Review Questions

R13)

Suppose users share a 2 Mbps link. Also suppose each user transmits continuously at 1 Mbps when transmitting, but each user transmits only 20 percent of the time. (See the discussion of statistical multiplexing in Section 1.3.)
a) When circuit switching is used, how many users can be supported?
b) For the remainder of this problem, suppose packet switching is used. Why will there be essentially no queuing delay before the link if two or fewer users transmit at the same time? Why will there be a queuing delay if three users transmit at the same time?
c) Find the probability that a given user is transmitting.
d) Suppose now there are three users. Find the probability that at any given time, all three users are transmitting simultaneously. Find the fraction of time during which the queue grows.

Given:

Link capacity: 2 Mbps
Each User Transmission continuously: 1 Mbps.
Each User transmits only 20% of the time = Probability that a user transmits = 20% = 0.2

A) When circuit switching is used, how many users can be supported?

In circuit switching, each user is allocated a fixed portion of the link's bandwidth for the entire duration of the connection, even when they are not transmitting. Each user requires 1 Mbps when transmitting, so the number of users can be supported is given by:

$$N\ X\ 1\ Mbps =< 2\ Mbps$$

$$N = 2$$

Therefore, it can support only 2 users when each user is allocated 1 Mbps, out of 2 Mbps link support.

B) For the remainder of this problem, suppose packet switching is used. Why will there be essentially no queuing delay before the link if two or fewer users transmit at the same time? Why will there be a queuing delay if three users transmit at the same time?

Packet switching allows users to dynamically share the link's capacity. In packet switching, the link's 2 Mbps capacity is shared on-demand. If only one or two users are transmitting simultaneously, the combined data rate is at most 2 Mbps. Since the link can handle up to 2 Mbps, these transmissions can occur without any delay.

If three users transmit simultaneously, their combined data rate would be 3 Mbps. Since the total demand (3 Mbps) exceeds the link's capacity (2 Mbps), not all packets can be transmitted immediately. The link will transmit 2 Mbps worth of data, but the remaining 1 Mbps of data will have to wait. This waiting data forms a queue, leading to a queuing delay.

C) Find the probability that a given user is transmitting.

Given that a user transmits only 20% of the time. The probability that a user transmits at any given time is given by:

$$P\ (transmitting) = 0.2 = \mathbf{20}\%$$

D) Suppose now there are three users. Find the probability that at any given time, all three users are transmitting simultaneously. Find the fraction of time during which the queue grows.

The probability $P\ (all\ 3\ users\ transmitting)$ that all 3 users are transmitting simultaneously is just the product of probability that each transmits.

i.e., $P\ (all\ 3\ users\ transmitting) = P\ (user\ 1\ Tx).P\ (user\ 2\ Tx).P\ (user\ 3\ Tx)$

$$P\ (all\ 3\ users\ transmitting) = 0.2\ X\ 0.2\ X\ 0.2 = \mathbf{0.008} = \mathbf{0.8}\%$$

The probability that all three users are transmitting simultaneously represents the likelihood of this specific event occurring at any given moment in time. Suppose we have 10,000-time units. If the probability that all three users are transmitting simultaneously is 0.008, then, on average, we expect this event to happen during 0.008×10,000=80 of those time units.

i.e., the fraction of time during which the queue grows would be = $\frac{\mathbf{80}}{\mathbf{10000}} = \mathbf{0.008} = \mathbf{0.8}\%$

R18)

Suppose Host A wants to send a large file to Host B. The path from Host A to Host B has three links of rates R1 = 500 kbps, R2 = 2 Mbps, and R3 = 1 Mbps.
a) Assuming no other traffic in the network, what is the throughput for the file transfer?
b) Suppose the file is 4 million bytes. Dividing the file size by the throughput, roughly how long will it take to transfer the file to Host B?
C) Repeat (a) and (b), but now with R2 reduced to 100 kbps.

Given:

a) Assuming no other traffic in the network, what is the throughput for the file transfer?

Host A to Host B has 3 links, with rates given by: **R1 = 500 kbps, R2 = 2 Mbps, and R3 = 1 Mbps**
The link with the lowest transmission rate along the path determines the throughput for the file transfer. Thus **0.5 Mbps**, will be the throughput for file transfer.

b) Suppose the file is 4 million bytes. Dividing the file size by the throughput, roughly how long will it take to transfer the file to Host B?

Given:

File Size = 4 million bytes = 4 * 10^6 bytes = 4 * 10^6 * 8 bits = 32 * 10^6 bits

Time required to transfer the file is given by:

$$Time\ Required\ to\ transfer\ given\ file = \frac{File\ size\ in\ bits}{Throughput}$$

$$Time\ Required\ to\ transfer\ given\ file = \frac{32\ M\ bits}{0.5\ Mbps}$$

$$Time\ Required\ to\ transfer\ given\ file = 64\ seconds = \mathbf{1.067\ minutes}$$

C) Repeat (a) and (b), but now with R2 reduced to 100 kbps.

For the new value of R2, now…
New rates are given by: **R1 = 500 kbps, R2 = 100 kbps = 0.1 Mbps, and R3 = 1 Mbps**
The link with the lowest transmission rate along the path determines the throughput for the file transfer. Thus **0.1 Mbps**, will be the throughput for file transfer.

Time required to transfer the file is given by:

$$Time\ Required\ to\ transfer\ given\ file = \frac{File\ size\ in\ bits}{Throughput}$$

$$Time\ Required\ to\ transfer\ given\ file = \frac{32\ M\ bits}{0.1\ Mbps}$$

$$Time\ Required\ to\ transfer\ given\ file = 320\ seconds = \mathbf{5.333\ minutes}$$

R19)

A user can directly connect to a server through either long-range wireless or a twisted-pair cable for transmitting a 1500-bytes file. The transmission rates of the wireless and wired media are 2 and 100 Mbps, respectively. Assume that the propagation speed in air is 3 X 10^8 m/s, while the speed in the twisted pair is 2 x 10^8 m/s. If the user is located 1 km away from the server, what is the nodal delay when using each of the two technologies?

Given:

File Size = 1500 bytes = 1500 * 8 bits = 12000 bits
Length of Physical link = 1000 m
Propagation Speed in air = 3 * 10^8 m/s
Propagation Speed in Twisted pair = 2 * 10^8 m/s
Transmission rate of wireless media = 2 Mbps
Transmission rate of wired media = 100 Mbps

$$Nodal\ Delay = Processing\ Delay + Queuing\ Delay + Transmission\ Delay + Propagtion\ Delay$$

Note: There is no information regarding the Processing and the Queuing Delay in the question, so those two components are ignored in the problem.

A) FOR LONG RANGE WIRELESS

To find Transmission Delay:

$$Transmission\ Delay = \frac{Packet\ Length}{Transmission\ rate\ of\ wireless\ media}$$

$$Transmission\ Delay = \frac{12000\ bits}{2 * 10^6\ bits/seconds}$$

$$Transmission\ Delay = \mathbf{6\ ms}$$

To find Propagation Delay:

$$Propagation\ Delay = \frac{length\ of\ physical\ link}{Propagation\ Speed\ in\ air}$$

$$Propagation\ Delay = \frac{1000\ m}{3 * 10^8 m/s}$$

$$Propagation\ Delay = \mathbf{3.33\ us}$$

Total Nodal Delay = Transmission Delay + Propagation Delay
= 6 ms + 3.33 us
= 6000 us + 3.33 us
= **6.0033 ms**

B) FOR TWISTED PAIR CABLE

To find Transmission Delay:

$$Transmission\ Delay = \frac{Packet\ Length}{Transmission\ rate\ of\ wired\ media}$$

$$Transmission\ Delay = \frac{12000\ bits}{100 * 10^6\ bits/seconds}$$

$$Transmission\ Delay = \mathbf{120\ us}$$

To find Propagation Delay:

$$Propagation\ Delay = \frac{length\ of\ physical\ link}{Propagation\ Speed\ in\ Twisted\ cable}$$

$$Propagation\ Delay = \frac{1000\ m}{2 * 10^8 m/s}$$

$$Propagation\ Delay = \mathbf{5\ us}$$

Total Nodal Delay = Transmission Delay + Propagation Delay
= 120 us + 5 us
= 125 us
= **0.125 ms**

INFERENCE: Due to its higher transmission rate, a wired connection typically offers significantly lower total nodal delay compared to a wireless connection, resulting in faster data transmission times.

Problem Questions

P7)

In this problem, we consider sending real-time voice from Host A to Host B over a packet-switched network (VoIP). Host A converts analog voice to a digital 64 kbps bit stream on the fly. Host A then groups the bits into 56-byte packets. There is one link between Hosts A and B; its transmission rate is 10 Mbps and its propagation delay is 10 msec. As soon as Host A gathers a packet, it sends it to Host B. As soon as Host B receives an entire packet, it converts the packet's bits to an analog signal. How much time elapses from the time a bit is created (from the original analog signal at Host A) until the bit is decoded (as part of the analog signal at Host B)?

Given:

Bit rate = 64 kbps
Packet size = 56 bytes = 56 × 8 bits = 448 bits
Transmission rate = 10 Mbps
Propagation delay = 10 ms

$$Total = Packetization\ Delay + Transmission\ Delay + Propagation\ Delay + Depacketization\ Delay$$

To find Packetization Delay:

$$Packetization\ Delay = \frac{Packet\ Size}{Bit\ Rate} = \frac{448\ bits}{64\ kbps} = \mathbf{7\ ms}$$

To find Transmission Delay:

$$Transmission\ Delay = \frac{Packet\ Size}{Transmission\ Rate} = \frac{448\ bits}{10\ Mbps} = \mathbf{44.8\ \mathit{us}\ (microseconds)}$$

Given the Propagation Delay:

$$Propagation\ Delay = \mathbf{10\ \mathit{ms}\ (\mathit{Given})}$$

Note: Assumed Host B begins decoding the bits immediately after receiving the entire packet, also it could a small time. Hence ignoring the decoding/ depacketization delay.

$$Total = Packetization\ Delay + Transmission\ Delay + Propagation\ Delay + Depacketization\ Delay$$

$$Total\ Time = 7\ ms + 44.8\ us + 10ms = \mathbf{17.0448\ ms}$$

P13)

(a) Suppose N packets arrive simultaneously to a link at which no packets are currently being transmitted or queued. Each packet is of length L and the link has transmission rate R. What is the average queuing delay for the N packets?
(b) Now suppose that N such packets arrive to the link every LN/R seconds. What is the average queuing delay of a packet?

A) Average Queuing Delay for N packets Arriving Simultaneously.

If N packets arrives simultaneously, each packet must wait for the previous packets to be transmitted before its transmission. Then, the first packet starts immediately, while the rest other packet has to wait for the packets ahead of it to get transmitted before its transmission.

Each packet (say i) must wait for the transmission of (N-i) packets before its transmission, except the first packet. Since the average queuing delay is under consideration, let us ignore the thing that first packet has no wait time.

Packet 1 starts transmitting immediately, so its queuing delay is 0.
Packet 2 must wait for Packet 1 to be transmitted, so its queuing delay is $\frac{L}{R}$
Packet 3 must wait for Packet 1 and Packet 2, so its queuing delay is $\frac{2L}{R}$

$$Queuing\ Delay\ for\ i\ th\ packet = (i-1) * \frac{L}{R}$$

Where, N represents all incoming packets, i represents the ith packet, L represents the length of the packet, and R represents the Transmission rate of the media.

$$Average\ Queuing\ Delay\ for\ N\ packets = \frac{1}{N}\sum_{i=1}^{N}((i-1) * \frac{L}{R})$$

$$Average\ Queuing\ Delay\ for\ N\ packets = \frac{1}{N} * \frac{L}{R}\sum_{i=1}^{N}((i-1))$$

<u>To find</u>: Sum of first (N-1) integers is given by:

For each term in the sum:

When i=1, (i−1)=0
When i=2, (i−1)=1
When i=3, (i−1)=2

And so on, thus the sum becomes:

1 + 2 + 3 + …. + (N-2)

WKT: The sum of first k terms is given by:

$$\sum_{i=1}^{k}(i) = \frac{k*(k+1)}{2}$$

For k = (N – 2), the above equation changes to

$$\sum_{i=1}^{N-2}(i) = \frac{(N-2)*(N-1)}{2}$$

$$\sum_{i=1}^{N-1}(i) = \frac{N*(N-1)}{2} \qquad \text{----------------------------- (1)}$$

Also $\sum_{i=1}^{N-1}(1) = N-1$ ----------------------------- (2)

The term we need is: $\sum_{i=1}^{N-1}(i-1)$ is also represented as $\sum_{i=1}^{N-1}(i)$ - $\sum_{i=1}^{N-1}(1)$

i.e., $\sum_{i=1}^{N-1}(i-1)$ = $\sum_{i=1}^{N-1}(i)$ - $\sum_{i=1}^{N-1}(1)$

Subtracting Equation (1) and (2), we get

$$\sum_{i=1}^{N-1}(i-1) \ = \frac{N*(N-1)}{2} - N - 1 \ = \ \frac{\mathbf{(N-1)*(N-2)}}{\mathbf{2}}$$

Therefore,

$$\boldsymbol{\sum_{i=1}^{N-1}(i-1) = \frac{(N-1)*(N-2)}{2}}$$

$$Average\ Queuing\ Delay\ for\ N\ packets = \frac{1}{N} * \frac{L}{R} * \sum_{i=1}^{N}(i-1)$$

$$Average\ Queuing\ Delay\ for\ N\ packets = \frac{1}{N} * \frac{L}{R} * \frac{(N-1)*(N-2))}{2}$$

$$\boxed{\boldsymbol{Average\ Queuing\ Delay\ for\ N\ packets = \frac{L}{2RN} * (N-1) * (N-2)}}$$

B) Average Queuing Delay with N Packets Arriving Every $\frac{LN}{R}$ Seconds.

Since N packets arrive every $\frac{NL}{R}$ seconds, the time interval between the arrival of one group of N packets and the next is exactly the time required to transmit those N packets. Thus,

$$\boldsymbol{Average\ Queuing\ Delay\ for\ N\ packets = \frac{L}{2RN} * (N-1) * (N-2)}$$

P31)

In modern packet-switched networks, including the Internet, the source host segments long, application-layer messages (for example, an image or a music file) into smaller packets and sends the packets into the network. The receiver then reassembles the packets back into the original message. We refer to this process as message segmentation. Figure 1.27 illustrates the end-to-end transport of a message with and without message segmentation. Consider a message that is 10^6 bits long that is to be sent from source to destination in Figure 1.27. Suppose each link in the figure is 5 Mbps. Ignore propagation, queuing, and processing delays.

a) Consider sending the message from source to destination without message segmentation. How long does it take to move the message from the source host to the first packet switch? Keeping in mind that each switch uses store-and-forward packet switching, what is the total time to move the message from source host to destination host?

b) Now suppose that the message is segmented into 100 packets, with each packet being 10,000 bits long. How long does it take to move the first packet from source host to the first switch? When the first packet is being sent from the first switch to the second switch, the second packet is being sent from the source host to the first switch. At what time will the second packet be fully received at the first switch?

c) How long does it take to move the file from source host to destination host when message segmentation is used? Compare this result with your answer in part (a) and comment.

d) In addition to reducing delay, what are reasons to use message segmentation?

e) Discuss the drawbacks of message segmentation.

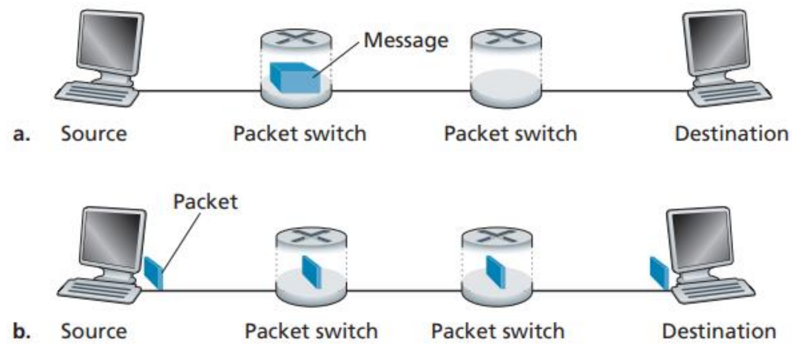

Figure 1.27 ♦ End-to-end message transport: (a) without message segmentation; (b) with message segmentation

Given:

a) Consider sending the message from source to destination without message segmentation. How long does it take to move the message from the source host to the first packet switch? Keeping in mind that each switch uses store-and-forward packet switching, what is the total time to move the message from source host to destination host?

Sending the Message Without Segmentation

Message length = 10^6 bits
Link Transmission rate: 5 Mbps
Ignoring propagation, queuing, and processing delays

Time to Move the Message from Source to First Packet Switch:

$$Transmission\ Time = \frac{Message\ Length}{Link\ Rate}$$

$$Transmission\ Time = \frac{10^6\ bits}{5\ Mbps}$$

$$Transmission\ Time = 0.2\ s$$

$$Total\ Time = Time\ of\ first\ switch + Time\ of\ second\ switch + Time\ to\ destination$$

$$Total\ Time = 0.2 + 0.2 + 0.2 = \mathbf{0.6\ s}$$

b) Now suppose that the message is segmented into 100 packets, with each packet being 10,000 bits long. How long does it take to move the first packet from source host to the first switch? When the first packet is being sent from the first switch to the second switch, the second packet is being sent from the source host to the first switch. At what time will the second packet be fully received at the first switch?

Sending the Message with Segmentation

Given:

Number of Packets = 100
Packet Size = 10,000 bits
Link Transmission Rate = 5 Mbps

$$Time\ for\ first\ Packet = \frac{Packet\ Size}{Link\ Transmission\ Rate}$$

$$Time\ for\ first\ Packet = \frac{10000\ bits}{5*10^6 \frac{bits}{seconds}} = \mathbf{2\ ms}$$

The second packet starts being sent from the source host to the first switch as soon as the first packet is sent, the second packet will be fully received at the first switch after:

$$Total\ Time = Time\ of\ first\ switch + Time\ of\ second\ switch$$

$$Total\ Time = 2\ ms + 2\ ms = \mathbf{4\ ms}$$

c) **How long does it take to move the file from source host to destination host when message segmentation is used? Compare this result with your answer in part (a) and comment.**

Total Time with Segmentation

Given:

Transmission Time per Packet = 0.002 seconds
Number of Packets = 100

Total time for the first packet to reach the destination is given by:
First Switch = 0.002 seconds; Second Switch = 0.002 seconds; Destination = 0.002 seconds

$$Total = 3 * 0.002 = \mathbf{0.006\ s}$$

Time for all packets to reach destination:

The last (100th) packet will be fully received at the destination after time:

$$= 99\ X\ 0.002 + 0.006 = \mathbf{0.204\ s}$$

Thus, the total time with segmentation is 0.204 seconds, which is significantly less than the 0.6 seconds required without segmentation.

d) In addition to reducing delay, what are reasons to use message segmentation?

Reduced Delay: segmentation significantly reduces the total time taken to send a large message from the source to the destination.
Error Recovery: If a packet is lost, only a small portion of the message needs to be retransmitted, rather than the entire message.
Parallelism: Multiple segments can be transmitted over different paths simultaneously.

e) Discuss the drawbacks of message segmentation.

Overhead: Each packet requires additional header information which adds overhead to the network.
Reassembly Complexity: The receiver must reassemble the packets in the correct order.
Fragmentation: Segmented packets may lead to fragmentation issues in networks with varying sizes.