521150A Introduction to Internet

Exercise 1A

Welcome to calculation exercises

In this non-mandatory part of the course, you will learn to

- answer concrete, numerical questions on the subject matter
- model different network scenarios
- use the presented algorithms and methods

Contact info for issues with these exercises

- email: lauri.haverinen@oulu.fi
- room: TS387 (prefer email for contacting)

Before the session

Complete pre-exercises in Moodle

- you will be better prepared for the exercise
- you can earn up to **1 point for final grading** (in Moodle, the points are scaled by 10)

During the session

Follow, participate and solve

- revisiting pre-exercises
- solving example problems together
- describing and going through how to solve the advanced problems

After the session

Solve the rest of the problems presented in this document

- return a scanned version (or good photo) as PDF of your hand-written solutions **with your name on it** to Moodle **before the next exercise**
- you can earn up to **0.5 points for each solved problem**, so a maximum of 1.5 points per exercise (in Moodle, the points are scaled by 10)

Pre-assignments

$$d_{transmission} = \frac{message\ length\,(bits)}{link\ data\ rate\,(bps)} = \frac{L}{R}$$

$$d_{propagation} = \frac{link\ length\,(m)}{propagation\ speed\,(m/s)} = \frac{d}{v}$$

1. **Envoy's mail bag carries 600 letters. There is a distance of 80 km between stations A and B. A single envoy is handling the route. The travelling time from A to B and then back is 8 hours to both directions (16 hours total), and the envoy needs an 8 hour rest after returning back. How many letters per hour on average this leg can deliver in one direction?**

$$\frac{600\ letters}{8\ h + 8\ h + 8\ h} = \frac{600\ letters}{24\ h} = 25\ letters/h$$

2. **Consider a link where signal propagation speed is 2×10^8m/s. The transmission rate in the link is 1 Mbps. How wide (in seconds) is a bit?**

$$1\ Mbit = 1s \rightarrow 1\ bit = \frac{1s}{1{,}000{,}000} \rightarrow 1\ bit = 0.000001\ seconds$$

3. **Consider a link where signal propagation speed is 2×10^8m/s. The transmission rate in the link is 100 Mbps. How long (in meters) is a bit?**

$$\frac{2 \cdot 10^8\ m/s}{100\ Mbps} = \frac{200{,}000{,}000\ m/s}{100{,}000{,}000\ bps} = 2\ m/b$$

Pre-assignments

$$d_{transmission} = \frac{message\ length\,(bits)}{link\ data\ rate\,(bps)} = \frac{L}{R}$$

$$d_{propagation} = \frac{link\ length\,(m)}{propagation\ speed\,(m/s)} = \frac{d}{v}$$

Consider a 1,000-byte (one byte = 8 bits) packet in 5000 km long link with 1 Mbps (Megabits per second) transmission rate and 2.5×10^8m/s signal propagation speed.

4. **What is the propagation delay for this link - in other words, how long does it take for the packet to traverse the link? Give your answer in milliseconds.**

$$\frac{5{,}000\ km}{2.5 \cdot 10^8\ m/s} = \frac{5{,}000{,}000\ m}{250{,}000{,}000\ m/s} = 0.02\ s = 20\ ms$$

5. **What is the transmission delay for sending one packet to the link? In other words, how long it takes for the transmitter to transmit the packet to the link? Give your answer in milliseconds.**

$$\frac{1{,}000\ B}{1\ Mbps} = \frac{8{,}000\ b}{1{,}000{,}000\ bps} = 0.008\ s = 8\ ms$$

6. **Consider two packet switches directly connected by a 5,000 km long link with 2.5×10^8m/s signal propagation speed and 1 Mbps transmission rate. How long does it take to move a packet of 1,000 bytes from the first packet switch to the other packet switch? Give your answer in milliseconds.**

$$d_{transmission} + d_{propagation} = 20\ ms\ +\ 8\ ms =\ 28\ ms$$

Problem #0

Suppose two hosts, A and B, are connected by a 10,000 km long 1 Mbps link (symmetric), where signal propagation speed is 2.5×10^8 m/s.

a) Consider sending a 400 kbit file from A to 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?

b) For what transmission speed (R) the width of one bit (in meters) would equal the length of the link?

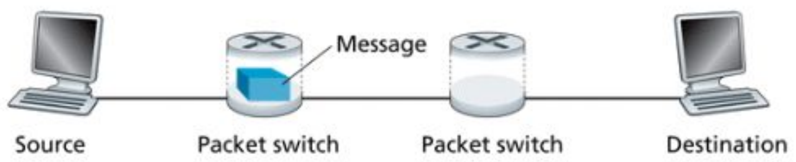
c) Let us next send a 30 Mbit MP3 file over the link. What is the end-to-end delay (transmission delay + propagation delay)?

d) Now suppose there are two 5,000 km long links between source (A) and destination (B), with one router connecting the two links. Again suppose the MP3 file is sent as one packet. Suppose there is no congestion, so that the message is transmitted onto the second link as soon as the router receives the entire message. What is the end-to-end delay?

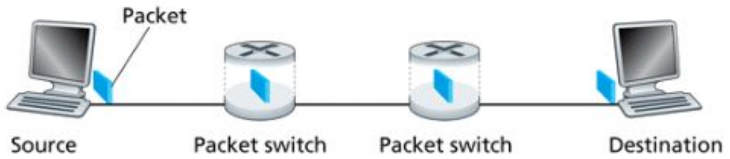
e) Now suppose that the MP3 file is broken into 3 packets, each of 10 Mbits. Ignore headers that may be added to these packets. Also ignore router processing delays. Assume store-and-forward packet switching is used at the router. What is the end-to-end delay?

Problem #1

a) In the network below, source host sends a 12 Mbit message to destination host. All three links have data transmission rate of 1.5 Mbps and the links have a signal propagation speed of 2×10^8 m/s. Determine the total time to move the message from source host to destination host, when switches are of ”store-and-forward” type (entire packet must arrive at router before packet can be transmitted on next link). Ignore queuing and processing delays. Note, that we don’t know the distance, so give your answer with the distance as a variable.



b) Now the source divides the message into 10,000 1,200-bit packets for transmission (message segmentation). Determine the total time to move the message from source host to destination host, when switches are of ”store-and-forward” type. Ignore queuing and processing delays.



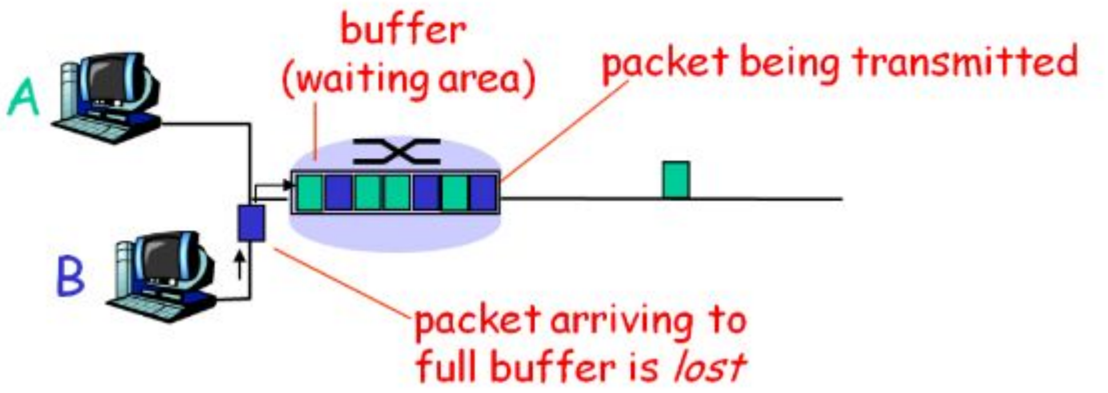
c) How will the time change if the switches use cut-through switching and can start transmitting after having received 150 bits of the 1,200-bit packet?

d) Discuss briefly advantages and disadvantages of message segmentation.

Problem #2

In the picture below, the computers A and B are producing 1,000 bit packets both at a rate of 600 packets per second.

a) What would be the traffic intensity if transmission rate R for the link was 10 Mbps?
b) What is the minimum rate in bits/s that the link needs to send data in order to prevent average delays becoming infinite?
c) Can packet loss happen at higher rates than that? Why, why not?
d) What limitation (something related to A and B) would prevent packet loss for sure?



Problems 1A (summary)

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$$intensity = \frac{packet\ length\ (bits) \cdot average\ packet\ arrival\ rate\ (pps)}{link\ bandwidth\ (bps)} = \frac{La}{R}$$

$La/R \approx 0$: average queuing delay small

$La/R \rightarrow 1$: queuing delays become large

$La/R > 1$: more "work" arriving than can be serviced, average delay infinite!

Problem #0: Suppose two hosts, A and B, are connected by a 10,000 km long 1 Mbps link (symmetric), where signal propagation speed is 2.5×10^8 m/s.

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c) Let us next send a 30 Mbit MP3 file over the link. What is the end-to-end delay (transmission delay + propagation delay)?

d) Now suppose there are two 5,000 km long links between source (A) and destination (B), with one router connecting the two links. Again suppose the MP3 file is sent as one packet. Suppose there is no congestion, so that the message is transmitted onto the second link as soon as the router receives the entire message. What is the end-to-end delay?

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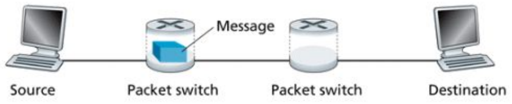

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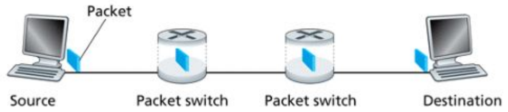

c) How will the time change if the switches use cut-through switching and can start transmitting after having received 150 bits of the 1,200-bit packet?

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Problem #2: In the picture below, the computers A and B are producing 1,000 bit packets both at a rate of 600 packets per second.

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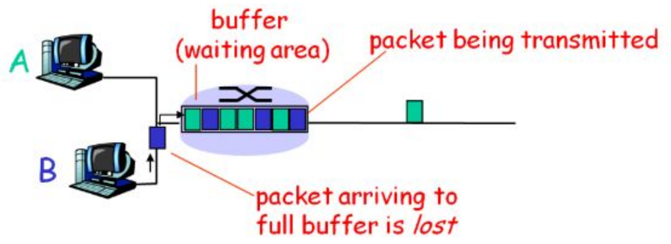

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e) Now suppose that the MP3 file is broken into 3 packets, each of 10 Mbits. Ignore headers that may be added to these packets. Also ignore router processing delays. Assume store-and-forward packet switching is used at the router. What is the end-to-end delay?

Solving

a) There is the maximum amount of bits in the link when the “first bit reaches the goal”, so what is the amount of bits in the link when the first bit is received? Solve 1) the propagation delay for the first bit, and 2) how many bits are transmitted during that time.

b) How long does it take for one bit to go through the link (=propagation delay=X)? So what is the transmission speed for sending one bit every X seconds?

c) Transmission delay for the file + propagation delay.

d) Solve 1) transmission delay from A to link and 2) propagation delay in link A->R to get the time when the file is received at router. Then, solve 3) transmission delay from R to link and 4) propagation delay in link R->B. Combine these to get the end-to-end delay.

e) Solve 1) transmission delay for the first 10Mbit packet from A to link, and 2) propagation delay in link A->R to get the time when first packet is received at R. The transmission of the next packet begins immediately after the previous packet is transmitted to link, so it takes 3*transmission delay + 1*propagation delay to receive all 3 packets at R. The first packet is already being sent from R by the time the second packet arrives at R.

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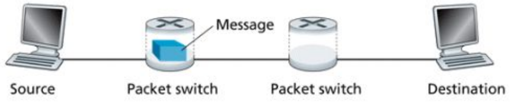

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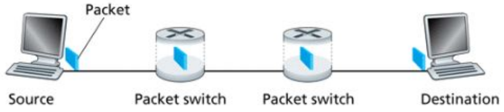

c) How will the time change if the switches use cut-through switching and can start transmitting after having received 150 bits of the 1,200-bit packet?

d) Discuss briefly advantages and disadvantages of message segmentation.

Solving

a) Solve 1) transmission delay and propagation delay for A->R1 using variables (e.g. a,b,c) for link lengths. Solve the same for 2) R1->R2 and 3) R2->B. Total time (A->B) = (A -> R1) + (R1 -> R2) + (R2 -> B)

b) Solve 1) how much time it takes to transmit one package (transmission delay) from A to A->R1 link, and 2) multiply that by the amount of packets to get the transmission delay for all of them. Packets are transmitted to link immediately after it has arrived to router, so additional transmission delay for the whole message in R1->R2 equals the transmission delay of the last packet. Solve 3) transmission delay and propagation delay for R1->R2 and 4) R2->B and combine them to get the total time.

c) Solve 1) time to send one packet, 2) time to send 150 bits of a packet, and use them to solve when the first 150 bits of the last packet are transmitted from A to A->R1 link. Additional transmission delay in routers equals the transmission delay of 150 bits. Solve 3) delays for R1->R2 and R2->B and 4) combine them.

d) Find out from lecture notes and web

Problem #2

$$d_{transmission} = \frac{message\ length\,(bits)}{link\ data\ rate\,(bps)} = \frac{L}{R}$$

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Problem #2: In the picture below, the computers A and B are producing 1,000 bit packets both at a rate of 600 packets per second.

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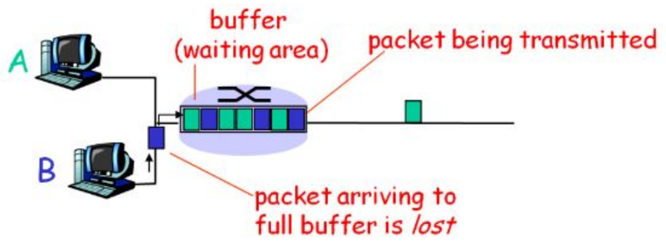

Solving

a) Check upper right corner and lecture notes

b) Check upper right corner and lecture notes

c) Find out from lecture notes and web

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Examples

$$d_{transmission} = \frac{\text{message length (bits)}}{\text{link data rate (bps)}} = \frac{L}{R}$$

$$d_{propagation} = \frac{\text{link length (m)}}{\text{propagation speed } (m/s)} = \frac{d}{v}$$

$$intensity = \frac{\text{packet length (bits)} \cdot \text{average packet arrival rate (pps)}}{\text{link bandwidth (bps)}} = \frac{La}{R}$$

$La/R \approx 0$: average queuing delay small

$La/R \to 1$: queuing delays become large

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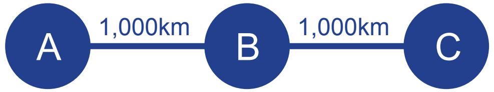
Suppose two hosts, A and B, are connected by a 1,000 km long 1 Mbps symmetric link, where signal propagation speed is 2.5×10^8 m/s.

a) You are sending a 100 kb file over the link from A to B. The file is sent continuously as one large message. What is the end-to-end delay?

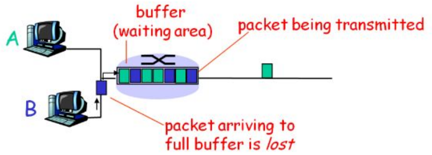
b) You are sending a 1 MB file over the link as one large message. What is the end-to-end delay?

c) You are sending a 1 MB file broken into 10 packets, each of 100 kB, over the link. What is the end-to-end delay for sending all packets?

d) Now suppose B is a router connected to both A and C with 1,000 km long 1 Mbps links. Signal propagation speed stays the same. Assume that B uses store-and-forward packet switching. What is end-to-end delay for sending a 1 MB file which is broken into 10 packets from A to C? Ignore packet headers and assume there is no congestion.



e) In the environment below, computers A and B produce 1 kb packets at a rate of 500 packets per second (pps). What is the minimum data rate for the link so it does not cause packet loss?



Solutions

a) $d_t = \frac{100\ kb}{1\ Mbps} = \frac{100{,}000\ b}{1{,}000{,}000\ bps} = 0.1\ s,\quad d_p = \frac{1{,}000\ km}{2.5 \cdot 10^8\ m/s} = \frac{1{,}000{,}000\ m}{2.5 \cdot 10^8\ m/s} = 0.04\ s,\quad d_{end-to-end} = d_t + d_p = 0.1\ s + 0.04\ s = 0.14\ s$

b) $d_t = \frac{1\ MB}{1\ Mbps} = \frac{8{,}000{,}000\ b}{1{,}000{,}000\ bps} = 8\ s,\quad d_p = \frac{1{,}000\ km}{2.5 \cdot 10^8\ m/s} = \frac{1{,}000{,}000\ m}{2.5 \cdot 10^8\ m/s} = 0.04\ s,\quad d_{end-to-end} = d_t + d_p = 8\ s + 0.04\ s = 8.04\ s$

c) Packets are transmitted one at a time, transmission begins immediately after previous is transmitted. Propagation of previous packets occurs during the transmission of the packet, so propagation delay needs to be taken into account only for the last packet.

$d_t \text{ for single packet } = \frac{100\ kB}{1\ Mbps} = \frac{800\ kb}{1\ Mbps} = \frac{800{,}000\ b}{1{,}000{,}000\ bps} = 0.8\ s,\quad d_p = \frac{1{,}000\ km}{2.5 \cdot 10^8\ m/s} = \frac{1{,}000{,}000\ m}{2.5 \cdot 10^8\ m/s} = 0.04\ s$

$d_t \text{ for all 10 packets } = 10 \cdot 0.8 s = 8 s,\quad d_{end-to-end} = d_t \text{ for all packets} + d_p \text{ for last packet} = 8\ s + 0.04\ s = 8.04\ s$

d) $d_t \text{ for single packet } = \frac{100\ kB}{1\ Mbps} = \frac{800\ kb}{1\ Mbps} = \frac{800{,}000\ b}{1{,}000{,}000\ bps} = 0.8\ s,\quad d_p = \frac{1{,}000\ km}{2.5 \cdot 10^8\ m/s} = \frac{1{,}000{,}000\ m}{2.5 \cdot 10^8\ m/s} = 0.04\ s,\quad \text{first packet received at B at } t = 0.84 s$

Size of a packet is 1 MB / 10 = 100 kB = 800 kb = 800,000 bits. First packet from A is received at B at t=0.84 s. The transmission for second packet has started at t=0.8 s when the first packet was completely transmitted, so the second packet is received at B at t=2*0.8 s +.0.04 s = 1.64 s, third at t = 3*0.8 s + 0.04 s = 2.44 s etc. B begins the transmission of the first packet immediately after receiving it at t=0.84 s, adding 0.8s of transmission delay. The second link (B->C) causes additional 0.04 s of propagation delay, so the first packet is received at C at t = 0.8 s + 0.04 s + 0.8 s + 0.04 s = 1.68 s

B receives and begins the transmission of the second packet at t=1.64 s, adding 0.8 s of transmission delay to the second packet's journey. The link causes additional 0.04 s of propagation delay, so the second packet is received at C at t = 2*0.8 s + 0.04 s + 0.8 s + 0.04 s = 2.48 s

B begins the transmission of the last packet at t = 10*0.8 s + 0.04 s = 8.04 s, adding 0.8 s of transmission delay. The propagation delay for the last packet is 0.04 s, so the total end-to-end delay for the whole file is 8.88 s

e) Average intensity needs to stay under 1, so $\frac{LA}{R} < 1 \Rightarrow \frac{1\ kb \cdot 500\ pps + 1\ kb \cdot 500\ pps}{R} < 1 \Rightarrow \frac{1{,}000\ kbps}{R} < 1 \Rightarrow R > 1{,}000\ kbps$