CHAPTER 12

Multiple Access

Solutions to Review Questions and Exercises

Review Questions

1. The three categories of multiple access protocols discussed in this chapter are random access, controlled access, and channelization.

2. In random access methods, no station is superior to another station and none is assigned the control over another. Each station can transmit when it desires on the condition that it follows the predefined procedure. Three common protocols in this category are ALOHA, CSMA/CD, and CSMA/CA.

3. In controlled access methods, the stations consult one another to find which station has the right to send. A station cannot send unless it has been authorized by other stations. We discuss three popular controlled-access methods: reservation, polling, and token passing.

4. Channelization is a multiple-access method in which the available bandwidth of a link is shared in time, frequency, or through code, between different stations. The common protocols in this category are FDMA, TDMA, and CDMA.

5. In random access methods, there is no access control (as there is in controlled access methods) and there is no predefined channels (as in channelization). Each station can transmit when it desires. This liberty may create collision.

6. In a random access method, the whole available bandwidth belongs to the station that wins the contention; the other stations needs to wait. In a controlled access method, either a central authority (in polling) or other stations (in reservation and token passing) control the access. Random access methods have less administration overhead. On the other hand, controlled access method are collision free.

7. In a random access method, the whole available bandwidth belongs to the station that wins the contention; the other stations needs to wait. In a channelization method, the available bandwidth is divided between the stations. If a station does not have data to send, the allocated channel remains idle.

8. In a controlled access method, the whole available bandwidth belongs to the station that is granted permission either by a central authority or by other stations. In a channelization method, the available bandwidth is divided between the stations. If a station does not have data to send the allocated channel remains idle.
9. We do not need a multiple access method in this case. The local loop provides a
dedicated point-to-point connection to the telephone office.

10. We do need a multiple access, because a channel in the CATV band is normally
shared between several neighboring customers. The cable company uses the random access
method to share the bandwidth between neighbors.

Exercises

11. To achieve the maximum efficiency in pure ALOHA, $G = 1/2$. If we let $ns$ to be the
number of stations and $nfs$ to be the number of frames a station can send per second.

$$G = ns \times nfs \times T_n = 100 \times nfs \times 1 \mu s = 1/2 \rightarrow nfs = 5000 \text{ frames/s}$$

The reader may have noticed that the $T_n$ is very small in this problem. This means
that either the data rate must be very high or the frames must be very small.

12. To achieve the maximum efficiency in slotted ALOHA, $G = 1$. If we let $ns$ to be
the number of stations and $nfs$ to be the number of frames a station can send per second.

$$G = ns \times nfs \times T_n = 100 \times nfs \times 1 \mu s = 1 \rightarrow nfs = 10,000 \text{ frames/s}$$

The reader may have noticed that the $T_n$ is very small in this problem. This means
that either the data rate must be very high or the frames must be very small.

13. We can first calculate $T_n$ and $G$, and then the throughput.

$$T_n = (1000 \text{ bits}) / 1 \text{ Mbps} = 1 \text{ ms}$$

$$G = ns \times nfs \times T_n = 100 \times 10 \times 1 \text{ ms} = 1$$

For pure ALOHA $\rightarrow S = G \times e^{-2G} \approx 13.53 \text{ percent}$

This means that each station can successfully send only 1.35 frames per second.

14. We can first calculate $T_n$ and $G$, and then the throughput.

$$T_n = (1000 \text{ bits}) / 1 \text{ Mbps} = 1 \text{ ms}$$

$$G = ns \times nfs \times T_n = 100 \times 10 \times 1 \text{ ms} = 1$$

For slotted ALOHA $\rightarrow S = G \times e^{-G} \approx 36.7 \text{ percent}$

This means that each station can successfully send only 3.67 frames per second.

15. Let us find the relationship between the minimum frame size and the data rate. We
know that

$$T_n = \frac{(\text{frame size})}{(\text{data rate})} = 2 \times T_p = 2 \times \frac{\text{distance}}{(\text{propagation speed})}$$

or

$$(\text{frame size}) = \left[2 \times \left(\frac{\text{distance}}{(\text{propagation speed})}\right)\right] \times (\text{data rate})$$

or

$$(\text{frame size}) = K \times (\text{data rate})$$
This means that minimum frame size is proportional to the data rate (K is a constant). When the data rate is increased, the frame size must be increased in a network with a fixed length to continue the proper operation of the CSMA/CD. In Example 12.5, we mentioned that the minimum frame size for a data rate of 10 Mbps is 512 bits. We calculate the minimum frame size based on the above proportionality relationship

\[
\text{Data rate} = 10 \text{ Mbps} \quad \Rightarrow \quad \text{minimum frame size} = 512 \text{ bits}
\]

\[
\text{Data rate} = 100 \text{ Mbps} \quad \Rightarrow \quad \text{minimum frame size} = 5120 \text{ bits}
\]

\[
\text{Data rate} = 1 \text{ Gbps} \quad \Rightarrow \quad \text{minimum frame size} = 51200 \text{ bits}
\]

\[
\text{Data rate} = 10 \text{ Gbps} \quad \Rightarrow \quad \text{minimum frame size} = 512000 \text{ bits}
\]

16. Let us find the relationship between the collision domain (maximum length of the network) and the data rate. We know that

\[
T_{fr} = \frac{\text{frame size}}{\text{data rate}} = \frac{2 \times \text{distance}}{\text{propagation speed}}
\]

or

\[
\text{distance} = \frac{\text{[frame size] \times \text{propagation speed}}}{2 \times \text{[data rate]}}
\]

or

\[
\text{distance} = \frac{K}{\text{data rate}}
\]

This means that distance is inversely proportional to the data rate (K is a constant). When the data rate is increased, the distance or maximum length of network or collision domain is decreased proportionally. In Example 12.5, we mentioned that the maximum distance for a data rate of 10 Mbps is 2500 meters. We calculate the maximum distance based on the above proportionality relationship.

\[
\text{Data rate} = 10 \text{ Mbps} \quad \Rightarrow \quad \text{maximum distance} = 2500 \text{ m}
\]

\[
\text{Data rate} = 100 \text{ Mbps} \quad \Rightarrow \quad \text{maximum distance} = 250 \text{ m}
\]

\[
\text{Data rate} = 1 \text{ Gbps} \quad \Rightarrow \quad \text{maximum distance} = 25 \text{ m}
\]

\[
\text{Data rate} = 10 \text{ Gbps} \quad \Rightarrow \quad \text{maximum distance} = 2.5 \text{ m}
\]

This means that when the data rate is very high, it is almost impossible to have a network using CSMA/CD.

17. We have \( t_1 = 0 \) and \( t_2 = 3 \mu s \)

\[
a. \ t_3 - t_1 = (2000 \text{ m}) / (2 \times 10^8 \text{ m/s}) = 10 \mu s \quad \Rightarrow \quad t_3 = 10 \mu s + t_1 = 10 \mu s
\]

\[
b. \ t_4 - t_2 = (2000 \text{ m}) / (2 \times 10^8 \text{ m/s}) = 10 \mu s \quad \Rightarrow \quad t_4 = 10 \mu s + t_2 = 13 \mu s
\]

\[
c. \ T_{fr(A)} = t_4 - t_1 = 13 - 0 = 13 \mu s \quad \Rightarrow \quad \text{Bits}_A = 10 \text{ Mbps} \times 13 \mu s = 130 \text{ bits}
\]

\[
d. \ T_{fr(C)} = t_3 - t_2 = 10 - 3 = 7 \mu s \quad \Rightarrow \quad \text{Bits}_C = 10 \text{ Mbps} \times 7 \mu s = 70 \text{ bits}
\]

18. We have \( t_1 = 0 \) and \( t_2 = 3 \mu s \)

\[
a. \ t_3 - t_1 = (2000 \text{ m}) / (2 \times 10^8 \text{ m/s}) = 10 \mu s \quad \Rightarrow \quad t_3 = 10 \mu s + t_1 = 10 \mu s
\]

\[
b. \ t_4 - t_2 = (2000 \text{ m}) / (2 \times 10^8 \text{ m/s}) = 10 \mu s \quad \Rightarrow \quad t_4 = 10 \mu s + t_2 = 13 \mu s
\]

\[
c. \ T_{fr(A)} = t_4 - t_1 = 13 - 0 = 13 \mu s \quad \Rightarrow \quad \text{Bits}_A = 100 \text{ Mbps} \times 13 \mu s = 1300 \text{ bits}
\]

\[
d. \ T_{fr(C)} = t_3 - t_2 = 10 - 3 = 7 \mu s \quad \Rightarrow \quad \text{Bits}_C = 100 \text{ Mbps} \times 7 \mu s = 700 \text{ bits}
\]
Note that in this case, both stations have already sent more bits than the minimum number of bits required for detection of collision. The reason is that with the 100 Mbps, the minimum number of bits requirement is feasible only when the maximum distance between stations is less than or equal to 250 meters as we will see in Chapter 13.

19. See Figure 12.1.

**Figure 12.1**  *Solution to Exercise 19*

\[
W_d = \begin{bmatrix}
+1 & +1 & +1 & +1 \\
+1 & -1 & +1 & -1 \\
+1 & +1 & -1 & -1 \\
+1 & -1 & -1 & +1 \\
+1 & +1 & +1 & +1 \\
+1 & -1 & +1 & -1 \\
+1 & +1 & -1 & +1 \\
+1 & -1 & -1 & +1
\end{bmatrix}
\]

20. See Figure 12.2.

**Figure 12.2**  *Solution to Exercise 20*

\[
W_1 = \begin{bmatrix}
1 \\
-1 \\
-1 \\
1
\end{bmatrix}
\]

\[
W_2 = \begin{bmatrix}
1 \\
-1 \\
-1 \\
1
\end{bmatrix}
\]

\[
W_3 = \begin{bmatrix}
1 \\
-1 \\
-1 \\
1
\end{bmatrix}
\]

\[
W_d = \begin{bmatrix}
-1 & -1 \\
-1 & +1 \\
-1 & -1 \\
+1 & +1
\end{bmatrix}
\]

21.  
**Third Property**: we calculate the inner product of each row with itself:

<table>
<thead>
<tr>
<th>Row 1</th>
<th>Row 2</th>
<th>[+1 +1 +1 +1]</th>
<th>[+1 +1 +1 +1]</th>
<th>= +1 + 1 + 1 + 1 = 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row 2</td>
<td>Row 2</td>
<td>[+1 -1 +1 -1]</td>
<td>[+1 -1 +1 -1]</td>
<td>= +1 + 1 + 1 + 1 = 4</td>
</tr>
<tr>
<td>Row 3</td>
<td>Row 1</td>
<td>[+1 +1 -1 -1]</td>
<td>[+1 +1 -1 -1]</td>
<td>= +1 + 1 + 1 + 1 = 4</td>
</tr>
<tr>
<td>Row 4</td>
<td>Row 4</td>
<td>[+1 -1 -1 +1]</td>
<td>[+1 -1 -1 +1]</td>
<td>= +1 + 1 + 1 + 1 = 4</td>
</tr>
</tbody>
</table>

**Fourth Property**: we need to prove 6 relations:

<table>
<thead>
<tr>
<th>Row 1</th>
<th>Row 2</th>
<th>[+1 +1 +1 +1]</th>
<th>[+1 -1 +1 -1]</th>
<th>= +1 - 1 + 1 + 1 = 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row 1</td>
<td>Row 3</td>
<td>[+1 +1 +1 +1]</td>
<td>[+1 +1 -1 -1]</td>
<td>= +1 + 1 - 1 - 1 = 0</td>
</tr>
<tr>
<td>Row 1</td>
<td>Row 4</td>
<td>[+1 +1 +1 +1]</td>
<td>[+1 -1 -1 +1]</td>
<td>= +1 - 1 - 1 + 1 = 0</td>
</tr>
<tr>
<td>Row 2</td>
<td>Row 3</td>
<td>[+1 +1 -1 -1]</td>
<td>[+1 +1 -1 -1]</td>
<td>= +1 + 1 - 1 - 1 = 0</td>
</tr>
<tr>
<td>Row 2</td>
<td>Row 4</td>
<td>[+1 -1 +1 -1]</td>
<td>[+1 -1 +1 -1]</td>
<td>= +1 - 1 + 1 - 1 = 0</td>
</tr>
<tr>
<td>Row 3</td>
<td>Row 4</td>
<td>[+1 +1 -1 -1]</td>
<td>[+1 -1 -1 +1]</td>
<td>= +1 - 1 - 1 + 1 = 0</td>
</tr>
</tbody>
</table>
22. **Third Property**: we calculate the inner product of each row with itself:

- Row 1 • Row 1 $\begin{bmatrix} -1 & -1 & -1 & -1 \end{bmatrix}$ • $\begin{bmatrix} -1 & -1 & -1 & -1 \end{bmatrix}$ = $+1 + 1 + 1 + 1 = 4$
- Row 2 • Row 2 $\begin{bmatrix} -1 & +1 & -1 & +1 \end{bmatrix}$ • $\begin{bmatrix} -1 & +1 & -1 & +1 \end{bmatrix}$ = $+1 + 1 + 1 + 1 = 4$
- Row 3 • Row 1 $\begin{bmatrix} -1 & -1 & +1 & +1 \end{bmatrix}$ • $\begin{bmatrix} -1 & -1 & +1 & +1 \end{bmatrix}$ = $+1 + 1 + 1 + 1 = 4$
- Row 4 • Row 4 $\begin{bmatrix} -1 & +1 & +1 & -1 \end{bmatrix}$ • $\begin{bmatrix} -1 & +1 & +1 & -1 \end{bmatrix}$ = $+1 + 1 + 1 + 1 = 4$

**Fourth Property**: we need to prove 6 relations:

- Row 1 • Row 2 $\begin{bmatrix} -1 & -1 & -1 & -1 \end{bmatrix}$ • $\begin{bmatrix} -1 & +1 & -1 & +1 \end{bmatrix}$ = $+1 - 1 - 1 + 1 = 0$
- Row 1 • Row 3 $\begin{bmatrix} -1 & -1 & -1 & -1 \end{bmatrix}$ • $\begin{bmatrix} -1 & -1 & +1 & +1 \end{bmatrix}$ = $+1 - 1 - 1 - 1 = 0$
- Row 1 • Row 4 $\begin{bmatrix} -1 & -1 & -1 & -1 \end{bmatrix}$ • $\begin{bmatrix} -1 & +1 & +1 & -1 \end{bmatrix}$ = $+1 - 1 - 1 - 1 = 0$
- Row 2 • Row 3 $\begin{bmatrix} -1 & +1 & -1 & +1 \end{bmatrix}$ • $\begin{bmatrix} -1 & -1 & +1 & +1 \end{bmatrix}$ = $+1 - 1 - 1 + 1 = 0$
- Row 2 • Row 4 $\begin{bmatrix} -1 & +1 & -1 & +1 \end{bmatrix}$ • $\begin{bmatrix} -1 & +1 & +1 & -1 \end{bmatrix}$ = $+1 - 1 - 1 - 1 = 0$
- Row 3 • Row 4 $\begin{bmatrix} -1 & -1 & +1 & +1 \end{bmatrix}$ • $\begin{bmatrix} -1 & +1 & +1 & -1 \end{bmatrix}$ = $+1 - 1 - 1 - 1 = 0$

23. Figure 12.3 shows the encoding, the data on the channel, and the decoding.

**Figure 12.3 Solution to Exercise 23**
24. We can say:

**Polling and Data Transfer**
- Station 1: \([\text{poll} + 5 \times (\text{frame} + \text{ACK})]\)
- Station 2: \([\text{poll} + 5 \times (\text{frame} + \text{ACK})]\)
- Station 3: \([\text{poll} + 5 \times (\text{frame} + \text{ACK})]\)
- Station 4: \([\text{poll} + 5 \times (\text{frame} + \text{ACK})]\)

**Polling and Sending NAKs**
- Station 1: \([\text{poll} + \text{NAK}]\)
- Station 2: \([\text{poll} + \text{NAK}]\)
- Station 3: \([\text{poll} + \text{NAK}]\)
- Station 4: \([\text{poll} + \text{NAK}]\)

**Total Activity:**
- 8 polls + 20 frames + 20 ACKs + 4 NAKs = 21024 bytes
- We have 1024 bytes of overhead.

25. We can say:

**Polling and Data Transfer**
- Frame 1 for all four stations: \(4 \times [\text{poll} + \text{frame} + \text{ACK}]\)
- Frame 2 for all four stations: \(4 \times [\text{poll} + \text{frame} + \text{ACK}]\)
- Frame 3 for all four stations: \(4 \times [\text{poll} + \text{frame} + \text{ACK}]\)
- Frame 4 for all four stations: \(4 \times [\text{poll} + \text{frame} + \text{ACK}]\)
- Frame 5 for all four stations: \(4 \times [\text{poll} + \text{frame} + \text{ACK}]\)

**Polling and Sending NAKs**
- Station 1: \([\text{poll} + \text{NAK}]\)
- Station 2: \([\text{poll} + \text{NAK}]\)
- Station 3: \([\text{poll} + \text{NAK}]\)
- Station 4: \([\text{poll} + \text{NAK}]\)

**Total Activity:**
- 24 polls + 20 frames + 20 ACKs + 4 NAKs = 21536 bytes
- We have 1536 bytes of overhead which is 512 bytes more than the case in Exercise 23. The reason is that we need to send 16 extra polls.