ECE 4380/6380: Computer Communications **Spring 2017**
Problem Set 4 Solutions

Each problem is worth 10 points

1. Binary Exponential Backoff.

We are told that host *A* chooses the first slot. In order for this transmission to be successful we need that the other three hosts do not choose the first slot, but instead choose any of their other slots. The probability that a host does not choose the first slot is given in the table below.

Host	Collision count	Possible slots to choose from	Probability node does not choose slot 1 but any of the other slots
A	5	We are told it chooses slot 1	Transmits in slot 1
B	2	4	3/4
C	3	8	7/8
D	4	16	15/16

So, the probably that host *A* is successful is event that hosts *B*, *C*, and *D* each do not choose slot 1. Each of these events is independent, so the probability of success is the product of the probability of each event. That is, *p*, the probability that *A* is successful is

$$p = \frac{3}{4}\frac{7}{8}\frac{15}{16} = 0.615\,.$$

2. Ethernet timing and access protocol.

(a) *A* is able to detect the collision before it finishes transmitting the frame. *A* begins at t=0 and if there is no collision, would transmit until (512 + 64 +8 bits)/10 Mbps = 58.4 μs. Terminal *B* begins at t=25μs, and the interference arrives at *A* at 50 μs. So, *A* detects the interference before it has stopped transmitting.

(b) For terminal *A*: at t=50.0μs *A* detects interference and by rule (i) in the problem statement, *A* transmits a 32 bit jamming signal. So, at t=53.2μs *A* stops transmitting.
For terminal *B*: *B* detects interference at t=25μs and by rule (ii) *B* transmits 96 bits. At t=34.6μs *B* stops transmitting.

(c) *A* stops transmitting at 53.2 μs but hears *B*'s jamming signal until (34.6 + 25) = 59.6 μs. So, *A* determines that the channel is idle at 59.6 μs.
B stops transmitting at 34.6μs but it continues to hear *A*'s transmission until (53.2 + 25) = 78.2μs.

(d) There is no delay between when the channel becomes idle at *A* and when *A* can detect this.

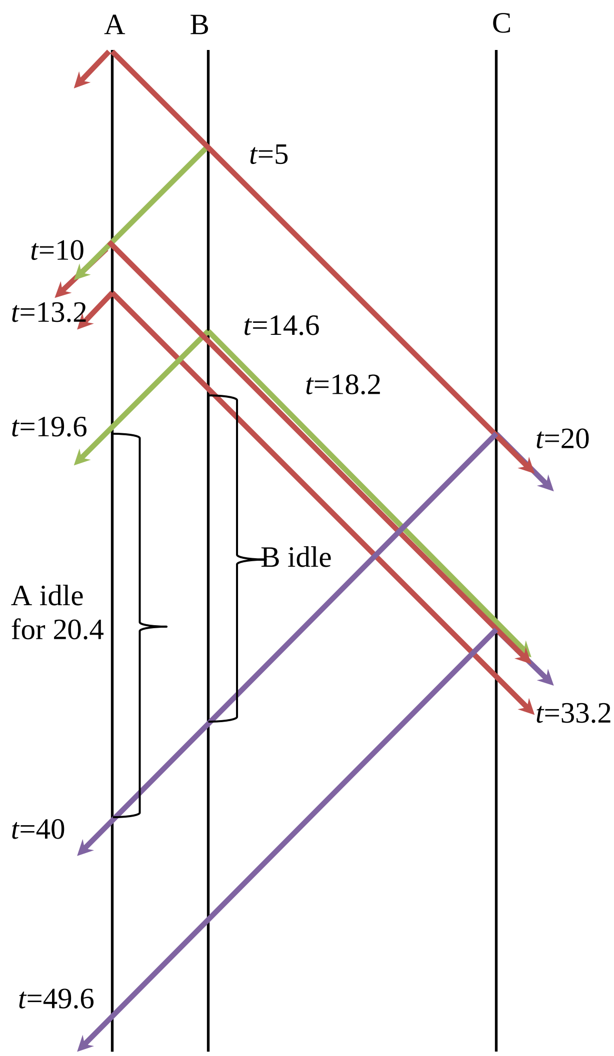
A's actions	*B*'s actions
Start transmission at (59.6 + 51.2) = 110.8 μs	Start transmission at (78.2 +51.2) = 129.4 μs
Hears *B* at (129.4 + 25) = 154.4 μs	Hears *A* at (110.8 + 25) = 135.8μs
By (i) jams until 157.6 μs then stops	By (i) has just transmitted 64 bit preamble so transmits jamming signal until 139.0 μs
Hears *B* until (139.0 + 25) = 164.0 μs then idle	Hears *A* until (157.6 + 25) = 182.6 μs then idle

(e) *B* will not attempt to transmit again until 182.6 + 51.2 = 223.8 μs. However, *A* begins its transmission at 164.0 μs. So, *B* detects *A*'s transmission at (164.0 + 25) = 189.0 μs. Because

B detects the channel to be busy it does not transmit its frame but waits until the channel is idle. Therefore, *A*'s transmission is successful.

3. Ethernet collisions

Three hosts, A, B, and C, are the only active hosts on a 10 Mbps Ethernet. The propagation time between A and B is 5 μsec and between B and C is 15 μsec, and host B is located between hosts A and C. Suppose A begins transmitting its frame at time t= 0, B begins transmitting its frame at time t=5 μsec, and C begins transmitting its frame at time t=20 μsec.



Host A begins to transmit at time *t*=0, and the first bit of A's' transmission reaches host B at *t*=5 and reaches host C at *t*=20. Consider host B: it begins its own transmission at *t*=5, and immediately detects a collision. Because B is just beginning to transmit it must transmit 96 bits, for duration of 9.6 μsec. Host B stops transmitting at 14.6 μsec (all transmissions propagates along the cable in both directions). Meanwhile, host A detects a collision at time *t*=10 due to the transmission from host B. Since host A has been transmitting for 10 μsec (i.e., A has transmitted 100 bits), A just transmits the 32 bit jamming

sequence and then stops transmitting. So the last bit host A transmits is at time 13.2 μsec. However, host A continues to see the bits from host B until time 19.6 μsec; after the last bit of host B's jamming signal passes host A, host A detects the channel as idle. A similar argument shows that host B stops transmitting its jamming signal at time 14.6 μsec, and sees the last bit of host A's jamming signal pass by at time 18.2 μsec.
Host C starts to transmit at 20 μsec and immediately detects a collision from the first bit of host A's signal. Host C transmits 96 bits for the jamming signal, and host C stops transmitting at time 29.6 μsec. Host C continues to see the combined energy from A's and B's transmissions until time 29.6 μsec, and then just the energy (i.e., bits) from host A's transmission until time 33.2 μsec.

(a) Host A detects the channel idle at 19.6 μsec
(b) Host B detects the channel idle at 18.2 μsec
(c) Host C detects the channel idle at 33.2 μsec
(d) Suppose that host A selects slot 0 for its retransmission (that is, there is no delay before beginning its retransmission after detecting the channel idle) and hosts B and C both select slot 1 (that is, wait for 51.2 μsec after detecting the channel is idle before attempting a retransmission).

Host A's retransmission attempt is not successful. Host A begins to transmit at time 19.6 μsec, but detects there is a collision at time 40 μsec; host A transmitted for 20.4 μsec (or 204 bits) before it detected the collision. Since the smallest frame size is 512 bits, host A is able to detect the collision.

4. Medium Access Control.

(a) Find the maximum distance of the cable if the number of bits in the frame is x. Because the frame is x bits, the transmission time is (x bits) / (y bits per second) = x / y seconds. Node A must still be transmitting when the jamming signal from node B arrives. If B does not start to transmit until just before A's first bit arrives at B, the B needs to starting transmitting at $x / 2y$ seconds. The length of cable corresponding to this propagation delay is ($x / 2y$ seconds) × (c meters per second) = $xc / 2y$ meters.
(b) Min cable length if late collision. Let d' be the new distance. If B starts to transmit just before A's signal arrives then we have the same situation as in part (a). A transmits $x + e$ bits in 2 d'/c seconds.

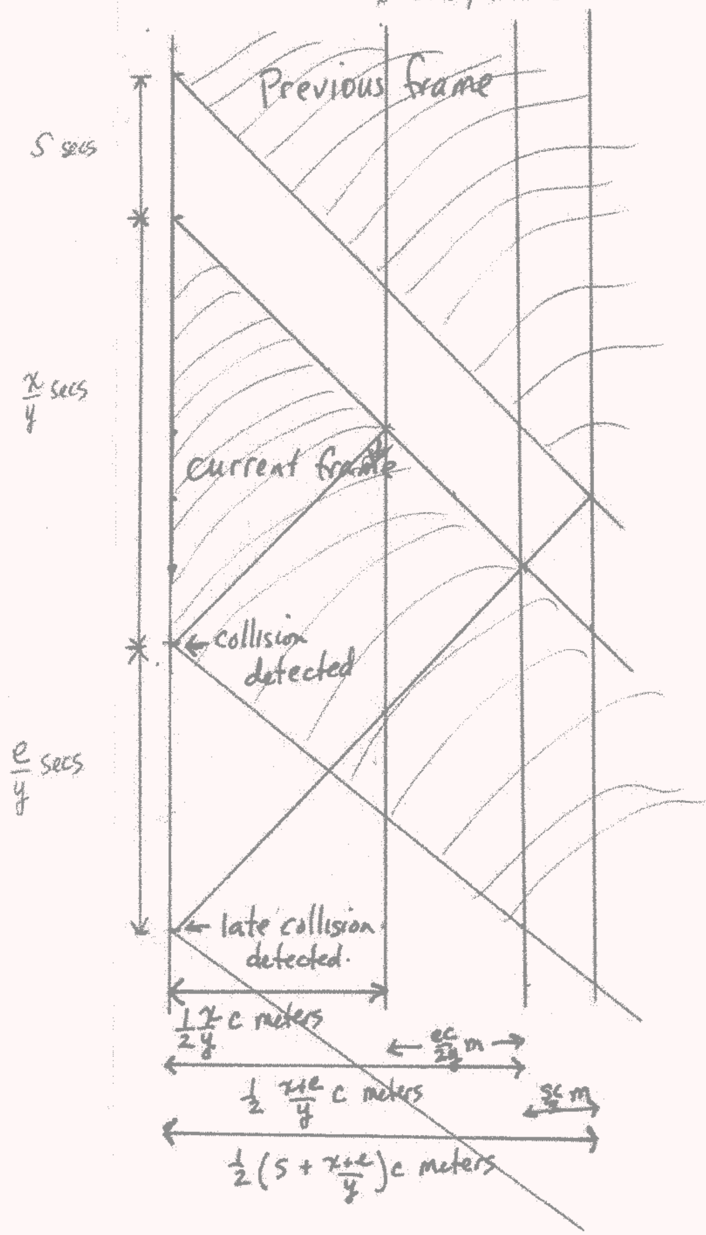
$$x + e = \frac{2d'}{c} y$$

$$d' = \frac{(x+e)c}{2y}$$

If you use $d = xc/2y$ from part (a), then we have $d' = d + ec/2y$. The cable is to long by $ec/2y$ meters.
(c) Max cable length. In the previous two parts we assume B does not start to transmit until right before A's signal arrives at B. B could transmit earlier, but not until it detects the channel is idle. Because B must have received the previous frame, B can only transmit s seconds earlier than in part (b). If we move B an additional (s/2 sec) (c meters per sec) = $sc/2$ meters then its signal still arrives at A at the same time as part (b). So the max distance, $d_{max} = d' + sc/2$.

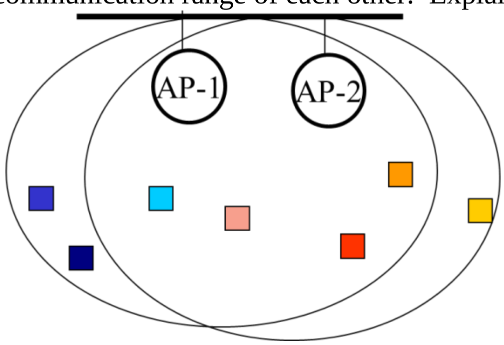
medium-access control

y bits/sec
c meters/sec
x bits / frame



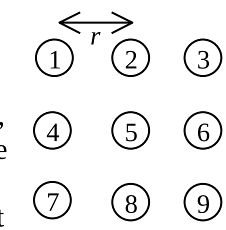
5. 802.11 access points

For a wireless network based on the IEEE 802.11 standard it is desirable that there is some overlap in the area that is covered by each of the access points (AP's). Consider two AP's that are configured to use the same frequency channel, and are located close enough to each other so as to be within communication range of each other. Explain why this configuration of AP's is undesirable.



The figure above illustrates an example. A problem with this configuration is that if either AP transmits an RTS or CTS, the other AP will overhear it. By the rules of the DCF channel-access protocol, a terminal that overhears an RTS or CTS is blocked from transmitting for the expected duration of the transmission it is overhearing. Thus, at most one transmission can occur at a time and there is very little benefit to having two AP's. If the two AP's are not within communication range of each other, then they can both send or receive packets simultaneously as long as the destination hosts are not within range of both AP's or each other.

6. 802.11 MAC



Consider an 802.11 ad hoc wireless network, and assume that nine wireless nodes are arranged in a uniform grid as shown in the figure to the right. For example, *r* meters separate nodes 1 and 2. Assume that each node has the same signal coverage and a circular shape represents the coverage (e.g., if the signal coverage is *r* meters then nodes 1 and 2 can transmit to each other but nodes 1 and 5 cannot). Assume that node 1 transmitted an RTS to node 2, node 2 transmitted a CTS to node 1, and node 1 is currently transmitting a data packet to node 2. At this instant, which nodes are permitted to transmit an RTS?

By the rules of the DCF channel-access protocol, when node 1 transmits the RTS, node 4 overhears it and is blocked. Node 2 responds with a CTS, and both nodes 3 and 5 overhear this transmission and are blocked. Nodes 6, 7, 8, and 9 are not blocked and thus are permitted to transmit an RTS. (However, if the RTS specifies nodes 3, 4, or 5 as the destination, then no CTS is sent and the host that transmitted the RTS must wait for a timeout and try again later. Unfortunately, the host does not know how long to wait since it does not know the data rate or the packet size that host 1 is using for its transmission to host 2.)

7. Hidden terminal problem

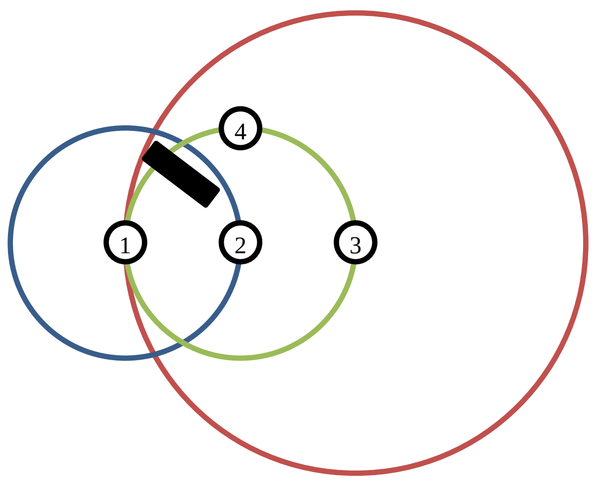
Consider an ad hoc wireless network, and assume that nine wireless nodes are arranged in a uniform grid as shown in the figure for the previous problem. Assume that each node has the same signal coverage and a circular shape represents the coverage (e.g., if the signal coverage is *r* meters then nodes 1 and 2 can transmit to each other but only if no other node is transmitting that is within *r* meters of the receiver).

The minimum signal coverage so that none of the nodes suffer from the hidden terminal problem is $2\sqrt{2}r$. For example, consider host 1: hosts 3, 6, and 9 must be able to detect that host 1 is transmitting to avoid initiating a transmission that creates interference at the intended receiver for host 1. Note the DCF channel-access protocol can reduce the chances of a collision due to a hidden terminal but it cannot eliminate the problem. For example, a receiver is vulnerable to a hidden terminal from the time is begins to receive the RTS until the hidden terminal detects the CTS.

8. Communication range versus carrier sense range

Define the maximum *communication range*, R, to be the maximum distance between two radios such that they can exchange RTS, CTS, data, and ACK frames if there is no interference. In many wireless systems, a receiver can detect that another radio is transmitting even if the receiver is unable to acquire or decode the transmission because its distance from the transmitter is greater than R. The receiver can sense the presence of the transmitter by detecting its carrier. Define the *carrier sensing range*, R_S as the maximum distance at which a receiver can detect the presence of a transmitter. Define the *interference range* to be R_I. A receiver that is within communication range of a transmitter can receive a frame if there are no other transmissions within range R_I of the receiver. A common assumption, and the one used in our textbook, is that the communication, sensing, and interference ranges are equal. However, the carrier sensing range can be tuned. For this problem set the carrier sensing range to be equal to $2R$. The interference range is more complex to model. Consider two simplistic cases for modeling the interference range, and determine if the hidden terminal problem occurs or not. Assume there are no obstacles.

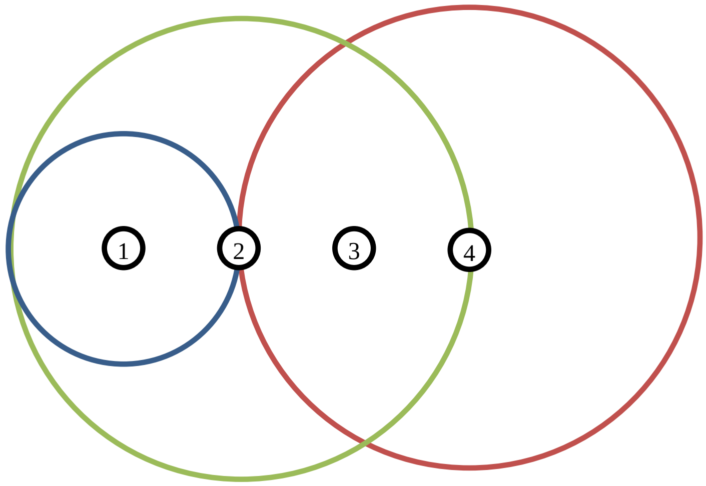
a. Let $R_I = R$. (This might apply to modulation techniques that are robust to interference like direct-sequence spread spectrum.)



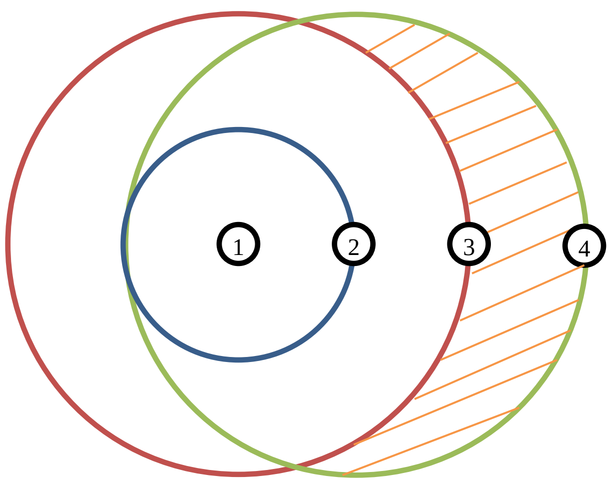
The hidden terminal problem is avoided. Consider a transmission from transmitter 1 to receiver 2. The blue circle centered at transmitter 1 shows its communication range. Assume receiver 2 is at distance R from transmitter 1. The green circle centered at receiver 2 shows 2's interference range $R_I = R$. Assume node 3 is located at distance R from receiver 2. Node 3 is at the farthest possible distance from receiver 2 yet still within range to interfere with receiver 2. However, the red circle centered at node 3 is the sensing range, and shows that node 3 can sense transmitter 1. Thus, node 3 is not hidden from transmitter 1. No node can be within distance R of receiver 2 but also at distance greater than $2R$ from transmitter 1, thus the hidden terminal problem is avoided.

We assumed there are no obstacles. However, if there is some obstacle between transmitter 1 and node 4, then 4 may fail to detect transmitter 1. Thus, the hidden terminal problem is created because the path loss may not be the same in all directions.

b. Let $R_I = 2R$. (High rate modulation techniques like OFDM are more sensitive to interference.)



The hidden terminal problem can occur. Again consider a transmission from transmitter 1 to receiver 2, and assume node 4 is at distance R from node 3. While node 3 can detect transmitter 1, node 4 cannot. However, a transmission by node 4 will cause interference at receiver 2.



In the above figure the red circle with radius R_S is centered at transmitter 1, and the green circle is centered at receiver 2 with radius R_I. Any node outside the red circle but inside the green circle is hidden from transmitter 1 but will create interference at receiver 2.

9. Ethernet capture effect (required for 638 students only).

(a) A can choose k_A=0 or 1. B can choose k_B=0, 1, 2, or 3. A wins outright if (k_A, k_B) is among (0, 1), (0, 2), (0, 3), (1, 2), or (1, 3). There is a 5/8 chance of this.

(b) For the third race k_B=0… 7. A does not win the race if (k_A, k_B) is among (0, 0), (1, 0), or (1, 1). In all other combinations A wins. Thus, P(A wins race 3 | A won race 1 and 2) = 1 – 3/16 = 13/16.

(c) In general for the *i*-th race, A wins unless one of the 3 patterns listed in part (b) occurs.

Thus, P(A wins race *i* | A won races *i* – 1, *i* – 2, …, 2, 1) = $1 - \frac{3}{2^{i+1}} = \frac{2^{i+1}-3}{2^{i+1}}$

(d) Recall that for events *X*, *Y*, and *Z*, P(*X* | *Z*) = P(*X* | *Y Z*)P(*Y* | *Z*) + P(*X* | Y^c *Z*)P(Y^c | *Z*)

P(A wins 5 | A won 3, 2, 1) = P(A wins 5 | A won 4, 3, 2, 1)P(A wins 4 | A won 3, 2, 1) + P(A wins 5 | A lost 4, won 3, 2, 1)P(A lost 4 | won 3, 2, 1)

= P(A wins 5 | A won 4, 3, 2, 1)P(A wins 4 | A won 3, 2, 1)

because A cannot win race 5 if it lost race 4. A similar approach gives,

$P(A wins\ j \mid A won 3,2,1) = \prod_{i=4}^{j} \frac{2^{i+1}-3}{2^{i+1}}$ and in the limit

$P(A wins all \mid A won 3,2,1) = \prod_{i=4}^{\infty} \frac{2^{i+1}-3}{2^{i+1}} \approx 0.82$. Note that the probability that A wins all the races starting with the first is about 0.10.

This problem illustrates a subtle flaw in the Ethernet protocol with regard to fairness. There is a significant probability that if station *A* has a large number of frames to transmit that it can capture the network and transmit all the frames and not allow the other node access to the channel.