Course Code: CSCE 513, Assignment-I

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Assignment Questions and Solutions

Question 1:

Problem Statement: Consider two hosts, A and B, connected by a single link of rate R bps. The hosts are separated by m meters, and the propagation speed along the link is s meters/sec. Host A sends a packet of size L bits to Host B.

Question 1(a): Express the propagation delay, $d_{\textbf{prop}}$, in terms of m and s

Solution: The propagation delay is actually the time required to reach for a single packet from host-A to host-B across the distance (m) of the physical link(cable, fiber) wih a propagation speed s. This can be derived using:

$$\text{time} = \frac{\text{distance}}{\text{speed}}$$

For m distance and s speed, the propagation delay is:

$$d_{\text{prop}} = \frac{m}{s}$$

Question 1b: Determine the transmission time of the packet, $d_{\textbf{trans}}$, in terms of L and R

Solution: The transmission time is the time required to push all L bits of the packet onto the link at the transmission rate R bits per second. The formula for transmission time is:

$$\text{time} = \frac{\text{number of bits}}{\text{rate}}$$

Substituting the given variables:

$$d_{\text{trans}} = \frac{L}{R}$$

Question 1(c): Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.

Solution: The end-to-end delay is the total time from when Host A starts transmitting the packet until the last bit arrives at Host B. This includes the time to transmit the packet (d_{trans}) and the time for the last bit to propagate to Host B (d_{prop}). Since processing and queuing delays are ignored, the total delay is the sum of these two components:

$$d_{\text{end-to-end}} = d_{\text{trans}} + d_{\text{prop}}$$

Substituting the expressions from parts (a) and (b):

$$d_{\text{end-to-end}} = \frac{L}{R} + \frac{m}{s}$$

Question 1(d): Suppose Host A begins to transmit the packet at time $t = 0$. At time $t = d_{\textbf{trans}}$, where is the last bit of the packet?

Solution: At time, t = 0, the host-A starts transmitting its first bit onto the link and it takes, t = d_{trans} to complete pushing all of the bits onto the link. Therefore, at time, t = d_{trans}, the last bit of the packet is on just the link and prepares to be propagated through host-B. Therefore, the last bit is at Host A, just entering the link.

Question 1(e): Suppose $d_{\textbf{prop}}$ is greater than $d_{\textbf{trans}}$. At time $t = d_{\textbf{trans}}$, where is the first bit of the packet?

Solution: When $d_{\text{prop}} > d_{\text{trans}}$, the propagation delay is longer than the transmission time. The first bit is transmitted at $t = 0$ and begins propagating immediately. By $t = d_{\text{trans}}$, the first bit has been propagating for d_{trans} seconds. The distance traveled by the first bit is:

$$\text{Distance} = s \times d_{\text{trans}}$$

Since $d_{\text{trans}} = \frac{L}{R}$, the distance is:

$$\text{Distance} = s \times \frac{L}{R}$$

Given that $d_{\text{prop}} = \frac{m}{s} > \frac{L}{R}$, the total link length m is greater than the distance traveled, so the first bit is somewhere along the link. Thus, the first bit is located $s \times \frac{L}{R}$ meters from Host A along the link.

Question 1.f:Suppose $d_{\textbf{prop}}$ is less than $d_{\textbf{trans}}$. At time $t = d_{\textbf{trans}}$, where is the first bit of the packet?

Solution: When $d_{\text{prop}} < d_{\text{trans}}$, the propagation delay is shorter than the transmission time. The first bit is transmitted at $t = 0$ and takes d_{prop} seconds to propagate the full distance m to Host B. Since $d_{\text{prop}} < d_{\text{trans}}$, by the time $t = d_{\text{trans}}$, the first bit has already propagated the entire distance and arrived at Host B. Therefore, the first bit is at Host B.

Question 1g: Suppose $s = 2.5 \times 10^8$ m/s, $L = 1500$ bytes, and $R = 10$ Mbps. Find the distance m so that $d_{\textbf{prop}} = d_{\textbf{trans}}$. Note that 1 bytes = 8 bits

Solution: Converting the units:

$$L = 1500\,\text{bytes} \times 8 = 12,000\,\text{bits}$$

$$R = 10\,\text{Mbps} = 10 \times 10^6\,\text{bits/s}$$

$$d_{\text{trans}} = \frac{L}{R} = \frac{12,000}{10 \times 10^6} = 1.2 \times 10^{-3}\,\text{sec}$$

According to the condition(given in question): $\text{d}_{\text{prop}} = d_{\text{trans}}$

$$d_{\text{prop}} = \frac{m}{s}$$

$$\frac{m}{s} = 1.2 \times 10^{-3}$$

Therefore m:

$$m = s \times d_{\text{prop}} = (2.5 \times 10^8) \times (1.2 \times 10^{-3})$$
$$m = 2.5 \times 1.2 \times 10^5 = 3 \times 10^5 \text{ meters}$$

$$m = 300\,\text{km}$$

Question 2: 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?

Solution: The transmission time for each packet is:

$$d_{\text{trans}} = \frac{L}{R}$$

Since all N packets arrive simultaneously and the link transmits one packet at a time, each packet must wait for the previous packets to be transmitted. The queuing delay for each packet is:

- Packet 1: 0 seconds (no wait).
- Packet 2: d_{trans} (waits for Packet 1).
- Packet 3: $2 \times d_{\text{trans}}$ (waits for Packets 1 and 2) .
- Packet i: $(i-1) \times d_{\text{trans}}$ (waits for the first $i-1$ packets).

The total queuing delay for all N packets is the sum of these delays:

$$\text{Total delay} = 0 + d_{\text{trans}} + 2 \times d_{\text{trans}} + \cdots + (N-1) \times d_{\text{trans}}$$

This is an arithmetic series where the number of terms is N, and the sum can be expressed as:

$$\text{Total delay} = d_{\text{trans}} \times \sum_{i=0}^{N-1} i$$

The sum of the first $N-1$ integers is:

$$\sum_{i=0}^{N-1} i = \frac{(N-1) \times N}{2}$$

So the total queuing delay is:

$$\text{Total delay} = d_{\text{trans}} \times \frac{(N-1) \times N}{2}$$

The average queuing delay is the total delay divided by the number of packets N:

$$\text{Average delay} = \frac{d_{\text{trans}} \times \frac{(N-1) \times N}{2}}{N}$$

$$\text{Average delay} = d_{\text{trans}} \times \frac{N-1}{2}$$

Since, $d_{\text{trans}} = \frac{L}{R}$, we can substitute with this term:

$$\text{Average delay} = \frac{L}{R} \times \frac{N-1}{2}$$

$$\text{Average delay} = \frac{L(N-1)}{2R}$$

Question 3: Throughput for M Client-Server Pairs

Problem Statement: Suppose there are M client-server pairs. Denote R_S, R_C, and R for the rates of the server links, client links, and core network link. Assume all other links have abundant capacity and no other traffic besides the M pairs. Derive a general expression for throughput.

Solution: Throughput is the rate at which data is successfully delivered from a server to its corresponding client. Throughput is always determined by the slowest element in the path, known as the "Bottleneck link" .

First, consider the individual constraints for each client-server pair:

- The server link has a capacity of R_S (the maximum rate at which the server can send data).
- The client link has a capacity of R_C (the maximum rate at which the client can receive data).

Without any shared constraints, the throughput for an individual pair:

$$\text{Individual throughput} = \min(R_S, R_C)$$

Since there is a shared core link (of R rate) that is definitely shared by a total of M client-server pairs simultaneously. The available bandwidth per pair from the core link is:

$$\text{Core share per pair} = \frac{R}{M}$$

This means that even if R_S and R_C allow a higher rate, the shared nature of the core link limits each pair to $\frac{R}{M}$ if the core becomes the constraining factor.

The actual throughput per pair is determined by the tightest constraint along the end-to-end path. This is the minimum of the individual pair limit ($\min(R_S, R_C)$) and the shared core limit ($\frac{R}{M}$):

$$\text{Throughput per pair} = \min\left(R_S, R_C, \frac{R}{M}\right)$$

$$\text{Total throughput} = M \times \text{Throughput per pair} = M \times \min\left(R_S, R_C, \frac{R}{M}\right)$$

For example: If $R_S = 10\,\text{Mbps}$, $R_C = 15\,\text{Mbps}$, $R = 200\,\text{Mbps}$, $M = 10$:

$$\min(10, 15, \frac{200}{10}) = \min(10, 15, 20) = 10\,\text{Mbps}$$

If $R = 100\,\text{Mbps}$:

$$\min(10, 15, \frac{100}{10}) = \min(10, 15, 10) = 10\,\text{Mbps}$$

If $R_S = 5\,\text{Mbps}$:

$$\min(5, 15, 20) = 5\,\text{Mbps}$$

Question 4: Maximum Number of Routers in Network (b)

Problem Statement: Assume a client and server communicate through network (a) or (b). Transmission rates are R_C and R_S for client and server links. In network (b), there are N routers, and the i-th link rate is $R_i = \frac{R_C+R_S}{i}$ for $i = 1, 2, \ldots, N$. Given $R_C < R_S$, determine the maximum N such that network (b) achieves higher throughput than network (a).

Solution:

$$\text{Throughput of (a)} = \min(R_C, R_S)$$

Since $R_C < R_S$, the throughput of network (a) is:

$$\text{Throughput of (a)} = R_C$$

For network (b), the path includes N routers, making it a series of $N + 1$ links. The rate of the i-th link is given by $R_i = \frac{R_C+R_S}{i}$. The effective throughput of network (b) is determined by the slowest link in this series, which is the last link (the N-th link) with rate:

$$R_N = \frac{R_C + R_S}{N}$$

To achieve higher throughput in network (b) than in network (a), the bottleneck rate of network (b) must be higher than the throughput of network (a):

$$\frac{R_C + R_S}{N} > R_C$$

Solve this inequality for N:

$$R_C + R_S > N \times R_C$$

$$R_S > N \times R_C - R_C$$

$$R_S > R_C(N - 1)$$

$$\frac{R_S}{R_C} > N - 1$$

$$N - 1 < \frac{R_S}{R_C}$$

$$N < \frac{R_S}{R_C} + 1$$

Since N must be an integer (as it represents the number of routers), the maximum value of N is the largest integer less than or equal to $\frac{R_S}{R_C} + 1$, which is the floor function:

$$N = \left\lfloor \frac{R_S}{R_C} + 1 \right\rfloor$$

However, since N is the number of routers and must be a positive integer, and given the constraint $R_C < R_S$, the practical maximum N is:

$$N = \left\lfloor \frac{R_S}{R_C} \right\rfloor$$

Question 5: Bandwidth-Delay Product and Bit Width

Problem Statement: Suppose two hosts, A and B, are separated by 20,000 kilometers, and are connected by a direct link of $R = 5\,\text{Mbps}$. Suppose the propagation speed over the link is 2.5×10^8 meters/sec.

a. Calculate the bandwidth-delay product, $R \times d_{\text{prop}}$.

b. Consider sending a file of 800,000 bits from Host A to Host B. Suppose the file is sent continuously as one large message. What is the maximum number of bits that will be in the link at any given time?

c. Provide an interpretation of the bandwidth-delay product.

d. What is the width (in meters) of a bit in the link? Is it longer than a football field?

e. Derive a general expression for the width of a bit in terms of the propagation speed s, the transmission rate R, and the length of the link m.

Solutions:

a. **Calculate the bandwidth-delay product, $R \times d_{\text{prop}}$**: The bandwidth-delay product represents the maximum number of bits that can be in transit on the link at any given time during continuous transmission. The distance between the hosts is given as $m = 20,000\,\text{km}$. Convert this to meters:

$$m = 20,000 \times 1,000 = 20,000,000\,\text{meters} = 2 \times 10^7\,\text{meters}$$

The propagation speed is $s = 2.5 \times 10^8$ meters/second. The propagation delay:

$$d_{\text{prop}} = \frac{m}{s}$$

Substitute the values:

$$d_{\text{prop}} = \frac{2 \times 10^7}{2.5 \times 10^8}$$

$$d_{\text{prop}} = \frac{2}{2.5} \times 10^{7-8} = 0.8 \times 10^{-1} = 0.08\,\text{seconds}$$

The transmission rate is $R = 5\,\text{Mbps}$.

R = 5 $\times 10^6$ bits/second

The bandwidth-delay product is:

$$R \times d_{\text{prop}} = (5 \times 10^6) \times 0.08$$

$$R \times d_{\text{prop}} = 0.4 \times 10^6 = 400,000\,\text{bits}$$

So, the bandwidth-delay product is $400,000$ bits.

b. **Maximum number of bits in the link**: The maximum number of bits in the link at any given time is determined by the bandwidth-delay product, as it represents the number of bits that can be "in flight" during steady-state transmission. The bandwidth-delay product is:

$$R \times d_{\text{prop}} = (5 \times 10^6) \times 0.08$$

[progration delay from previous solution Q.5(a)]

$$R \times d_{\text{prop}} = 0.4 \times 10^6 = 400,000\,\text{bits}$$

So, the maximum number of bits in the link is: $400,000$ bits.

c. **Interpretation of the bandwidth-delay product**: The bandwidth-delay product is a measure of the maximum number of bits that can be simultaneously present on the link during continuous transmission (while the first bit is still propagating to the receiver).

- A large BDP means: The sender must transmit a large amount of data before waiting for acknowledgements, otherwise the link will not be utilized.
- A small BDP means: Only a small amount of data can be in transit, so the sender doesn't need a big buffer or large window.

d. **Width of a bit and comparison to a football field**: The width of a bit is the physical distance a single bit travels as it propagates along the link, determined by the time to transmit one bit and the propagation speed. The time to transmit one bit is the reciprocal of the transmission rate:

$$\text{Time per bit} = \frac{1}{R} = \frac{1}{5 \times 10^6} = 2 \times 10^{-7}\text{ seconds}$$

The width of a bit is the distance traveled in this time at the propagation speed s:

$$\text{Width} = s \times \text{Time per bit}$$

$$\text{Width} = (2.5 \times 10^8) \times (2 \times 10^{-7})$$

$$\text{Width} = 5 \times 10^1 = 50\,\text{meters}$$

A standard American football field is 100 yards long.

$$1\,\text{yard} = 0.914\,\text{meters}$$

$$100\,\text{yards} = 100 \times 0.9144 = 91.40\,\text{meters}$$

Compare: $50\,\text{meters} < 91.40\,\text{meters}$. Therefore, the width of a bit (50 meters) is shorter than a football field.

e. **General expression for the width of a bit**: The width of a bit is the physical distance a single bit travels as it propagates along the link, determined by the time to transmit one bit and the propagation speed. The time to transmit one bit is:

$$\text{Time per bit} = \frac{1}{R}$$

The distance (width) is the product of the propagation speed s and this time:

$$\text{Width} = s \times \frac{1}{R}$$

Thus, the general expression is:

$$\text{Width} = \frac{s}{R}$$

Question 6: Circuit vs. Packet Switching with Statistical Multiplexing

Problem Statement: 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.

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.

Solutions:

a. **Number of users with circuit switching**: In circuit switching, a dedicated circuit with a fixed bandwidth is allocated to each user for the duration of the connection. Each user requires 1 Mbps when transmitting, and this bandwidth must be reserved continuously during the connection, regardless of whether the user is actively transmitting. The total link capacity is 2 Mbps.

$$\text{Number of users} = \frac{\text{Total capacity}}{\text{Required bandwidth per user}} = \frac{2\,\text{Mbps}}{1\,\text{Mbps}} = 2$$

Therefore, the number of users that can be supported is 2.

b. **Queuing delay analysis with packet switching**: In packet switching, bandwidth is allocated on demand, and statistical multiplexing allows multiple users to share the link based on their activity. The average transmission rate per user is:

$$\text{Average rate per user} = 1\,\text{Mbps} \times 0.20 = 0.2\,\text{Mbps}$$

No queuing delay with two or fewer users: If two users are transmitting at the same time, the total average demand is:

$$2 \times 0.2\,\text{Mbps} = 0.4\,\text{Mbps}$$

The link capacity is 2 Mbps, which is greater than 0.4 Mbps. Even if both users transmit simultaneously at their peak rate of 1 Mbps each (total 2 Mbps), the link can handle this demand without exceeding its capacity. Since the probability of both transmitting at the same time is low (due to the 20% duty cycle), the link can accommodate the traffic without queuing, assuming packets are sent immediately. Thus, there is essentially no queuing delay.

Queuing delay with three users: If three users transmit simultaneously, the total peak demand is:

$$3 \times 1\,\text{Mbps} = 3\,\text{Mbps}$$

The link capacity is 2 Mbps, which is less than 3 Mbps. When all three users transmit at their peak rate, the link cannot handle the full 3 Mbps, leading to excess packets that must wait in a queue. This queuing delay occurs because the aggregate demand exceeds the link's capacity, causing packets to be buffered until the link becomes available. Therefore, no queuing delay occurs with two or fewer users due to sufficient capacity, while queuing delay arises with three users due to overload.

c. **Probability that a given user is transmitting**: Each user transmits 20% of the time, as stated in the problem. This represents the probability that a user is actively transmitting at any given moment, assuming independent transmission behavior. Thus, the probability is:

$$P(\text{user transmitting}) = 0.20$$

d. **Probability all three users transmit simultaneously and queue growth fraction**: With three users, the probability that all three are transmitting simultaneously is the product of their individual transmission probabilities, assuming independence:

$$P(\text{all three transmitting}) = (0.20) \times (0.20) \times (0.20) = (0.20)^3$$

$$P(\text{all three transmitting}) = 0.008$$

The fraction of time during which the queue grows is equal to the probability that all three users are transmitting, since this is the only scenario where queuing occurs. Therefore, the fraction of time the queue grows is:

$$\text{Fraction of time queue grows} = 0.008(0.8\%)$$

Question 7: Throughput and File Transfer Time

Problem Statement: 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 $R_1 = 500\,\text{kbps}$, $R_2 = 2\,\text{Mbps}$, and $R_3 = 1\,\text{Mbps}$.

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 R_2 reduced to 100 kbps.

Solutions:

a. **Throughput with no other traffic**: Throughput is the rate at which data can be successfully transferred from Host A to Host B, limited by the bottleneck link in the path. The path consists of three links in series with rates $R_1 = 500\,\text{kbps}$, $R_2 = 2\,\text{Mbps}$, and $R_3 = 1\,\text{Mbps}$. Convert all rates to a consistent unit (kbps):

$$R_1 = 500\,\text{kbps}$$

$$R_2 = 2\,\text{Mbps} = 2 \times 1,000 = 2,000\,\text{kbps}$$

$$R_3 = 1\,\text{Mbps} = 1 \times 1,000 = 1,000\,\text{kbps}$$

In a series of links, the throughput is determined by the link with the lowest rate, as it acts as the bottleneck. Compare the rates:

$$\min(500, 2000, 1000) = 500\,\text{kbps}$$

The first link ($R_1 = 500\,\text{kbps}$) is the slowest, so the throughput for the file transfer is:

$$\text{Throughput} = 500\,\text{kbps}$$

b. **Transfer time for 4 million bytes**: The file size is 4 million bytes.

$$\text{File size} = 4 \times 10^6 \times 8 = 32 \times 10^6 \text{ bits}$$

The transfer time is the file size divided by the throughput:

$$\text{Transfer time} = \frac{\text{File size}}{\text{Throughput}}$$

$$\text{Transfer time} = \frac{32 \times 10^6}{500 \times 10^3}$$

$$\text{Transfer time} = \frac{32 \times 10^6}{5 \times 10^5} = 64 \,\text{seconds}$$

So, it will take approximately 64 seconds to transfer the file to Host B.

c. **Repeat with R_2 reduced to 100 kbps**: - **Throughput**: Update the link rates: $R_1 = 500\,\text{kbps}$, $R_2 = 100\,\text{kbps}$, $R_3 = 1,000\,\text{kbps}$. The new bottleneck is:

$$\min(500, 100, 1000) = 100\,\text{kbps}$$

The second link ($R_2 = 100\,\text{kbps}$) is now the slowest, so the throughput is:

$$\text{Throughput} = 100\,\text{kbps}$$

- **Transfer time**: Using the same file size of 32×10^6 bits:

$$\text{Transfer time} = \frac{32 \times 10^6}{100 \times 10^3}$$

$$\text{Transfer time} = \frac{32 \times 10^6}{1 \times 10^5} = 320 \,\text{seconds}$$

So, with $R_2 = 100\,\text{kbps}$, the transfer time is approximately 320 seconds.

Question 8: Microwave Link Analysis

Problem Statement: Suppose there is a 10 Mbps microwave link between a geostationary satellite and its base station on Earth. Every minute the satellite takes a digital photo and sends it to the base station. Assume a propagation speed of 2.4×10^8 meters/sec.

a. What is the propagation delay of the link?

b. What is the bandwidth-delay product, $R \times d_{\text{prop}}$?

c. Let x denote the size of the photo. What is the minimum value of x for the microwave link to be continuously transmitting?

Solutions:

a. **Propagation delay of the link**: A geostationary satellite orbits at approximately 35,786 kilometers above the Earth's equator. This is the one-way distance from the satellite to the base station on Earth.

$$\text{Distance} = 35,786\,\text{km} \times 1,000 = 35,786,000\,\text{meters} = 3.5786 \times 10^7\,\text{meters}$$

The propagation delay d_{prop} is:

$$d_{\text{prop}} = \frac{\text{distance}}{s}$$

$$d_{\text{prop}} = \frac{3.5786 \times 10^7}{2.4 \times 10^8}$$

$$d_{\text{prop}} = \frac{35,786,000}{2.4 \times 10^8} = 0.1491083\,\text{seconds}$$

This is approximately 149.11 milliseconds.

b. **Bandwidth-delay product, $R \times d_{\text{prop}}$**: The bandwidth-delay product is the product of the link's transmission rate and the propagation delay, representing the maximum number of bits that can be in transit. The transmission rate is:

$$R = 10\,\text{Mbps} = 10 \times 10^6\,\text{bits/second}$$

Using the propagation delay from part (a):

$$R \times d_{\text{prop}} = (10 \times 10^6) \times 0.1491$$

$$R \times d_{\text{prop}} = 1.491 \times 10^6\,\text{bits}$$

This is approximately 1.491 megabits.

c. **Minimum value of x for continuous transmission**: The satellite sends a photo every 60 seconds. For the link to be continuously transmitting, the transmission time x/R must equal or exceed the 60-second interval between photos: The transmission time for a photo of size x bits is:

$$\text{Transmission time} = \frac{x}{R}$$

$$\text{Transmission time} = \frac{x}{10 \times 10^6}$$

This must be greater than or equal to 60 seconds interval:

$$\frac{x}{10 \times 10^6} \geq 60$$

Solve for x:

$$x \geq 60 \times 10 \times 10^6$$

$$x \geq 600 \times 10^6\,\text{bits}$$

So, the minimum value of x is approximately 600 Megabits.

Question 9: Message Segmentation

Problem Statement: 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.

Solutions:

a. **Time without message segmentation**: Without segmentation, the entire message of 10^6 bits is sent as a single unit. Each link has a transmission rate of 5 Mbps, which is 5×10^6 bits/second. The path involves the source host to the first packet switch, the first switch to the second switch, and the second switch to the destination host, with each segment using store-and-forward switching.

   Time to move from source to first switch: The transmission time for the entire message over the first link is:

$$\text{Transmission time} = \frac{\text{Message size}}{\text{Rate}}$$

$$\text{Transmission time} = \frac{10^6}{5 \times 10^6}$$

$$\text{Transmission time} = 0.2\,\text{seconds}$$

   Since propagation, queuing, and processing delays are ignored, the time to move the message from the source to the first switch is 0.2 seconds.

   Total time to destination: With store-and-forward switching, each switch must receive the entire message before forwarding it. The message travels through two switches, making three hops (source to first switch, first to second, second to destination). The transmission time is the same for each hop because all links have the same rate:

   - First hop: 0.2 seconds
   - Second hop: The first switch must wait until the entire 10^6 bits is received (0.2 seconds), then transmit it, taking another 0.2 seconds.

- Third hop: The second switch waits 0.2 seconds, then transmits for 0.2 seconds.

The total time is the sum of the transmission times for all hops:

$$\text{Total time} = 0.2 + 0.2 + 0.2 = 0.6\,\text{seconds}$$

b. **Time with message segmentation**: The message is segmented into 100 packets, each $10,000$ bits long. The transmission rate is still 5 Mbps.

Time to move the first packet to the first switch: The transmission time for one packet is:

$$\text{Transmission time per packet} = \frac{10,000}{5 \times 10^6}$$
$$\text{Transmission time per packet} = 0.002\,\text{seconds}$$

So, it takes 0.002 seconds to move the first packet from the source to the first switch.

Time for the second packet to be fully received at the first switch: The first packet starts transmission at $t = 0$ and takes 0.002 seconds to reach the first switch. The first switch begins forwarding the first packet to the second switch at $t = 0.002$ seconds, and this transmission also takes 0.002 seconds. Meanwhile, the source starts transmitting the second packet immediately after the first, at $t = 0.002$ seconds (since the first packet's transmission is complete at the source). The second packet takes 0.002 seconds to be fully transmitted from the source to the first switch:

$$\text{Start of second packet transmission} = 0.002\,\text{seconds}$$

$$\text{End of second packet transmission} = 0.002 + 0.002 = 0.004\,\text{seconds}$$

Thus, the second packet is fully received at the first switch at $t = 0.004$ seconds.

c. **Total time with segmentation and comparison**: With 100 packets, each hop (source to first switch, first to second, second to destination) takes 0.002 seconds per packet. Using store-and-forward, the first packet takes 0.002 seconds per hop, and subsequent packets can pipeline: - First hop for all packets: $100 \times 0.002 = 0.2$ seconds (serial transmission to first switch). - Second hop: The first switch forwards packets, but the pipeline effect means the last packet's second hop starts after the first packet's second hop. Total time is dominated by the last packet's journey through all hops. Each packet takes 3 hops (0.002 seconds per hop), but packets overlap: - Time for all packets to reach destination = time for first packet to complete all hops + time for remaining 99 packets to be sent. - First packet total time: $3 \times 0.002 = 0.006$ seconds (but pipelining reduces effective delay). Correct approach: Total time is the time to transmit all packets across all links, limited by the last packet. With pipelining, the time is:

$$\text{Time per hop} \times \text{Number of packets} \times \text{Number of hops adjusted}$$

$$\text{Total time} = (\text{Number of packets} - 1) \times \text{Transmission time per hop} + \text{Time for first packet}$$

First packet: $3 \times 0.002 = 0.006$ seconds. Remaining 99 packets add $99 \times 0.002 = 0.198$ seconds (one hop delay per packet due to pipelining). Total:

$$\text{Total time} = 0.006 + 0.198 = 0.204\,\text{seconds}$$

Compare with 0.6 seconds (non-segmented): Segmentation reduces time due to pipelining, allowing parallel transmission across hops.

Question 10: Circuit-Switched vs. Packet-Switched Networks

Problem Statement: What advantage does a circuit-switched network have over a packet-switched network? What advantages does TDM have over FDM in a circuit-switched network?
Solution:
Advantages of Circuit-Switched Network over Packet-Switched Network:

- Guaranteed bandwidth, ensuring consistent data rates for real-time applications like voice calls.
- Low latency once the circuit is established, with no queuing delays.
- No congestion control overhead, simplifying the transmission process.
- Reliable delivery for constant bit rate traffic, such as traditional telephony.
- Simpler quality of service management due to reserved circuits.

Advantages of TDM over FDM in Circuit-Switched Network:

- Efficient use of bandwidth with bursty traffic, avoiding waste seen in FDM.
- No frequency interference, eliminating the need for guard bands.
- Flexibility to adjust time slots for variable user demand.
- Simpler hardware requirements, operating in the time domain.
- Greater scalability by increasing time slots rather than frequency bands.