ECE/CS 438: Communication Networks **Fall 2023**

Homework 1

Handed Out: August 28^{th}*,* 2023 *Due: 11:59pm, September* 11^{th}*,* 2023

Students Name:

- Homework assignments must be submitted online through Gradescope. Hard copies are not accepted. Please submit a pdf file to Gradescope (`https://www.gradescope.com/courses/581425`). You can either type your solution or scan a **legible** hand-written copy. We will not correct anything we do not understand. Contact the TAs via email if you face technical difficulties in submitting the assignment.
- While we encourage discussion within and outside of the class, cheating and copying is strictly prohibited. Copied solutions will result in the entire assignment being discarded from grading at the very least and a report filed in the FAIR system. It is also your responsibility to ensure that your partner obeys the academic integrity rules as well.
- This assignment has a total of 110 points. The grade will be capped at 100 points.
- **Please write your answer in the white space to the right of the corresponding problem.**

1 Choose all that apply - 4×7 points

Each question may have more than one correct answer. You will only get points if you identify all the correct answers.

1. Data rate is a function of the transmitted signal's _____.
   (a) center frequency
   (b) time duration
   (c) bandwidth
   (d) propagation delay
2. Which of the following are valid relationships between the bandwidth (BW) and the carrier frequency (CF) of a signal, both in Hz? Choose all possible answers from the following.
   (a) BW >= CF
   (b) BW = CF
   (c) BW <= CF
   (d) BW > 2 × CF
3. A signal from a WiFi base station is composed of a set of frequencies, say $\{f_1, f_3, f_7, ...f_{39}\}$. When the WiFi base station transmits this signal, a static laptop receives this signal in addition to reflections of the signal from walls and other surfaces. When the laptop computes the FFT of the received signal, which of the following statements would hold true (assume this is the only transmission received by the laptop):
   (a) The received signal would contain only the frequencies of the transmitted signal.
   (b) The received signal would contain the frequencies of the transmitted signal, plus some other frequencies from the reflections.
   (c) The received signal will contain frequencies that are shifted versions of the transmitted frequencies.
   (d) Nothing can be said about the content of the received signal; it all depends on the pattern of the echoes.
4. Consider a remote space telescope transmitting a packet of 1500 bits from 48000 km away, at a data rate of 1 Mbps. Assuming delay is expressed as $n \times 10^{-k}$ (seconds), where $1 \neq n < 10$, the value k for propagation delay is _____(choose from a to d). In this example, the statement that "total packet delivery time is dominated by transmit time" is _____(choose from e and f).
   (a) 1
   (b) 2
   (c) 3
   (d) 4
   (e) false
   (f) true

5. The total time it takes for a transmitter to send a packet to the receiver is the sum of 3 components: (1) propagation delay of the first bit, (2) transmit time of all of the bits, (3) propagation delay of the last bit.

   (a) TRUE, because the total time is calculated from the time the first bit goes out of the transmitter till the time when the last bit is received at the receiver

   (b) FALSE, because the total time should be counted when the transmitter starts transmitting to when the same transmitter completes transmission.

   (c) TRUE, because the receiver must wait for the first bit and the transmitter must wait for the last bit.

   (d) FALSE, because the propagation delay of the first bit is in parallel to the transmit time of the subsequent bits.

6. Choose all the following statement(s) that is (are) correct about 'La/r', where 'a' is the packet arrival rate, 'L' is the number of bits per packet, and 'r' is the router's service rate.

   (a) If average La/r$<$1, then no packets will be waiting in the router queue

   (b) If average La/r$>$1, then all packets need to be waiting in the router queue

   (c) When average La/r increases, the average waiting time in router queue will also increase

   (d) Average waiting time increase super linearly (faster than linearly) as La/r increases and approaches 1

   (e) Average waiting time increases linearly as La/r increases and approaches 1

7. A network administrator tells you that at most 500 users can be accommodated by statistical multiplexing, given that each user needs 1 Mbps bandwidth and has a 25% chance of being active. This means, the total bandwidth is _____(choose from a and b) 125 Mbps. With FDM, 500 such users _____(choose from c and d) be accommodated.

   (a) no less than

   (b) less than

   (c) can surely

   (d) might not

2 Applications of Probability - 6×3 points

1. **Statistical multiplexing**
   An airplane has 20 seats but the airline sells 22 tickets under the assumption that some passengers would cancel their flight. Assume the probability of cancellation for each passenger is 0.3 and are independent. Calculate the probability that the airline will fail to accommodate all its ticketed passengers on the plane.

2. **User satisfaction 1/2**
   A user streams a video over the Internet and the throughput at her laptop varies uniform randomly from 4Mbps to 20Mbps. Assume that the user's satisfaction S is proportional to the throughput, i.e., S = kP, where k is a constant and P is the throughput in Mb at each time unit. Assuming k=5, calculate the user's average satisfaction.

3. **User satisfaction 2/2**
   For the problem above, assume that the user's satisfaction is $S = log_{10}(P)+k$, meaning that the user's happiness saturates with increased throughput. For k=5, calculate the user's average satisfaction. Note that `average` is a linear function but `log` is not.

3 Throughput and Queuing Delay - 4×5 points

A router processes packets at the rate R=1 packet per second. Packets are arriving into the router's queue at time ticks (in seconds) shown in the table below. For each table (Q3.1 to Q3.4), compute (A) the average packet throughput in the first 10 seconds and (B) the average queuing delay. Please only type in the final result in the text box. (Round your answer to 2 decimal places)

1.

P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
0	1	2	3	4	5	6	8	8	9

Average packet throughput:

Average queueing delay:

2.

P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
0	0	0	0	0	5	5	5	5	5

Average packet throughput:

Average queueing delay:

3.

P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
7	7	7	7	7	7	7	7	7	7

Average packet throughput:

Average queueing delay:

4.

P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
2	2	4	6	6	6	8	8	9	9

Average packet throughput:

Average queueing delay:

5. In one sentence, explain why the average queueing delay may increase monotonically even though the average packet arrival rate is less than the router's average packet processing rate.

4 Bandwidth, data rate, and SNR (1/2) - 5×3 points

Shannon's ground breaking equation says that: $C = Blog_2(1 + SNR)$ where C is the data rate in bits/s achievable on the communication link (also called capacity), B is the bandwidth in Hz, and SNR is the ratio of received signal power to the receiver's noise power. Please upload screenshot of typed math formulas and use another color to highlight the final results for the following questions.

1. A laptop intends to transmit to its WiFi base station located $R = 8$m away. What data rate can a WiFi laptop achieve, when transmitting at a bandwidth of 20 MHz? Assume that received signal power density follows $Q = P/R^2$, and the signal power density measured at 1 meter from the transmitter is $Q = 12 milliWatt/m^2$. Also assume that noise power density at the receiver is $N = 0.02 milliWatt/m^2$.

2. If the laptop intends to double its data rate, how close should it move to the WiFi base station? (Round to 3 decimal places)

3. If moving closer is not an option, how much should it increase its bandwidth to triple its data rate?

5 Bandwidth, data rate, and SNR (2/2) - 6 + 3 points

1. Alice wants to send a packet of size R bits to Bob, and also wants the packet to reach within T seconds from the start of transmission. Bob is at a far away distance D from Alice, and the only parameter that Alice needs to decide is the bandwidth B that the wire should support (assume the noise power at the receiver is 1, Alice's transmit power is P, and the wire is non-dispersive). Write an inequality for the minimum bandwidth B_{min} that will allow Alice to meet her intentions. You can use the Shannon equation from the previous question, and use c for speed of light.

2. Write a sentence on how each of the following scientists contributed towards the Internet:
   (a) Leonard Kleinrock
   (b) Radia Perlman
   (c) Bob Metcalfe
   (d) Martin Cooper
   (e) Vint Cerf
   (f) Tim Berners Lee

6 Internet concepts - $10 + 10$ points

1. Packet errors can be broadly classified into 4 categories as follows:

`Fading:`	When the received signal is too weak for decoding the bits
`Interference:`	When a foreign signal corrupts the decoded bits at the receiver.
`Outage:`	When signals are not going through a link to arrive at the receiver.
`Congestion:`	When a receiver lacks memory to queue up the incoming packets.

   Diagnose each of the following scenarios with the most likely cause of error: (-2pt per option wrong until 0)

   (a) A ship drops anchor on a trans-Atlantic backbone cable.

   (b) A satellite transmission cannot be decoded correctly on earth.

   (c) A phone call from a car experiences very choppy phone quality.

   (d) A malicious individual attacks an airport by jamming communication between airplanes and control towers.

   (e) Policemen cannot hear each other on their walky-talkie even though they have not moved, and were able to hear each other few minutes back.

   (f) My Netflix connection works but my Amazon Prime is really slow.

   (g) I re-booted my computer from 1995 and surprisingly I am able to connect to the Internet but Internet access is really slow.

2. Mark all statements that are correct based on the classical principles of the network protocol stack: (-1pt per option wrong until 0)

   (a) The transport layer header is not read or modified, except at the source and the destination.

   (b) When your laptop is sending an email to your friend's laptop in a different country, your data packet's link layer header contains your friend's link layer address.

   (c) The network layer at a Comcast router reads the network layer header and then modifies the network layer header.

   (d) The network layer at Youtube's server reads the network layer header and modifies the network layer header.

   (e) The network layer header is read at every device in the Internet.

   (f) The application layer header is read at every device in the Internet.

   (g) Reducing the size of headers improves the goodput of the network.

   (h) Virtual circuits are one way to reduce the size of the headers.

   (i) Typically, queueing delay is greater than transmission delay, which is greater than propagation delay.

   (j) Typically, transmission delay is greater than propagation delay, which is greater than queueing delay.