ECE 257A Fall'23 Homework Assignment 2

University of California San Diego

Instruction:

Please submit the answers in pdf to Canvas, by 6pm Monday 11/13/2022. Late submission will only get half grade. This assignment must be done *individually*. Discussion is encouraged, but copying solutions from elsewhere will be considered as plagiarism.

Problem Set:

Problem 1 (16pt). True or false questions. If false, explain why.

(1) With Nt transmit antennas, closed-loop MIMO can increase the link capacity by Nt times compared with SISO.

(2) MU-MIMO requires time, frequency and phase synchronization between different receivers.

(3) MU-MIMO can scale network capacity linearly with the number of transmitters.

(4) Channel partitioning MAC has higher efficiency than random access MAC because the former doesn't have to waste time on carrier sensing or random backoff

(5) In pure ALOHA, a node does not need a local clock. So pure ALOHA is much simpler than slotted ALOHA

(6) In 802.11 CSMA/CA, during backoff, a node needs to freeze its timer if the channel becomes busy again

(7) In 802.11 CSMA/CA, a transmitter's backoff counter is doubled if it doesn't hear an ACK confirmation from the receiver after a transmission.

(8) A WiFi access point can be considered a router running IP routing protocols.

Problem 1 (26pt). Understand MIMO gains.

(1) (10pt) Explain the asymptotic gains from the following 4 MIMO schemes: receiver diversity, open-loop transmit diversity, closed-look transmit diversity, spatial multiplexing, and multi-user MIMO. In particular, explain how the MIMO capacity increases with the number of antennas, and intuitively why. Review the lecture notes and references, and provide the answers based on your own understanding.

(2) (8pt) Compare two networks: a single-user MIMO network with one 4-antenna transmitter and one 4-antenna receiver, versus a MU-MIMO network with 4-antenna access point and 4 single-antenna users. Suppose the channel matrices are the same for these two setups. Will the two networks have the same total throughput? Why? (Note: Here we count the net throughput, not bit-rate. So transmission overhead matters.).

(3) (8pt) Consider a 2x2 MIMO link, if both transmitter's antennas are placed very close to each other, and receiver's antennas are also close to each other, then the spatial multiplexing gain may be low due to channel correlations of nearby antennas.

What if we separate the receiver's antennas far enough away from each other, but keep the transmitter's antennas close to each other? (Hint: Think of the problem of achieving multiplexing gain as the problem of solving a system of equations)

In this case, will the link still likely have higher capacity than SISO? (Hint: Can there be any diversity gain?)

Problem 2 (15pt). Understand the working principle of MU-MIMO.

(1) Consider the following MU-MIMO scenario: a single 3-antenna transmitter (TX) is transmitting data to 3 single-antenna users RX1, RX2, and RX3 simultaneously. Suppose the channel gain values h_{ij} are known to the TX. Suppose the transmitter wants to ensure RX1 receivers a symbol x, but RX2 and RX3 hear nothing (essentially they hear 0, or a null value). Then what should each of the 3 transmit antennas send? (Hint: Construct a system of equations and solve it.)

(2) Consider a MU-MIMO network where a 2-antenna transmitter is transmitting data to 2 single-antenna users RX1 and RX2. Suppose the announcement packet and data packet are 100 Bytes and 1 KB respectively. The CSI feedback packet and ACK packet are 100 Bytes, 100 Bytes for both users. The data packet is sent at 100MBps, and all other packets are sent at 10MBps. Then what is the maximum achievable throughput of the network?

Problem 3 (16pt). MAC protocols. Summarize the pros and cons of the following MAC protocols: TDMA, FDMA, Polling, Token Rings, Slotted LOHA, pure ALOHA, CSMA/CD.

Problem 5 (15pt). Slotted ALOHA with heterogeneous nodes. Consider two nodes, A and B, that use the slotted ALOHA protocol to contend for a channel. Suppose node A has more data to transmit than node B, and node A's retransmission probability p_A is greater than node B's retransmission probability, p_B.
a) Provide a formula for node A's average throughput. What is the total efficiency of the protocol with these two nodes?
b) If $p_A = 2\ p_B$, is node A's average throughput twice as large as that of node B? Why or why not? If not, how can you choose p_A and p_B to make that happen?
c) In general, suppose there are N nodes, among which node A has retransmission probability $2p$ and all other nodes have retransmission probability p. Provide expressions to compute the average throughputs of node A and of any other node.

Problem 6 (12pt). Understanding CSMA/CA. Answer the following questions:
(1) CSMA/CD is not used in current wireless networks such as WiFi. Suppose WiFi radios become full-duplex in future, will CSMA/CD work just like in classical Ethernet?
(2) What's the hidden terminal problem in CSMA/CA? Does RTS/CTS fully solve the problem?
(3) What're the negative impacts of the exposed terminal problem in CSMA/CA? Does RTS/CTS solve the problem?
(4) What's causing the performance anomaly of 802.11? Explain the difference between time fairness and packet fairness.