Communication and Wireless Network **Name:** _____
Spring 2024 **ID:** _____
Midterm (04/17/2024 10:10-12:10)

This exam contains 3 pages (including this cover page) and 6 questions. Total of points is 100.

1. (16 points) **Definition:**
   (a) (2 points) Explain what is the difference between *baseband signals* and *passband signals*.
   (b) (2 points) Explain what is a *LOS link* and a *NLOS link*.
   (c) (2 points) Explain what is the *multipath effect*.
   (d) (4 points) What does a *collision* event mean? Why a collision event could still occur even if every device listens before talk?
   (e) (2 points) Derive what is the *wavelength* of a 5GHz channel.
   (f) (4 points) Explain what is the *channel state information* (CSI) (or *channel* in short) of a wireless link. Assume the channel of a wireless link is equal to $h = \alpha e^{2j\pi f\phi}$. What do the parameters α and ϕ mean?

2. (12 points) **Medium access control:** Consider a network with three nodes, A, B and C, sharing the wireless medium based on slotted ALOHA. Assume that all the three nodes only need to transmit a single packet and transmit simultaneously in the first time slot. Let p_1, p_2 and p_3 denote the retransmission probability of each node in each time slot, respectively.
   (a) (3 points) What is the probability that someone can transmit successfully in the second time slot?
   (b) (3 points) What is the probability that A can transmit successfully in the second time slot?
   (c) (3 points) What is the probability that the second time slot is idle (i.e., wasted).
   (d) (3 points) What is the expected number of time slots required by all the nodes to transmit their packets? (Hint: (1) the first time slot, where all nodes collide each other, should also be counted. (2) You can sum up the expected number of slots required to transmit any individual packet sequentially. (3) You can just give the equation. No need to derive the final answer.)

3. (10 points) **Path loss and capacity:**
   (a) (3 points) Consider the Friis free-space path loss model. What is the path loss (P_{rx}/P_{tx}) of a 50m link operating on a 5GHz channel? (Assume both the transmit and receive antenna gains $G_{tx} = G_{rx} = 1$.)

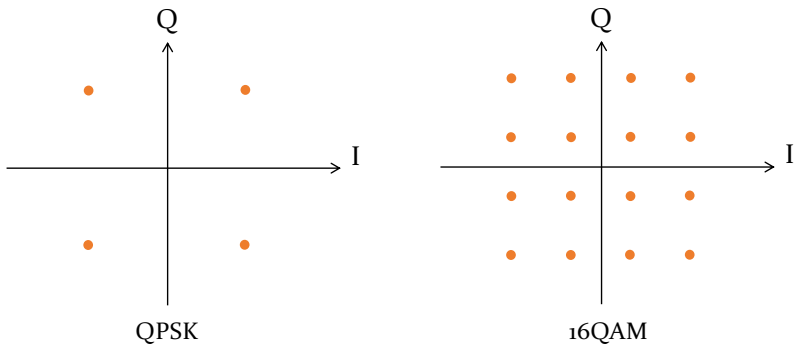
(b) (3 points) Follow the above question. Assume the transmitter transmits at 20dBm. Assume that the noise power is -90dBm. What is the SNR in dB? (Hint: $P_{dB} = 10 \log_{10} P$. $\log_{10}(4\pi/c) = -7.3781$. $\log_{10}(5e9) = 9.6989$.)

(c) (2 points) Follow the above question. Assume a WiFi link occupies 20MHz bandwidth. What is the theoretical capacity of the above link? (Hint: you just need to give the equation. No need to derive the final answer.)

(d) (2 points) Explain why the coverage range of the WiFi 5GHz mode is shorter than that of the WiFi 2.4GHz mode.

4. (22 points) **Modulation and throughput:**

(a) (4 points) Assume we set the transmit power to 4. For BPSK, the transmitter maps bit '1' to $2 + 0i$, while mapping bit '0' to $-2 + 0i$. List all the constellation points of QPSK and 16-QAM, respectively, if we have to follow the same power constraint (i.e., $P = 4$).



(b) (2 points) Explain why QPSK is less reliable than BPSK (i.e., introducing a higher bit-error rate for a given SNR).

(c) (4 points) What is the difference between SER (symbol error rate) and BER (bit error rate)? Typically, is SER of a modulation scheme larger than or smaller than BER? Why?

(d) (6 points) Assume that the symbol duration equals to $4\mu s$. What is the data rate of BPSK, QPSK and 16-QAM, respectively?

(e) (6 points) Following the above question, consider a scenario where the transmitter transmits a packet with only 4 bits. Assume a link experiences a BER of 0.1, 0.01 and 0.001, respectively, when the transmitters transmit the packet using BPSK, QPSK and 16-QAM. What is the PDR of each modulation scheme? What is the average throughput of each modulation scheme if the transmitter transmits multiple packets?

5. (16 points) **Rate adaptation (AutoRate):**

(a) (2 points) Explain what is synchronous ACK and what is asynchronous ACK.

(b) (2 points) Explain what is the difference between transmitter-based rate adaptation and receiver-based rate adaptation.

(c) (2 points) Give a pros and cons of receiver-based rate adaptation.

(d) (2 points) Give a pros and cons of transmitter-based rate adaptation.

(e) (8 points) Consider the following scenario of SampleRate. Assume that the packet includes 2,000 bits and the overall packet overhead occupies the channel time of $20\mu s$. Consider $r = 20$, $r' = 10$ and $r'' = 40$ Mbps. What is the estimated throughput of r' and r'', respectively? Which rate (modulation scheme) will the transmitter select at time T_1 and T_2, respectively. (Note: The throughput of $r = 20$ at $T1$ and $T2$ should be derived by estimating the throughput of packets $p1$–$p5$ and $p1$–$p11$, respectively.)

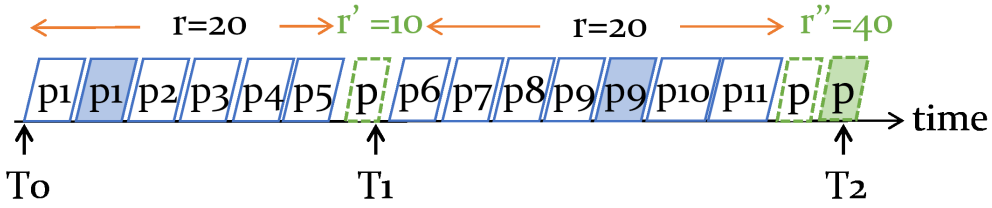


Figure 1: SampleRate scenario

6. (24 points) **Packet detection and equalization:** In most of the communication protocols, there exists a preamble in the physical-layer header of a packet.

(a) (2 points) Explain what is *packet detection*.

(b) (2 points) Explain how to use the preamble to perform packet detection (in WiFi).

(c) (2 points) Explain what is *channel estimation*.

(d) (2 points) Consider a protocol that require each transmitter to transmit the preamble three times in the beginning of a packet. Assume the preamble is defined as $-1+0i$. Assume the receiver receives the three preambles equal to $2.7+0.3i$, $2-0.4i$ and $2.5+0.1i$. What should be the estimated channel?

(e) (3 points) Following the above question, assume that the receiver receives three samples $2.5+0.6i, -1.5-0.12i$ and $2+0.8i$ in the data payload and apply *zero-forcing* to decode the samples. What are the decoded samples of the three received samples?

(f) (8 points) Following the above question, assume that the transmitter uses BPSK to modulate the data bit '1' as $1+0i$ and modulate the data bit '0' as $-1+0i$. What is the demodulated samples of the three decoded samples? What is the decoding error of each sample? What is the average decoding SNR (ratio)?

(g) (2 points) Explain what is the *channel coherence time*.

(h) (3 points) Consider two scenarios: static and mobile. In which scenario should the transmitter re-estimate the channel state information more often. Why?