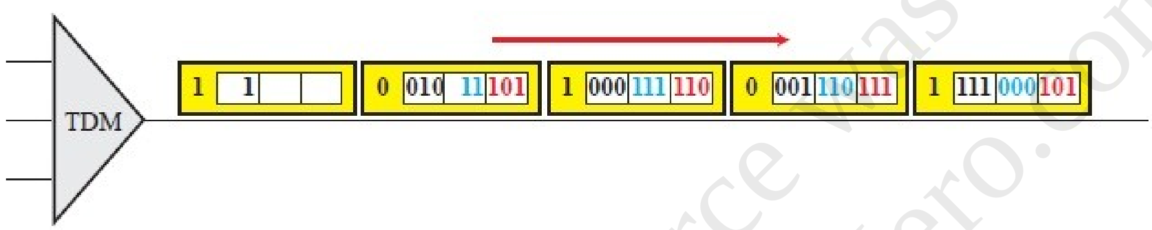
23. Show the contents of the five output frames for a synchronous TDM multiplexer that combines four sources sending the following characters. Note that the characters are sent in the same order that they are typed. The third source is silent.
a. Source 1 message: HELLO
b. Source 2 message: HI
c. Source 3 message:
d. Source 4 message: BYE
Ans: TDM multiplexar: 4 input



24. Figure shows a multiplexer in a synchronous TDM system. Each output slot is only 10 bits long (3 bits taken from each input plus 1 framing bit). What is the output stream? The bits arrive at the multiplexer as shown by the arrows.



Ans:



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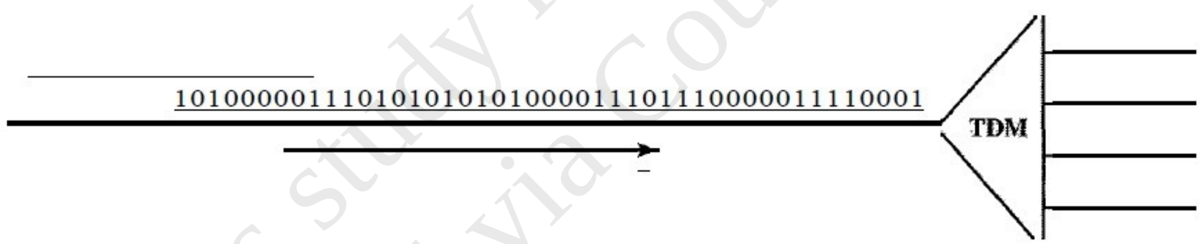
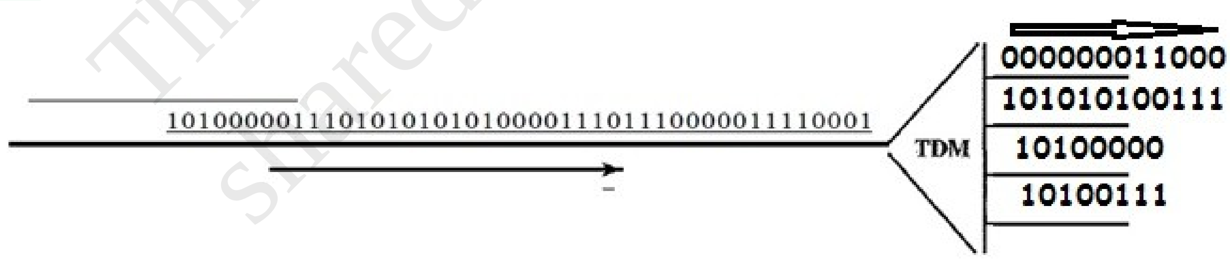
25. Figure 6.35 shows a demultiplexer in a synchronous TDM. If the input slot is 16 bits long (no framing bits), what is the bit stream in each output? The bits arrive at the demultiplexer as shown by the arrows.



Ans:



26. Answer the following questions about the digital hierarchy in Figure 6.23:
a. What is the overhead (number of extra bits) in the DS-l service?
b. What is the overhead (number of extra bits) in the DS-2 service?

c. What is the overhead (number of extra bits) in the DS-3 service?
d. What is the overhead (number of extra bits) in the DS-4 service?
Ans:

27. What is the minimum number of bits in a PN sequence if we use FHSS with a channel bandwidth of B =4 KHz and Bss =100 KHz?
Ans:

28. An FHSS system uses a 4-bit PN sequence. If the bit rate of the PN is 64 bits per second, answer the following questions:
a. What is the total number of possible hops?
b. What is the time needed to finish a complete cycle of PN?
Ans:

29. A pseudorandom number generator uses the following formula to create a random series:

$$N_{i+1} = (5 + 7N_i) \bmod 17 - 1$$

In which Nj defines the current random number and Nj +1 defines the next random number. The term mod means the value of the remainder when dividing $(5 + 7N_j)$ by 17.
Ans:

30. We have a digital medium with a data rate of 10 Mbps. How many 64-kbps voice channels can be carried by this medium if we use DSSS with the Barker sequence?
Ans: