Chapter-01

Circuit Switching

Question List

1. What is the maximum number of connections that can be ongoing in the network at any one time?

2. Suppose that these maximum number of connections are all ongoing. What happens when another call connection request arrives to the network, will it be accepted? Answer Yes or No

3. Suppose that every connection requires 2 consecutive hops, and calls are connected clockwise. For example, a connection can go from A to C, from B to D, from C to A, and from D to B. With these constraints, what is the is the maximum number of connections that can be ongoing in the network at any one time?

4. Suppose that 15 connections are needed from A to C, and 12 connections are needed from B to D. Can we route these calls through the four links to accommodate all 27 connections? Answer Yes or No.

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Solution:

1. The maximum number of connections that can be ongoing at any one time is the sum of all circuits, which happens when 15 connections go from A to B, 10 connections go from B to C, 19 connections go from C to D, and 12 connections go from D to A. This sum is 56.

2. No, it will be blocked because there are no free circuits.

3. There can be a maximum of 22 connections. Consider routes A->C and C->A, sum the bottleneck links, consider any leftover capacity that would allow for B->D and D->B connections, and compare that value to the equivalent of B->D and D->B.

4. Using our answer from question 4, the sum of our needed connections is 27, and we have 22 available connections, so it is NOT possible.

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Quantitative Comparison of Packet Switching and Circuit Switching

Question List

1. When circuit switching is used, what is the maximum number of users that can be supported?

2. Suppose packet switching is used. If there are 9 packet-switching users, can this many users be supported under circuit-switching? Yes or No.

3. Suppose packet switching is used. What is the probability that a given (specific) user is transmitting, and the remaining users are not transmitting?

4. Suppose packet switching is used. What is the probability that one user (*any* one among the 9 users) is transmitting, and the remaining users are not transmitting?

5. When one user is transmitting, what fraction of the link capacity will be used by this user? Write your answer as a decimal.

6. What is the probability that any 6 users (of the total 9 users) are transmitting and the remaining users are not transmitting?

7. What is the probability that *more* than 5 users are transmitting?

Solution:

1. When circuit switching is used, at most 5 users can be supported. This is because each circuit-switched user must

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be allocated its 20 Mbps bandwidth, and there is 100 Mbps of link capacity that can be allocated.

2. No. Under circuit switching, the 9 users would each need to be allocated 20 Mbps, for an aggregate of 180 Mbps - more than the 100 Mbps of link capacity available.

3. The probability that a given (specific) user is busy transmitting, which we'll denote p, is just the fraction of time it is transmitting, i.e. 0.1. The probability that one specific other user is not busy is (1-p), and so the probability that all of the other N_{ps}-1 users are not transmitting is $(1-p)^{N_{ps}-1}$. Thus the probability that one specific user is transmitting and the remaining users are not transmitting is $p*(1-p)^{N_{ps}-1}$, which has the numerical value of 0.043.

4. The probability that exactly one (any one) of the N_{ps} users is transmitting is N_{ps} times the probability that a given specific user is transmitting and the remaining users are not transmitting. The answer is thus $N_{ps} * p * (1-p)^{N_{ps}-1}$, which has the numerical value of 0.39.

5. This user will be transmitting at a rate of 20 Mbps over the 100 Mbps link, using a fraction 0.2 of the link's capacity when busy.

6. The probability that 6 specific users of the total 9 users are transmitting and the other 3 users are idle is $p^6(1-p)^3$. Thus the probability that any 4 of the 7 users are busy is

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choose(9, 6) * $p^6(1\text{-}p)^3$, where choose(9, 6) is the (9, 6) coefficient of the binomial distribution). The numerical value of this probability is 6.12E-5.

7. The probability that more than 5 users of the total 9 users are transmitting is $\Sigma_{i=6,9}$ choose(9, i) * $p^i(1\text{-}p)^{9-i}$. The numerical value of this probability is 6.42E-5. Note that 5 is the maximum number of users that can be supported using circuit switching. With packet switching, nearly twice as many users (9) are supported with a small probability that more than 5 of these packet-switching users are busy at the same time.

Car - Caravan Analogy:

Question List

1. Once a car enters service at the tollbooth, how long does it take until it leaves service?

2. How long does it take for the entire caravan to receive service at the tollbooth (that is the time from when the first car enters service until the last car leaves the tollbooth)?

3. Once the first car leaves the tollbooth, how long does it take until it arrives at the next tollbooth?

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4. Once the last car leaves the tollbooth, how long does it take until it arrives at the next tollbooth?

5. Once the first car leaves the tollbooth, how long does it take until it enters service at the next tollbooth?

6. Are there ever two cars in service at the same time, one at the first toll booth and one at the second toll booth? Answer Yes or No

7. Are there ever zero cars in service at the same time, i.e., the caravan of cars has finished at the first toll both but not yet arrived at the second tollbooth? Answer Yes or No

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Solution

1. Service time is 1 seconds

    2. It takes 20 seconds to service every car, (20 cars * 1 seconds per car)

3. It takes 50 seconds to travel to the next toll booth (500 km / 10 km/s)

4. Just like in the previous question, it takes 50 seconds, regardless of the car

5. It takes 69 seconds until the first car gets serviced at the next toll booth (20-1 cars * 1 seconds per car + 500 km / 10 km/s)

6. No, because cars can't get service at the next tollbooth until all cars have arrived

7. Yes, one notable example is when the last car in the caravan is serviced but is still travelling to the next toll booth; all other cars have to wait until it arrives, thus no cars are being serviced .

Computing the one-hop transmission delay:

Question List

1.What is the transmission delay?

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2. What is the maximum number of packets per second that can be transmitted by this link?

Solution

The transmission delay = L/R = 4000 bits / 100000000 bps = 4.00E-seconds

The number of packets that can be transmitted in a second into the link = R / L = 100000000 bps / 4000 bits = 25000 packets .

<u>Queuing Delay:</u>

Question List

1. In practice, does the queuing delay tend to vary a lot? Answer with Yes or No

2. Assuming that a = 38, what is the queuing delay? Give your answer in milliseconds (ms)

3. Assuming that a = 58, what is the queuing delay? Give your answer in milliseconds (ms)

4. Assuming the router's buffer is infinite, the queuing delay is 0.1062 ms, and 1899 packets arrive. How many packets will be in the buffer 1 second later?

5. If the buffer has a maximum size of 992 packets, how many

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of the 1899 packets would be dropped upon arrival from the previous question?

Solution

1. Yes, in practice, queuing delay can vary significantly. We use the above formulas as a way to give a rough estimate, but in a real-life scenario it is much more complicated.

2. Queuing Delay = I(L/R)(1 - I) * 1000 = 0.0536*(2400/1700000)*(1-0.0536) * 1000 = 0.0716 ms.

3. Queuing Delay = I(L/R)(1 - I) * 1000 = 0.0819*(2400/1700000)*(1-0.0819) * 1000 = 0.1062 ms.

4. Packets left in buffer = a - floor(1000/delay) = 1899 - floor(1000/0.1062) = 0 packets.

5. Packets dropped = packets - buffer size = 1899 - 992 = 907 dropped packets.

Computing end-end delay (transmission and propagation delay):

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Question List

1. What is the transmission delay of link 1?
2. What is the propogation delay of link 1?
3. What is the total delay of link 1?
4. What is the transmission delay of link 2?
5. What is the propogation delay of link 2?
6. What is the total delay of link 2?
7. What is the transmission delay of link 3?
8. What is the propogation delay of link 3?
9. What is the total delay of link 3?
10. What is the total delay?

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Solution

Link 1 transmission delay = L/R = 16000 bits / 100 Mbps = 0.00016 seconds

Link 1 propagation delay = d/s = ()3 Km) * 1000 / $3*10^8$ m/sec = 1.00E-5 seconds

Link 1 total delay = d_t + d_p = 0.00016 seconds + 1.00E-5 seconds = 0.00017 seconds

Link 2 transmission delay = L/R = 16000 bits / 10 Mbps = 0.0016 seconds

Link 2 propagation delay = d/s = ()500 Km) * 1000 / $3*10^8$ m/sec = 0.0017 seconds

Link 2 total delay = d_t + d_p = 0.0016 seconds + 0.0017 seconds = 0.0033 seconds

Link 3 transmission delay = L/R = 16000 bits / 1000 Mbps = 1.60E-5 seconds

Link 3 propagation delay = d/s = ()1 Km) * 1000 / $3*10^8$ m/sec = 3.33E-6 seconds

Link 3 total delay = d_t + d_p = 1.60E-5 seconds + 3.33E-6 seconds = 1.93E-5 seconds

The total delay = d_{L1} + d_{L2} + d_{L3} = 0.00017 seconds + 0.0033 seconds + 1.93E-5 seconds = 0.0035 seconds

End to End Throughput and Bottleneck Links:

Question List

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1. What is the maximum achievable end-end throughput (in Mbps) for each of four client-to-server pairs, assuming that the middle link is fairly shared (divides its transmission rate equally)?

2. Which link is the bottleneck link? Format as Rc, Rs, or R

3. Assuming that the servers are sending at the maximum rate possible, what are the link utilizations for the server links (R_S)? Answer as a decimal

4. Assuming that the servers are sending at the maximum rate possible, what are the link utilizations for the client links (R_C)? Answer as a decimal

5. Assuming that the servers are sending at the maximum rate possible, what is the link utilizations for the shared link (R)? Answer as a decimal

Solution

1. The maximum achievable end-end throughput is the capacity of the link with the minimum capacity, which is 20 Mbps

   2. The bottleneck link is the link with the smallest capacity between R_S, R_C, and R/4. The bottleneck link is Rc.

   3. The server's utilization = $R_{bottleneck}$ / R_S = 20 / 30 = 0.67

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4. The client's utilization = $R_{bottleneck}$ / R_C = 20 / 20 = 1

5. The shared link's utilization = $R_{bottleneck}$ / (R / 4) = 20 / (400 / 4) = 0.2

The IP Stack and Protocol Layering:

Question List

1. What layer in the IP stack best corresponds to the phrase: 'passes frames from one node to another across some medium'

2. What layer in the IP stack best corresponds to the phrase: 'bits live on the wire'

3. What layer in the IP stack best corresponds to the phrase: 'moves datagrams from the source host to the destination host'

4. What layer in the IP stack best corresponds to the phrase: 'handles messages from a variety of network applications'

5. What layer in the IP stack best corresponds to the

phrase: 'handles the delivery of segments from the application layer, may be reliable or unreliable'

6. What layer corresponds to box 1?

7. What layer corresponds to box 2?

8. What layer corresponds to box 3?

9. What layer corresponds to box 4?

10. What layer corresponds to box 5?

11. What layer corresponds to box 6?

12. What layer corresponds to box 7?

13. What layer corresponds to box 8?

14. What layer corresponds to box 9?

15. What layer corresponds to box 10?

16. What layer corresponds to box 11?

17. What layer corresponds to box 12?

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18. What layer corresponds to box 13?

19. What layer corresponds to box 14?

20. What layer corresponds to box 15?

Solution

1. The given phrase corresponds to the Link Layer.

2. The given phrase corresponds to the Physical Layer.

3. The given phrase corresponds to the Network Layer.

4. The given phrase corresponds to the Application Layer.

5. The given phrase corresponds to the Transport Layer.

6. Box 1 is the Application Layer.

7. Box 2 is the Transport Layer.

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8. Box 3 is the Network Layer.

9. Box 4 is the Link Layer.

10. Box 5 is the Physical Layer.

11. Box 6 is the Physical Layer.

12. Box 7 is the Link Layer.

13. Box 8 is the Physical Layer.

14. Box 9 is the Link Layer.

15. Box 10 is the Network Layer.

16. Box 11 is the Physical Layer.

17. Box 12 is the Link Layer.

18. Box 13 is the Network Layer.

19. Box 14 is the Transport Layer.

20. Box 15 is the Application Layer.

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