College of Computer & Information Science
Northeastern University
CSG250: Wireless Networks

Spring 2007
Handout 8
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Sample Solution to Problem Set 3

(The problem numbers from the text are the same in both the first and second editions.)

1. (8 points) The DCF mode of IEEE 802.11

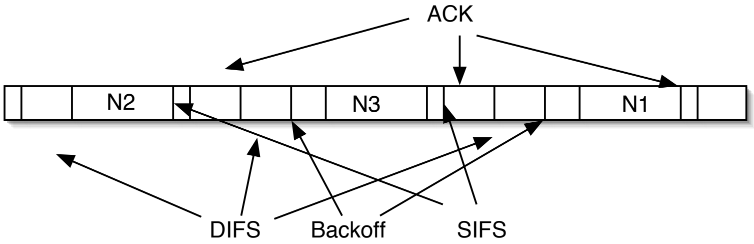
An ad hoc network using a 1 Mb/s IEEE 802.11 has 4 nodes: N1, N2, N3, N4. Assume that SIFS is 25 μs, PIFS 50 μs,, DIFS 100 μs, and slot time is 50 μs. Assume that at the beginning the channel is idle (no transmission), and that at slot 1, N2 has a packet to be sent to N4. At slot 2, both N1 and N3 have a packet to be sent to N4. Assume that the random number generator (for backoff) will give the following values for N1: 2, 5, . . . ; for N2: 4, 3, . . . ; and for N3: 1, 4, ...

Assume that we don't use RTS/CTS or fragmentation, and that all data packets have the same length of 500 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. Show the execution of the DCF mode of IEEE 802.11.

Answer: We have the following sequence of events, labeled by the time (in μs) of their occurrence:

- 50: A packet arrives at N2. It senses the channel free and waits for DIFS time units.
- 100: Packets arrive at N1 and N3. Each waits for DIFS time units.
- 150: N2 transmits its packet, noting that the channel is free.
- 150: N1 and N3 select a backoff time of $2 \cdot 50 = 100$ and $1 \cdot 50 = 50$ time units, respectively. (The factor of 50 corresponds to the slot time.) Their backoff times will not start until (at least) DIFS time units after the transmission of N2 ends.
- 4150: N2 completes its transmission. N4 waits for SIFS time units to send its ACK.
- 4175: N4 sends its ACK. The backoff counters of N1 and N3 are still frozen.
- 4375: N2 receives the ACK.
- 4475: DIFS units have passed since last transmission. So the backoff counters of N1 and N3 resume (begin).
- 4525: N3's backoff counter times out. So N3 transmits its packet. N1 freezes its backoff counter.
- 8525: N3's transmission completes. N4 waits for SIFS before sending ACK.
- 8550: N4 sends ACK.
- 8750: ACK transmission complete.
- 8850: N1 resumes its backoff counter.

- 8900: N2's backoff counter times out and it transmits its packet.
- 12900: N2's packet received at N4. It waits for SIFS before sending ACK.
- 12925: ACK sent by N4.
- 13125: ACK received by N2.



2. (6 points) The PCF mode of IEEE 802.11

Suppose that four stations in an IEEE 802.11 infrastructure network are in a polling list. The stations transmit 20 ms voice frames produced by 64 kbps speech encoders. Suppose that the contention-free period is set to 20 ms. Sketch a point-coordination frame transfer with the appropriate values for interframe spacings, NAV, and data and ACK frames.

Answer: The solution is depicted in Figure 1.

In PCF mode, at the start of the superframe, a beacon is sent that indicates the length of the contention-free period. All the stations then set the NAV to be the contention-free period.

In the following, we make the following assumptions: SIFS = 10 μs, PIFS = 30 μs, POLL = 400μs, ACK = 250 μs, CF-END = 400μs. The length of a voice frame is $64 \cdot 20 = 1280\mu$s. We also need to add some time for a header that would be added to the frame, but we will ignore it for simplicity.

Suppose the superframe starts at 0.

After PIFS = 30 μs, the Point Coordinator (henceforth, PC) sends a beacon containing the contention-free period. Each station sets their NAV to be the contention-free period.

At time 40 μs, PC sends a poll to Station 1, which completes at time 440μs.

At time 450μs, Station 1 sends a voice frame, which completes at time 1730μs.

At time 1740 μs, PC sends a poll to Station 2, together with an ACK for the previous frame. This transmission completes at time $1740 + 400 + 250 = 2390\mu$s.

At time 2400 μs, Station 2 sends a voice frame, which completes at time $2400 + 1280 = 3680\mu$s.

At time 3690 μs, PC sends a poll to Station 3, together with an ACK for the previous frame. This transmission completes at time $3690 + 400 + 250 = 4340\mu$s.

At time 4350 μs, Station 3 sends a voice frame, which completes at time $4350 + 1280 = 5630\mu$s.

At time 5640 μs, PC sends a poll to Station 4, together with an ACK for the previous frame. This transmission completes at time $5640 + 400 + 250 = 6290\mu$s.

At time 6300 μs, Station 4 sends a voice frame, which completes at time $6300 + 1280 = 7580\mu$s.

When there are no other stations on the polling list, then the PC ends the contention-free period with an ACK and CF-End frame.

3. (6 points) Mobile IP

Problem 12.1.

Answer: We list the key parts of the IP headers.

(a) When E is on the same LAN as D.

MAC Header: Destination address is that of E on LAN Z. Source address is the MAC address of D. Also include length of frame and other fields.

When the LLC protocol is used, the LLC header contains the Destination Service Access Point (DSAP) of E and Source SAP of D, protocol type field, and other appropriate fields.

IP Header: Destination address is IP address of E and source address is the IP address of D. Rest of the fields as in standard IP.

This is followed by the transport layer header and data.

(b) When E is in a foreign network and IP-to-IP encapsulation is used. For the packet from D to R3, we have

MAC Header: Destination address is that of R3 on LAN Z. Source address is the MAC address of D. Also includes length of frame and other fields.

When the LLC protocol is used, the LLC header contains the Destination Service Access Point (DSAP) of R3 and Source SAP of D, protocol type field, and other appropriate fields.

IP Header: Destination address is IP address of E and source address is the IP address of D. Rest of the fields as in standard IP.

This is followed by transport layer header and data.

For the packet from R3 to E, the IP datagram is as in Figure 12.7(a) of the text. The destination address is care-of-address of E and the source address is the IP address of R3. The payload of the new IP packet contains the old IP header and its payload (that is, the portion of the D → R3 packet beginning from its IP header).

(c) When E is in a foreign network and minimal encapsulation is used, the D-to-R3 packet is the same as before.

For the packet from R3 to E, the IP datagram is as in Figure 12.7(b) of the text. The destination address is care-of-address of E and the source address is the IP address of R3. The payload of the new IP packet contains only the non-redundant parts of the old IP header and the original payload.

4. (6 points) Efficiency of cellular networks

Problem 10.15.

(a) The number of subscribers equals traffic/0.03. So it is 1026.7, 2223.3, 1620.0, 1106.7, 1273.3, 1260.0, and 1086.7, respectively.

(b) Number of calls per hour per subscriber is $0.03/(120/3600) = 0.9$.

(c) Multiply each number in part (a) by 0.9 to get 924, 2001, 1458, 996, 1146, 1134, and 978, respectively.

(d) The value of A is given in the problem statement. For a grade of service of 0.02, and using Table 10.3 of book, we get the required number of channels to be 40, 78, 59, 43, 48, 48, and 42, respectively.

(e) Adding the values of part (a), we get 9597.

(f) The average number of subscribers per channel is $9597/358 = 26.8$.

(g) $9597/3100 = 3.1$.

(h) Adding the values in the table, we get 287.9.

(i) $287.9/3100 = .09$ per km^2.

(j) Assuming each cell is a hexagon, we get the radius to be $\sqrt{3100/(7 \cdot 1.5 \cdot \sqrt{3})} \approx 13$km.

5. (18 points) Access points and handoffs

Consider a network consisting of two access points: AP1 and AP2, located at positions (-100, 0) and (100, 0) on the plane, respectively, where the distance unit is meter. A mobile unit is communicating through this network, which offers a data rate of 1 Mbps, using BPSK modulation and operating at a frequency spectrum centered around 2.4 GHz. Each access point transmits at the level of 100mW and the noise density in the area is 10^{-16} W/Hz. Assume that all packets have the same size: 100 bytes.

(a) Draw a two-dimensional graph that (approximately) indicates the region in which the mobile incurs a frame error rate of at most 5% on transmissions from access point AP1.

Answer: Consider a point (x, y). Assuming the free-space loss model, we obtain that the received power at the mobile station for a transmission from AP1 equals

$$\frac{100 \cdot 3^2 \cdot 10^16}{16\pi^2 \cdot 2.4^2 \cdot 10^{18} \cdot ((x+100)^2 + y^2))} = \frac{0.01}{(x+100)^2 + y^2} mW.$$

Similarly, the received power for a transmission from AP2 equals

$$\frac{0.01}{(x-100)^2 + y^2} mW.$$

We thus obtain the E_b/N_0 values as

$$\frac{10^{-5}}{10^{-16} \cdot 10^6 \cdot ((x+100)^2 + y^2)} = \frac{10^5}{(x+100)^2 + y^2}$$

and

$$\frac{10^5}{(x-100)^2+y^2},$$

respectively.

Plugging this value into the BPSK BER formula, we obtain the bit-error rate for a transmission from AP1 and AP2, as received at (x, y). We can compute the frame-error rate as $1-(1-BER)^{800}$.

The frame-error rate of 5% is obtained at point $(0, 60)$ from AP1 (more precisely, $(0, 60.3)$), i.e., at a distance of $\sqrt{100^2+60^2}=116.6$.

The solution is depicted in Figure 2.

(b) Suppose the mobile decides to switch from one access point to another whenever the signal from the newer access point is at least 20% stronger than from the first one. Draw a two-dimensional graph that indicates the points at which a mobile will switch from AP1 to AP2.

Answer: We can compare the E_b/N_0 values to determine the points where the signal strength of AP2 is better than that of AP1 by at least 20%. We obtain the region to be defined by:

$$\frac{10^5}{(x-100)^2+y^2} \geq 1.2\frac{10^5}{(x+100)^2+y^2},$$

which can rewritten as

$$x^2+y^2-2200x+10000 \leq 0,$$

and as

$$(x-1100)^2+y^2-1200000 \leq 0.$$

The solution is depicted in Figure 3.

(c) Repeat part (b) for the case when the mobile decides to switch whenever the signal from the newer access point is at least 20% stronger than from the first one *and* the frame error rate for communication with previous access point exceeds 5%. An approximate curve will suffice.

Answer: All we need is the intersection of the two regions above. Thus, the mobile will switch from AP1 to AP2 when it leaves the inside of both the circles.

The solution is depicted in Figure 4.

You may adopt a free-space loss model for idealized isotropic antenna (ignoring gains) and may use the following formula for the Bit-Error-Rate (BER) of BPSK modulation:

$$BER = \int_{\sqrt{2E_b/N_0}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{u^2}{2}} du.$$

(To calculate the above numerically, you can use the complement of the error function used in statistical analysis – e.g., the ERFC function in Excel.)

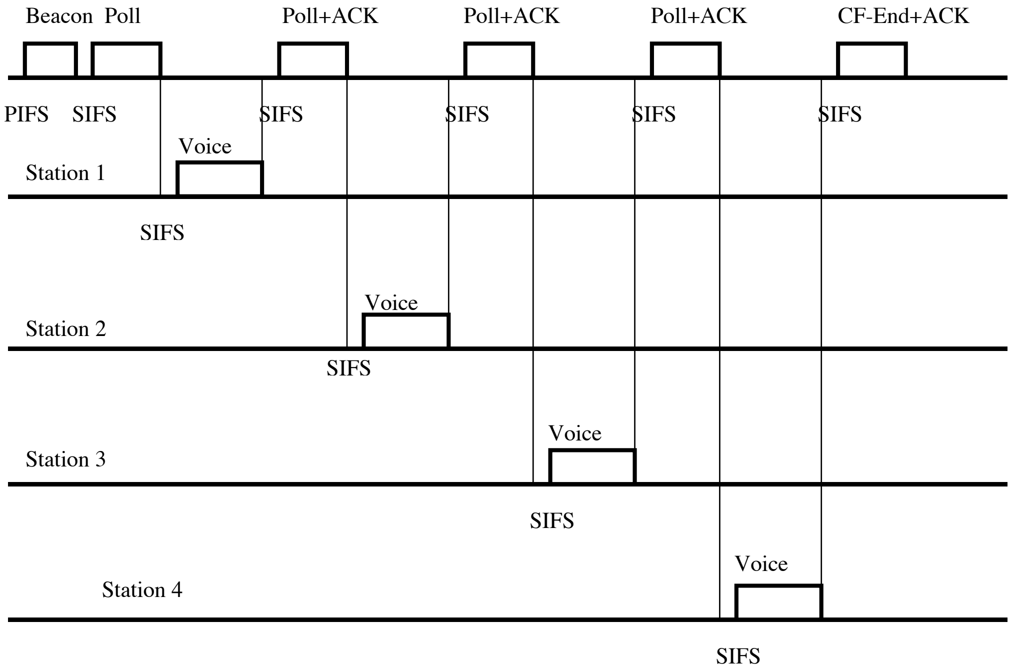


Figure 1: Problem 2

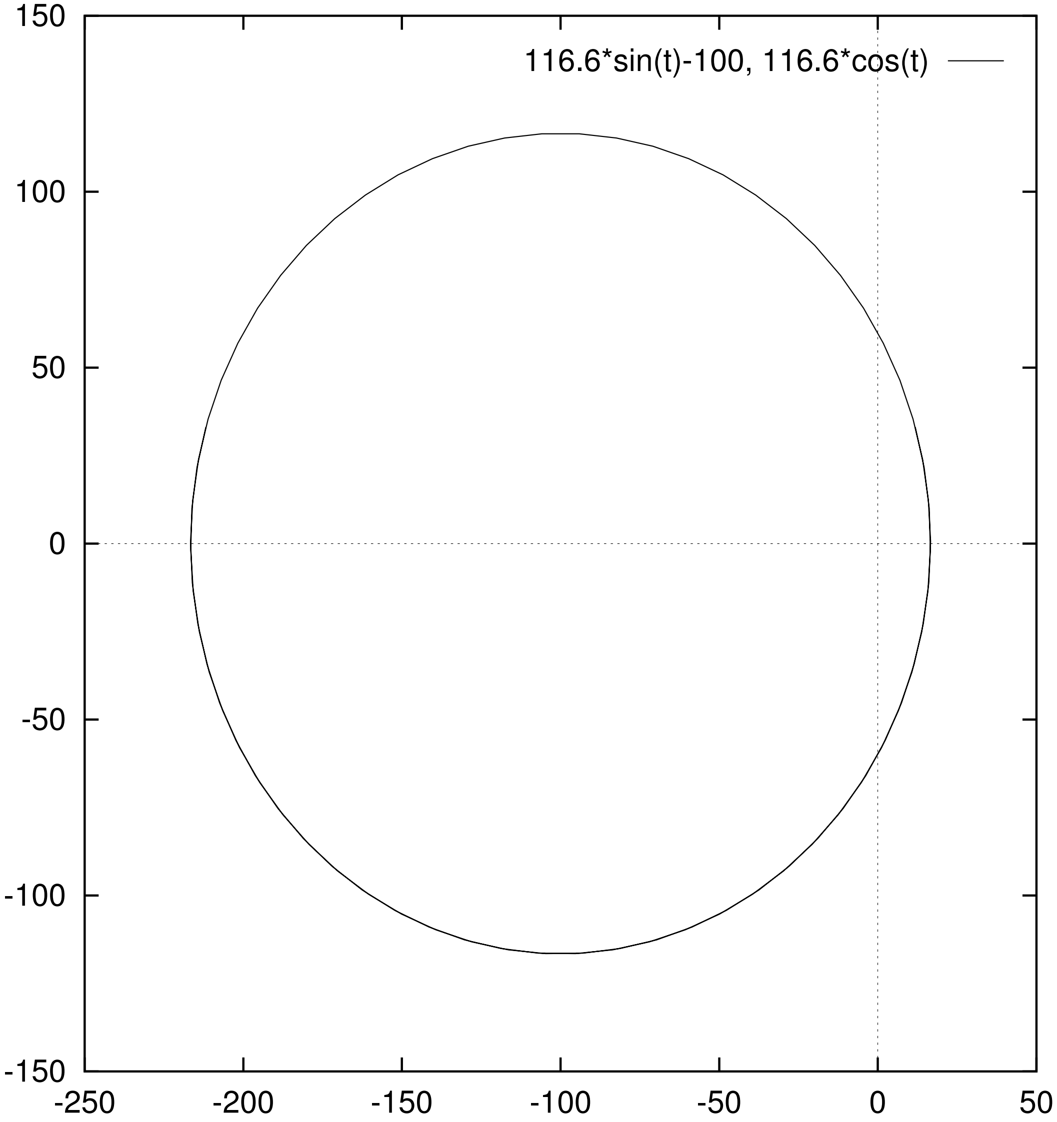


Figure 2: Frame error rate at most 5% for transmission from AP1 in the region inside the circle.

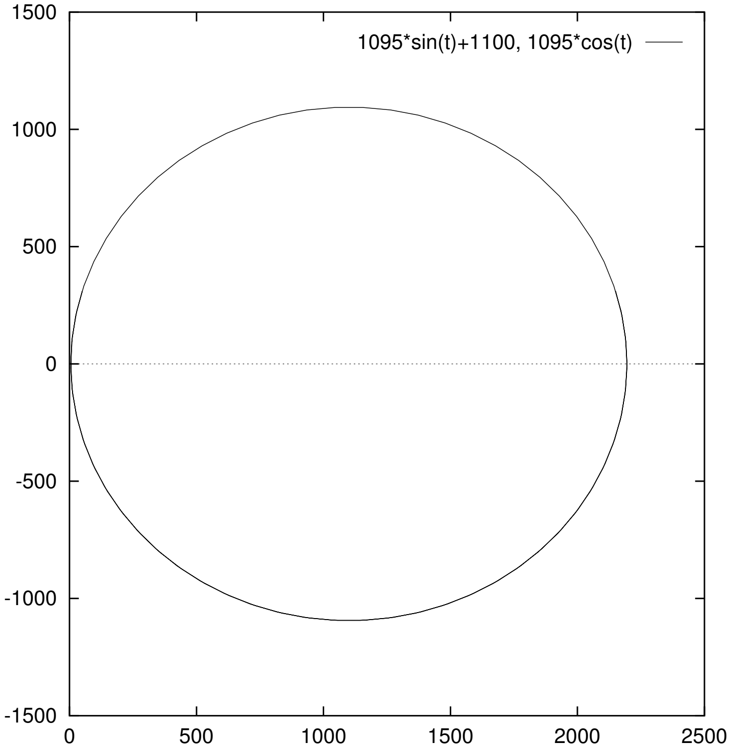


Figure 3: Signal strength from AP2 is stronger than that from AP1 by at least 20% in the region inside the circle (and including the circle boundary).

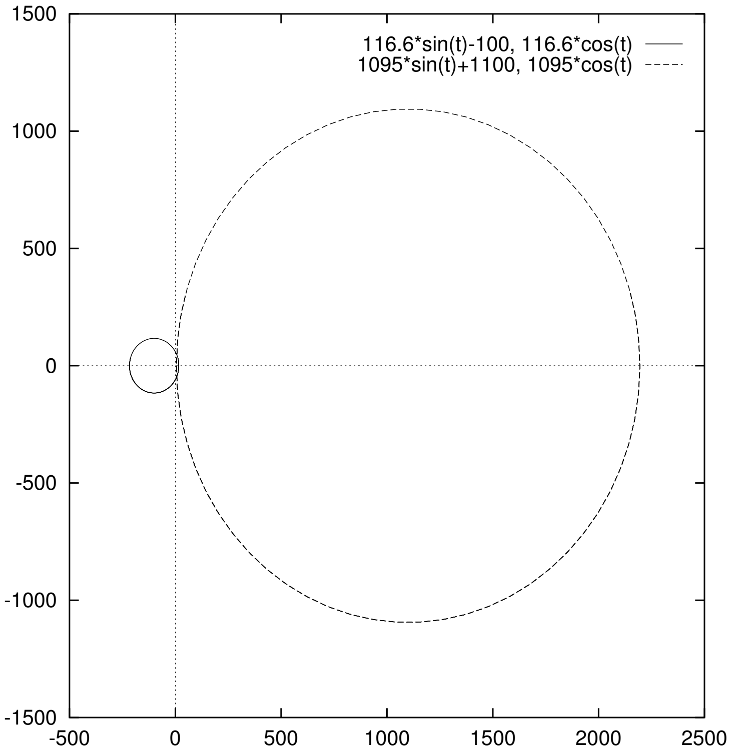


Figure 4: Assuming the mobile is connected to AP1, it will switch to AP2 when it leaves the inside of the smaller circle and enters the larger circle.