College of Computer & Information Science — Fall 2007
Northeastern University — Handout 8
CSG250: Wireless Networks — 13 November 2007

Sample solution to Midterm

Part I ($5 \times 4 = 20$ points)

1. Inter-frame spacings in 802.11

Explain the rationale behind the different interframe-spacings in IEEE 802.11 MAC (infrastructure mode). In particular, define DIFS, PIFS, and SIFS and explain why DIFS is set larger than PIFS and PIFS is set larger than SIFS.

Answer: DIFS = distributed inter frame spacing, a new transmission can begin only after DIFS of idle time. PIFS = spacing after which point coordinator can take over. SIFS = spacing between transmission and ACK, between polling and response.

Having PIFS < DIFS allows point coordinator to take over and separate contention-free and contention periods. Having SIFS smaller than both PIFS and DIFS prevents ACK and important control packets from getting killed.

2. TCP enhancements for wireless networks

This question compares two TCP enhancements proposed for wireless networks: indirect TCP and snooping TCP.

(a) In which case is the handoff latency (when the mobile host moves from one cell/foreign network to another) higher? Briefly justify your answer.

Answer: Higher for indirect TCP since state information and buffered data need to be transferred from one FA to the other.

(b) Suppose the latency of the wireless link is much smaller than that of the fixed portion (wired Internet) of a TCP connection but the error rate of the wireless link is high, and that the mobile host is not moving. Which of the two schemes would provide better performance in such a scenario? Briefly justify your answer.

Answer: Indirect TCP isolates link better and retransmits lost packets quickly. A snooping TCP agent can also initiate retransmissions, just over the wireless link, but cannot maintain high throughput over the wired portion of the connection. If there is high variability in the quality of the wireless link, indirect TCP will outperform indirect TCP.

3. Error-correction codes

Can we design an error-correction code that corrects any 1- or 2- bit errors in a 16-bit block with 11 data bits and 5 correction bits? Justify your answer.

Answer: To correct all possible 1- and 2-bit errors, need to be able to encode (16 choose 2 + 16) possibilities, which equals 136. Need at least 7 bits for this.

4. Impact of cell size on capacity and performance

Discuss the impact of cell size on the capacity and the performance of a cellular system. In particular, what are the advantages and disadvantages of having small cells (as compared to large cells)?

Answer: Advantages: Can allocate the same number of channels per cell as with larger cells, and hence serve a larger number of users. Hence, capacity can potentially increase. Also, maximum transmission powers can be reduced, potentially reducing the cost of communicating devices. Disadvantage: frequent handoffs since users cross cell boundaries more often; this has an adverse effect on performance. Also, need more base stations, increasing the cost of deployment.

5. Modulation of analog data into digital signals

Why should Pulse-Code Modulation be preferable to Delta Modulation for encoding analog signals that represent digital data?

Answer: Analog signals representing digital data would typically have sudden changes in the signal values; this essentially means that the frequency spectrum of the underlying signal is wide. PCM is better at encoding such signals since it attempts to approximate the actual signal value and can handle large variations in short time (high frequency components). On the other hand, Delta Modulation encodes the difference to within some level of precision, and would have high overload/underload effects when signal values have large sudden variations.

Part II

6. (4 + 4 = 8 points) Antennas and propagation

An antenna A is separated from two other antennas B and C by a distance of 1 km and 5 km, respectively. The directivity gains of A, B, and C are 5 dB, 5 dB, and 15 dB, respectively. A sends out a broadcast signal to B and C using BPSK modulation and operating at a frequency band centered around 1 GHz. Assume that path loss is captured by the free space model and the antennas are aligned so that directive gains are achieved.

(a) If the signal sent by A is received by B with a power of 0.05 microwatts, what is the power of the same signal received at C?

Answer: The product of the gains of A and B equal 10, while that of A and C equal 100. The antenna C is 5 times further from A than B is from A. Therefore, the power received at C is 10/25 times that received at B and equals 0.02 microwatts.

(b) Suppose the transmission date rata is 1 Mbps and the transmission from A uses 125-byte packets. What are the frame error rates observed at B and C assuming the received powers of part (a)? Assume that the noise density in the area is 10^{-14} W/Hz and there is no other interference. Use the following formula for bit-error rate of BPSK.

$$BER = Q\left(\sqrt{\frac{2E_b}{N_0}}\right).$$

A table for the Q-function is given on the following page. Please use the nearest values whenever you do not find the exact values you are looking for.

Answer: We calculate the E_b/N_0 value for B as follows.

$E_b/N_0 = 5 \cdot 10^{-8}/(10^6)10^{-14} = 5.$

So BER = 0.00069. For a frame size of 1000 bits, the frame-error rate is 0.499.

For C, $E_b/N_0 = 2$. So BER = 0.02, implying a high FER of $1 - 10^{-7}$.

z	$Q(z)$	z	$Q(z)$
0.0	0.50000	2.0	0.02275
0.1	0.46017	2.1	0.01786
0.2	0.42074	2.2	0.01390
0.3	0.38209	2.3	0.01072
0.4	0.34458	2.4	0.00820
0.5	0.30854	2.5	0.00621
0.6	0.27425	2.6	0.00466
0.7	0.24196	2.7	0.00347
0.8	0.21186	2.8	0.00256
0.9	0.18406	2.9	0.00187
1.0	0.15866	3.0	0.00135
1.1	0.13567	3.1	0.00097
1.2	0.11507	3.2	0.00069
1.3	0.09680	3.3	0.00048
1.4	0.08076	3.4	0.00034
1.5	0.06681	3.5	0.00023
1.6	0.05480	3.6	0.00016
1.7	0.04457	3.7	0.00011
1.8	0.03593	3.8	0.00007
1.9	0.02872	3.9	0.00005

7. (3 + 3 + 1 = 7 points) Spread Spectrum

Consider a Frequency-Hopping Spread Spectrum (FHSS) system using MFSK as the underlying modulation scheme.

For MFSK, the number of different signal elements M in MFSK modulation is 4 (so $L = 2$), and the difference frequency f_d is 25 KHz. So the total MFSK bandwidth is $2Mf_d = 200$ KHz.

The FHSS scheme uses 4 different channels, each of width 200 KHz (the MFSK bandwidth). Assume that the total FHSS bandwidth (800 KHz) is given by the spectrum 1 MHz to 1.8 MHz.

The data rate is 250 kbps and the frequency hopping scheme hops to a new channel every 1 μs.

(a) For the MFSK modulation scheme, make a frequency assignment for each of the four possible 2-bit data combinations.

Answer: In KHz, 1000-1050 for 00, 1050-1100 for 01, 1100-1150 for 10, and 1150-1200 for 11.

(b) List the frequencies used (center frequencies) over time when the bit stream 1011 is transmitted. And the hopping sequence is given by 0,1,2,3,0,1,2,3, ... (round robin through the 4 channels).

Answer: We assume channel 1 is 1000-1200 KHz, channel 2 is 1200-1400 KHz, channel 3 is 1400-1600 KHz, and channel 4 is 1600-1800 KHz. The bit period equals $1/(250 \cdot 10^3) = 4\mu$s. So the symbol period equals 8 μs. Since the hopping time period is 1 μs, the frequencies used are (in KHz):

1125, 1325, 1525, 1725, 1125, 1325, 1525, 1725 for the symbol 10, followed by

1175, 1375, 1575, 1775, 1175, 1375, 1575, 1775 for the symbol 11.

(c) What kind of frequency-hopping system (slow or fast) is the above scheme?

Answer: Since the symbol time period is larger than the hopping time period, this is a fast frequency-hopping system.

8. (8 points) The DCF mode of 802.11

An infrastructure network using a 1 Mb/s IEEE 802.11 has 2 nodes N1, and N2 connecting to an access point AP. At time 0, there is no ongoing transmission. At times 10 μs, 40 μs and 60 μs, a new packet arrives at N1, N2, and N1, respectively, to be sent to AP. Assume that the random number generator (for backoff) will give the following values – for N1's first packet: 1, 2, . . . ; for N1's second packet: 1, 3; for N2: 1, 4, ... Furthermore, assume that the backoff counter is used even for the very first transmission attempt and that if a node does not start receiving an ACK within 2*SIFS time units, it assumes the transmission is unsuccessful and resumes its backoff process.

Show the execution of the DCF mode of IEEE 802.11 for the above transmissions. Assume that SIFS is 10 μs, DIFS 50 μs, and slot time is 20 μs. Assume that we don't use RTS/CTS or fragmentation, and that all data packets have the same length of 125 bytes and that the ACK packet has length 25 bytes. Furthermore the channel bit error rate is assumed to be 0, and 802.11 provides the maximum possible throughput when there are no collisions.

Answer: All times are in μs. Below, the backoff at a node that has encountered a collision resumes 2*SIFS time after the transmission is complete. Some of you assumed that the resumption of backoff, on a collision, happens 2*SIFS *plus DIFS* time after the completion of the transmission – and also received full credit.

10: N1's first packet arrives

40: N2's packet arrives

60: DIFS completed at N1, backoff starts, second packet arrives

80: N1 starts transmitting, N2 waits

1080: N1's packet completed

1090: SIFS completed

1290: ACK completed, DIFS starts for N1 and N2

1340: DIFS completed, backoff begins

1360: Both N1 and N2 transmit

2360: N1 and N2 transmissions completed

2380: 2*SIFS completed, no ACK, so backoff resumes

2440: N1 transmits second packet, N2 suspends backoff

3440: N1 completes transmission

3450: SIFS completed

3650: ACK completed

3700: DIFS completed, N2 backoff resumes

3720: N2 transmits

4720: N2 completes

4730: SIFS completed

4930: ACK completed

9. (2 + 2 + 3 = 7 points) Capacity of a cellular network

A city has an area of 1600 square miles and is covered by a cellular system that uses square cells and has a reuse factor of 5. Each cell has a side length of 4 miles and the city is allocated 50 MHz of spectrum with channel bandwidth of 50 KHz. Assuming a grade of service of 0.02, a traffic load per user of 0.03 Erlangs, and an allocation of 10 control channels per cell, answer the following questions.

(a) Determine the number of cells in the service area.

Answer: $1600/16 = 100$.

(b) Determine the number of voice channels per cell.

Answer: Owing to a reuse factor of 5, we need to allocate for 5 cells. We have 1000 channels in all. So 200 channels per cell. 10 control channels. So 190 voice channels.

(c) Determine the total number of users that can be served within the grade of service requirement. Please refer to the Erlang table given in the text, if needed.

Answer: With 190 voice channels, 0.02 GOS capacity is about 170 erlangs. So number of users per cell equals approximately $170/0.03 \approx 5667$. Multiplying by 100 gives the total number of users, 566700.