COMP2322 Computer Networking

Homework 1

Author
Wang Yuqi
[redacted]

Lecturer
Dr. LOU Wei

BsC in Computer Science
Academic year: 2024/2025 Sem 2

Questions

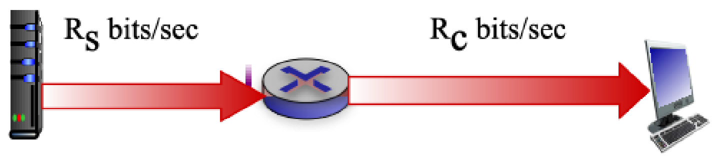
Question 1

Consider a packet of length L which 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 the transmission rate of link i, for i = 1, 2, 3. The packet switch delays each packet by d_{proc}.

- a) Assuming no queuing delays, in terms of d_i, s_i, R_i (i = 1,2,3), and L, what is the total end-to-end delay for the packet? (2 points)
- b) Suppose the packet is 2,000 bytes, the propagation speed on all three links is 3×10^8 m/s, the transmission rates of all three links are 2 Mbps, the packet switch processing delay is 2 msec, the length of the first link is 3,600 km, the length of the second link is 3,000 km, and the length of the last link is 4,500 km. Please compute the end-to-end delay for the packet. (2 points)

Question 2

Consider an end-to-end path from a server to a client shown as the figure. Assume that the links along the path from the server to the client are the first link with rate R_s bits/sec and the second link with rate R_c bits/sec. Suppose the server sends a pair of packets back to back to the client, and there is no other traffic on this path. Assume each packet of size L bits, and both links have the same propagation delay d_{prop}.



- a) What is the packet inter-arrival time at the destination? That is, how much time elapses from when the last bit of the first packet arrives until the last bit of the second packet arrives? (2 points)
- b) Now assume that the second link is the bottleneck link (i.e., $R_c < R_s$). Is it possible that the second packet queues at the input queue of the second link? Explain. (2 points)
- c) Now suppose that the server sends the second packet T seconds after sending the first packet. How large must T be to ensure no queuing before the second link? Explain. (2 points)

Answer 1(a)

$$d_{\text{nodal}}^{i} = d_{\text{proc}}^{i} + d_{\text{queue}}^{i} + d_{\text{trans}}^{i} + d_{\text{prop}}^{i}$$

Where, d_{nodal}^{i} is the total packet delay at hop i, d_{queue}^{i}, d_{trans}^{i}, d_{prop}^{i} are queuing, transmission, and propagation delays at hop i, respectively. Thus, end-to-end delay D is:

$$\begin{aligned} D &= \sum_i d_{\text{nodal}}^{i} \\ &= \sum_i \left(d_{\text{proc}}^{i} + d_{\text{queue}}^{i} + d_{\text{trans}}^{i} + d_{\text{prop}}^{i}\right) \\ &= \sum_i d_{\text{proc}}^{i} + \sum_i d_{\text{queue}}^{i} + \sum_i d_{\text{trans}}^{i} + \sum_i d_{\text{prop}}^{i} \end{aligned}$$

Now, let's consider each term ($i = 1, 2, 3$):

$$\begin{aligned} &\sum_i d_{\text{proc}}^{i} = 2 \times d_{\text{proc}} \text{ (A} \to \text{link1} \to \text{switch1} \to \text{link2} \to \text{switch2} \to \text{link3} \to B) \\ &\sum_i d_{\text{queue}}^{i} = 0 \text{ (since no queuing delays is assumed)} \\ &\sum_i d_{\text{trans}}^{i} = \sum_i L/R_i \\ &\sum_i d_{\text{prop}}^{i} = \sum_i d_i/s_i \end{aligned}$$

Finally,

$$\begin{aligned} D &= 2 \cdot d_{\text{proc}} + \sum_i L/R_i + \sum_i d_i/s_i \\ &= 2 \cdot d_{\text{proc}} + \left(\frac{L}{R_1} + \frac{L}{R_2} + \frac{L}{R_3}\right) + \left(\frac{d_1}{s_1} + \frac{d_2}{s_2} + \frac{d_3}{s_3}\right) \end{aligned}$$

Answer 1(b)

Converting the values to unified units:

- $L = 2,000 \text{ bytes} = 16,000 \text{ bits} = 1.6 \times 10^4 \text{ bits}$
- $R = 2\text{Mbps} = 2 \times 10^6 \text{ bits/s}$
- $d_{\text{proc}} = 2\text{msec} = 2 \times 10^{-3} s$
- $s = 3 \times 10^8 \text{ m/s} = 3 \times 10^5 \text{ km/s}$

Subsituting the values into the equation in Answer 1(a), we get:

$$
\begin{aligned}
D &= 2 \cdot d_{\text{proc}} + \left(\frac{L}{R} + \frac{L}{R} + \frac{L}{R}\right) + \left(\frac{d_1}{s} + \frac{d_2}{s} + \frac{d_3}{s}\right) \\
&= 2 \cdot d_{\text{proc}} + \left(3 \cdot \frac{L}{R}\right) + \left(\frac{d_1 + d_2 + d_3}{s}\right) \\
&= (4 \times 10^{-3} s) + \left(3 \cdot \frac{1.6 \times 10^4 \text{ bits}}{2 \times 10^6 \text{ bits/s}}\right) + \left(\frac{(3.6 + 3.0 + 4.5) \times 10^3 \text{ km}}{3 \times 10^5 \text{ km/s}}\right) \\
&= 4 \times 10^{-3} s + \times 10^{-3} s + 3.7 \times 10^{-2} s \\
&= (0.004 + 0.024 + 0.037) s \\
&= 0.065 s = 65 \text{ msec}
\end{aligned}
$$

Answer 2(a)

Since the packet arrival rate at the destinations bottlenecked by the minimum of the two links, we denote the arrival rate $R_a = \min(R_s, R_c)$.

So the packet inter-arrival time, which we denote as $T_{\text{inter-arrival}}$ is essentially the time it takes to transmit the size of a packet at bottlenecked arrival rate R_a,

$$T_{\text{inter-arrival}} = \max\left(\frac{L}{R_s}, \frac{L}{R_c}\right) = \frac{L}{R_a}$$

Answer 2(b)

Answer: Yes, given the server sends packets at transmission rate greater than R_c

Explanation

Intuitively, since $R_s > R_c$, the server sends packets through the 1st link at higher rate than the 2nd link can transmit them, thus cause packets queuing.

Quantitatively, the network intensity is $\rho = \frac{LR_s}{R_c}$. The average network delay d_{queue} based on the M/M/1 model is $\frac{\rho}{1-\rho}$. Since $R_s > R_c$, we have $\rho > 1$. And when $\rho > 1$, $d_{\text{queue}} \to \infty$, which means packets will pile up at the input queue of the 2nd link until it reaches maximum buffer where further packets are dropped.

(See Next Page)

Answer 2(c)

Issue: There's **ambiguity** in
1. the precise phrase "*after sending the first packet*" and
2. whether propagation delay should be considered. Therefore, I will be answering this question based on two different assumptions.

Assumption 1:
1. after the 1st packet has fully **fully left link 1**
2. no d_{prop} is considered

In assumption 1, for no queuing to occure, the 2nd packet must be sent only after the 1st packet has fully exited the 2nd link. **Proof by contradiction**: if the 2nd packet is sent before the 1st packet is fully transmitted, then any bits of the 2nd packet arrived at link 2 will inevitably queue behind the 1st packet.

Thus, T must be $\geq$ the transmission delay of the 1st packet through the 2nd link,

$$T \geq \frac{L}{R_c}$$

Assumption 2:
1. after the 1st packet has **fully left link 1**
2. d_{prop} is considered

In assumption 2, the 2nd packet can start transmitting early, as long as when it arrives (delayed by d_{prop}), the 1st packet has been fully transmitted. Therefore, the propagation delay through link 2 + the waited time T must be greater than or equal to the time it takes to the transmission delay of link 2. Mathematically, this is:

$$T + d_{\text{prop}} \geq \frac{L}{R_c}$$
$$T \geq \frac{L}{R_c} - d_{\text{prop}}$$

Assumption 3:
1. after the 1st packet has just **started leaving link 1**
2. d_{prop} is considered

Similar to assumption 2, but since we start counting once the 1st packet begin transmitting, the waited time T must be greater, as it would need to account for the time it takes for the 1st packet to fully transmit through the 2nd link.

$$T + d_{\text{prop}} \geq \frac{L}{R_s} + \frac{L}{R_c} + d_{\text{prop}}$$

$$T \geq \frac{L}{R_s} + \frac{L}{R_c}$$

Assumption 4:

1. after the 1st packet has just **started leaving link 1**
2. no d_{prop} is considered

Identical to assumption 3, since d_{prop} is removed from both sides of the inequality.

$$T \geq \frac{L}{R_s} + \frac{L}{R_c}$$

Summarize Assumptions 1 ~ 4:

	when 1st packet start leaving link 1	when 1st packet left link 1
no d_{prop}	$T \geq \frac{L}{R_s} + \frac{L}{R_c}$	$T \geq \frac{L}{R_c}$
yes d_{prop}	$T \geq \frac{L}{R_s} + \frac{L}{R_c}$	$T \geq \frac{L}{R_c} - d_{\text{prop}}$

Assumption 5:

Depending on hardware and software implementation, partially arrived packets can be stored in separated cache / buffers, isolated from the actual *queue*. In such rare cases, partially arrived packets **do not** count as queued. Thus, the waited time T can be less than the transmission delay of the 1st packet through the 2nd link.

For no queuing to occur in this special case, the 2nd packet must **arrive** at the 2nd link **only after** the 1st packet has been fully transmitted through the 2nd link. Therefore, the delay to transmit the 2nd packet through link 1 + the waited time T must be greater than or equal to the time it takes to transmit the 1st packet through link 2. Mathematically, this is:

$$\frac{L}{R_s} + T \geq \frac{L}{R_c}$$

The cruicial insight here is that the 2nd packet **do not** have to wait for the 2nd link to be idle. It can start transmitting early, as long as when it arrives, the 1st packet has been fully transmitted.

Thus, the answer is

$$T \geq \frac{L}{R_c} - \frac{L}{R_s}$$