521150A Introduction to Internet

Exercise 1C

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

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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

1. **Stop-and-wait flow control is suitable for short and low bit rate links. How many packets a link that uses stop-and-wait flow control can have in transmit at any time?**

   stop-and-wait -> only 1 packet at any time

2. **A has link transmission rate of 1Mbps, and it transmits packets that have size of 1 000 bits to B. Distance from A to B is 400km and the propagation speed is 2 x 10^8 m/s. You can ignore acknowledgement (ACK) transmission time, but not propagation time. Processing delays and bit errors are ignored. What is the smallest window size, which enables link utilization of 100%, i..e. A can transmit all the time.**

   5, the first ACK packet arrives when the fifth packet has been transmitted

3. **A sends packets to B. B responds with ACKs. Packets are numbered as follows: 0,1,2,3,4,5… A has transmit rate of 1Mbps, and the packet size is 1,000 bits. Propagation delay between A and B is 4ms in one direction. No processing delays, ACK transmit time can be ignored. Packet 2 will be dropped! All other packets arrive at the destination. When using Stop-and-wait ARQ, which packets A has to transmit again? Give list of packets that have to be transmitted again as your answer (max 10, use comma as list element separator)**

   stop-and-wait -> only 1 packet at any time -> only packet 2 is sent again

Pre-assignments

4. **A sends packets to B. B responds with ACKs. Packets are numbered as follows: 0,1,2,3,4,5… A has transmit rate of 1Mbps, and the packet size is 2,000 bits. Propagation delay between A and B is 4ms in one direction. No processing delays, ACK transmit time can be ignored. Packet 2 will be dropped! All other packets arrive at the destination. When using <u>Go-back-N ARQ</u> (ACK has to arrive within 10 ms ["timeout"]), which packets A has to transmit again? Window size can be ignored. Give list of packets that have to be transmitted again as your answer (max 10, use comma as list element separator)**

   all packets that were transmitted after 2 until the ACK timeout of packet 2 have to be transmitted again (timeout 10ms, transmission delay 2kb/1Mbps=2ms) -> 2,3,4,5,6,7

5. **A sends packets to B. B responds with ACKs. Packets are numbered as follows: 0,1,2,3,4,5… A has transmit rate of 1Mbps, and the packet size is 1000 bits. Propagation delay between A and B is 3ms in one direction. No processing delays, ACK transmit time can be ignored. Packet 2 will be dropped! All other packets arrive at the destination. When using <u>Selective repeat ARQ</u>, which packets A has to transmit again (ACK has to arrive within 10 ms from the moment it was transmitted ["timeout"])? Give list of packets that have to be transmitted again as your answer (max 10, use comma as list element separator)**

   Only packets that were not acknowledged have to be transmitted again -> 2

Pre-assignments

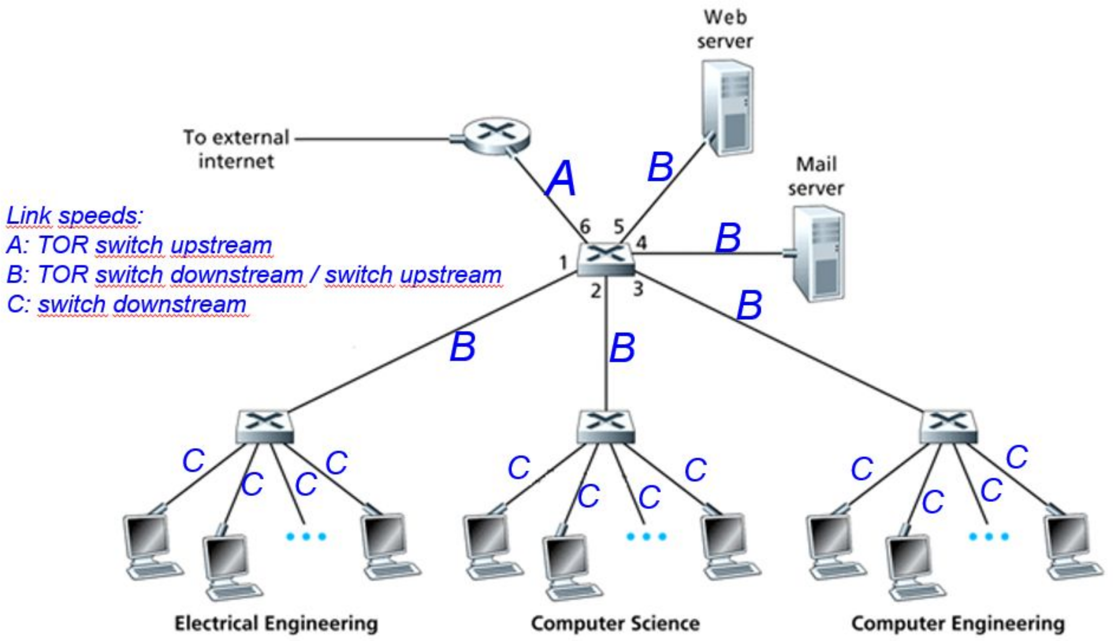
6. **What is the maximum distance between two hosts, connected by a hub according to the 100 Mbps Ethernet standard?**

   100m (mentioned also in lecture slides), so with a hub in the middle -> 200m

7. **Let's take a look at the network in the following diagram, where each of the three switches interconnect four hosts to the TOR switch, and additionally, two servers are connected to the TOR switch. Let's assume following link transmission rates:**
   - **C = 100Mbps**
   - **B = 1Gbps**
   - **A = 10Gbps**

   What is the network throughput towards to the external internet when all hosts (computers and servers) transmit at the link transmission rates?

   3,2

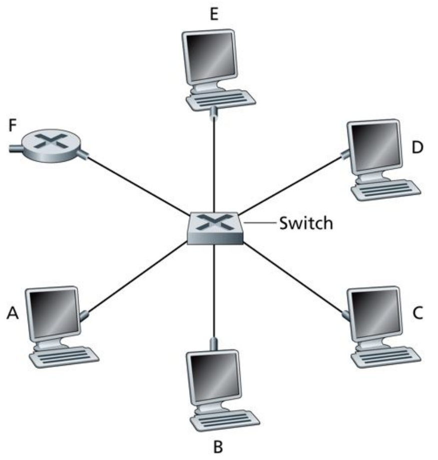


Pre-assignments

8. In LAN, how does a receiver know that a frame was intended for them?

MAC address

9. After, following packets are sent (SENDER -> RECEIVER):



1. A->D
2. B->D
3. D->A
4. D->B
5. C->D
6. D->C
7. C->E

Which packets the switch has to broadcast to all ports (because the switch does not know, to which port the destination host is connected to)?

Hosts “expose” their location to switch when they send packets, not when they receive -> 1,2,7

10. Data link layer is divided into logical link control (LLC) sublayer and MAC sublayer, and the physical layer (PHY) operates one layer below. Which of the following are NOT MAC layer functionalities?

Encoding and decoding of signals

Problem #6

A sends packets to B. Transmission time of one packet is 1ms, propagation delay 4ms to one direction and sequence numbers are 3 bits. Acknowledgement transmission time is negligible, and acknowledgements are never in error.

a) What is the utilization of the link in error-free

   i. Stop-and-wait ARQ (Idle RQ)
   ii. Selective repeat ARQ
   iii. Go-back-N

b) How will the utilization change for these three methods, if the probability of packet error was P = 0,1 (10%)?

c) How will the utilization change for these three methods, if the probability of packet error was P = 0,5 (50%)?

Problem #7

Packet P arrives at a packet switch where one other packet is halfway done being transmitted on the outbound link and three other packets are waiting to be transmitted. Packets are transmitted in the order of arrival. Suppose all packets are 1,000 bytes and the link rate is 1 Mbps.

a) What is the queuing delay for the packet P?

b) More generally, what is the queuing delay when all packets have length L, transmission rate is R, x bits of the currently-being transmitted packet have been transmitted and N packets are already in the queue?

Secondly, suppose that N packets of L bits simultaneously arrive to a link at which no packets are currently being transmitted or queued. The link has transmission rate R.

c) What is the average queuing delay for all the N packets?

Problem #8

Suppose two nodes, A and B, are attached to opposite ends of a 1,000 m cable, where the transmission rate is 10 Mbps and the signal propagation speed is 2*10^8 m/s. Both nodes have one frame of 1,000 bits (including all headers and preambles) to send to each other. Suppose there are four repeaters evenly spread between A and B, each inserting a 50-bit delay. CSMA/CD with backoff intervals of multiples of 512 bits is used for medium access control. Both nodes attempt to transmit at time t=0. After the first collision, A draws to wait 0*512 bit times and B draws to wait 1*512 bit times in the exponential backoff algorithm.

a) Show the relevant transmission events on a timeline from t=0 onwards.

b) Determine at what time (in seconds) A's packet is completely delivered at B.

c) Determine at what time (in seconds) B's packet is completely delivered at A.

You can ignore the jam signal and the interframe gap time.

Problems 1C

$$W \geq 2a+1 \begin{cases} \text{Selective repeat ARQ: } U = 1-P \\ \text{Go-back-N ARQ: } U = \dfrac{1-P}{1+2aP} \end{cases}$$

$$W < 2a+1 \begin{cases} \text{Stop-and-wait ARQ: } U = \dfrac{1-P}{1+2a} \\ \text{Selective repeat ARQ: } U = \dfrac{W(1-P)}{1+2a} \\ \text{Go-back-N ARQ: } U = \dfrac{W(1-P)}{(2a+1)(1-P+WP)} \\ a = \dfrac{\text{frame propagation time (s)}}{\text{frame transmission time (s)}} = \dfrac{T_p}{T_{ix}} \end{cases}$$

Problem #6: A sends packets to B. Transmission time of one packet is 1ms, propagation delay 4ms to one direction and sequence numbers are 3 bits. Acknowledgement transmission time is negligible, and acknowledgements are never in error.

a) What is the utilization of the link in error-free
   i) Stop-and-wait ARQ (Idle RQ)
   ii) Selective repeat ARQ
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b) How will the utilization change for these three methods, if the probability of packet error was P = 0,1 (10%)?

c) How will the utilization change for these three methods, if the probability of packet error was P = 0,5 (50%)?

Tips for #6

- Equations for calculating utilization for each method can be found in lecture slides and top right corner (W=maximum window size, P=packet error probability)
- Maximum window sizes for N-bit sequence numbers
    - Selective repeat: 2^(N-1)
    - Go-back-N: (2^N)-1

Problem #7: Packet P arrives at a packet switch where one other packet is halfway done being transmitted on the outbound link and three other packets are waiting to be transmitted. Packets are transmitted in the order of arrival. Suppose all packets are 1,000 bytes and the link rate is 1 Mbps.

a) What is the queuing delay for the packet P?

b) More generally, what is the queuing delay when all packets have length L, transmission rate is R, x bits of the currently-being transmitted packet have been transmitted and N packets are already in the queue?

Secondly, suppose that N packets of L bits simultaneously arrive to a link at which no packets are currently being transmitted or queued. The link has transmission rate R.

c) What is the average queuing delay for all the N packets?

Tips for #7

a) Solve transmission delays for other packets in queue (3.5 packets)
b) Same as a) but with variables
c) It takes NL/R to transmit N packets. First packet has no queuing delay, second has L/R, third 2L/R… so how much queuing delay does packet N have? Use it to solve the average queuing delay

Problem #8: Suppose two nodes, A and B, are attached to opposite ends of a 1,000 m cable, where the transmission rate is 10 Mbps and the signal propagation speed is 2*10^8 m/s. Both nodes have one frame of 1,000 bits (including all headers and preambles) to send to each other. Suppose there are four repeaters evenly spread between A and B, each inserting a 50-bit delay. CSMA/CD with backoff intervals of multiples of 512 bits is used for medium access control. Both nodes attempt to transmit at time t=0. After the first collision, A draws to wait 0*512 bit time and B draws to wait 1*512 bit time in the exponential backoff algorithm.

a) Show the relevant transmission events on a timeline from t=0 onwards.

b) Determine at what time (in seconds) A's packet is completely delivered at B.

c) Determine at what time (in seconds) B's packet is completely delivered at A.

You can ignore the jam signal and the interframe gap time.

Tips for #8

CSMA/CD is introduced in lecture 5. Solve 1) transmission time, 2) propagation time (notice delay from repeaters) and 3) wait times. The whole scenario takes less than 500 μs to complete. One example on how to do could be by listing the events like this
- t=0 ms: A and B start to transmit
- t=x ms: collision detected and both stop transmitting
…
- t=y ms: last bit arrives to A, both frames are transmitted

Examples

$$W \geq 2a+1 \begin{cases} \text{Selective repeat ARQ: } U = 1-P \\ \text{Go-back-N ARQ: } U = \dfrac{1-P}{1+2aP} \end{cases}$$

$$W < 2a+1 \begin{cases} \text{Stop-and-wait ARQ: } U = \dfrac{1-P}{1+2a} \\ \text{Selective repeat ARQ: } U = \dfrac{W(1-P)}{1+2a} \\ \text{Go-back-N ARQ: } U = \dfrac{W(1-P)}{(2a+1)(1-P+WP)} \\ a = \dfrac{\text{frame propagation time } (s)}{\text{frame transmission time } (s)} = \dfrac{T_p}{T_{ix}} \end{cases}$$

Problems

a) A sends packets to B. Transmission delay for one packet is 1ms, propagation delay is 2ms to one direction, and you are using 3-bit sequence numbers. Acknowledgements are error-free and you can ignore their transmission times. Solve the link utilization with
   i) error-free Stop-and-wait ARQ
   ii) Selective repeat ARQ with 10% error probability
   iii) Go-back-N ARQ with 20% error probability

b) Packet P arrives at a packet switch where another packet is halfway done being transmitted on the outbound link and one other packet is waiting to be transmitted. All packets are 1,000 bytes and they are transmitted in the order of arrival. The transmission rate for the link is 1 Mbps. What is the queuing delay for packet P?

c) Suppose A and B are attached with a 1,000 m cable, where the transmission rate is 1 Mbps and the signal propagation speed is 2*10^8 m/s. There are two repeaters between A and B, each inserting a 10-bit delay.
   i) A is sending a 100 bit frame to B. How long does it take to deliver the frame to B?
   ii) Both nodes are sending one 100 bit frame to each other. CSMA/CD with backoff intervals of multiples of 512 bits is used for medium access control. Both nodes attempt to transmit at the same time. If A draws to wait 0*512 bit time and B 1*512 bit time, how long does it take to deliver the frame from A to B? You can ignore the jam signal and the interframe gap time.

Solutions

a)
   i) $U = \dfrac{1-0}{1+2\cdot\dfrac{0.002}{0.001}} = 0.2$
   ii) $U = \dfrac{2^{3-1}(1-0.1)}{1+2\cdot\dfrac{0.002}{0.001}} = 0.72$
   iii) $U = \dfrac{(2^3-1)\cdot(1-0.2)}{\left(2\cdot\dfrac{0.002}{0.001}+1\right)(1-0.2+(2^3-1)\cdot 0.2)} = 0.50909...$

b) Here, queuing delay equals the transmission delay of the previous packets that are being transmitted, so

$$U = 1\cdot\frac{1{,}000\ B\cdot 8}{1\cdot 10^6\ bps} + \frac{(1{,}000\ B - 500\ B)\cdot 8}{1\cdot 10^6\ bps} = 0.012\ s$$

c) propagation delay (without repeater delays): 1000m / (2*10^8 m/s)= 5 µs
repeater delays: 2 * 10b / 1Mbps = 20 µs
transmission delay for a frame: 100b / 1Mbps = 0.1 ms = 100 µs
   i) 100 µs + 20 µs + 0.5 µs = 125 µs
   ii) t=12.5µs: collision occurs
   t=25µs: A and B receive collision signals. A starts to wait for the link to become available, B starts its 1*512 bit wait time
   t=50µs: both were transmitting at t=25µs, so last bits arrive at t=50µs. A starts to transmit
   t=175µs: the frame has been transmitted from A to B and the link is available for B.