CHAPTER 12

PRACTICE SET

Questions

Q12-1. The answer is CDMA.

- **a.** ALOHA is a random-access protocol.
- **b.** Token-passing is a controlled-access protocol.
- **c.** CDMA is a channelization protocol.

Q12-2. The transmission rate of this network is T_{fr} = (1000 bits)/(1Mbps) = 1 ms. The vulnerable time in pure Aloha is $2 \times T_{fr} = 2$ ms.

Q12-3. The last bit is 10 μs behind the first bit.

- **a.** It takes 5 μs for the first bit to reach the destination.
- **b.** The last bit arrives at the destination 10 μs after the first bit.
- **c.** The network is involved with this frame for 5 + 10 = 15 μs.

Q12-4. As shown in Figure 12.15, each station should wait IFS seconds before creating the random number and before sending a frame. This means that a station with IFS value of 5 milliseconds has priority over the station with IFS value of 7 milliseconds.

Q12-5. In a slotted Aloha, the throughput at G = 1/2 is 30.2%.

- **a.** When G = 1, the throughput is increased to the maximum value of 36.8%.
- **b.** When G = 1/4, the throughput is increased to 32.1%

Q12-6. The use of K in Figure 12.15 decreases the probability that a station can immediately send when the number of failures increases. This means decreasing the probability of collision.

- **a.** After two failure (K = 2), the value of R is 0 to 3. The probability that the station gets R = 0 (send immediately) is 1/4 or 25%.

b. After five failures (K = 5), the value of R is 0 to 31. The probability that the station gets R = 0 (send immediately) is 1/32 or 3%.

Q12-7. In CSMA/CD, the lack of detecting collision before the last bit of the frame is sent out is interpreted as an acknowledgment. In CSMA/CA, the sender cannot sense collision; there is a need for explicit acknowledgments.

Q12-8. The answer is *token-passing* and *polling.*

a. Token-passing is a controlled-access protocol.

b. Polling is a controlled-access protocol.

c. FDMA is a channelization protocol.

Q12-9. In random-access methods, there is no control over the medium access. Each station can transmit when it desires. This liberty may create collisions. In controlled-access methods, the access to the medium is controlled, either by an authority or by the priority of the station. There is no collision.

Q12-10. *Success* in a CSMA/CD network is interpreted as not receiving collision news before sending all bits in the frame.

Q12-11. We can mention the following strategies:

a. It uses the combination of RTS and CTS frames to warn other stations that a new station will be using the channel.

b. It uses NAV to prevent other stations to transmit.

c. It uses acknowledgments to be sure the data has arrived and there is no need for resending the data.

Q12-12. The sender needs to detect the collision before the last bit of the frame is sent out. If the collision occurs near the destination, it takes $2 \times 6 = 12$ µs for the collision news to reach the sender. The sender has already sent out the whole frame; it is not listening for a collision anymore.

Q12-13. The sender needs to detect the collision before the last bit of the frame is sent out. If the collision occurs near the destination, it takes $2 \times 3 = 6$ µs for the collision news to reach the sender. The sender has already sent out the whole frame; it is not listening for a collision anymore.

Q12-14. In a pure Aloha, the throughput at G = 1/2 is 18.4% (maximum value).

a. When G = 1, the throughput is decreased to 13.5%.

b. When G = 1/4, the throughput is decreased to 15.2%.

Q12-15. *Success* in an Aloha network is interpreted as receiving an acknowledgment for a frame.

Q12-16. The last bit is 8 μs behind the first bit.

a. It takes 12 μs for the first bit to reach the destination.

b. The last bit arrives at the destination 8 μs after the first bit.

c. The network is involved with this frame for 8 + 12 = 20 μs.

Q12-17. The answer is *CSM/CD*.

a. CSMA/CD is a random-access protocol.

b. Polling is a controlled-access protocol.

c. TDMA is a channelization protocol.

Q12-18. In random access methods, there is no control over medium access. Each station can transmit when it desires. This liberty may create collisions. In channelization methods, the medium is divided into channels and each station has its own channel.

Q12-19. The use of K in Figure 12.13 decreases the probability that a station can immediately send when the number of failures increases. This means decreasing the probability of collision.

a. After one failure (K = 1), the value of R is 0 or 1. The probability that the station gets R = 0 (send immediately) is 1/2 or 50%.

b. After four failures (K = 4), the value of R is 0 to 15. The probability that the station gets R = 0 (send immediately) is 1/16 or 6.25%.

Q12-20. NAV in CSMA/CA prevents other stations to send when two stations is exchanging data. It prevents collision.

Q12-21. The transmission rate of this network is T_{fr} = (1000 bits)/(1Mbps) = 1 ms. The vulnerable time in slotted Aloha is T_{fr} = 1ms.

Q12-22. The use of K in Figure 12.3 decreases the probability that a station can immediately send when the number of failures increases. This means decreasing the probability of collision.

a. After one failure (K = 1), the value of R is 0 or 1. The probability that the station gets R = 0 (send immediately) is 1/2 or 50%.

b. After three failures (K = 3), the value of R is 0 to 7. The probability that the station gets R = 0 (send immediately) is 1/8 or 12.5%.

Q12-23. *Success* in an CSMA/CA network is interpreted as receiving an acknowledgment for a frame.

Q12-24. The last bit is 10 μs behind the first bit.

a. It takes 5 μs for the first bit to reach the destination.

b. The last bit arrives at the destination 10 μs after the first bit.

c. The network is involved with this frame for 5 + 10 = 15 μs.

Problems

P12-1. In both pure and slotted Aloha networks, the average number of frames created during a frame transmission time (T_{fr}) is G.

a. For a pure Aloha network, the vulnerable time is ($2 \times T_{fr}$), which means that $\lambda = 2G$.

$$p[x] = (e^{-\lambda} \times \lambda^x) / (x!) = (e^{-2G} \times (2G)^x) / (x!)$$

b. For a slotted Aloha network, the vulnerable time is (T_{fr}), which means that $\lambda = G$.

$$p[x] = (e^{-\lambda} \times \lambda^x) / (x!) = (e^{-G} \times (G)^x) / (x!)$$

P12-2. The probability of success for a station is the probability that the rest of the network generates no frame during the vulnerable time. However, since the number of stations is very large, it means that the network generates no frame. In other words, we are looking for $p[0]$ in the Poisson distribution.

a. For a pure Aloha network, the vulnerable time is ($2 \times T_{fr}$), which means that $\lambda = 2G$.

$$P\,[\text{success for a frame}] = p[0] = (e^{-\lambda} \times \lambda^0) / (0!) = e^{-\lambda} = e^{-2G}$$

b. For a slotted Aloha network, the vulnerable time is (T_{fr}), which means that $\lambda = G$.

$$P\,[\text{success for a frame}] = p[0] = (e^{-\lambda} \times \lambda^0) / (0!) = e^{-\lambda} = e^{-G}$$

P12-3. The throughput for each network is $S = G \times P[\text{success for a frame}]$.

a. For a pure Aloha network, $P[\text{success for a frame}] = e^{-2G}$.

$$S = G \times P[\text{success for a frame}] = Ge^{-2G}$$

b. For a pure Aloha network, $P[\text{success for a frame}] = e^{-G}$.

$$S = G \times P[\text{success for a frame}] = Ge^{-G}$$

P12-4. We find dS/dG for each network and set the derivative to 0 to find the value of G. We then insert the G in the expression for S to find the maximum. It can be seen that the maximum throughput is the same for each network as we discussed in the text.

a. For a pure Aloha network, $S = Ge^{-2G}$.

$dS/dG = e^{-2G} - 2Ge^{-2G} = 0 \quad \rightarrow \quad G_{max} = 1/2$

$S = Ge^{-2G} \quad \rightarrow \quad \text{If } G = 1/2,\ S_{max} = (e^{-1}) / 2 \approx 0.184$

b. For a slotted Aloha network, $S = Ge^{-G}$.

$dS/dG = e^{-G} - Ge^{-G} = 0 \quad \rightarrow \quad G_{max} = 1$

$S = Ge^{-G} \quad \rightarrow \quad \text{If } G = 1,\ S_{max} = e^{-1} \approx 0.3678$

P12-5. We can find the probability for each network type separately:

a. In a pure Aloha network, a station can send a frame successfully if no other station has a frame to send during two frame transmission times (vulnerable time). The probability that a station has no frame to send is $(1 - p)$. The probability that none of the $N - 1$ stations have a frame to send is definitely $(1 - p)^{N-1}$. The probability that none of the $N - 1$ stations have a frame to send during a vulnerable time is $(1 - p)^{2(N-1)}$. The probability of success for a station is then

$$P[\text{success for a particular station}] = p\,(1 - p)^{2(N-1)}$$

b. In a slotted Aloha network, a station can send a frame successfully if no other station has a frame to send during one frame transmission time (vulnerable time).

$$P[\text{success for a particular station}] = p\,(1 - p)^{(N-1)}$$

P12-6. We found the success probability for each network type in the previous problem. If we multiply the success probability in each case by N, we have the throughput.

a. In a pure Aloha network with a limited number of stations, the throughput is

$$S = N \times P[\text{success for a particular station}] = Np\,(1 - p)^{2(N-1)}$$

b. In a slotted Aloha network with a limited number of stations, the throughput is

$$S = N \times P[\text{success for a particular station}] = Np\,(1 - p)^{(N-1)}$$

P12-7. To find the value of p that maximizes the throughput, we need to find the derivative of S with respect to p, dS/dp, and set the derivative to zero. Note that for large N, we can say $N - 1 \approx N$.

a. The following shows that, in a pure Aloha network, for a maximum throughput $p = 1/(2N)$ and the value of the maximum throughput for a large N is $S_{max} = e^{-1}/2$, as we found using the Poisson distribution:

$$S = Np\,(1-p)^{2(N-1)} \;\rightarrow\; dS/dp = N\,(1-p)^{2(N-1)} - 2Np(N-1)(1-p)^{2(N-1)-1}$$

$$dS/dp = 0 \;\rightarrow\; (1-p) - 2(N-1)p = 0 \;\rightarrow\; p = 1/(2N-1) \approx 1/(2N)$$

$$S_{max} = N[1/(2N)]\,[1 - 1/(2N)]^{2N} = (1/2)\,[1 - 1/(2N)]^{2N} = (1/2)\,e^{-1}$$

b. The following shows that, in a slotted Aloha network, for a maximum throughput $p = 1/N$ and the value of the maximum throughput for a large N is $S_{max} = e^{-1}$, as we found using the Poisson distribution:

$$S = Np\,(1-p)^{(N-1)} \;\rightarrow\; dS/dp = N\,(1-p)^{(N-1)} - Np(N-1)(1-p)^{(N-1)-1}$$

$$dS/dp = 0 \;\rightarrow\; (1-p) - (N-1)p = 0 \;\rightarrow\; p = 1/N.$$

$$S_{max} = N[1/(N)]\,[1 - 1/(N)]^{N} = [1 - 1/(N)]^{N} = e^{-1}$$

P12-8. A slotted Aloha network is working with maximum throughput when $G = 1$.

a. The probability of an empty slot can be found by using the Poisson distribution when $x = 0$:

$$p[\text{empty slot}] = p[0] = (G^0\, e^{-G})/0! = e^{-1} = 0.3679$$

b. To calculate the average number of empty slots before getting a non-empty slot, we can use the Geometric distribution, which tells us that if a probability of an event is p, the number of experiments we need to try before getting that event is $1/p$. The following shows that we should wait on average 2.72 slots before getting an empty slot.

$$n = 1 / p[\text{empty slot}] \approx 2.72$$

P12-9. We calculate the probability in each case:

a. After the first collision (k = 1), R has the range (0, 1). There are four possibilities (00, 01, 10, and 11), in which 00 means that both station have come up with R = 0, and so on. In two of these four possibilities (00 or 11), a collision may occur. Therefore the probability of collision is 2/4 or 50 percent.

b. After the second collision (k = 2), R has the range (0, 1, 2, 3). There are sixteen possibilities (00, 01, 02, 03, 10, 11, …, 33). In four of these sixteen possibilities (00, 11, 22, 33), a collision may occur. Therefore the probability of collision is 4/16 or 25 percent.

P12-10. We can first find the throughput for each station. Throughput of the network is the sum of the throughputs.

a. The throughput of each station is the probability that the station has a frame to send and other stations have no frame to send.

$S_A = p_A\,(1-p_B)\,(1-p_C) = 0.2 \times 0.7 \times 0.6 \approx 0.084$

$S_B = p_B\,(1-p_A)\,(1-p_C) = 0.3 \times 0.8 \times 0.6 \approx 0.144$

$S_B = p_C\,(1-p_A)\,(1-p_B) = 0.4 \times 0.8 \times 0.7 \approx 0.224$

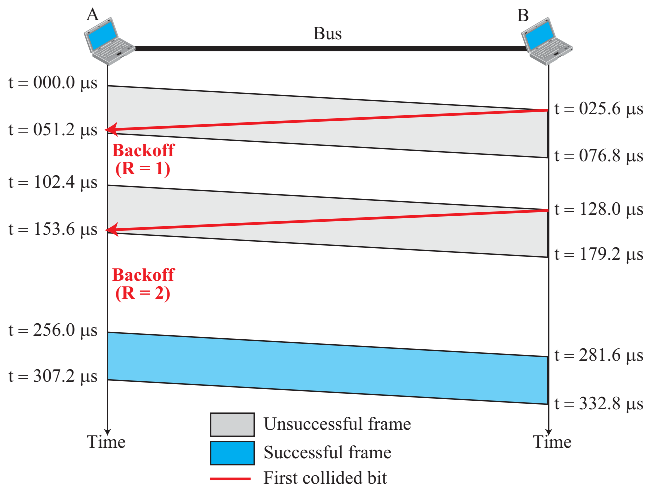
b. The throughput of the network is the sum of the throughputs.

$S = S_A + S_B + S_C \approx 0.452$

P12-11. The data rate (R) defines how many bits are generated in one second and the propagation speed (V) defines how many meters each bit is moving per second. Therefore, the number of bits in each meter $n_{b/m}$= R / V. In this case,

$$n_{b/m} = R / V = (100 \times 10^6 \text{ bits/s}) / (2 \times 10^8 \text{ m/s}) = 1/2 \text{ bits/m}.$$

P12-12. See the following figure.



P12-13. We first find the probability of success for each station in any slot (P_{SA}, P_{SB}, and P_{SC}). A station is successful in sending a frame in any slot if it has a frame to send and the other stations do not.

$$P_{SA} = (p_A)\,(1 - p_B)\,(1 - p_C) = (0.2)\,(1 - 0.3)\,(1 - 0.4) = 0.084$$

$P_{SB} = (p_B)\,(1 - p_A)\,(1 - p_C) = (0.3)\,(1 - 0.2)\,(1 - 0.4) = 0.144$

$P_{SC} = (p_C)\,(1 - p_A)\,(1 - p_B) = (0.4)\,(1 - 0.2)\,(1 - 0.3) = 0.224$

We then find the probability of failure for each station in any slot (P_{FA}, P_{FB}, and P_{FC}).

$P_{FA} = (1 - P_{SA}) = 1 - 0.084 = 0.916$

$P_{FB} = (1 - P_{SB}) = 1 - 0.144 = 0.856$

$P_{FC} = (1 - P_{SC}) = 1 - 0.224 = 0.776$

a. Probability of success for any frame in any slot is the sum of probabilities of success.

$$P[\text{success in first slot}] = P_{SA} + P_{SB} + P_{SC} = (0.084) + (0.144) + (0.224) \approx 0.452$$

b. Probability of success for the first time in the second slot is the product of failure in the first and success in the second.

$$P[\text{success in second slot for A}] = P_{FA} \times P_{SA} = (0.916) \times (0.084) \approx 0.077$$

c. Probability of success for the first time in the third slot is the product of failure in two slots and success in the third.

$$P[\text{success in third slot for C}] = P_{FC} \times P_{FC} \times P_{SC} = (0.776)^2 \times (0.224) \approx 0.135$$

P12-14. We need to check three properties: number of sequences in each chip, dot product of any pair of chips, and dot product of each chip with itself.

a. The number of sequences, $N = 4$, is a power of 2.

b. $[+1, -1, -1, +1] \bullet [-1, +1, +1, -1] = (-1) + (-1) + (-1) + (-1) = -4$. It should be 0.

The code does not pass the second properties; it is not orthogonal.

P12-15. We need to check three properties: the number of sequences (N) in each chip should be a power of 2, the dot product of any pair of chips should be 0, and the dot product of each chip with itself should be N.

a. The number of sequences, $N = 2$, is a power of 2.

b. $[+1, +1] \bullet [+1, -1] = (+1) + (-1) = 0$

c. $[+1, +1] \bullet [+1, +1] = (+1) + (+1) = 2 = N$
$[+1, -1] \bullet [+1, -1] = (+1) + (+1) = 2 = N$

The code passes the text for the three properties; it is orthogonal.

P12-16. The maximum efficiency in a pure Aloha network is 0.184.

$S_{max} = 0.184 \times 10 \text{ Mbps} = 1{,}840{,}000 \text{ bps}$

Maximum number of frames per second = 1,840,000 / 1000 = 1840

P12-17. We use the definition to find the throughput as S = 1 / (1 + 6.4a).

$$S = (T_{fr}) / (\text{channel is occupied for a frame})$$
$$S = (T_{fr}) / (k \times 2 \times T_p + T_{fr} + T_p)$$
$$S = 1 / [2e\,(T_p) / (T_{fr}) + (T_{fr}) / (T_{fr}) + T_p / (T_{fr})]$$
$$S = 1 / [2ea + 1 + a] = 1 / [1 + (2e + 1)a] = 1 / (1 + 6.4a)$$

P12-18. The probability of a free slot is the probability that a frame, generated from any station, is successfully transmitted. We discussed this in previous problems to be $Np(1 - p)^{N - 1}$.

a. The probability of getting a free slot is then $P_{free} = Np(1 - p)^{N - 1}$.

b. As we discussed in previous problems, the maximum occurs when $p = 1/N$ and the maximum of P_{free} is 1/e.

c. The probability that the jth slot is free is the probability that previous (j – 1) slots were not free and the next one is free. $P_{jth} = j\ P_{free}\ (1 - P_{free})$.

d. The average number of slots that need to be passed is the average of P_{jth} when j is between 0 and infinity: $n = \Sigma\ P_{jth}$. Since P_{jth} is less than one, the series converges and the result is $n = 1/P_{free}$. The result is somewhat intuitive because, if the probability of the success for an event is P, the average number of times that the event should be repeated before getting a successful result is 1/P.

e. Since P_{free} = 1/e when N is a very large number, the value n = e in this case. In other words, a station needs to wait 2.7182 slots before being able to send a frame.

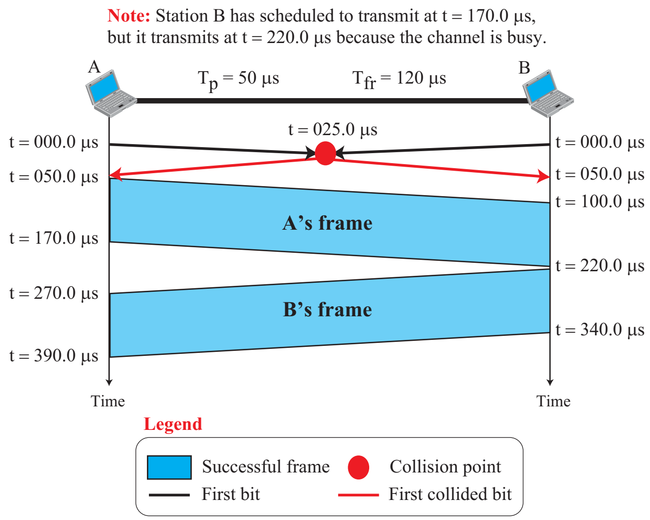
P12-19. Let L_m be the length of the medium in meters, V the propagation speed, R the data rate, and $n_{b/m}$ the number of bits that can fit in each meter of the medium (defined in the previous problems). We can then proceed as follows:

$$a = (T_p) / (T_{fr}) = (L_m / V) / (F_b / R) = (L_m / F_b) \times (R / V)$$

We have $(R / V) = n_{b/m} \rightarrow a = (L_m / F_b) \times (n_{b/m})$

Since $L_b = L_m \times n_{b/m} \rightarrow a = (L_b / F_b)$

P12-20. Assume both stations start transmitting at t = 0 µs. The collision occurs at the middle of the bus at time t = 25 µs. Both stations hear the collision at time t = 50 µs. Station A (using R = 0) senses the medium and finds it free. It retransmits at time t = 50 µs. The frame arrives successfully. Station B (using R = 1) is scheduled to transmit at time t = 50 + 120 = 170 µs. The channel, however, is busy from t = 50 µs to t = 50 + 50 + 120 = 220 µs. This means that when station B senses the channel at t = 170, it finds it busy. It needs to continuously sense the channel. At t = 220 µs, it finds the channel free. This shows the benefit of creating a random number to make the stations schedule at different times and avoid the collision.



P12-21. The propagation delay for this network is T_p = (2000 m) /(2×10^8 m/s) = 10 µs. The first bit of station A's frame reaches station B at (t_1 + 10 µs).

a. Station B has not received the first bit of A's frame at (t_1 + 10 µs). It senses the medium and finds it free. It starts sending its frame, which results in a collision.

b. At time (t_1 + 11 µs), station B has already received the first bit of station A's frame. It knows that the medium is busy and refrains from sending.

P12-22. In the previous problem, we defined the number of bits in one meter of the medium ($n_{b/m}$ = R/V), in which R is the data rate and V is the propagation speed in the medium. If the length of the medium in meters is L_m, then L_b = $L_m \times n_{b/m}$. In this case, we have

$$n_{b/m} = R / V = (1 \times 2^8 \text{ m / s}) / (2 \times 2^8 \text{ m / s}) = 1/2 \text{ m/s}$$

$$L_b = L_m \times \ n_{b/m} \ = 200 \times (1/2) = 200 \times (1/2) = 100 \text{ bits}$$

P12-23. The first bit of each frame needs at least 25 μs to reach its destination.

a. The frames collide because 2 μs before the first bit of A's frame reaches the destination, station B starts sending its frame. The collision of the first bit occurs at t = 24 μs.

b. The collision news reaches station A at time t = 24 μs + 24 μs = 48 μs. Station A has finished transmission at t = 0 + 40 = 40 μs, which means that the collision news reaches station A 8 μs after the whole frame is sent and station A has stopped listening to the channel for collision. Station A cannot detect the collision because $T_{fr} < 2 \times Tp$.

c. The collision news reaches station B at time t = 24 + 1 = 25 μs, just two μs after it has started sending its frame. Station B can detect the collision.

P12-24. For the sender to detect the collision, the last bit of the frame should not have left the station. This means that the transmission delay (T_{fr}) needs to be greater than 40 μs (20 μs + 20 μs) or the frame length should be at least 10 Mbps × 40 μs = 400 bits.

P12-25. Alice sends the code $(0110)_2$ and Bob sends the code $(1011)_2$. A 0 bit is changed to −1 and a 1 bit is changed to +1. In other words, Alice is sending d_A = (−1, +1, +1, −1) and Bob is sending d_B = (+1, −1, +1, +1). Each data item is multiplied by the corresponding code.