**Question 1**

Consider five wireless stations, *A*, *B*, *C*, *D*, and *E*. Station *A* can communicate with all other stations. *B* can communicate with *A*, *C* and *E*. *C* can communicate with *A*, *B* and *D*. *D* can communicate with *A*, *C* and *E*. *E* can communicate *A*, *D* and *B*.

(a) When *A* is sending to *B*, what other communications are possible?

(b) When *B* is sending to *A*, what other communications are possible?

(c) When *B* is sending to *C*, what other communications are possible?

***Solution***

For successful communication we require that the sender can reach (communicate with) the receiver, and that there be no other sender who can reach (now interfere with) the receiver. Also, a station cannot send and receive at the same time.

(a) Since all stations will see A’s packet, it will interfere with receipt of any other packet by any other station. So, no other communication is possible in this case.

(b) B’s packet will be seen by E, A and C, but not by D. Thus, E or C might try to send to D at the same time. However, E and C can communicate with A, so this would interfere with B’s transmission to A. Thus no other communication is possible.

(c) B’s packet will be seen by E, A and C, but not by D. Thus, E or A might try to send to D at the same time. Of these two possibilities, A can communicate with C, so this would interfere with B’s transmission to A. But E can safely send to D since it will not interfere with C’s reception.

**Question 2**

Six stations, *A* through *F*, communicate using the MACA protocol. Is it possible for two transmissions to take place simultaneously? Explain your answer.

***Solution***

Yes. Imagine that they are in a straight line and that each station can reach only its nearest neighbours. Then A can send to B while E is sending to F.

**Question 3**

CSMA/CA (CSMA with Collision Avoidance) is conceptually similar to Ethernet’s CSMA/CD (CSMA with Collision Detection). Provide the two main differences between the two protocols.

Compared to Ethernet, there are two main differences. First, starting backoffs early helps to avoid collisions. This avoidance is worthwhile because collisions are expensive, as the entire frame is transmitted even if one occurs. Second, acknowledgements are used to infer collisions because collisions cannot be detected.

**Question 4**

Describe using a suitable diagram the Hidden Terminal Problem Hidden and the Exposed Terminal Problem in wireless networks that rely on **CSMA/CA.**

***Solution***

Since not all stations are within radio range of each other, transmissions going on in one part of a cell may not be received elsewhere in the same cell. In this example, station *C* is transmitting to station *B*. If *A* senses the channel, it will not hear anything and will falsely conclude that it may now start transmitting to *B*. This decision leads to a collision.



Figure 1. (a) The hidden terminal problem. (b) The exposed terminal problem.

The inverse situation is the exposed terminal problem, illustrated in Fig. 1-(b). Here, *B* wants to send to *C*, so it listens to the channel. When it hears a transmission, it falsely concludes that it may not send to *C*, even though *A* may in fact be transmitting to *D* (not shown). This decision wastes a transmission opportunity.

**Question 5**

Both the hidden and exposed terminal problems lead to degradation of throughput. Explain how.

***Solution***

In the case of hidden terminal problem, unsuccessful transmissions result from collisions between a transmission originated by a node such as A which cannot hear the ongoing transmissions to its corresponding node B. The probability of such a collision is proportional to the total number of terminals hidden from A.

In the case of exposed terminal, unsuccessful transmissions result from nodes such as A being prevented from transmitting, because their corresponding node is unable to send a CTS. Again such unsuccessful transmissions are proportional to the number of exposed terminals.

**Question 6**

Consider the hidden and exposed terminal problems. In the topology given below, there is a line connecting two nodes if they are within transmission/interference range of one another. Node-1 is transmitting to Node-2, and Node-2 is receiving from Node-1. While this transmission is going on, for each node, state which nodes it can successfully transmit to or

receive from? More specifically, fill out a table similar to the table below. At each row, list which nodes can successfully transmit to the node in the first column, and which nodes can successfully receive from the node in the first column. Insert “None” when transmission or receiving is not possible for a node. *Do not make any assumptions on multicast, multihop, CS or RTS/CTS.*

Figure 3. Network topology

|  |  |  |
| --- | --- | --- |
| Node # | Can Transmit  Successfully to: | Can Receive  Successfully from: |
| 3 | None | None |
| 4 | 5 | None |
| 5 | None | 4 |
| 6 | None | None |
| 7 | None | None |
| 8 | None | None |

***Solution***

This question was designed to be as simple as possible. Basically, there is a transmission going on from node 1 to node 2; and we want to see what else can be received successfully without any interference. Transmission between 8 and 3 would collide with the ongoing transmission at node 2, so we would not want it to happen.

**Question 7**

In Fig. 2, four stations, *A*, *B*, *C*, and *D*, are shown. Which of the last two stations do you think is closest to *A* and why?



Figure 2. Virtual channel sensing using CSMA/CA

Note: *To reduce ambiguities about which station is sending, 802.11 defines channel sensing to consist of both physical sensing and virtual sensing. Physical sensing simply checks the medium to see if there is a valid signal. With virtual sensing, each station keeps a logical record of when the channel is in use by tracking the* ***NAV*** *(****Network Allocation Vector****). Each frame carries a NAV field that says how long the sequence of which this frame is part will take to complete. Stations that overhear this frame know that the channel will be busy for the period indicated by the NAV, regardless of whether they can sense a physical signal. For example, the NAV of a data frame includes the time needed to send an acknowledgement. All stations that hear the data frame will defer during the acknowledgement period, whether or not they can hear the acknowledgement.*

***Solution***

Station C is the closest to A since it heard the RTS and responded to it by asserting its NAV signal. D did not respond, so it must be outside A’s radio range.

**Question 8**

Give an example to show that the RTS/CTS in the 802.11 protocol is a little different than in the MACA protocol.



Figure 3. B and C are exposed terminals when transmitting to A and D

RTS/CTS in 802.11 does not help with the exposed terminals problem. So, given the scenario in the Figure 3, MACA protocol will allow simultaneous communication, B to A and C to D, but 802.11 will allow only one of these communications to take place at a time.

**Question 9**

Give two reasons why networks might use an error-correcting code instead of error detection and retransmission.

One reason is the need for real-time quality of service. If an error is discovered, there is no time for a retransmission. The show must go on. Forward error correction can be used here. Another reason is that on very low-quality lines (e.g., wireless channels), the error rate can be so high that practically all frames would have to be retransmitted, and the retransmissions would probably damaged as well. To avoid this, forward error correction is used to increase the fraction of frames that arrive correctly.

**Question 10**: What are the differences between the following types of wireless channel impairments: path loss, multipath propagation, interference from other sources?

***Solution***

Path loss is due to the attenuation of the electromagnetic signal when it travels through matter. Multipath propagation results in blurring of the received signal at the receiver and occurs when portions of the electromagnetic wave reflect off objects and ground, taking paths of different lengths between a sender and receiver. Interference from other sources occurs when the other source is also transmitting in the same frequency range as the wireless network.

**Question 11**: Describe the role of the beacon frames in 802.11.

***Solution***

APs transmit beacon frames. An AP’s beacon frames will be transmitted over one of the 11 channels. The beacon frames permit nearby wireless stations to discover and identify the AP.

**Question 12**: Suppose the IEEE 802.11 RTS and CTS frames were as long as the standard

DATA and ACK frames. Would there be any advantage to using the CTS and RTS frames? Why or why not?

*Solution*

No, there wouldn’t be any advantage. Suppose there are two stations that want to transmit at the same time, and they both use RTS/CTS. If the RTS frame is as long as a DATA frames, the channel would be wasted for as long as it would have been wasted for two colliding DATA frames. Thus, the RTS/CTS exchange is only useful when the RTS/CTS frames are significantly smaller than the DATA frames.

**Question 13**: Suppose there are two ISPs providing WiFi access in a particular café, with

each ISP operating its own AP and having its own IP address block.

a. Further suppose that by accident, each ISP has configured its AP to operate over channel 11. Will the 802.11 protocol completely break down in this situation? Discuss what happens when two stations, each associated with a different ISP, attempt to transmit at the same time.

b. Now suppose that one AP operates over channel 1 and the other over channel 11. How do your answers change?

***Solution***

The two APs will typically have different SSIDs and MAC addresses. A wireless station arriving to the café will associate with one of the SSIDs (that is, one of the APs). After association, there is a virtual link between the new station and the AP. Label the APs AP1 and AP2. Suppose the new station associates with AP1. When the new station sends a frame, it will be addressed to AP1. Although AP2 will also receive the frame, it will not process the frame because the frame is not addressed to it. Thus, the two ISPs can work in parallel over the same channel. However, the two ISPs will be sharing the same wireless bandwidth. If wireless stations in different ISPs transmit at the same time, there will be a collision. For 802.11b, the maximum aggregate transmission rate for the two ISPs is 11 Mbps.

Now if two wireless stations in different ISPs (and hence different channels) transmit at the same time, there will not be a collision. Thus, the maximum aggregate transmission rate for the two ISPs is 22 Mbps for 802.11b.

**Question 14**: In step 4 of the CSMA/CA protocol, a station that successfully transmits a frame begins the CSMA/CA protocol for a second frame at step 2, rather than at step 1. What rationale might the designers of CSMA/CA have had in mind by having such a station not transmit the second frame immediately (if the channel is sensed idle)?

***Solution***

Suppose that wireless station H1 has 1000 long frames to transmit. (H1 may be an AP that is forwarding an MP3 to some other wireless station.) Suppose initially H1 is the only station that wants to transmit, but that while half-way through transmitting its first frame, H2 wants to transmit a frame. For simplicity, also suppose every station can hear every other station’s signal (that is, no hidden terminals). Before transmitting, H2 will sense that the channel is busy, and therefore choose a random backoff value.

Now suppose that after sending its first frame, H1 returns to step 1; that is, it waits a short period of times (DIFS) and then starts to transmit the second frame. H1’s second frame will then be transmitted while H2 is stuck in backoff, waiting for an idle channel. Thus, H1 should get to transmit all of its 1000 frames before H2 has a chance to access the channel. On the other hand, if H1 goes to step 2 after transmitting a frame, then it too chooses a random backoff value, thereby giving a fair chance to H2. Thus, fairness was the rationale behind this design choice.

**Question 15**: Suppose an 802.11b station is configured to always reserve the channel with the RTS/CTS sequence. Suppose this station suddenly wants to transmit 1,000 bytes of data, and all other stations are idle at this time. As a function of SIFS and DIFS, and ignoring propagation delay and assuming no bit errors, calculate the time required to transmit the frame and receive the acknowledgment.

***Solution***

A frame without data is 32 bytes long. Assuming a transmission rate of 11 Mbps, the time to transmit a control frame (such as an RTS frame, a CTS frame, or an ACK frame) is (256 bits)/(11 Mbps) = 23 usec. The time required to transmit the data frame is (8256 bits)/(11 Mbps) = 751

DIFS + RTS + SIFS + CTS + SIFS + FRAME + SIFS + ACK

= DIFS + 3SIFS + (3\*23 + 751) usec = DIFS + 3SIFS + 820 usec

**Question 16**: Consider the scenario shown in Figure 5, in which there are four wireless nodes, A, B, C, and D. The radio coverage of the four nodes is shown via the shaded ovals; all nodes share the same frequency. When A transmits, it can only be heard/received by B; when B transmits, both A and C can hear/receive from B; when C transmits, both B and D can hear/receive from C; when D transmits, only C can hear/receive from D. Suppose now that each node has an infinite supply of messages that it wants to send to each of the other nodes. If a message’s destination is not an immediate neighbour, then the message must be relayed. For example, if A wants to send to D, a message from A must first be sent to B, which then sends the message to C, which then sends the message to D. Time is slotted, with a message transmission time taking exactly one time slot, e.g., as in slotted Aloha. During a slot, a node can do one of the following: (*i*) send a message; (*ii*) receive a message (if exactly one message is being sent to it), (*iii*) remain silent. As always, if a node hears two or more simultaneous transmissions, a collision occurs and none of the transmitted messages are received successfully. You can assume here that there are no bit-level errors, and thus if exactly one message is sent, it will be received correctly by those within the transmission radius of the sender.

a. Suppose now that an omniscient controller (i.e., a controller that knows the state of every node in the network) can command each node to do whatever it (the omniscient controller) wishes, i.e., to send a message, to receive a message, or to remain silent. Given this omniscient controller, what is the maximum rate at which a data message can be transferred

from C to A, given that there are no other messages between any other.

b. Suppose now that A sends messages to B, and D sends messages to C. What is the combined maximum rate at which data messages can flow from A to B and from D to C?

c. Suppose now that A sends messages to B, and C sends messages to D. What is the combined maximum rate at which data messages can flow from A to B and from C to D?

d. Suppose now that the wireless links are replaced by wired links. Repeat questions (a) through (c) again in this wired scenario.

e. Now suppose we are again in the wireless scenario, and that for every data message sent from source to destination, the destination will send an ACK message back to the source (e.g., as in TCP). Also suppose that each ACK message takes up one slot. Repeat questions (a) – (c) above for this scenario.



Figure 5. Network scenario

***Solution***

1. 1 message/ 2 slots
2. 2 messages/slot
3. 1 message/slot
4. i) 1 message/slot

ii) 2 messages/slot

iii) 2 messages/slot

1. i) 1 message/4 slots

ii) slot 1: Message A🡪 B, message D🡪 C

slot 2: Ack B🡪 A

slot 3: Ack C🡪 D

= 2 messages/ 3 slots

iii)

slot 1: Message C🡪 D

slot 2: Ack D🡪C, message A🡪 B

Repeat

slot 3: Ack B🡪 A

= 2 messages/3 slots