Department of Computer Science and Engineering

CSE 3213: Computer Networks I (Fall 2009)

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Date: Dec 11, 2009

Final Examination

Instructions:

- Examination time: 180 min.
- Print your name and CS student number in the space provided below.
- This examination is closed book and closed notes. Calculator and one-sided cheat-sheet are allowed.
- There are 8 questions. The points for each question are given in square brackets, next to the question title. The overall maximum score is 100.
- Answer each question in the space provided. If you need to continue an answer onto the last page, clearly indicate that and label the continuation with the question number.

FIRST NAME: ______________________________

LAST NAME: ______________________________

STUDENT #: ______________________________

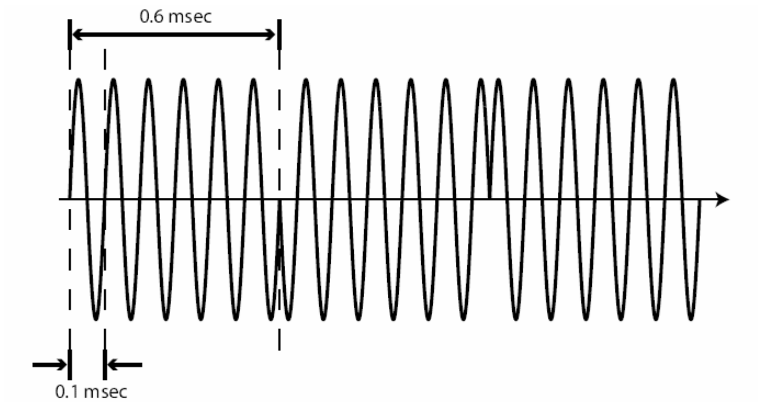
Question	Points
1	/ 15
2	/ 10
3	/ 10
4	/ 15
5	/ 10
6	/ 15
7	/ 15
8	/ 10
Total	/ 100

1. Multiple Choice [15 points]

Circle the letter beside the choice that is the best answer for each question. For each question choose only ONE answer.

(1.1) Which carrier frequency corresponds to the binary modulated signal shown below.

(a) 1 Hz
(b) 100 Hz
(c) 1 kHz
(d) 10 kHz



(1.2) What is the approximate (overall) transmission bandwidth required for the binary modulated signal of the previous problem?

(a) 1.6 Hz
(b) 3.3 Hz
(c) 1.6 kHz
(d) 3.3 kHz

(1.3) Which of the following is most affected by noise.

(a) ASK
(b) FSK
(c) PSK
(d) all are affected equally

(1.4) If an analog signal has a continuous frequency characteristics (i.e. spectrum) with the lowest frequency of the spectrum at 2000Hz and the highest frequency at 5000 Hz, then the optimal PCM sampling rate for this signal is:

(a) 2000 samples/sec
(b) 5000 samples/sec
(c) 6000 samples/sec
(d) none of the above

(1.5) Stop-And-Wait protocol is highly inefficient when:

- (a) There is a short distance between source and destination and the transmission rate is high.
- **(b) There is a large distance between source and destination and the transmission rate is high.**
- (c) There is a short distance between source and destination and the transmission rate is low.
- (d) There is a large distance between source and destination and the transmission rate is low.

(1.6) In Go-Back-N, if 5 is the number of bits for the sequence numbers, then the maximum size of the send window must be:

- (a) 4
- (b) 5
- (c) 10
- **(d) none of the above**

(1.7) The vulnerable time for (collision) in case of CSMA is _____________ the network's end-to-end propagation time.

- **(a) the same as**
- (b) two times
- (c) three times
- (d) none of the above

(1.8) ____________ protocol requires that a transmitting node stay connected and listening to the cable for at least a minimal duration of time, i.e. source-to-destination round trip delay.

- (a) ALOHA
- (b) Slotted-ALOHA
- (c) CSMA
- **(d) CSMA/CD**

(1.9) The total required channel bandwidth to accommodate a 5-channel FDM, with each channel occupying 20 kHz and assuming 2 kHz guard bands in between channels, is ___________ .

- (a) 102 kHz
- (b) 110 kHz
- (c) 500 kHz
- **(d) none of the above**

(1.10) In an Ethernet network, which of the following is true.

(a) Ethernet bridges learn addresses by looking at the destination address of packets as they pass by.

(b) Ethernet bridges learn addresses by looking at the source address of packets as they pass by.

(c) A correctly operating Ethernet bridge never sends a packet to the wrong outgoing port/interface.

(d) None of the above.

2. Layering [10 points]

Assume a layered networking architecture. The packet structure in this architecture, as seen at the lowest (physical) layer, is as follows:

foo header	fing header	yaya header	user data field
5 bytes	10 bytes	20 bytes	Maximum of 150 bytes

2.1) [4 points]
Sketch the layered protocol model that applies to the given architecture (i.e. packet) by labelling each layer in the figure below with the appropriate layer name. Your choices are **foo**, **fing**, **yaya**, and **user data**.

______________	**Layer**
______________	**Layer**
______________	**Layer**
______________	**Layer**

2.2) [3 points]
If the maximum length for the user data field is 150 bytes, what is the overhead (as a percentage!) to send a 1600 byte user message?

Ceil (1600/150) = 11 packets
Each packet has 35 bytes overhead. Overall overhead: 11*35 = 385 bytes.
Overhead: 385 / (1600 + 385) = 19.3%

2.3) [4 points]
What would be the overhead to send 1600 bytes of user data, if the user data field in every packet had to be exactly 150 bytes 'long'? (In those packets where the actual amount of user data was less than 150 bytes, padding would have to be used.)

Ceil (1600/150) = 11 packets
Each packet has 35 bytes overhead. Overall overhead: 11*35 = 385 bytes of headers + 50 bytes of padding in the last packet = 435.
Overhead: 435 / (1650 + 385) = 21.3%

3. Channel Capacity Potpourri [10 points]

3.1) [4 points]

What bandwidth (in [Hz]) is required of a coaxial cable to realize a bit rate of 10 [Mbps] if the signal is transmitted using Manchester encoding and the noise is negligible?

Answer:

First, let us consider the provided information.

- **Negligible noise => Nyquist's (not Shannon's) theorem applies.**
- **Manchester encoding => on average, two transitions per bit are required, i.e. baud (pulse) rate = 2 * actual bit rate. In this specific case, to achieve the rate of 10 [Mbps], the channel needs to support 20 [Mpulse/sec].**

Nyquist's theorem: R [pulse/sec] = 2 * B [Hz] * $\log_2$(discrete levels) = 2 * B [Hz]
B = 10 [MHz]

3.2) [6 points]

You are planning a WAN to encompass LANs at two nearby office buildings. One vendor proposes the use of terrestrial radio band of 100 MHz and a SNR of 10 dB with a 4-bit per baud line encoding technique. Another vendor proposes running cable, with a bandwidth of 500 MHz, a 2-bit per baud line encoding, and a drastically lower SNR of only 1 dB. Which vendor's approach will yield a higher effective bit rate? (Effective bit rate refers to the number of actual data/user bits per second.)

Answer:

<u>Option 1</u>

Shannon's T.: R [baud] = B $\log_2$(SNR +1) = 100 MHz * $\log_2(10^1 + 1)$ = 346 Mbaud
Actual bit rate: R [bps] = R [baud] * k [bit/baud] = 1.384 [Gbps]

<u>Option 1</u>

Shannon's T.: R [baud] = B $\log_2$(SNR +1) = 500 MHz * $\log_2(10^{0.1} + 1)$ = 500 MHz * 1.16
= 580 Mbaud
Actual bit rate: R [bps] = R [baud] * k [bit/baud] = 1.16 [Gbps]

Clearly, vendor #1 proposes a better channel.

4. Error Control [15 points]

The mapping between messages **$a_1 a_2 a_3 a_4$** and respective codewords **$a_1 a_2 a_3 r_3 a_4 r_2 r_1$** of a (7, 4) block code is obtained by adding even-parity-check bits **r_1**, **r_2** and **r_3** at the 7^{th}, 6^{th} and 4^{th} bit-location of the resultant codeword. The parity-check bits are calculated using the following expressions:

$$r_1 = a_1 \oplus a_3 \oplus a_4$$
$$r_2 = a_1 \oplus a_2 \oplus a_4$$
$$r_3 = a_1 \oplus a_2 \oplus a_3$$

A list of messages and their respective codewords generated using the above scheme is presented in the table below.

message	codeword	message	codeword
0000	0000000	1000	?
0001	0000111	1001	1001100
0010	0011001	1010	1010010
0011	0011110	1011	1010101
0100	0101010	1100	1100001
0101	?	1101	1100110
0110	0110011	1110	1111000
0111	0110100	1111	1111111

4.1) [3 points]

Given two messages, **m_1** = 1000 and **m_2** = 0101, find their respective codewords **w_1** and **w_2**?

For m_1 = 1000, r_3 = 1, r_2 = 1, r_1 = 1. Hence, w_1 = 1001011.

For m_2 = 0101, r_3 = 1, r_2 = 0, r_1 = 1. Hence, w_1 = 0101101.

4.2) [2 points]

What is the Hamming distance of codewrods **w_1** and **w_2**?

Hamming distance (w_1, w_2) = 4

4.3) [5 points]
Determine the minimum Hamming distance and error-correction capacity of this code?

To determine the minimum Hamming distance, let us look at two messages with Hamming distance of only 1, i.e. two messages that differ at only one of the four bits. The other three bits are the same.

If difference-bit is a_1 => all three parity bits will be affected / different => **Hamming distance of respective codewords will be 4.**

If difference-bit is a_2 => only two parity bits – r_2 and r_3 - will be affected / different => **Hamming distance of respective codewords will be 3.**

If difference-bit is a_3 => only two parity bits – r_1 and r_3 - will be affected / different => **Hamming distance of respective codewords will be 3.**

If difference-bit is a_4 => only two parity bits – r_1 and r_2 - will be affected / different => **Hamming distance of respective codewords will be 3.**

Based on the above, we conclude that d_{min} of this code is 3, and the error-correction capacity of the code is:

$$t = \left\lfloor \frac{d_{\min} - 1}{2} \right\rfloor = 1\,[bit]$$

4.3) [5 points]
Assume we extend the above described error-control algorithm to an (8, 4) scheme by introducing the fourth parity-check bit $\mathbf{r_4}$:

$$r_4 = a_2 \oplus a_3 \oplus a_4$$

and adding this bit at the end of the existing (7, 4) codewords. Thus, the new resultant (8, 4) codewords comprise the following bits: $\mathbf{a_1\, a_2\, a_3\, r_3\, a_4\, r_2\, r_1\, r_4}$.

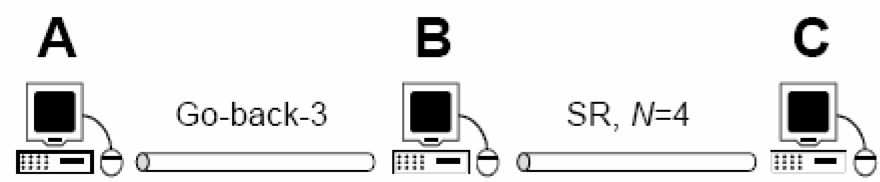
What is the error-correction capacity of the new code? Explain.

With the new code, for each difference-bit in two observed messages, the Hamming distance between codes is 4. Hence, d_{min} of the new code is 4.

Unfortunately, a code with d_{min} of 4 is still capable of correcting only 1 bit error.

5. Flow Control [10 points]

Suppose three hosts are connected as shown in the figure. Host A sends packets to host C and host B server merely as a relay. However, as indicated in the figure, they use different ARQ's for reliable communication (Go-Back-N vs. Selective Repeat). Notice that B is not a router, it is a regular host running both as a receiver (to receive packets from A) and sender (to forward A's packets to C). B's receiver immediately relays in-order packets to B's sender.

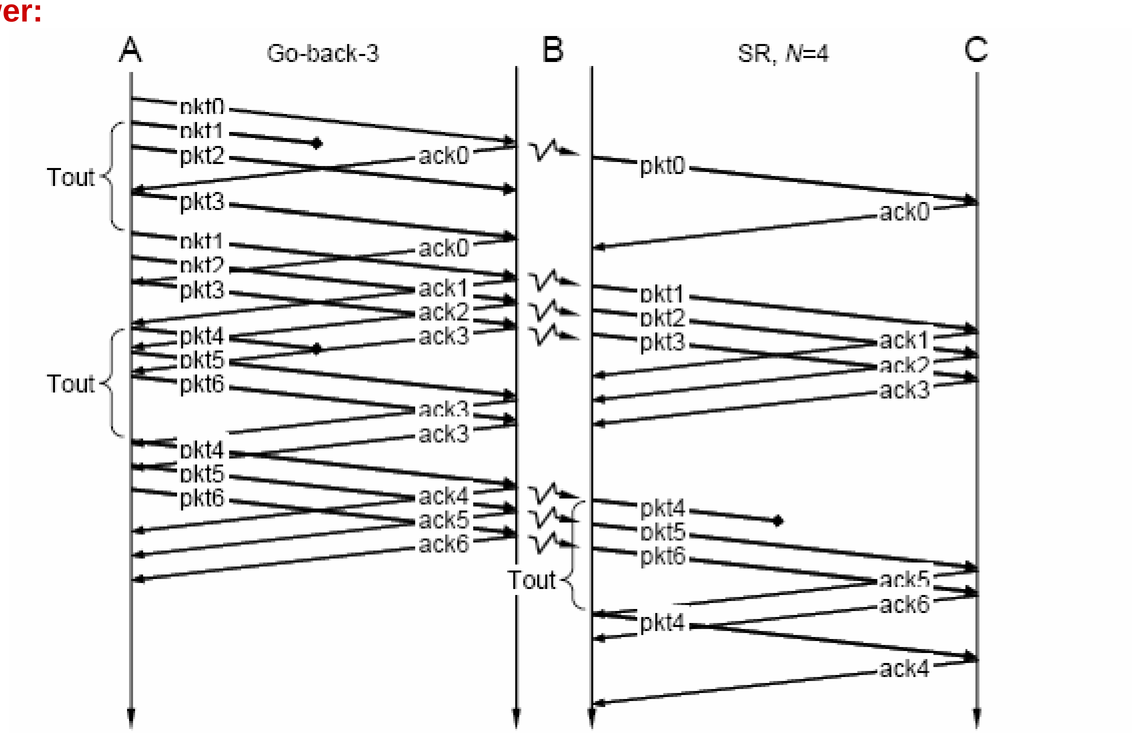


5.1 Draw side-by-side the timing diagram for A→B and B→C transmission up to the time where the first seven packets from A show up on C. Assume that the 2nd and 5th packets arrive in error to host B on their first transmission, and the 5th packet arrives in error to host C on its first transmission.

5.2 Discuss whether, in addition to exchange of ACKs from B to A, and from C to B, ACKs should be sent from C back to A.

Assume that round-trip-time (RTT) for a single packet, i.e. time for a packet to arrive to the receiver plus time for acknowledgment to arrive back to the sender, is slightly longer than the 3 packet transmission times. RTT = 3*TRANSP + δ, where $\delta \approx 0$. A packet timeout interval is slightly longer than RTT, i.e. timeout = RTT + δ.

Answer:



6. Random Medium Access Control [15 points]

A large population of slotted-ALOHA users manages to generate 50 frames/sec, including both original and retransmitted frames. Time is slotted in units of 40 msec.

6.1) [4 points]

What is the probability of a successful frame transmission in such a network?

Load G [frame / frame time] = 50 [frame / sec] * 40 [msec / frame time] =
= 2 [frame / frame time]

$P_{succ} = e^{-G} = e^{-2} = 0.135$

6.2) [4 points]

Based on the results from 6.1), what is the probability that a frame undergoes exactly 3 collisions and then a successful transmission?

P(k collisions AND success) = $(1-P_{succ})^k * P_{succ} = (1-0.135)^3 * 0.135 = 0.087$

6.3) [4 points]

Based on the results from 6.1), what is the (overall) expected number of transmission attempts needed to ensure a successful transmission of a single frame?

If a single/first frame transmission 'succeeds' only 0.135 times, then on average $1/P_{success}$ = 7.4 attempts are required to eventually ensure a successful transmission.

6.4) [3 points]
Overall, in the given system, how many frames are successfully transmitted each second?

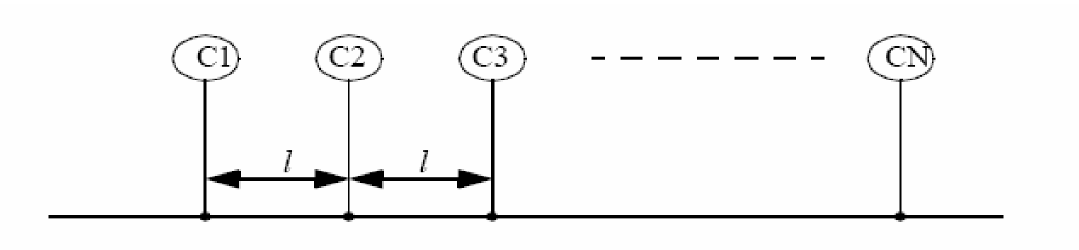
Throughput S = G*$P_{success}$ = 0.135 * 2 = 0.27 [frame / frame time]

S [frame / sec] = S [frame / frame time] / 40 [msec / frame time] = 6.75 [frame / sec]

7. Token Ring [15 points]

N Computers are connected to the same shared bus network, as shown below. Access to the bus is controlled by a modified token passing protocol. This protocol operates like the 'early token release' (ETR) token ring protocol discussed in class. Namely, when computer C(i) receives the token, it may hold the token while it transmits one packet. The computer then passes the token to computer C(i+1). When the token reaches computer C(N), it is passed back to computer C(1). You may assume that:

(a) The distance between each pair of computers equals L;
(b) It takes PROP seconds for a bit to propagate from one to another end of the network, i.e. from C(1) to C(N);
(c) On average, it takes TRANSP seconds to transmit a packet.
(d) Transmission of token takes TRANST seconds.



7.1 [6 points]

Find an expression for the efficiency, η, of this network. Justify your work.

Answer:

$T_{1,2}$ = TRANSP + TRANST + L/c = TRANSP + TRANST + PROP/(N-1)

$T_{N,1}$ = TRANSP + TRANST + PROP

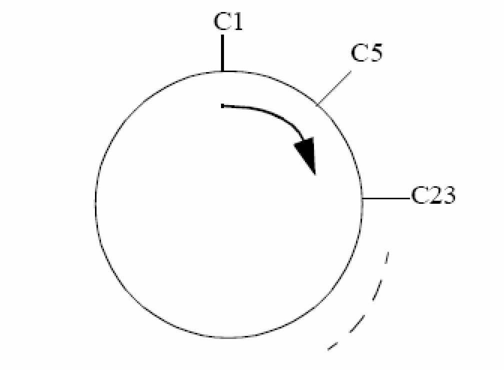
$T_{1,1}$ = (N-1)*$T_{1,2}$ + $T_{N,1}$ = N*(TRANSP + TRANST) + 2*PROP

$$\eta_{LINEAR} = \frac{N \cdot TRANSP}{N \cdot (TRANSP + TRANST) + 2 \cdot PROP} = \frac{1}{1 + \frac{TRANST}{TRANSP} + \frac{2 \cdot PROP}{N \cdot TRANSP}} \approx \frac{1}{1 + \frac{2 \cdot a'}{N}}$$

7.2 [6 points]

Now assume that the computers are renumbered <u>randomly</u> and arranged in a ring as shown below. As before, the token is passed clockwise in sequence form C(1) to C(2), and so on to C(N). Assume a propagation time of PROP around the ring. Find an expression for the efficiency, η, of this network. Justify your work.

Note: Under this scheme, the best case scenario would imply that computer(K+1) is placed 'just after' computer(K), for any K=1,..,(N-1). In this case, the passing of the token from computer(K) to computer(K+1) takes minimum time. Nevertheless, due to the random placement of computers, it possible that computer(K+1) ends up 'just before' computer(K) on the ring. In this case, the passing of the token would take the longest possible time.



Answer:

$T_{1,2}$ = TRANSP + TRANST + PROP/2 (on average)

$T_{1,1}$ = N*(TRANSP + TRANST) + N*PROP/2

$$\eta_{RANDOM} = \frac{N \cdot TRANSP}{N \cdot (TRANSP + TRANST) + \frac{N \cdot PROP}{2}} = \frac{1}{1 + \frac{TRANST}{TRANSP} + \frac{PROP}{2 \cdot TRANSP}} \approx \frac{1}{1 + \frac{a'}{2}}$$

7.3 [3 points]

When N is large, how many times more efficient is the ETR token ring network from question 7.1 than the 'random' token ring network from question 7.2? Express your result as a function of parameter a' = PROP / TRANSP. Briefly explain your result.

$$\lim_{N \to \infty} \eta_{LINEAR} = 1 \qquad \lim_{N \to \infty} \eta_{RANDOM} = \frac{1}{1 + \frac{a'}{2}}$$

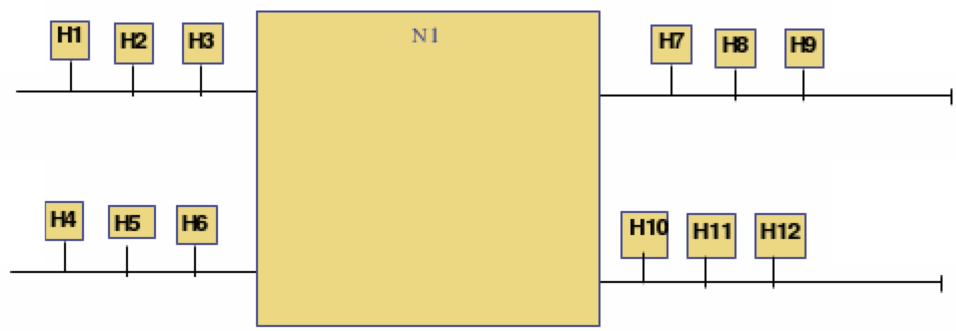
$$\lim_{N \to \infty} \frac{\eta_{LINEAR}}{\eta_{RANDOM}} = 1 + \frac{a'}{2}$$

8. Addressing and Connecting LANs [10 points]

For each of the following questions, determine if N1 is a **hub**, **bridge** or **router**. In some cases, more than one answer is possible!
The MAC and IP addresses of stations H2 and H8 are as follows:

H2 MAC address: ab:89:09:67:45:12
H2 IP address: 192.134.171.2

H8 MAC address: ab:89:09:67:45:ad
H8 IP address: 192.134.173.8



8.1 [3 points]
Host H2 sends a frame with the destination Ethernet address set to ab:89:09:67:45:ad. The frame reaches the intended destination (H8). What is Network element N1? Justify your answer.

Network element N1 is a HUB or a BRIDGE. Otherwise the destination MAC/Ethernet address would have to be the address of the router.

8.2 [3 points]
Host H2 sends ten frames with the destination Ethernet address set to ab:89:09:67:45:ad. All ten frames are seen by (i.e. reach) the intended destination (H8) as well as hosts H5 and H10. What is Network element N1? Justify your answer.

Network element N1 is a HUB or a BRIDGE (assuming initially empty tables). N1 is not a router, as the destination Ethernet/MAC address would have to be the Ethernet address different from H8's Ethernet address.

8.3 [4 points]

Host H2 wants to send an packet to IP address 192.134.173.8. To have this accomplished, host H2 places the given IP packet into a MAC-layer frame, and uses Ethernet address 12:42:65:ef:89:cd as the frame's destination address. The IP packet successfully reaches the final receiving host (H8). What is Network element N1? Justify your answer.

Network element N1 must be a ROUTER, since the MAC address is different from the destination's (H8's) MAC address.