Chapter 6

Bandwidth Utilization: Multiplexing and Spreading
Bandwidth utilization is the wise use of available bandwidth to achieve specific goals.

Efficiency can be achieved by multiplexing; privacy and anti-jamming can be achieved by spreading.
Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared. Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link. As data and telecommunications use increases, so does traffic.
Figure 6.1  *Dividing a link into channels*
Figure 6.2 Categories of multiplexing

- Frequency-division multiplexing (Analog)
- Wavelength-division multiplexing (Analog)
- Time-division multiplexing (Digital)
Figure 6.3 Frequency-division multiplexing
FDM is an analog multiplexing technique that combines analog signals.
Figure 6.4  *FDM process*
Figure 6.5  FDM demultiplexing example
Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. Show the configuration, using the frequency domain. Assume there are no guard bands.

Solution

We shift (modulate) each of the three voice channels to a different bandwidth, as shown in Figure 6.6. We use the 20- to 24-kHz bandwidth for the first channel, the 24- to 28-kHz bandwidth for the second channel, and the 28- to 32-kHz bandwidth for the third one. Then we combine them as shown in Figure 6.6.
Figure 6.6 Example 6.1
Example 6.2

Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?

Solution

For five channels, we need at least four guard bands. This means that the required bandwidth is at least

$$5 \times 100 + 4 \times 10 = 540 \text{ kHz},$$

as shown in Figure 6.7.
Figure 6.7  Example 6.2

Guard band of 10 kHz

100 kHz  100 kHz  100 kHz  100 kHz  100 kHz

540 kHz
Figure 6.12 TDM
Figure 6.13  *Synchronous time-division multiplexing*

Each frame is 3 time slots. Each time slot duration is $T/3$ s.
In Figure 6.13, the data rate for the link is 3 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 $1/3 \text{ ms}$.

c. Each frame carries three output time slots. So the duration of a frame is $3 \times 1/3 \text{ ms}$, or $1 \text{ ms}$. 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.

Solution

We can answer the questions as follows:

a. The input bit duration is the inverse of the bit rate: 
   \[ 1/1 \text{ Mbps} = 1 \mu s. \]

b. The output bit duration is one-fourth of the input bit duration, or \( 1/4 \mu s. \)
c. The output bit rate is the inverse of the output bit duration or $1/(4\mu s)$ 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 $= 4 \times 1$ Mbps $= 4$ Mbps.

d. 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.
Figure 6.14 Example 6.6
Figure 6.18  *Empty slots*
6-1 SPREAD SPECTRUM
Figure 6.27 Spread spectrum
Figure 6.28  *Frequency hopping spread spectrum (FHSS)*
Figure 6.29 Frequency selection in FHSS
Figure 6.30  *FHSS cycles*
Figure 6.31 Bandwidth sharing

a. FDM

b. FHSS
Figure 6.32  \textit{DSSS}
Figure 6.33  

DSSS example