

IUG - Faculty of Engineering
Department of Computer Engineering
Data communications Lab
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Data Communications

Lab 8

Chapter 6

Bandwidth Utilization: Multiplexing and Spectrum Spreading

Abdullah Idris Ouda

P6-1. 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.

Solution:

Channels can be separated by strips of unused bandwidth—**guard bands**—to prevent signals from overlapping.

10 channels => 9 guard bands

$$B_{\text{fdm}} = (4 \times 10^3)(10) + 9(500) = 44500 \text{ Hz} = 44.5 \text{ KHz}$$

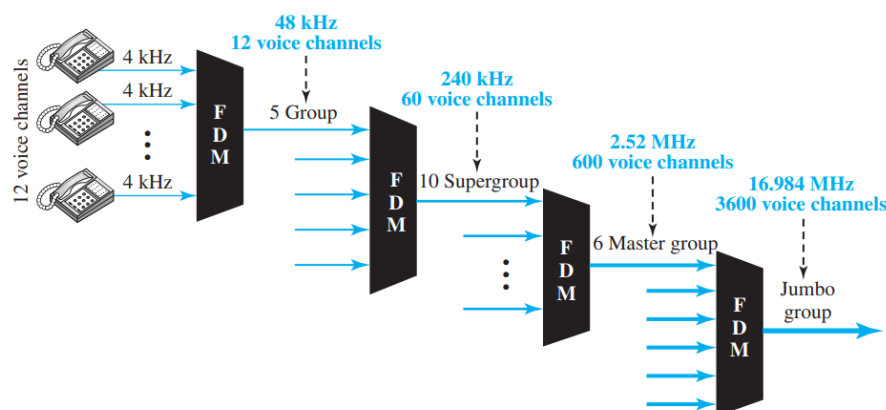
P6-2. We need to transmit 100 digitized voice channels using a passband channel of 20 KHz. What should be the ratio of bits/Hz if we use no guard band?

Solution:

- Bandwidth is allocated to each voice channel is **20 KHz / 100 = 200 Hz**
- As we saw in previous chapters, each digitized voice channel => 8000 samples * 8 bit/sample = 64 kbps.
- The ratio = 64000 / 200 = 320 bits / Hz

P6-3. In the analog hierarchy of Figure 6.9, find the overhead (extra bandwidth for guard band or control) in each hierarchy level (group, supergroup, master group, and jumbo group).

Figure 6.9 Analog hierarchy



Solution:

a.) 12 voice channels, $B_{\text{channel}} = 4 \text{ KHz} \Rightarrow 48 \text{ KHz} - 12(4 \text{ KHz}) = 0 \text{ Hz}$ overhead.

b.) 5 groups $\Rightarrow 240 \text{ KHz} - 5(48 \text{ KHz}) = 0 \text{ Hz}$ overhead

c.) 10 Super Groups $\Rightarrow 2.52 \times 10^6 - 10(240 \times 10^3) = 120 \text{ KHz}$ overhead

d.) 6 Master Groups $\Rightarrow 16.984 \times 10^6 - 6(2.52 \times 10^6) = 1864000 \text{ Hz} = 1.864 \text{ MHz}$ overhead

- P6-4.** 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)?

Solution:

- a. Each output frame carries 1 bit from each source plus one extra bit for synchronization. **Frame size** = $20 \times 1 + 1 = 21$ bit
- b. Each frame carries 1 bit from each source. **Frame rate** = **100,000 frames/s.**
- c. **Frame duration** = $1 / (\text{frame rate}) = 1 / 100,000 = 10 \mu\text{s}.$
- d. **Data rate** = **Frame rate * bits/frame(Frame size)** = $(100,000 \text{ frames/s}) \times (21 \text{ bits/frame}) = 2.1 \text{ Mbps}$
- e. In each frame 20 bits out of 21 are useful. **Efficiency** = **useful bits / total bits** = $20/21 = 95\%$

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- P6-5.** Repeat Problem 6-4 if each output slot carries 2 bits from each source.

Solution:

- a. Each output frame carries **2 bits from each source** plus one extra bit for synchronization. **Frame size** = $20 \times 2 + 1 = 41$ bits.
- b. Each frame carries 2 bit from each source. **Frame rate** = $100,000/2 = 50,000 \text{ frames/s.}$
- c. **Frame duration** = $1 / (\text{frame rate}) = 1 / 50,000 = 20 \mu\text{s}$
- d. **Data rate** = $(50,000 \text{ frames/s}) \times (41 \text{ bits/frame}) = 2.05 \text{ Mbps.}$
- e. In each frame 40 bits out of 41 are useful. **Efficiency** = $40/41 = 97.5\%$

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- P6-6.** 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 4-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?

Solution:

- a. **Frame size** = (# of slots) x (character size + slot address) = 6 x (8 bits + 4 bits) = 72 bits
- b. We can assume that we have only 6 input lines. Each frame needs to carry one character from each of these lines. This means that the link needs to send **500 frames/s**
- c. **Frame duration** = 1 / (frame rate) = 1 / 500 = 2ms.
- d. Data rate = (500 frames/s) x (72 bits/frame) = 36 Kbps

P6-7. 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?

Solution:

- a. We combine **six 200-kbps sources into three 400-kbps**. Now we have **seven 400-kbps** channel. Each output frame carries **1 bit from** each of the seven **400-kbps** line. **Frame size** = $7 \times 1 = 7$ bits.
- b. **Frame rate** = 400k frames/s.
- c. **Frame duration** = 1 / (frame rate) = 1 / 400,000 = 2.5 μ s.
- d. Data rate = (400,000 frames/s) x (7 bits/frame) = 2.8 Mbps.

P6-8. 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?

Solution:

- a. Divide all of them into 50Kbps lines => in total $(200/50) \times 2 + (150/50) \times 2 = 14$, then aggregate => 14 bits/frame
- b. **Frame rate** = 50k frame/s
- c. Frame duration = 1 / (frame rate) = 1 / 50k = 20 μ s
- d. Data rate = 50k * 14 = 700kbps

P6-9. 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?

Solution:

- a. We need to **add extra bits** to the second source to make both bit rates = **190Kbps**.

Now we have **two sources**, each of **190 Kbps**. Since the data unit was not specified, assume that it is one bit. **Frame size = 2 bits**.

- b. **Frame rate = 190k frames/s**
- c. **Frame duration = 1/frame rate = 1/190k = 5.26 μ s**
- d. **Data rate = 190k*2 = 380kbps**

P6-10. 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)?

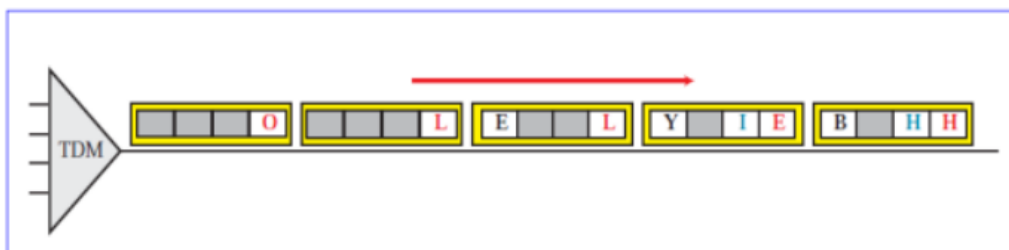
Solution:

- a. T-1 line sends **8000 fps** => duration = 1/8000 = .125 milliseconds
- b. Each frame carries 1 extra bit => Overhead = 8000*1= 8000 Kbps

P6-11. 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.

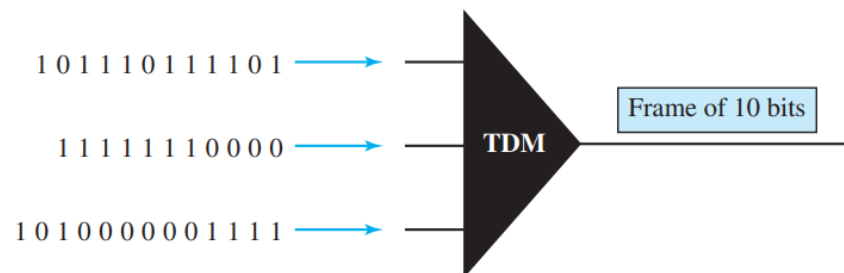
- a. Source 1 message: HELLO
- b. Source 2 message: HI
- c. Source 3 message:
- d. Source 4 message: BYE

Solution:

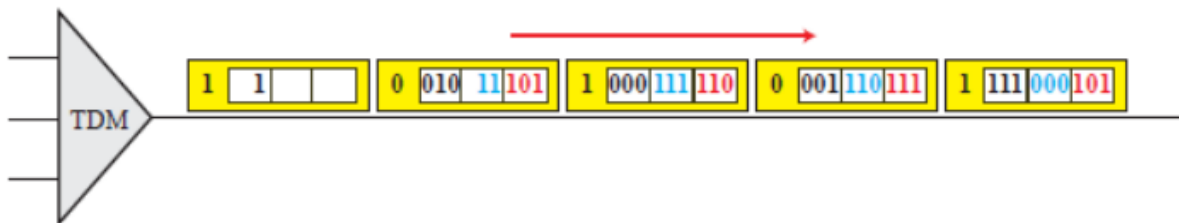


P6-12. Figure 6.34 shows a multiplexer in a synchronous TDM system. Each output slot is only 10 bits long (3 bits taken from each input plus 1 framing bit). What is the output stream? The bits arrive at the multiplexer as shown by the arrows.

Figure 6.34 Problem P6-12

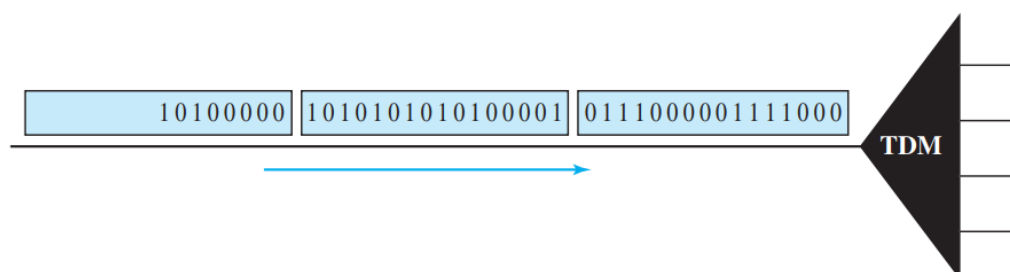


Solution:

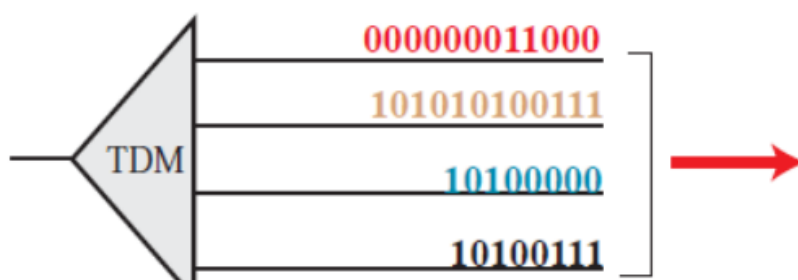


P6-13. Figure 6.35 shows a demultiplexer in a synchronous TDM. If the input slot is 16 bits long (no framing bits), what is the bit stream in each output? The bits arrive at the demultiplexer as shown by the arrows.

Figure 6.35 Problem P6-13



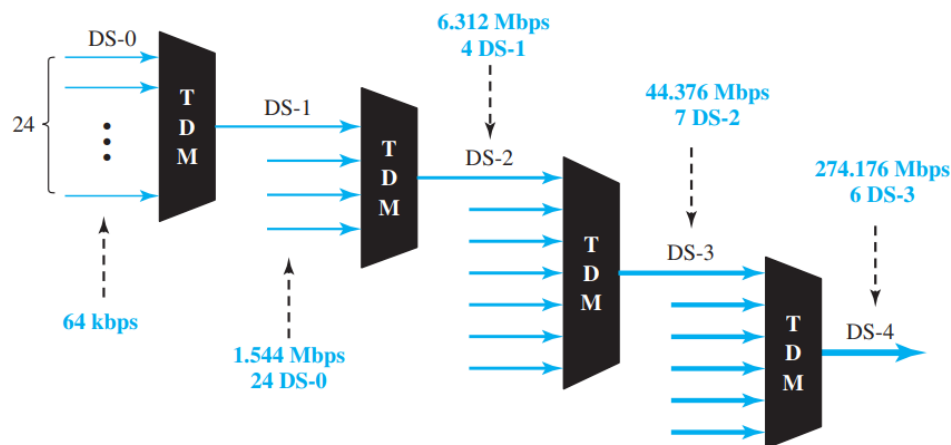
Solution:



P6-14. Answer the following questions about the digital hierarchy in Figure 6.23:

- What is the overhead (number of extra bits) in the DS-1 service?
- What is the overhead (number of extra bits) in the DS-2 service?
- What is the overhead (number of extra bits) in the DS-3 service?
- What is the overhead (number of extra bits) in the DS-4 service?

Figure 6.23 Digital hierarchy



Solution:

- DS-1: $1.544 \text{ Mbps} - 64 \text{ Kbps} \times 24 = 8000 \text{ bps}$ overhead
- DS-2: $6.312 \text{ Mbps} - (1.544 \text{ Mbps} \times 4) = 136 \text{ Kbps}$ overhead
- DS-3: $44.376 \text{ Mbps} - (6.312 \text{ Mbps} \times 7) = 192 \text{ Kbps}$ overhead
- DS-4: $274.176 \text{ Mbps} - (44.376 \text{ Mbps} \times 6) = 7.92 \text{ Mbps}$ overhead

P6-15. What is the minimum number of bits in a PN sequence if we use FHSS with a channel bandwidth of $B = 4 \text{ KHz}$ and $B_{ss} = 100 \text{ KHz}$?

Solution:

of hopping freq. = $B_{ss} / B = 100 \text{ KHz} / 4 \text{ KHz} = 25$

$\log_2 25 = \text{approx. } 5 \text{ bits}$

P6-16. 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:

- What is the total number of possible channels?
- What is the time needed to finish a complete cycle of PN?

Solution:

- $2^4 = 16$ channels
- $16 \times 4 \text{ bits} = 64 \text{ bits}$
 $64 \text{ bits} / 64 \text{ bits/s} = 1 \text{ sec}$

P6-17. A pseudorandom number generator uses the following formula to create a random series:

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

In which N_i defines the current random number and N_{i+1} defines the next random number. The term *mod* means the value of the remainder when dividing $(5 + 7N_i)$ by 17. Show the sequence created by this generator to be used for spread spectrum.

Solution:

$\Rightarrow$ Random numbers: 11, 13, 10, 6, 12, 3, 8, 9 :

$i=0, N_1 = 11$

$i=1 \Rightarrow N_2 = (5 + 7 \times 11) \bmod 17 - 1 = 13$

$i=2 \Rightarrow N_3 = (5 + 7 \times 13) \bmod 17 - 1 = 10$

$i=3 \Rightarrow N_4 = (5 + 7 \times 10) \bmod 17 - 1 = 6$

$i=4 \Rightarrow N_5 = (5 + 7 \times 6) \bmod 17 - 1 = 12$

$i=5 \Rightarrow N_6 = (5 + 7 \times 12) \bmod 17 - 1 = 3$

$i=6 \Rightarrow N_7 = (5 + 7 \times 3) \bmod 17 - 1 = 8$

$i=7 \Rightarrow N_8 = (5 + 7 \times 8) \bmod 17 - 1 = 9$

$i=8 \Rightarrow N_9 = (5 + 7 \times 9) \bmod 17 - 1 = 11$

(The sequence repeats from 11)

P6-18. 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?

Solution:

Barker chips are 11 bits $\Rightarrow$ increase bit rate 11 times

$\Rightarrow 64 \text{ Kbps} \times 11 = 704 \text{ Kbps}$

$\Rightarrow 10 \text{ Mbps} / 704 \text{ Kbps} = 14 \text{ Channels}$