National University of Computer and Emerging Sciences

Assignment 01

Chapter 01

CS-3001 Computer Networks – Spring 2026

Section: BSE-6B1 **Max Marks: 50**

Instructions:

- **Show all work.** Full credit is only given for deriving the correct final expressions and values.
- Assume 1 kbps = 10^3 bps, 1 Mbps = 10^6 bps, unless otherwise stated.
- **Answer all questions.** Partial credit may be awarded if your reasoning is clear, even if the final answer is incorrect.
- **Use neat and organized work.** Clearly label all steps, diagrams, and equations.
- **Units matter.** Always include appropriate units in your answers.
- **Academic Integrity:** Students are expected to submit their own original work. Plagiarism, copying from others, or sharing solutions is strictly prohibited and may result in zero marks and disciplinary action.
- **Submission Guidelines:** Submit your assignment by the deadline in the format specified by the instructor. Late submissions may be penalized unless prior permission is granted.

Question	**Max Marks**	**Obtained**
1	20	
2	15	
3	15	
Total	**50**	

Question 1: Textbook Problems (20 Marks)

Part A: Review Questions (4 + 4 = 8 Marks)

R12. 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:

Circuit-switching vs. Packet-switching: A circuit-switched network guarantees a constant amount of end-to-end bandwidth for the duration of a communication session. This is critical for real-time applications (like traditional telephone calls) that require steady data transmission without the jitter or variable delay found in packet switching.

TDM vs. FDM: TDM (Time Division Multiplexing) processes signals in the digital domain (time slots), which is generally cheaper and easier to implement with modern digital VLSI circuits. FDM (Frequency Division Multiplexing) requires complex analog hardware to shift signals into different frequency bands and is more susceptible to analog noise.

R19. 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 $R_1 = 500$ kbps, $R_2 = 2$ Mbps, and $R_3 = 1$ 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 part (a) and part (b), but now with R_2 reduced to 100 kbps.

Solution:

(a) Throughput: The throughput is determined by the bottleneck link (the link with the lowest capacity).

$$\text{Throughput} = \min(R_1, R_2, R_3) = \min(500 \text{ kbps}, 2000 \text{ kbps}, 1000 \text{ kbps}) = 500 \text{ kbps}$$

(b) Transfer Time:

$$\text{File Size} = 4 \times 10^6 \text{ bytes} = 32 \times 10^6 \text{ bits}$$

$$\text{Time} = \frac{\text{File Size}}{\text{Throughput}} = \frac{32,000,000 \text{ bits}}{500,000 \text{ bps}} = 64 \text{ seconds}$$

(c) Reduced R_2: New rates: $R_1 = 500$ kbps, $R_2 = 100$ kbps, $R_3 = 1$ Mbps.

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

$$\text{New Time} = \frac{32,000,000}{100,000} = 320 \text{ seconds}$$

Part B: Problems (4 + 4 + 4 = 12 Marks)

P3. Consider an application that transmits data at a steady rate (for example, the sender generates an N-bit unit of data every k time units, where k is small and fixed). Also, when such an application starts, it will continue running for a relatively long period of time. Answer the following questions, briefly justifying your answer:

(a) Would a packet-switched network or a circuit-switched network be more appropriate for this application? Why?

(b) Suppose that a packet-switched network is used and the only traffic in this network comes from such applications as described above. Furthermore, assume that the sum of the application data rates is less than the capacities of each and every link. Is some form of congestion control needed? Why?

Solution:

(a) Appropriate Network: A **circuit-switched network** is more appropriate. Since the application has a predictable, steady data rate and runs for a long time, reserving bandwidth ensures zero queuing delay and guaranteed delivery. Packet headers and routing overhead in packet switching would be unnecessary waste.

(b) Congestion Control: No, strictly speaking, congestion control is not needed in the core network. Since the sum of the application data rates is strictly less than the link capacities, the queues will never grow unboundedly (traffic intensity $I < 1$). There is no risk of sustained congestion or buffer overflow.

P6. This elementary problem begins to explore propagation delay and transmission delay, two central concepts in data networking. Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link is s meters/sec. Host A is to send a packet of size L bits to Host B.

- **a.** Express the propagation delay, d_{prop}, in terms of m and s.
- **b.** Determine the transmission time of the packet, d_{trans}, in terms of L and R.
- **c.** Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.
- **d.** Suppose Host A begins to transmit the packet at time $t = 0$. At time $t = d_{\text{trans}}$, where is the last bit of the packet?
- **e.** Suppose d_{prop} is greater than d_{trans}. At time $t = d_{\text{trans}}$, where is the first bit of the packet?
- **f.** Suppose d_{prop} is less than d_{trans}. At time $t = d_{\text{trans}}$, where is the first bit of the packet?
- **g.** Suppose $s = 2.5 \times 10^8$ m/s, $L = 1500$ bytes, and $R = 10$ Mbps. Find the distance m so that d_{prop} equals d_{trans}.

Solution:

(a) $d_{\text{prop}} = \frac{m}{s}$
(b) $d_{\text{trans}} = \frac{L}{R}$
(c) $D_{\text{end-to-end}} = \frac{L}{R} + \frac{m}{s}$
(d) At $t = d_{\text{trans}}$, the sender has just finished pushing the last bit. The last bit is at the beginning of the link (just leaving Host A).
(e) The first bit has traveled distance $d = s \times t = s \times (L/R)$. Since $d_{\text{prop}} > d_{\text{trans}}$, this distance is less than m. The first bit is still traveling inside the link.
(f) The first bit has already arrived at Host B.
(g) We set $d_{\text{prop}} = d_{\text{trans}}$:

$$\frac{m}{s} = \frac{L}{R} \implies m = \frac{L \cdot s}{R}$$

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

$$m = \frac{12,000 \cdot 2.5 \times 10^8}{10 \times 10^6} = \frac{30,000 \times 10^8}{10^7} = 300,000 \text{ meters} = 300 \text{ km}$$

P10. Consider a packet of length L that begins at end system A and travels over three links to a destination end system. These three links are connected by two packet switches. Let d_i, s_i, and R_i denote the length, propagation speed, and transmission rate of link i, for $i = 1, 2, 3$. The packet switch delays each packet by d_{proc}. Assuming no queuing delays:

(a) In terms of d_i, s_i, R_i $(i = 1, 2, 3)$, L, and d_{proc}, what is the total end-to-end delay for the packet?

(b) Suppose now the packet is 1,500 bytes, the propagation speed on all three links is $s_i = 2.5 \times 10^8$ m/s, the transmission rates of all three links are $R_i = 2.5$ Mbps, the packet switch processing delay is $d_{\text{proc}} = 3$ ms, the length of the first link is $d_1 = 5,000$ km, the length of the second link is $d_2 = 4,000$ km, and the length of the last link is $d_3 = 1,000$ km. For these values, what is the end-to-end delay?

Solution:

(a) General Expression: Total Delay = (Transmission delays for 3 links) + (Propagation delays for 3 links) + (Processing delays for 2 switches).

$$D_{\text{total}} = \sum_{i=1}^{3} \left(\frac{L}{R_i} + \frac{d_i}{s_i} \right) + 2 \cdot d_{\text{proc}}$$

(b) Calculation:

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

$$R = 2.5 \text{ Mbps} = 2.5 \times 10^6 \text{ bps}$$

Transmission Delay: Since R is same for all 3 links:

$$3 \times \frac{12,000}{2.5 \times 10^6} = 3 \times 4.8 \text{ ms} = 14.4 \text{ ms}$$

Propagation Delay:

$$d_1 + d_2 + d_3 = 5000 + 4000 + 1000 = 10,000 \text{ km} = 10^7 \text{ m}$$

$$\text{Total Prop} = \frac{10^7}{2.5 \times 10^8} = 0.04 \text{ s} = 40 \text{ ms}$$

Processing Delay:

$$2 \times 3 \text{ ms} = 6 \text{ ms}$$

Total Delay:

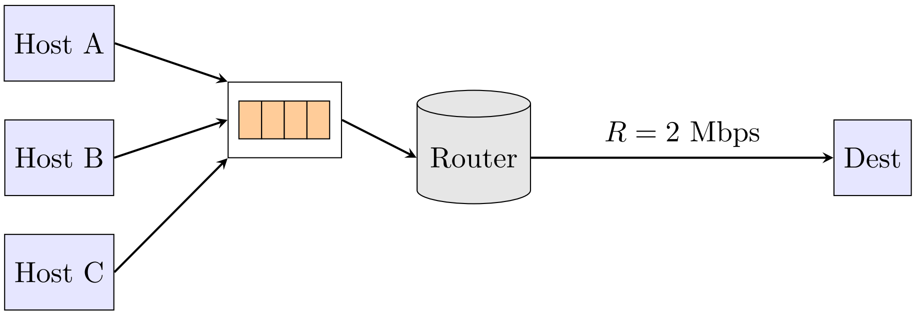
$$14.4 + 40 + 6 = 60.4 \text{ ms}$$

Question 2: Traffic Intensity & Buffer Overflow (15 Marks)

Scenario: Consider a router buffer preceding a bottleneck link. Traffic arrives in ”bursts” rather than a smooth flow.

- The output link capacity is $R = 2$ Mbps.
- The router has a finite buffer that can hold exactly **4 packets** (excluding the one currently being transmitted).

- Three hosts (A, B, and C) are connected to this router.
- At time $t = 0$, Host A, Host B, and Host C **simultaneously** send a burst of 2 packets each.
- Each packet size is $L = 10,000$ bits.
- Assume the input links are infinitely fast (packets arrive instantly at the buffer at $t = 0$).



(a) Calculate the total Traffic Intensity (I) relative to the buffer capacity at the instant $t = 0$.

(b) How many packets are dropped (lost) due to buffer overflow?

(c) Calculate the Queuing Delay for the **last** packet that is successfully transmitted.

(d) What is the total Nodal Delay for that last successful packet? (Assume processing delay $d_{proc} = 2$ ms and propagation delay $d_{prop} = 5$ ms).

Solution:

(a) Traffic Intensity Calculation:
Total packets arriving simultaneously = 3 hosts $\times$ 2 packets/host = 6 packets.
The "intensity" at $t = 0$ is theoretically infinite because arrival rate is infinite (instantaneous), but we look at the load.
Load = 6 packets. Capacity = 1 (in transmission) + 4 (in buffer) = 5 packets.

(b) Packet Loss:
Total Arriving: 6 packets.
System Capacity: 1 packet immediately enters transmission, 4 packets fill the queue. Total capacity = 5.
Dropped Packets = Total Arriving - Total Capacity = $6 - 5 = 1$ packet.

(c) Queuing Delay for the last packet:
The last successfully buffered packet is the 4th packet in the queue.
It must wait for:

- The packet currently transmitting (1st packet).
- The 3 packets ahead of it in the queue.

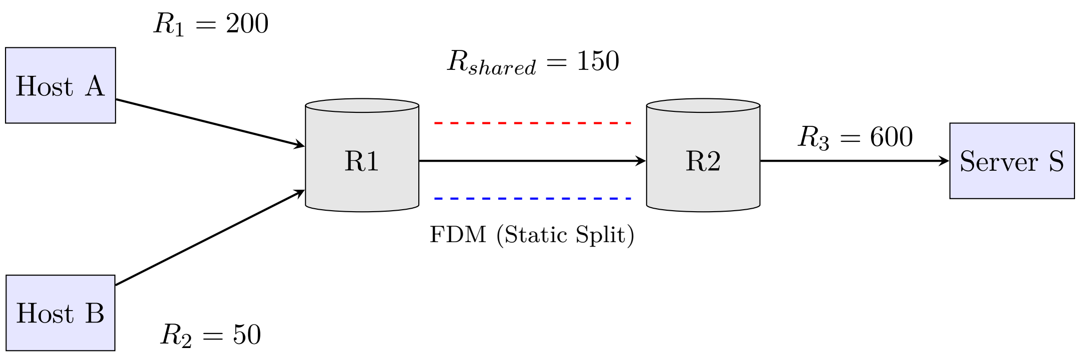
Total waiting time is the transmission time of 4 packets.
$d_{trans} = L/R = \frac{10{,}000 \text{ bits}}{2\times10^6 \text{ bits/sec}} = 0.005 \text{ sec} = 5 \text{ ms}.$
Queue Delay $d_{queue} = 4 \times d_{trans} = 4 \times 5 \text{ ms} = 20 \text{ ms}.$

(d) Total Nodal Delay:
$d_{total} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$
Note: It waits for 4 packets (d_{queue}), then takes d_{trans} to transmit itself.
$d_{total} = 2 \text{ ms}(proc) + 20 \text{ ms}(queue) + 5 \text{ ms}(trans) + 5 \text{ ms}(prop) = 32 \text{ ms}.$

Question 3: Throughput & Heterogeneous Networks (15 Marks)

Scenario: Consider the network topology below.

- Host A sends a large file to Server S.
- Host B sends a large file to Server S simultaneously.
- The shared link (R1-R2) uses **Frequency Division Multiplexing (FDM)** and splits the bandwidth evenly into 2 static channels.
- $R_1 = 200$ Mbps (Access link for A)
- $R_2 = 50$ Mbps (Access link for B)
- $R_{shared} = 150$ Mbps (Shared backbone link)
- $R_3 = 600$ Mbps (Server access link)



(a) Because FDM is used on the shared link, R_{shared} is split into two dedicated channels of 75 Mbps each. Determine the End-to-End Throughput for Host A.

(b) Determine the End-to-End Throughput for Host B.

(c) Calculate the total network utilization efficiency of the shared link. (i.e., What percentage of the 150 Mbps is actually carrying data?).

(d) If the network administrator switches from FDM to **Packet Switching** (statistical multiplexing), what would be the maximum theoretical throughput for Host A (assuming Host B stops transmitting)?

Solution:

(a) Throughput for Host A (FDM):

The path consists of three logical links:

1. Access Link $R_A = 200$ Mbps.
2. Dedicated Shared Channel $R_{FDM\_A} = 150/2 = 75$ Mbps.
3. Server Link $R_S = 600$ Mbps (shared capacity, but we check bottleneck).

Throughput is the minimum of capacities along the path.
$Th_A = \min(200, 75, 600) = 75$ Mbps.

(b) Throughput for Host B (FDM):

Logical links:

1. Access Link $R_B = 50$ Mbps.

2. Dedicated Shared Channel $R_{FDM\_B} = 150/2 = 75$ Mbps.

3. Server Link $R_S = 600$ Mbps.

$Th_B = \min(50, 75, 600) = 50$ Mbps.

(c) Shared Link Efficiency:

The shared link has 150 Mbps capacity.
Host A is using 75 Mbps (100% of its allocated channel).
Host B is bottlenecked at its own access link (50 Mbps), so it only uses 50 Mbps of its allocated 75 Mbps channel. The remaining 25 Mbps in B's channel is **wasted**.
Total Usage $= 75 + 50 = 125$ Mbps.
Efficiency $= \frac{125}{150} \times 100 = 83.3\%$.

(d) Packet Switching Scenario:

If B stops transmitting, Host A has the full shared link available.
$Th_A = \min(R_1, R_{shared}, R_3) = \min(200, 150, 600)$.
$Th_A = 150$ Mbps.
(This demonstrates the advantage of statistical multiplexing: A can use the bandwidth B isn't using).