12.4.3 Summary

- Many formal protocols have been devised to handle access to a shared link .
- We categorize them into three groups: random access protocols, controlled access protocols, and channelization protocols .
- In random access or contention methods, no station is superior to another station and none is assigned the control over another .
- ALOHA allows multiple access (MA) to the shared medium.There are potential collisions in this arrangement .
- To minimize the chance of collision and, therefore, increase the performance, the CSMA method was developed .
- The chance of collision can be reduced if a station senses the medium before trying to use it .
- Carrier sense multiple access (CSMA) requires that each station first listen to the medium before sending .
- Carrier sense multiple access with collision detection (CSMA/CD) augments the CSMA algorithm to handle collision .
- In this method, a station monitors the medium after it sends a frame to see if the transmission was successful .
- If so, the station is finished .
- If, however, there is a collision, the frame is sent again .
- To avoid collisions on wireless networks, carrier sense multiple access with collision avoidance (CSMA/CA) was invented .
- Collisions are avoided through the use of three strategies: the interframe space, the contention window, and acknowledgments .
- In controlled access, 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 discussed three popular controlled-access methods: reservation, polling, and token passing .
- In the reservation access method, a station needs to make a reservation before sending data .
- Time is divided into intervals .
- In each interval, a reservation frame precedes the data frames sent in that interval .

- In the polling method, all data exchanges must be made through the primary device even when the ultimate destination is a secondary device .
- The primary device controls the link; the secondary devices follow its instructions .
- In the token-passing method, the stations in a network are organized in a logical ring .
- Each station has a predecessor and a successor .
- A special packet called a token circulates through the ring .
- 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 .
- We discussed three channelization protocols: FDMA, TDMA, and CDMA .
- In frequencydivision multiple access (FDMA), the available bandwidth is divided into frequency bands .
- Each station is allocated a band to send its data .
- In other words, each band is reserved for a specific station, and it belongs to the station all the time .
- In time-division multiple access (TDMA), the stations share the bandwidth of the channel in time .
- Each station is allocated a time slot during which it can send data .
- Each station transmits its data in its assigned time slot .
- In code-division multiple access (CDMA), the stations use different codes to achieve multiple access .
- CDMA is based on coding theory and uses sequences of numbers called chips .
- The sequences are generated using orthogonal codes such as the Walsh tables .

Q12-1. Which of the following is a random-access protocol?

a. CSMA/CD **b.** Polling **c.** TDMA

Q12-1. 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.

Q12-2. Which of the following is a controlled-access protocol?

a. Token-passing **b.** Polling **c.** FDMA

Polling is a Controlled Access Protocol.

Q12-3. Which of the following is a channelization protocol?

a. ALOHA **b.** Token-passing **c.** CDMA

Q12-3. 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.

Q12-4. Stations in a pure Aloha network send frames of size 1000 bits at the rate of 1 Mbps. What is the vulnerable time for this network?

Pure ALOHA:

For pure Aloha, the station can be send one after the other as soon as the before station completes. The Vulnerable time for pure ALOHA is, $2 \times T_{fr}$

Slotted ALOHA:

This is the advanced network to improve the efficiency of pure ALOHA, in which the time slot is divided into T_{fr} seconds and it sends the station forcibly at the beginning of

the time slot.

The vulnerable time for slotted ALOHA is, T_{fr}.

The transmission rate for the slotted ALOHA is,

$$
\begin{aligned}
T_{fr} &= \frac{1000 \text{ bits}}{1\text{mbps}} \text{ (where 1mbps = 1000kbps)} \\
&= \frac{1000 \text{ bits}}{1000} \\
&= 1\text{ms}
\end{aligned}
$$

$$T_{fr} = 1\text{ms}$$

The vulnerable time for slotted ALOHA is, T_{fr} = 1ms.

Q12-5. Stations in an slotted Aloha network send frames of size 1000 bits at the rate of 1 Mbps. What is the vulnerable time for this network?

Q12-5. The transmission rate of this network is T_{fr} = (1000 bits)/(1Mbps) = 1 ms. The vulnerable time in slotted Aloha is T_{fr} = 1ms.

Q12-6. In a pure Aloha network with $G = 1/2$, how is the throughput affected in each of the following cases?

a. G is increased to 1. **b.** G is decreased to 1/4.

For one frame transmission, Consider 'G' as an average number of frames generated by the system. Then the successful transmitted frame for pure ALOHA would be derived as,

The maximum throughput for pure ALOHA, $s_{max} = G \times e^{-2G}$

$$\text{For } G = \frac{1}{2},$$

$$s_{max} = (\frac{1}{2}) \times e^{-2\times0.5}$$

$$s_{max} = (\frac{1}{2}) \times e^{-1}$$

$$s_{max} = (\frac{1}{2}) \times 0.368$$

$$s_{max} = 0.184$$

$$= 18.4 \text{ (percent)}$$

a)

If 'G' is increased to '1' then the transmitted frames for pure ALOHA is,

$$s_{max} = G \times e^{-2\times G}$$

$$\text{For } G = 1,$$

$$s_{max} = 1 \times e^{-2\times1}$$

$$s_{max} = 1 \times e^{-2}$$

$$s_{max} = 1 \times 0.135$$

$$s_{max} = 0.135$$

$$= 13.5 \text{ (percent)}$$

b)

If 'G' is decreased to '1/4' then the transmitted frames for pure ALOHA is,

$$s_{max} = G \times e^{-2\times G}$$

$$\text{For } G = \frac{1}{4},$$

$$s_{max} = (\frac{1}{4}) \times e^{-2\times\frac{1}{4}}$$

$$s_{max} = (\frac{1}{4}) \times e^{-0.5}$$

$$s_{max} = 1/4 \times 0.606$$

$$s_{max} = 0.152$$

$$= 15.2 \text{ (percent)}$$

Q12-7. In a slotted Aloha network with $G = 1/2$, how is the throughput affected in each of the following cases?

a. G is increased to 1. **b.** G is decreased to 1/4.

Q12-7. 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%

Q12-8. To understand the uses of K in Figure 12.3, find the probability that a station can send immediately in each of the following cases:

a. After one failure. **b.** After three failures.

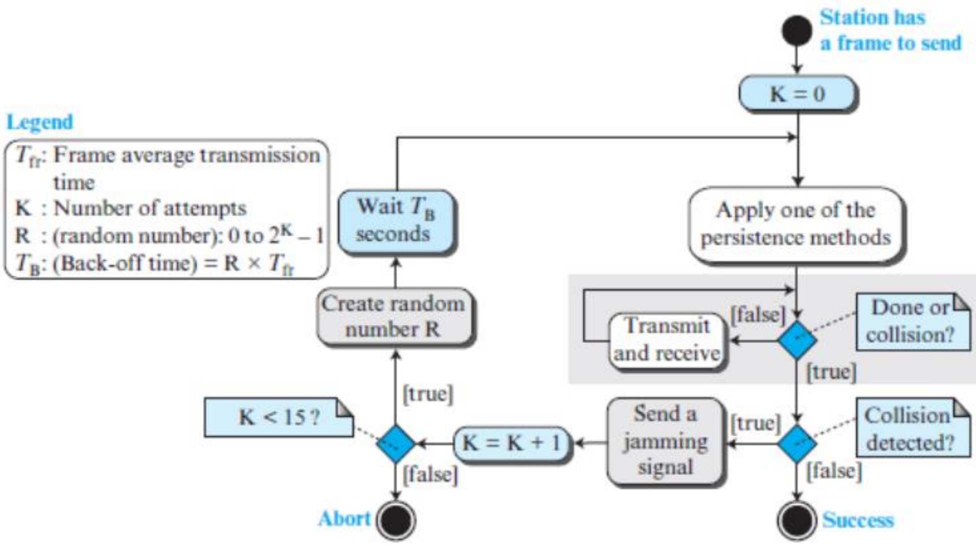


Figure 5.40 *Flow diagram for the CSMA/CD*

According to the value of 'K', the probability of sending the frames decreases when the failure increases.

To calculate the random number for K value is as follows,

$$R = 0 \text{ to } 2^k - 1$$

a)

The value of ‘R’ after one failure i.e. at (k=1) is,

$R = 0 \text{ to } 2^k - 1$

$R = 0 \text{ to } 2^1 - 1$

$R = 0 \text{ to } 2 - 1$

$R = 0 \text{ to } 1$

$R = 0 \text{ or } 1$

The probability for sending the frames immediately at K=0 the station gets, $\frac{1}{2^k}$

$$= \frac{1}{2^k}$$
$$= \frac{1}{2^1}$$
$$= \frac{1}{2}$$
$$= 50\ \%$$

b)

The value of ‘R’ after three failure i.e. at (k=3) is,

$R = 0 \text{ to } 2^k - 1$

$R = 0 \text{ to } 2^3 - 1$

$R = 0 \text{ to } 8 - 1$

$R = 0 \text{ to } 7$

$R = 0 \text{ or } 7$

The probability for sending the frames immediately at K=0 the station gets, $\frac{1}{2^k}$

$$= \frac{1}{2^k}$$
$$= \frac{1}{2^3}$$
$$= \frac{1}{8}$$
$$= 0.125$$
$$= 12.5\ \%$$

Q12-9. To understand the uses of *K* in Figure 12.13, find the probability that a station can send immediately in each of the following cases:

a. After one failure. **b.** After four failures.

Q12-9. 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%.

Q12-10. To understand the uses of *K* in Figure 12.15, find the probability that a station can send immediately in each of the following cases:

a. After two failures. **b.** After five failures.

Q12-11. Based on Figure 12.3, how do we interpret *success* in an Aloha network?

Q12-11. *Success* in an Aloha network is interpreted as receiving an acknowledgment for a frame.

Q12-12. Based on Figure 12.13, how do we interpret *success* in an Aloha network?

Q12-13. Based on Figure 12.15, how do we interpret *success* in an Aloha network?

Q12-13. *Success* in an CSMA/CA network is interpreted as receiving an acknowledgment for a frame.

Q12-14. Assume the propagation delay in a broadcast network is 5 μs and the frame transmission time is 10 μs.

a. How long does it take for the first bit to reach the destination?

b. How long does it take for the last bit to reach the destination after the first bit has arrived?

c. How long is the network involved with this frame (vulnerable to collision)?

Consider the given data.

The propagation delay for the broadcast network = $5\mu s$.

The frame transmission time = $10\mu s$.

a)

Calculate the time taken for the first bit to reach the destination using the below formula

Formula:

The time taken for the first bit to reach the destination = The propagation delay for the broadcast network.

The time taken for the first bit to reach the destination = $5\mu s$.

Therefore, the first bit takes $\boxed{5\mu s}$ to reach the destination.

b)

Calculate the time taken for the last bit to reach the destination after the first bit has arrived using the below formula

Formula:

The time taken for the last bit to reach the destination = The frame transmission time.

The time taken for the last bit to reach the destination = $10\mu s$.

Therefore, the last bit takes $\boxed{10\mu s}$ to reach the destination.

c)

Calculate the time taken by the network is involved with the frame using the below formula.

Formula:

The total time taken for the frame to collide within the network = The time taken for the first bit + The time taken for the last bit

The total time taken for the frame to collide within the network is,

$$= 5\ \mu s + 10\ \mu s$$
$$= 15\ \mu s$$

Therefore, the time taken by the network for the frame is $\boxed{15\mu s}$.

Q12-15. Assume the propagation delay in a broadcast network is 3 μs and the frame transmission time is 5 μs. Can the collision be detected no matter where it occurs?

Q12-15. 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.

Q12-16. Assume the propagation delay in a broadcast network is ~~6~~ 3 μs and the frame transmission time is ~~4~~ 5 μs. Can the collision be detected no matter where it occurs?

Before the last bit of the frame is transmitted the sender has to detect the collision for that frame. As the complete frame is sent already by the sender so it is not in a state listen for a collision anymore.

Given that,

Propagation delay for the broadcast network is, $3\mu s$

The time taken for a collision to occur near a destination is,

$= 2 \times 3\mu s$

$= 6\ \mu s$

No more collision will take place as the frame is received by the sender.

Q12-17. Explain why collision is an issue in random access protocols but not in controlled access protocols.

Q12-17. 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.

Q12-18. Explain why collision is an issue in random access protocols but not in channelization protocols.

In Random protocol none of the station has control over each other and it does not allow another station to send the data. In this the data can be sent through the procedure provided by the protocol and it decides whether the data can be send or not.

In Controlled access the two stations interact with each other and provide authentication by other station to send the data.

In channelization the bandwidth of a link is shared in frequency or time between the stations. It is a multiple access method.

The control access has control over the stations where as random access does not have that control. There is no predefined channel in channelization to transmit. This may create a collision.

Q12-19. Assume the propagation delay in a broadcast network is 5 μs and the frame transmission time is 10 μs.

a. How long does it take for the first bit to reach the destination?

b. How long does it take for the last bit to reach the destination after the first bit has arrived?

c. How long is the network involved with this frame (vulnerable to collision)?

Q12-19. 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.

Q12-20. Assume the propagation delay in a broadcast network is ~~10~~ 5 μs and the frame transmission time is ~~5~~ μs. 10 us

a. How long does it take for the first bit to reach the destination?

b. How long does it take for the last bit to reach the destination after the first bit has arrived?

c. How long is the network involved with this frame (vulnerable to collision)?

Consider the given data.

The propagation delay for the broadcast network = $5\mu s$.

The frame transmission time = $10\mu s$.

a)

Calculate the time taken for the first bit to reach the destination using the below formula

Formula:

The time taken for the first bit to reach the destination = The propagation delay for the broadcast network.

The time taken for the first bit to reach the destination = $5\mu s$.

Therefore, the first bit takes $\boxed{5\mu s}$ to reach the destination.

b)

Calculate the time taken for the last bit to reach the destination after the first bit has arrived using the below formula

Formula:

The time taken for the last bit to reach the destination = The frame transmission time.

The time taken for the last bit to reach the destination = $10\mu s$.

Therefore, the last bit takes $\boxed{10\mu s}$ to reach the destination.

c)

Calculate the time taken by the network is involved with the frame using the below formula.

Formula:

The total time taken for the frame to collide within the network = The time taken for the first bit + The time taken for the last bit

The total time taken for the frame to collide within the network is,

$= 5\ \mu s + 10\ \mu s$
$= 15\ \mu s$

Therefore, the time taken by the network for the frame is $\boxed{15 \mu s}$.

Q12-21. List some strategies in CSMA/CA that are used to avoid collision.

Q12-21. 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.

Q12-22. In a wireless LAN, station A is assigned IFS = 5 milliseconds and station B is assigned IFS = 7 milliseconds. Which station has a higher priority? Explain.

- In this strategy a station when identifies the transmission link is idle. Before starting a communication it waits for a specific amount of time.
- This time frame is called as Inter-frame space(IFS).
- The station waits for this duration because in case if any other station has already started communication, the data will reach other stations within this time period thus avoiding collision.
- When multiple stations are present each station is allocated with different IFS time frames, the station with lowest IFS time frame has high priority.
- Low IFS time means less waiting time for the station thus indicating the tasks of such station are more important had to be finished early.

- From that station A IFS time frame is 5, station B IFS time frame is 7.
- The station with less IFS time frame has more priority.

Therefore station A has higher priority than station B.

Q12-23. There is no acknowledgment mechanism in CSMA/CD, but we need this mechanism in CSMA/CA. Explain the reason.

Q12-23. 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.

Q12-24. What is the purpose of NAV in CSMA/CA?

• NAV means network allocation vector it is used for sensing a carrier on the transmission medium.

• This vector holds a value this value is decremented periodically when the data is being transmitted; when the value is '0' the channel is idle.

• NAV is a mechanism used in CSMA/CA to detect whether a channel is busy or idle, as in wireless networks the stations cannot sense other stations NAV is used to detect transmission on a channel.

• NAV duration is mentioned in the MAC layer header this value decrements periodically, a station which wants to transmit data reads this value in the MAC header, if the value is not zero the station differs its transmission until NAV value is '0'.

12.5.3 Problems

P12-1. To formulate the performance of a multiple-access network, we need a mathematical model. When the number of stations in a network is very large, the Poisson distribution, $p[x] = (e^{-\lambda} \times \lambda^{x})/(x!)$, is used. In this formula, $p[x]$ is the probability of generating x number of frames in a period of time and λ is the average number of generated frames during the same period of time. Using the Poisson distribution:

a. Find the probability that a pure Aloha network generates x number of frames during the vulnerable time. Note that the vulnerable time for this network is two times the frame transmission time (T_{fr}).

b. Find the probability that a slotted Aloha network generates x number of frames during the vulnerable time. Note that the vulnerable time for this network is equal to the frame transmission time (T_{fr}).

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. In the previous problem, we used the Poisson distribution to find the probability of generating x number of frames, in a certain period of time, in a pure or slotted Aloha network as $p[x] = (e^{-\lambda} \times \lambda^x)/(x!)$. In this problem, we want to find the probability that a frame in such a network reaches its destination without colliding with other frames. For this purpose, it is simpler to think that we have G stations, each sending an average of one frame during the frame transmission time (instead of having N frames, each sending an average of G/N frames during the same time). Then, the probability of success for a station is the probability that no other station sends a frame during the vulnerable time.

a. Find the probability that a station in a pure Aloha network can successfully send a frame during a vulnerable time.

b. Find the probability that a station in a slotted Aloha network can successfully send a frame during a vulnerable time.

a) Given that the probability of a pure Aloha network generating 'x' frames during the vulnerable time is $p(x) = \frac{(e^{-\lambda} * \lambda^x)}{x!}$

• The probability of success of one station sending a frame that is (N-1) or 'G' stations generating 'x' frames are not sending any frames during the vulnerable time indicates that x=0.

• Therefore the probability that a station in a pure Aloha network can send a frame successfully without collision during the vulnerable time is

$p(S) = \frac{(e^{-\lambda} * \lambda^0)}{0!}$ = $e^{-\lambda}$, where $\lambda = 2G$ as in pure Aloha systems vulnerable time is twice the frame transmission time $2*T_{fr}$, where T_{fr}= G.

$p(S) = e^{-2G}$

b) Given that the probability of a Slotted Aloha network generating 'x' frames during the vulnerable time is $p(x) = \frac{(e^{-\lambda} * \lambda^x)}{x!}$

• The probability of success of one station sending a frame that is (N-1) or 'G' stations generating 'x' frames are not sending any frames during the vulnerable time indicates that x=0.

• Therefore the probability that a station in a slotted Aloha network can send a frame successfully without collision during the vulnerable time is

$p(S) = \frac{(e^{-\lambda} * \lambda^0)}{0!}$ = $e^{-\lambda}$, where $\lambda = G$ as in slotted Aloha systems vulnerable time is twice the frame transmission time T_{fr}, where T_{fr}= G.

$p(S) = e^{-G}$

P12-3. In the previous problem, we found that the probability of a station (in a G-station network) successfully sending a frame in a vulnerable time is $P = e^{-2G}$ for a pure Aloha and $P = e^{-G}$ for a slotted Aloha network. In this problem, we want to find the throughput of these networks, which is the probability that any station (out of G stations) can successfully send a frame during the vulnerable time.

a. Find the throughput of a pure Aloha network.

b. Find the throughput of a slotted Aloha network.

P12-3. The throughput for each network is S = G × P[success for a frame].

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

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

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

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

P12-4. In the previous problem, we showed that the throughput is $S = Ge^{-2G}$ for a pure Aloha network and $S = Ge^{-G}$ for a slotted Aloha network. In this problem, we want to find the value of G in each network that makes the throughput maximum and find the value of the maximum throughput. This can be done if we find the derivative of S with respect to G and set the derivative to zero.

a. Find the value of G that makes the throughput maximum, and find the value of the maximum throughput for a pure Aloha network.

b. Find the value of G that makes the throughput maximum, and find the value of the maximum throughput for a slotted Aloha network.

Consider that,

Throughput for a pure aloha network, $S = G \times e^{-2G}$

Throughput for a slotted aloha network, $S = G \times e^{-G}$

Now to find the maximum throughput for both pure and slotted aloha network we need to differentiate it with respect to 'G' and equal the differentiation to zero.

a)

By using the optimum loading value of 'G' the maximum throughput for a pure aloha network can be obtained. A lower value of 'G' reduces the load and a higher value of 'G' inflates excessive collision. Now differentiate it with respect to 'G' and equal the differentiation to zero.

Throughput for a pure aloha network, $S = G \times e^{-2G}$

$$\frac{dS}{dG} = \frac{dS}{dG}(G) \times e^{-2G} + G \times \frac{dS}{dG}(e^{-2G})$$

$$\frac{dS}{dG} = 1 \times e^{-2G} + G \times (-2) \times e^{-2G} = e^{-2G} - 2Ge^{-2G}$$

now substitute, $\frac{dS}{dG} = 0$

$$= e^{-2G} - 2Ge^{-2G}$$

To get the value of 'G' for maximum throughput let us consider half the frame per frame time.

$$= e^{-2G} - 2Ge^{-2G} = e^{-2G}(1-2) = \frac{1}{2}e^{-2G} = \frac{1}{2}e^{-2\times\frac{1}{2}} = \frac{1}{2}e^{-1}$$

$$= \frac{1}{2} \times 0.368 = 0.183 = 18.3\%$$

b)

By using the optimum loading value of 'G' the maximum throughput for a slotted aloha network can be obtained. Now differentiate it with respect to 'G' and equal the differentiation to zero.

Throughput for a pure aloha network, $S = G \times e^{-G}$

$$\frac{dS}{dG} = \frac{dS}{dG}(G) \times e^{-G} + G \times \frac{dS}{dG}(e^{-G})$$

$$\frac{dS}{dG} = 1 \times e^{-G} + G \times (-1) \times e^{-G} = e^{-G} - Ge^{-G}$$

$$\text{now substitute, } \frac{dS}{dG} = 0$$

$$= e^{-G} - Ge^{-G}$$

To get the value of 'G' for maximum throughput let us consider one frame per frame time.

$$0 = e^{-G} - Ge^{-G} = e^{-G}(1-G)$$

$$0 = 1 \times e^{-1}$$

$$= \frac{1}{e} = \frac{1}{2.718} = 0.368 = 36.8\%$$

P12-5. A multiple access network with a large number of stations can be analyzed using the Poisson distribution. When there is a limited number of stations in a network, we need to use another approach for this analysis. In a network with N stations, we assume that each station has a frame to send during the frame transmission time (T_{fr}) with probability p. In such a network, a station is successful in sending its frame if the station has a frame to send during the vulnerable time and no other station has a frame to send during this period of time.

a. Find the probability that a station in a pure Aloha network can successfully send a frame during the vulnerable time.

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

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

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).

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

P12-6. In the previous problem, we found the probability of success for a station to send a frame successfully during the vulnerable time. The throughput of a network with a limited number of stations is the probability that any station (out of *N* stations) can send a frame successfully. In other words, the throughput is the sum of *N* success probabilities.

a. Find the throughput of a pure Aloha network.

b. Find the throughput of a slotted Aloha network.

a) Given that the throughput of a pure Aloha network is the probability of transmitting a frame N successful times or sum of N success probabilities.

• Step1: calculate the probability of successfully sending a frame.

• Let the probability of a station to send a frame is 'p'. then the probability that a station is not sending a frame is '1-p'

• A frame can be sent successfully only when no other station is sending another frame.

• The probability that N-1 stations are not sending a frame is $(1-p)^{N-1}$

• Vulnerable time is amount of time between two successive transmissions. In pure Aloha systems vulnerable time is twice the frame transmission time.

• Therefore the probability that one station is successfully sending a frame in the given vulnerable time is $p*(1-p)^{2(N-1)}$

• Step2: calculate the throughput of a pure Aloha network

• Throughput of a pure Aloha network is the sum of probability of transmitting frame N successful times.

• If P is the probability of sending a frame by one station then the throughput = N*P = $N*p\,(1-p)^{2(N-1)}$ = $N\,p\,(1-p)^{2(N-1)}$

b) Given that the throughput of a slotted Aloha network is the probability of transmitting a frame N successful times or sum of N success probabilities.

- Step1: calculate the probability of successfully sending a frame.
- Let the probability of a station to send a frame is ‘p’. then the probability that a station is not sending a frame is ‘1-p’
- A frame can be sent successfully only when no other station is sending another frame.
- The probability that N-1 stations are not sending a frame is $(1-p)^{N-1}$
- Vulnerable time is amount of time between two successive transmissions.
- Therefore the probability that one station is successfully sending a frame in the given vulnerable time is $p*(1-p)^{(N-1)}$
- Step2: calculate the throughput of a slotted Aloha network
- Throughput of a slotted Aloha network is the sum of probability of transmitting frame N successful times.
- If P is the probability of sending a frame by one station then the throughput = N*P = $N*p(1-p)^{(N-1)}$ = $Np(1-p)^{(N-1)}$

P12-7. In the previous problem, we found the throughputs of a pure and a slotted Aloha network as $S = Np\ (1-p)^{2(N-1)}$ and $S = Np\ (1-p)^{(N-1)}$ respectively. In this problem we want to find the maximum throughput with respect to p.

a. Find the value of p that maximizes the throughput of a pure Aloha network, and calculate the maximum throughput when N is a very large number.

b. Find the value of p that maximizes the throughput of a slotted Aloha network, and calculate the maximum throughput when N is a very large number.

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:

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

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

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

P12-8. There are only three active stations in a slotted Aloha network: A, B, and C. Each station generates a frame in a time slot with the corresponding probabilities $p_A = 0.2$, $p_B = 0.3$, and $p_C = 0.4$ respectively.

a. What is the throughput of each station?

b. What is the throughput of the network?

Probability for each station A, B and C is given as,

$$P_A = 0.2$$
$$P_B = 0.3$$
$$P_C = 0.4$$

Suppose if a station has a frame to send and the other frames do not have frames then

$$P_{SA} = P_A \times (1 - P_B) \times (1 - P_C) = 0.2 \times (1 - 0.3) \times (1 - 0.4) = 0.2 \times 0.7 \times 0.6 = 0.084$$
$$P_{SB} = P_B \times (1 - P_A) \times (1 - P_C) = 0.3 \times (1 - 0.2) \times (1 - 0.4) = 0.3 \times 0.8 \times 0.6 = 0.144$$
$$P_{SC} = P_C \times (1 - P_A) \times (1 - P_B) = 0.4 \times (1 - 0.2) \times (1 - 0.3) = 0.4 \times 0.8 \times 0.7 = 0.224$$

Probability for the failure frames is given as,

$$P_{FA} = (1 - P_{SA}) = 1 - 0.084 = 0.916$$
$$P_{FB} = (1 - P_{SB}) = 1 - 0.144 = 0.856$$
$$P_{FC} = (1 - P_{SC}) = 1 - 0.224 = 0.776$$

a)

Probability to find the frames sent to the first slot is the sum of probability of success frames,

$$P_{SA} + P_{SB} + P_{SC} = 0.084 + 0.144 + 0.224 = 0.452$$

b)

Probability for sending a successful frame in the second slot is calculated as,

$$P_{SB} = P_{FA} * P_{SA} = 0.916 \times 0.084 = 0.077$$

c)

Probability for sending a successful frame in the third slot is calculated as,

$$= P_{FC} \times P_{FC} \times P_{SC} = 0.776 \times 0.776 \times 0.224 = 0.135$$

P12-9. There are only three active stations in a slotted Aloha network: A, B, and C. Each station generates a frame in a time slot with the corresponding probabilities $p_A = 0.2$, $p_B = 0.3$, and $p_C = 0.4$ respectively.

a. What is the probability that any station can send a frame in the first slot?

b. What is the probability that station A can successfully send a frame for the first time in the second slot?

c. What is the probability that station C can successfully send a frame for the first time in the third slot?

P12-9. 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.

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

P12-10. A slotted Aloha network is working with maximum throughput.

a. What is the probability that a slot is empty?

b. How many slots, *n*, on average, should pass before getting an empty slot?

Formula:

The maximum throughput for the Aloha network at G=1 is given as,

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

Formula to calculate n slots on an average before getting an empty slot is, $\frac{1}{P[x]}$

a)

At x=0, the empty slot for an Aloha network can be found using the Poisson distribution,

$$P[x] = \frac{(G^x \times e^{-G})}{x!}$$

$$P[0] = \frac{(G^0 \times e^{-G})}{0!}$$

$$p[0] = \frac{e^{-1}}{1}$$

$$p[0] = e^{-1} = 0.3679$$

b)

By using the geometric distribution we can calculate the average slots before getting an empty slot.

Assume the probability of an event is 'P', and the number of trials made before getting an event is $\frac{1}{P}$.

Formula to calculate n slots on an average before getting an empty slot is, $\frac{1}{P[x]}$

$$\frac{1}{p[x]} = \frac{1}{p[0]} = \frac{1}{0.3679} = 2.718 = 2.72$$

P12-11. One of the useful parameters in a LAN is the number of bits that can fit in one meter of the medium ($n_{b/m}$). Find the value of $n_{b/m}$ if the data rate is 100 Mbps and the medium propagation speed is 2×10^8 m/s.

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. Another useful parameter in a LAN is the bit length of the medium (L_b), which defines the number of bits that the medium can hold at any time. Find the bit length of a LAN if the data rate is 100 Mbps and the medium length in meters (L_m) for a communication between two stations is 200 m. Assume the propagation speed in the medium is 2×10^8 m/s.

Formula:

The number of bits in one meter of the medium is, $n_{\frac{b}{m}} = \frac{R}{V}$

Length of the medium $l_b = l_m \times n_{\frac{b}{m}}$

To find the bit length of the LAN, first we need to find the number of bits in one meter of the medium.

The number of bits in one meter of the medium is, $n_{\frac{b}{m}} = \frac{R}{V}$

$$= \frac{100 \times 2^6}{2 \times 2^8}$$
$$= \frac{1}{2} b/s$$

Given communication between the two stations are 200 meters and the propagation speed is $2 \times 10^8 m/s$.

Now the Length of the medium $l_b = l_m \times n_{\frac{b}{m}}$

$$= 200 \times \frac{1}{2}$$
$$= 100 \text{ bits}$$

P12-13. We have defined the parameter a as the number of frames that can fit the medium between two stations, or $a = (T_p)/(T_{fr})$. Another way to define this parameter is $a = L_b/F_b$, in which L_b is the bit length of the medium and F_b is the frame length of the medium. Show that the two definitions are equivalent.

P12-13. 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 $L_b = L_m \times n_{b/m} \rightarrow a = (L_b / F_b)$

P12-14. In a bus CSMA/CD network with a data rate of 10 Mbps, a collision occurs 20 μs after the first bit of the frame leaves the sending station. What should the length of the frame be so that the sender can detect the collision?

Given data rate for CSMD network $= 10Mbps$

Collision after the first bit of the frame $= 20\mu s$

To detect the collision at the last bit of the frame for the sender, the last bit should leave the station.

The transmission delay should be $40\mu s(20\mu s + 20\mu s)$

That is, $T_{fr} = 40\mu s$

Then the length of the frame $= 10 \times 40\mu s$

$= 400bits$

The sender can detect the collision at 400 bits.

P12-15. Assume that there are only two stations, A and B, in a bus CSMA/CD network. The distance between the two stations is 2000 m and the propagation speed is 2×10^8 m/s. If station A starts transmitting at time t_1:

a. Does the protocol allow station B to start transmitting at time $t_1 + 8$ μs? If the answer is yes, what will happen?

b. Does the protocol allow station B to start transmitting at time $t_1 + 11$ μs? If the answer is yes, what will happen?

P12-15. The propagation delay for this network is $T_p = (2000 \text{ m}) / (2 \times 10^8 \text{ m/s}) = 10$ 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.

P12-16. There are only two stations, A and B, in a bus 1-persistence CSMA/CD network with $T_p = 25.6\ \mu s$ and $T_{fr} = 51.2\ \mu s$. Station A has a frame to send to station B. The frame is unsuccessful two times and succeeds on the third try. Draw a time line diagram for this problem. Assume that the R is 1 and 2 respectively and ignore the time for sending a jamming signal (see Figure 12.13).

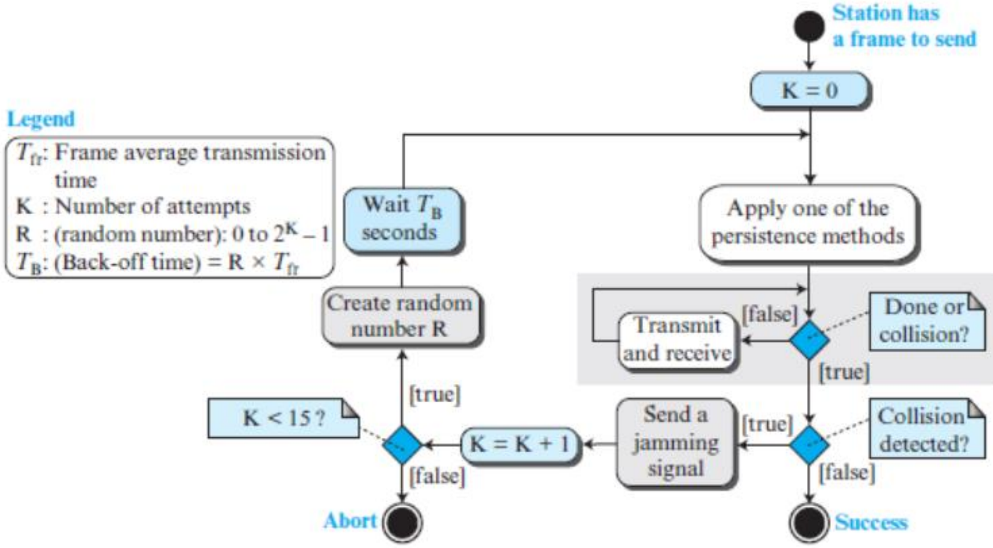
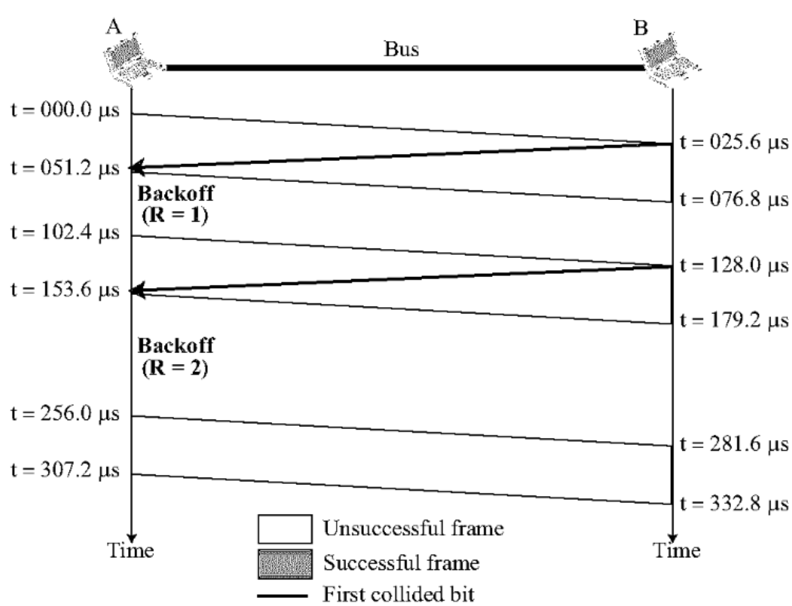


Figure 5.40 *Flow diagram for the CSMA/CD*

Ans

P5-39. See the following figure.



P12-17. To understand why we need to have a minimum frame size $T_{fr} = 2 \times T_p$ in a CDMA/CD network, assume we have a bus network with only two stations, A and B, in which $T_{fr} = 40$ μs and $T_p = 25$ μs. Station A starts sending a frame at time $t = 0.0$ μs and station B starts sending a frame at $t = 23.0$ μs. Answer the following questions:

a. Do frames collide?

b. If the answer to part *a* is yes, does station A detect collision?

c. If the answer to part *a* is yes, does station B detect collision?

P12-17. 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.

P12-18. In a bus 1-persistence CSMA/CD with $T_p = 50$ µs and $T_{fr} = 120$ µs, there are two stations, A and B. Both stations start sending frames to each other at the same time. Since the frames collide, each station tries to retransmit. Station A

comes out with $R = 0$ and station B with $R = 1$. Ignore any other delay including the delay for sending jamming signals. Do the frames collide again? Draw a time-line diagram to prove your claim. Does the generation of a random number help avoid collision in this case?

Estimate the transmission time is t=0µs for both stations A and B and collision occurs at time $t = 25\mu s$. Collision heard by the station at time, $t = 50\mu s$.

At R=0 the station finds the free medium to transmit and it retransmit at time $t = 50\mu s$ and the frame arrives successfully at station A.

At R=1, the station B transmit the frame at time,

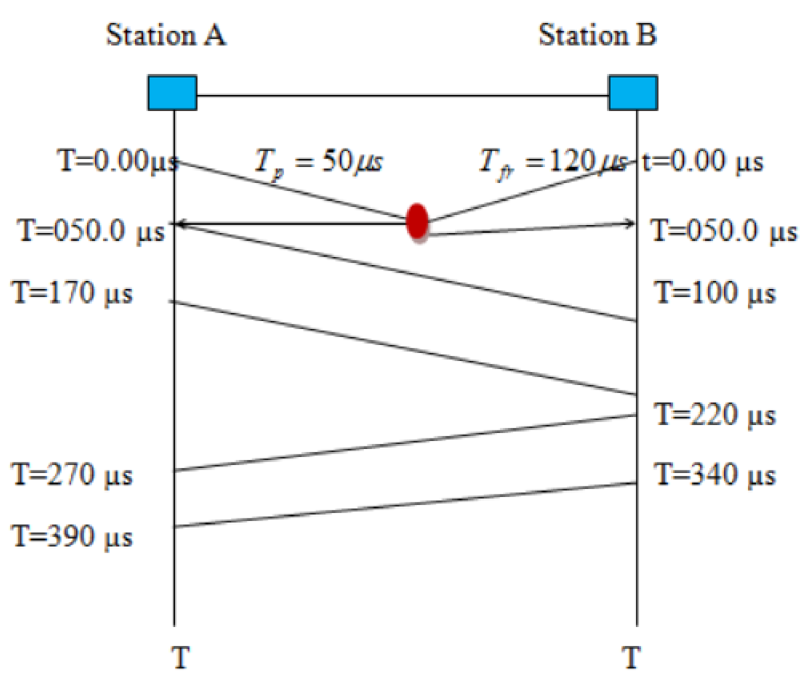
$t = 50 + 120 = 170\mu s$

The busy channels start from time,

$t = 50\mu 0 \text{ to } t = 50 + 50 + 120 = 220\mu 2$

At time $t = 170\mu s$ the channels will be busy at station B and it will be free at time $t = 220\mu s$

By generating random number we can avoid collisions between the frames. Below is the time line diagram which shows the schedules for different time line to avoid collision.



P12-19. The random variable R (Figure 12.13) is designed to give stations different delays when a collision has occurred. To alleviate the collision, we expect that different stations generate different values of R. To show the point, find the probability that the value of R is the same for two stations after

a. the first collision. **b.** the second collision.

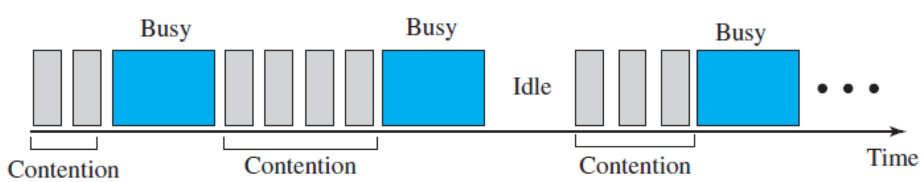
P12-19. We calculate the probability in each case:

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.

P12-20. Assume we have a slotted CSMA/CD network. Each station in this network uses a contention period, in which the station contends for access to the shared channel before being able to send a frame. We assume that the contention period is made of contention slots. At the beginning of each slot, the station senses the channel. If the channel is free, the station sends its frame; if the channel is busy, the station refrains from sending and waits until the beginning of the next slot. In other words, the station waits, on average, for *k* slots before sending its frame, as shown in Figure 12.30. Note that the channel is either in the contention state, the transmitting state, or the idle state (when no station has a frame to send). However, if *N* is a very large number, the idle state actually disappears.

Figure 12.30 *Problem P12-20*



a. What is the probability of a free slot (P_{free}) if the number of stations is *N* and each station has a frame to send with probability *p*?

b. What is the maximum of this probability when *N* is a very large number?

c. What is the probability that the *j*th slot is free?

d. What is the average number of slots, *k*, that a station should wait before getting a free slot?

e. What is the value of *k* when *N* (the number of stations) is very large?

The probability for a successfully transmitted frame is the probability of a free slot.

a)

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

b)

The maximum probability when N is large number, when $p = \frac{1}{n}$

So, maximum of $P_{free} = \frac{1}{e}$

c)

The probability for the j^{th} slot is not free is (j-1).

The probability that the j^{th} slot is free is the probability that the (j-1) slot is not free would be represented as,

$$p_{j^{th}} = jp_{free}(1 - p_{free})$$

d)

When 'j' value is between 0 and infinity $\sum p_{jth}$. The average number of slots that should be passed is the average of $p_{j^{th}}$.

Since the $p_{j^{th}}$ value is less than one the result of n would be, $n = \frac{1}{p_{free}}$

Consider the probability for success event is 'P'. Before getting a successful frame the average number of times the event should be repeated is, $\frac{1}{p}$

e)

Since we know that the value of $P_{free} = \frac{1}{e}$ where n is very large number then n=e, which means before sending a frame the station needs to wait for 2.718 slots.

P12-21. Although the throughput calculation of a CSMA/CD is really involved, we can calculate the maximum throughput of a slotted CSMA/CD with the specification we described in the previous problem. We found that the average number of contention slots a station needs to wait is $k = e$ slots. With this assumption, the throughput of a slotted CSMA/CD is

$$S = (T_{fr})/(\text{time the channel is busy for a frame})$$

The time the channel is busy for a frame is the time to wait for a free slot plus the time to transmit the frame plus the propagation delay to receive the good news about the lack of collision. Assume the duration of a contention slot is $2 \times (T_p)$ and $a = (T_p)/(T_{fr})$. Note that the parameter a is the number of frames that occupy the transmission media. Find the throughput of a slotted CSMA/CD in terms of the parameter a.

P12-21. We use the definition to find the throughput as $S = 1 / (1 + 6.4a)$.

$$S = (T_{fr}) / (\text{channel is occupied for a frame})$$

$$S = (T_{fr}) / (k \times 2 \times T_p + T_{fr} + T_p)$$

$$S = 1 / [2e\,(T_p) / (T_{fr}) + (T_{fr}) / (T_{fr}) + T_p / (T_{fr})]$$

$$S = 1 / [2ea + 1 + a] = 1 / [1 + (2e + 1)a] = 1 / (1 + 6.4a)$$

P12-22. We have a pure ALOHA network with a data rate of 10 Mbps. What is the maximum number of 1000-bit frames that can be successfully sent by this network?

The maximum efficiency of a pure Aloha network is, 0.184

Formula to find the maximum efficiency, $S_{max} = \text{Maximum efficiency} \times \text{Data Rate}$

Given data rate CDMA/CD network is, 10Mbps

$$S_{max} = 0.184 \times 10^7 \text{ bps}$$
$$= 1840000\text{bps}$$

$$\text{Maximum number of frames per second} = \frac{1840000}{1000}$$
$$= 1840$$

P12-23. Check to see if the following set of chips can belong to an orthogonal system.

[+1, +1] and [+1, −1]

P12-23. 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.

P12-24. Check to see if the following set of chips can belong to an orthogonal system.

$[+1, +1, +1, +1]$, $[+1, -1, -1, +1]$, $[-1, +1, +1, -1]$, $[+1, -1, -1, +1]$

- For a given set of chips to be orthogonal the following properties must be satisfied.
- In CDMA coding technique, each user is represented by a code, and the number of elements in each code represents the number of users or stations.
- The number of elements in the code must be a power of 2.
- In CDMA coding The dot product of a code with any other code in the given code set is '0' That is $C_i * C_j = 0$ where i != j
- The dot product of a code with itself gives the number of elements in the code $C_i * C_j = N$ where i== j and N is the number of elements.

- Consider chip sets are [+1 +1 +1 +1], [+1 -1 -1 +1], [-1 +1 +1 -1], [+1 -1 -1 +1]
- The number of elements in each code is 4, it is a power of 2.
- The dot product of any two chip sets is

[-1 +1 +1 -1]*[+1 -1 -1+1] = [-1-1-1-1]= -4 != 0

The dot product of this set is violating the condition3.

- Therefore the given chip sets are not orthogonal.

P12-25. Alice and Bob are experimenting with CSMA using a W_2 Walsh table (see Figure 12.29). Alice uses the code [+1, +1] and Bob uses the code [+1, −1]. Assume that they simultaneously send a hexadecimal digit to each other. Alice sends $(6)_{16}$ and Bob sends $(B)_{16}$. Show how they can detect what the other person has sent.

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. The signal generated by Alice and Bob is shown below.