ECE257A HW3

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I. Problem 1 - Understand 802.11 CSMA/CA.

(1) Why does collision still occur even if all transmitters perform “listen before talk” in 802.11 CSMA/CA?

(2) Does RTS/CTS eliminate the hidden terminal problem? Why? How about exposed terminal problem.

(3) During random backoff, why does a transmitter need to freeze the backoff timer when the channel becomes busy again?

(4) Why doesn’t 802.11 CSMA/CA set the minimum back-off window size to 0?

Answer :

(1) The collision may still occur when two transmitters have the same back-off time. But this probability is low since each user’s back-off time is uniformly distributed among [0,1,..., CW-1].

(2) The hidden terminal problem is when there are two client’s which they cannot hear each other, but they can both hear the access point. Since they couldn’t hear each other they send message to the AP at the same time, and it may cause collision at the access point. RTS/ CTS only alleviates the problem but not solve the problem since RTSs from different clients may still collide with each other.

The exposed terminal problem happens when there are two access points and two clients client1 - AP1 - AP2 - client2. Client1 and AP1 can hear each other, AP1 and AP2 can hear each other, AP2 and client2 can hear each other, but no other pairs. When AP1 wants to send to client1 and AP2 wants to send to client2, they can do so simultaneously because they will not interfere with each other. But in reality, because of listen before talk, AP1 will hear that the channel is busy with AP2 transmitting, and decide not to transmit the signal. RTS/CTS will not solve the problem but only make things worse because will make them more unlikely to send signals simultaneously, even if it doesn’t it still need extra time to send the RTS/CTS signals.

(3) A transmitter need to freeze the back-off timer since it cannot have the timer count to zero and send a signal while others are transmitting.

(4) If 802.11 CSMA/CA set the minimum back-off window size to zero, the back-off time of each transmitter will be zero, which means all the transmitters who have a message to send will send simultaneously DIFS time after the ACK message, this will cause severe collision.

II. Problem 2 - Understanding wireless transmissions.

Figure below, 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 neighbor, 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 source/destination pairs?

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.

Answer :

a. C sends a message to B requires one time slot and B sends the same message to A requires another time slot. Since there are no other messages between any other source/destination pairs, the maximum rate is 1 message per 2 slots.

b. D can send message to C while A sends message to B within one time slot, so the combined maximum rate is 2 messages per slot.

c. A and C cannot transmit simultaneously since B will hear both of them, so A transmit to B takes one slot and C transmits to D takes another slot, so two messages are transmitted in two time slots, the combined maximum rate is 1 message per slot.

d. (a) If wireless links are replaced by wired links, C is directly connected to B and B is directly connected to A. C sends a message to B requires one time slot and B sends the same message to A requires another time slot. So the maximum rate is 1 message per 2 slots. (b) A is directly connected to B and D is connected to C, D can send message to C while A sends message to B within one time slot, so the combined maximum rate is 2 messages per slot. (c) A is directly connected to B and C is connected to D, and sending through the wired link doesn't cause any interference problem so C can send message to D while A sends message to B within one time slot, so the combined maximum rate is 2 messages per slot.

e. (a) C sends message to B requires 1 slot, B sends ACK to C requires 1 slot, B sends message to A requires 1 slot, A send ACK to B requires 1 slot. So the maximum rate 1 message per 4 slots. (b) A can send to B while D sends message to C. But B sends ACK to A and C sends ACK to D requires different slots. So the combined maximum rate is 2 messages per 3 slots. (c) First time slot : C sends message to D, second time slot : D sends ACK to C and A sends message to B, third time slot : B sends ACK to A. So the combined maximum rate is 2 messages per 3 slots.

III. Problem 3 - Stochastic models of pure ALOHA.

Assume an N-user pure ALOHA (unslotted ALOHA) network that is operating at its equilibrium state. What is the average number of attempts needed for a user to successfully transmit a frame? How about a slotted ALOHA network? Hint: Use basic analysis in probability to answer the questions.

Answer :

For pure ALOHA, assume the probability for a transmitter to transmit at a slot is p. The average attempts needed for a user to successfully transmit a frame is :

$$\sum_{i=1}^{\infty} i*(1-(1-p)^{2N-2}*p)^{i-1}*((1-p)^{2N-2}*p) =$$

$$((1-p)^{2N-2}*p)*\sum_{i=1}^{\infty} i*(1-(1-p)^{2N-2}*p)^{i-1} =$$

$$((1-p)^{2N-2}*p)*\sum_{i=1}^{\infty} \frac{r^{i-1}}{1-r} =$$

$$((1-p)^{2N-2}*p)*\frac{1}{(1-r)^2} = \frac{1}{(1-p)^{2N-2}*p}$$

where

$$r = 1-(1-p)^{2N-2}*p$$

For

$$p = \frac{1}{N}$$

which is

$$\frac{N^{2N-1}}{(N-1)^{2N-2}}$$

For slotted ALOHA, assume the probability for a transmitter to transmit at a slot is p. The average attempts needed for a user to successfully transmit a frame is :

$$\sum_{i=1}^{\infty} i*(1-(1-p)^{N-1}*p)^{i-1}*((1-p)^{N-1}*p) =$$

$$((1-p)^{N-1}*p)*\sum_{i=1}^{\infty} i*(1-(1-p)^{N-1}*p)^{i-1} =$$

$$((1-p)^{N-1}*p)*\sum_{i=1}^{\infty} \frac{r^{i-1}}{1-r} =$$

$$((1-p)^{N-1}*p)*\frac{1}{(1-r)^2} = \frac{1}{(1-p)^{N-1}*p}$$

where

$$r = 1-(1-p)^{N-1}*p$$

For

$$p = \frac{1}{N}$$

which is

$$\frac{N^{N}}{(N-1)^{N-1}}$$

IV. Problem 4 - Markov chain models of CSMA/CD.

Assume a CSMA/CD network where the frame length is not constant. In that case, the number of time slots required by the transmitted frames could take between Nmin and Nmax slots with equal probability.

(a) Draw the resulting state transition diagram.

(b) Indicate on the diagram the transition probabilities.

(c) Write down the state transition matrix.

Answer:

(a)(b) See figure 1.

(c) See the end of the assignment.

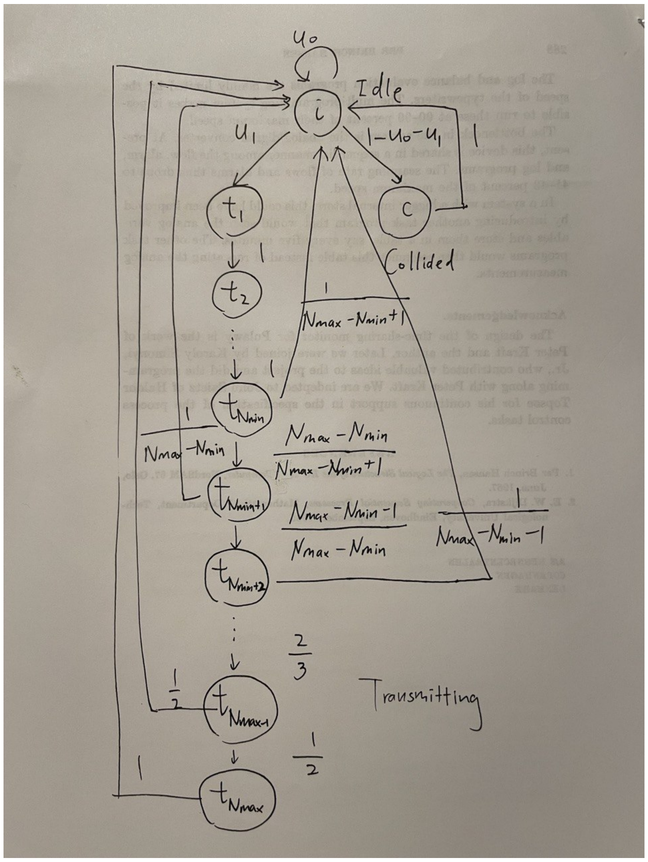

Fig. 1.

V. Problem 5 - Markov chain models of an arbitrary MAC protocol.

Consider a modified CSMA/CA protocol. The protocol operates in the same way as the 802.11 CSMA/CA, except that

it doesn't have any backoff mechanism. Each transmitter will attempt to transmit as long as it has a packet to send and it senses the channel to be idle. All other parameters and assumptions are the same as the 802.11 CSMA/CA model in Lecture 12.

(a) Draw the resulting state transition diagram.

(b) Write down the state transition matrix.

Answer:

(a)

Suppose that the probability that a user has a frame waiting to be transmitted at any time slot equals a,

$$u_k = \binom{N}{k} a^k (1-a)^{N-k}$$

$$u_0 = (1-a)^N, u_1 = Na(1-a)^{N-1}$$

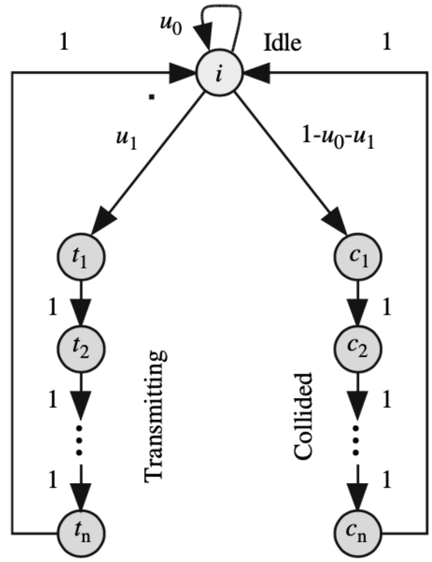

Fig. 2.

(b)

$$P = \begin{bmatrix} u_0 & 0 & 0 & ... & 1 & 0 & ... & 0 & 1 \\ u_1 & 0 & 0 & ... & 0 & 0 & ... & 0 & 0 \\ 0 & 1 & 0 & ... & 0 & 0 & ... & 0 & 0 \\ 0 & 0 & 1 & ... & 0 & 0 & ... & 0 & 0 \\ ... & ... & ... & ... & ... & ... & ... & ... & ... \\ 1-u_0-u_1 & 0 & 0 & ... & 0 & 0 & ... & 0 & 0 \\ 0 & 0 & 0 & ... & 0 & 1 & ... & 0 & 0 \\ ... & ... & ... & ... & ... & ... & ... & ... & ... \\ 0 & 0 & 0 & ... & 0 & 0 & ... & 0 & 0 \\ 0 & 0 & 0 & ... & 0 & 0 & ... & 1 & 0 \end{bmatrix}$$

VI. Problem 6 - Millimeter-wave networking.

(a) What's the difference between digital beamforming (used in 802.11n/ac, etc.) and analog beamforming (used in 802.11ad, 5G NR, etc.)?

(b) Consider a 60 GHz linear phased array with 4 antenna elements. Neighboring antenna elements are separated by $\frac{\lambda}{2}$. Suppose a transmitter wants to steer the beam towards $\theta = 0$, where θ is defined in the same way as in lecture 12. What is the ratio between the antenna gain at $\theta = 45°$ vs. $\theta = 0$? At what angles will the antenna gain become 0?

(c) Explain the deafness problem in the CSMA mode of mmWave networks.

(d) Explain why it is challenging for a mmWave network to maintain high performance in practical mobile scenarios.

Answer:

(a) In analog beamforming, the same signal is fed to each antenna where phase-shifters are multiplied to each signal to change the phase of each signal to form a beam of particular angular direction.In digital beamforming or pre-coding, different signals are fed to different antenna in applications like spatial multiplexing. Signals of different phase and power can be made on different frequency bands and antennas, forming a superposition of signals which will combine in the air.

Reference :

https://ma-mimo.ellintech.se/2017/10/03/what-is-the-difference-between-beamforming-and-precoding/

(b) Antenna gain at angle at $\Delta\theta$ is

$$\frac{sin(N\Delta w/2)}{Nsin(\Delta w/2)} =$$

Where

$$\Delta w = \pi sin(\theta + \Delta\theta) - \pi sin(\theta)$$

For $\theta = 45°$,

$$\Delta w = \pi sin(\theta+\Delta\theta)-\pi sin(\theta) = \pi sin(0+\frac{\pi}{4})-\pi sin(0) = \frac{\pi}{\sqrt{2}}$$

Antenna gain =

$$|\frac{sin(N\Delta w/2)}{Nsin(\Delta w/2)}| = |\frac{sin(2\frac{\pi}{\sqrt{2}})}{4sin(\frac{\pi}{\sqrt{2}}/2)}| = |\frac{sin(\sqrt{2}\pi)}{4sin(\frac{\pi}{2\sqrt{2}})}| = 0.269$$

(c) The deafness problem happens when A and B is transmitting through beamforming, where A is steered to B, so A can only hear messages transmitted from the direction of B. Transmitter C keeps sending RTS to receiver A, but A cannot hear. So eventually C drops the packet after many trials.

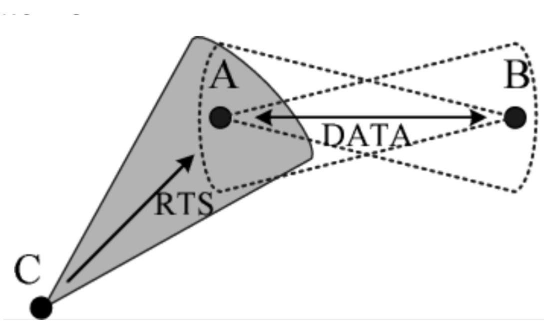

Fig. 3.

(d) It is challenging for a mmWave network to maintain high performance in practical mobile scenarios since it has shorter wavelengths and higher attenuation. Therefore it requires the Tx and Rx beams keep aligned which is the mobility problem. Another problem is blockage, when human body or other stuff block the transmission of the waves.

$$P = \begin{bmatrix} u_0 & 0 & 0 & ... & \frac{1}{N_{max}-N_{min}+1} & \frac{1}{N_{max}-N_{min}} & ... & \frac{1}{2} & 1 & 1 \\ u_1 & 0 & 0 & ... & 0 & 0 & ... & 0 & 0 & 0 \\ 0 & 1 & 0 & ... & 0 & 0 & ... & 0 & 0 & 0 \\ ... & ... & ... & ... & ... & ... & ... & ... & ... & ... \\ 0 & 0 & 0 & ... & 0 & 0 & ... & 0 & 0 & 0 \\ 0 & 0 & 0 & ... & \frac{N_{max}-N_{min}}{N_{max}-N_{min}+1} & 0 & ... & 0 & 0 & 0 \\ 0 & 0 & 0 & ... & 0 & \frac{N_{max}-N_{min}-1}{N_{max}-N_{min}} & ... & 0 & 0 & 0 \\ ... & ... & ... & ... & ... & ... & ... & ... & ... & ... \\ 0 & 0 & 0 & ... & 0 & 0 & ... & \frac{1}{2} & 0 & 0 \\ 1-u_0-u_1 & 0 & 0 & ... & 0 & 0 & ... & 0 & 0 & 0 \end{bmatrix}$$