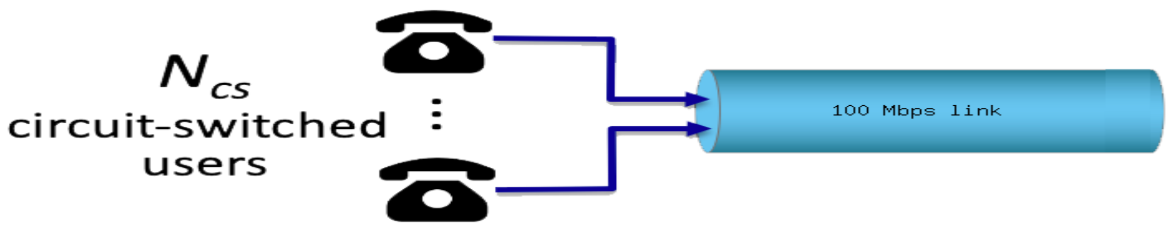
**Quantitative Comparison of Packet Switching and Circuit Switching**

Consider the two scenarios below:

- A circuit-switching scenario in which $N_{cs}$ users, each requiring a bandwidth of 20 Mbps, must share a link of capacity 100 Mbps.
- A packet-switching scenario with $N_{ps}$ users sharing a 100 Mbps link, where each user again requires 20 Mbps when transmitting, but only needs to transmit 30 percent of the time.





Round your answer to two decimals after leading zeros

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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? (9 packet-switching users)

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?

**Solution**

1. When circuit switching is used, at most 5 users can be supported. This is because each circuit-switched user must be allocated its 20 Mbps bandwidth, and there is 100 Mbps of link capacity that can be allocated.

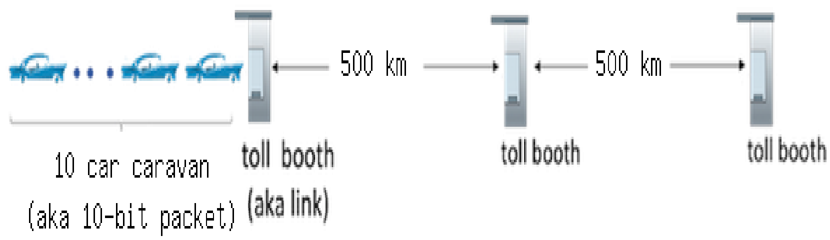
2. No. Under circuit switching, the 9 users would each need to be allocated 20 Mbps, for an aggregate of 180 Mbps - more than the 100 Mbps of link capacity available.

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. 0.3. 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 0.017.

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 0.153

**Car - Caravan Analogy**

Consider the figure below,




Suppose the caravan has **10 cars**, and that the tollbooth services (that is, transmits) a car at a rate of **one car per 2 seconds**. Once receiving serving a car proceeds to the next tool both, which is 500 kilometers away at a rate of **20 kilometers per second**. Also assume that whenever the first car of the caravan arrives at a tollbooth, it must wait at the entrance to the tollbooth until all of the other cars in its caravan have arrived, and lined up behind it before being serviced at the toll booth. (That is, the entire caravan must be stored at the tollbooth before the first car in the caravan can pay its toll and begin driving towards the next tollbooth).

**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?

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

**Solution**

1. Service time is 2 seconds

2. It takes 20 seconds to service every car, (10 cars * 2 seconds per car)

3. It takes 25 seconds to travel to the next toll booth (500 km / 20 km/s)

4. Just like in the previous question, it takes 25 seconds, regardless of the car

5. It takes 43 seconds until the first car gets serviced at the next toll booth (10-1 cars * 2 seconds per car + 500 km / 20 km/s = 18 + 25=43)

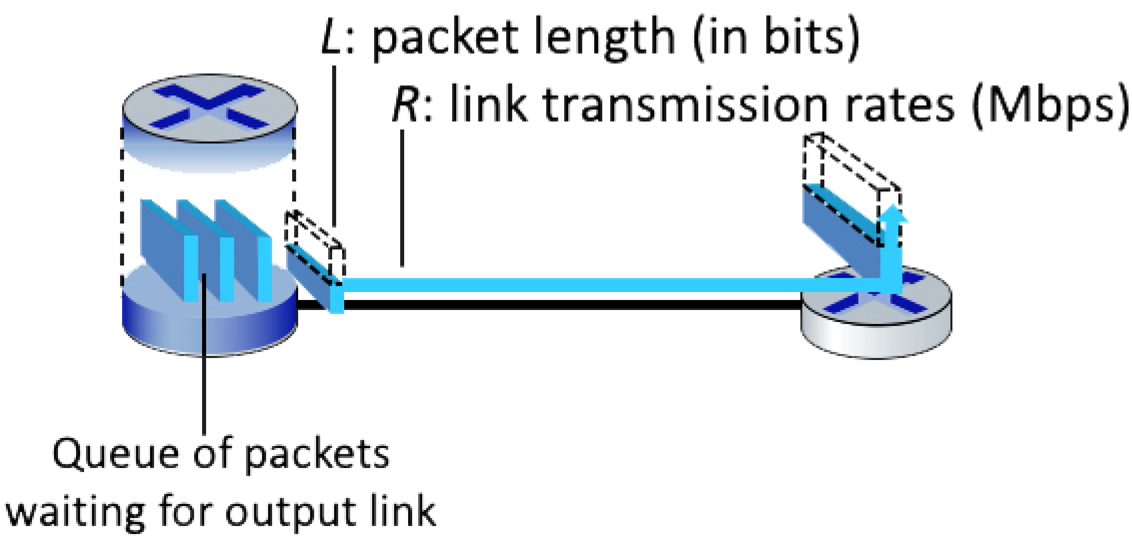
6. No, because cars can't get service at the next tollbooth until all cars have arrived

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

Transmission Delay

**Computing the one-hop transmission delay**

Consider the figure below, in which a single router is transmitting packets, each of length $L$ bits, over a single link with transmission rate $R$ Mbps to another router at the other end of the link.




Suppose that the packet length is $L$= 8000 bits, and that the link transmission rate along the link to router on the right is $R$ = 100 Mbps.

Round your answer to two decimals after leading zeros

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**Question List**

1. What is the transmission delay?

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

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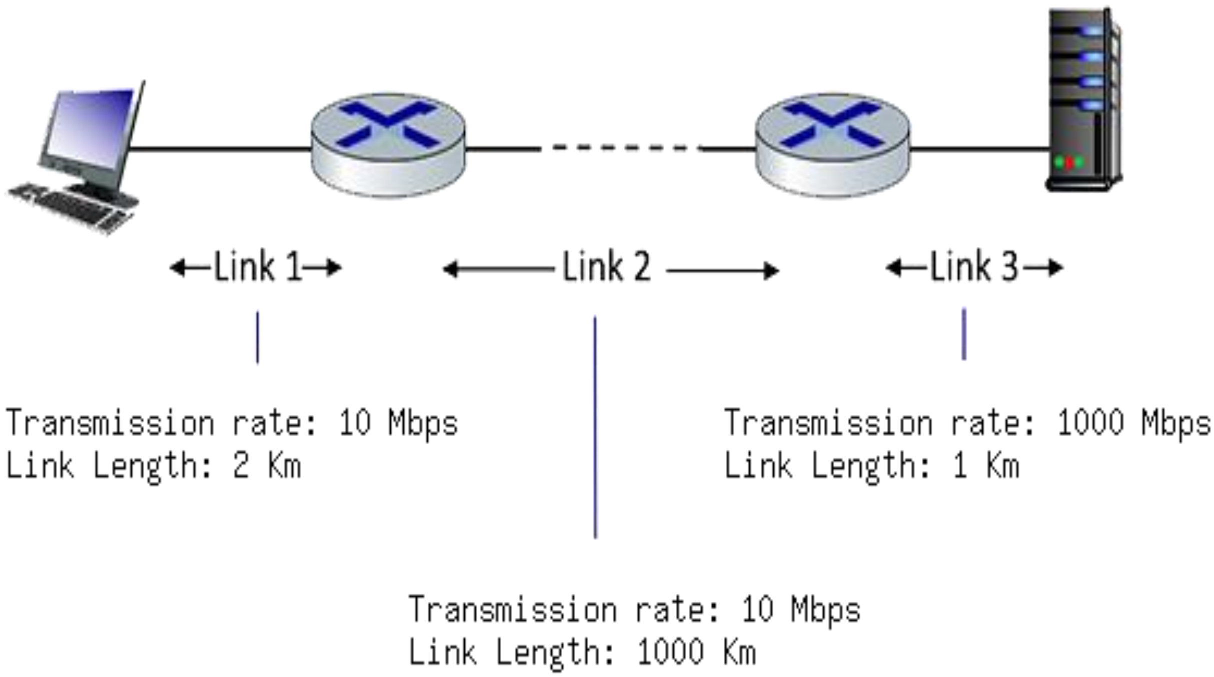
**Solution**

The transmission delay = L/R = 8000 bits / 100000000 bps = 8.00E-5 seconds

The number of packets that can be transmitted in a second into the link = R / L = 100000000 bps / 8000 bits = 12500 packets

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

Consider the figure below, with three links, each with the specified transmission rate and link length.




Assume the length of a packet is 16000 bits. The speed of light propagation delay on each link is 3x10^8 m/sec

Round your answer to two decimals after leading zeros

**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 / 10 Mbps = 0.0016 seconds

Link 1 propagation delay = d/s = ()2 Km) * 1000 / 3*10^8 m/sec = 6.67E-6 seconds

Link 1 total delay = d_t + d_p = 0.0016 seconds + 6.67E-6 seconds = 0.0016 seconds

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

Link 2 propagation delay = d/s = ()1000 Km) * 1000 / 3*10^8 m/sec = 0.0033 seconds

Link 2 total delay = d_t + d_p = 0.0016 seconds + 0.0033 seconds = 0.0049 seconds

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

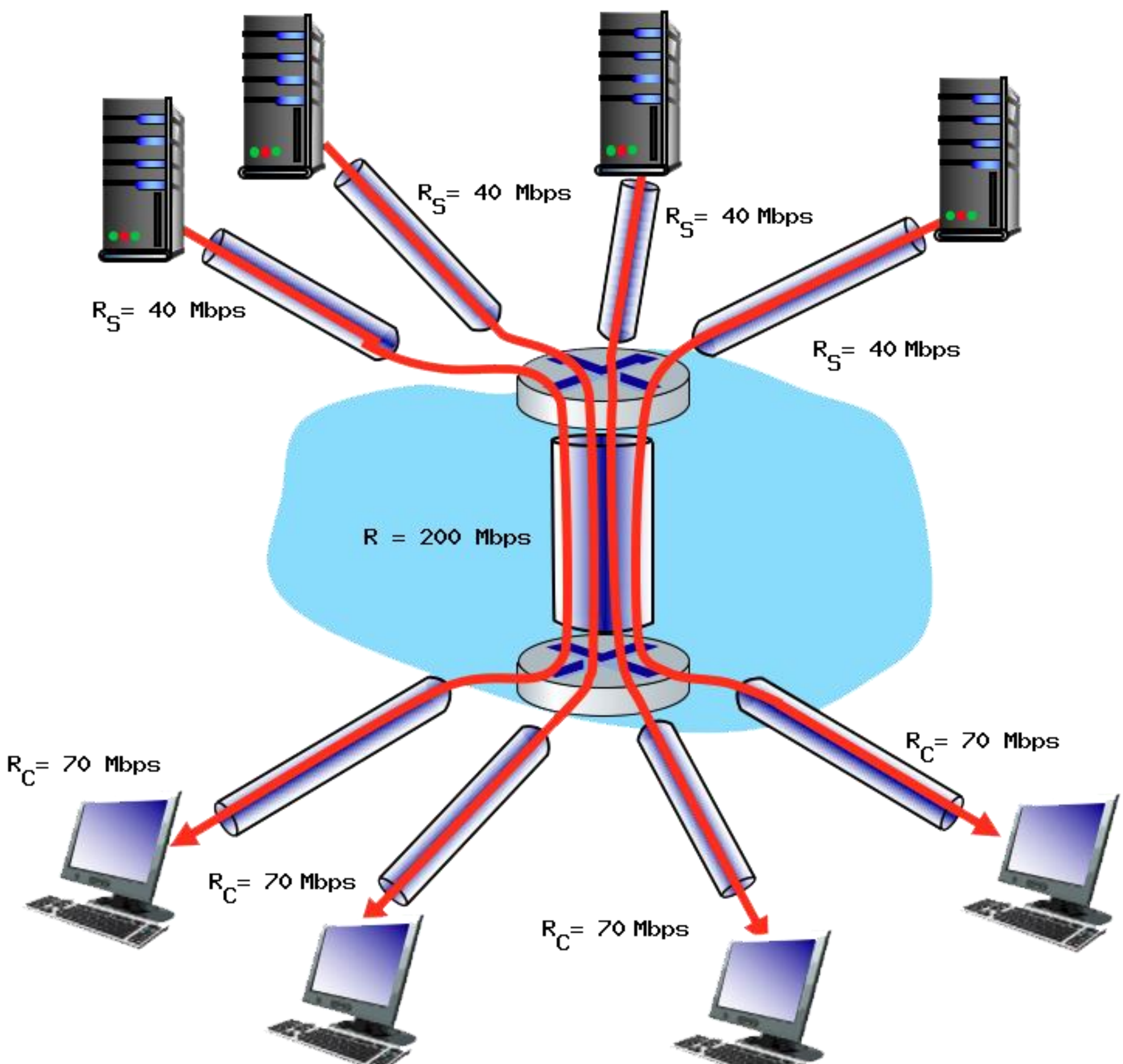
Link 3 propagation delay = d/s = ()1 Km) * 1000 / 3*10^8 m/sec = 3.33E-6 seconds

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 = 0.0016 seconds + 0.0049 seconds + 1.93E-5 seconds = 0.0066 seconds

**End to End Throughput and Bottleneck Links**

Consider the scenario shown below, with four different servers connected to four different clients over four three-hop paths. The four pairs share a common middle hop with a transmission capacity of R = 200 Mbps. The four links from the servers to the shared link have a transmission capacity of $R_S$ = 40 Mbps. Each of the four links from the shared middle link to a client has a transmission capacity of $R_C$ = 70 Mbps.




You might want to review Figure 1.20 in the text before answering the following questions

**Question List**

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

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**Solution**

1. The maximum achievable end-end throughput is the capacity of the link with the minimum capacity, which is 40 Mbps

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

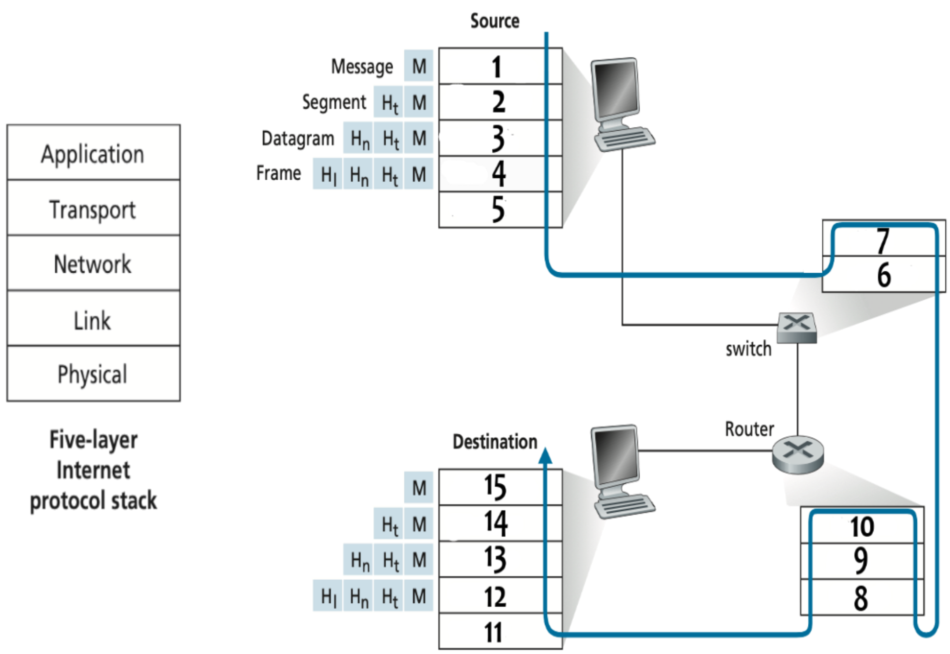
3. The server's utilization = $R_{bottleneck}$ / $R_S$ = 40 / 40 = 1

4. The client's utilization = $R_{bottleneck}$ / $R_C$ = 40 / 70 = 0.57

5. The shared link's utilization = $R_{bottleneck}$ / (R / 4) = 40 / (200 / 4) = 0.8

## The IP Stack and Protocol Layering

In the scenario below, imagine that you're sending an http request to another machine somewhere on the network.

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## Question List

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

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

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

4. 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'

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

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?

18. What layer corresponds to box 13?

19. What layer corresponds to box 14?

20. What layer corresponds to box 15?

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**Solution**

1. The given phrase corresponds to the Network Layer.

2. The given phrase corresponds to the Application Layer.

3. The given phrase corresponds to the Link Layer.

4. The given phrase corresponds to the Transport Layer.

5. The given phrase corresponds to the Physical Layer.

6. Box 1 is the Application Layer.

7. Box 2 is the Transport Layer.

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.