Question 1

Choose all that apply **28** / 32 pts

1.1 **(no title)** **4** / 4 pts

✔ **+ 4 pts** Correct

+ 0 pts Incorrect

1.2 **(no title)** **4** / 4 pts

✔ **+ 4 pts** Correct

+ 0 pts Incorrect

1.3 **(no title)** **0** / 4 pts

+ 4 pts Correct

✔ **+ 0 pts** Incorrect

1.4 **(no title)** **4** / 4 pts

✔ **+ 4 pts** Correct

+ 0 pts Incorrect

1.5 **(no title)** **4** / 4 pts

✔ **+ 4 pts** Correct

+ 0 pts Incorrect

1.6 **(no title)** **4** / 4 pts

✔ **+ 4 pts** Correct

+ 0 pts Incorrect

1.7 **(no title)** **4** / 4 pts

+ 0 pts Incorrect

✔ **+ 4 pts** Correct

1.8 **(no title)** **4** / 4 pts

✔ **+ 4 pts** Correct

+ 0 pts Incorrect

Question 2

Applications of Probability **18** / 18 pts

2.1 **Statistical multiplexing** **6** / 6 pts

✔ **+ 6 pts** Correct

+ 0 pts Incorrect

2.2 **User satisfaction 1/2** **6** / 6 pts

✔ **+ 6 pts** Correct

+ 0 pts Incorrect

2.3 **User satisfaction 2/2** **6** / 6 pts

✔ **+ 6 pts** Correct

+ 0 pts Incorrect

Question 3

Throughput and Queuing Delay **20** / 20 pts

3.1 **(no title)** **5** / 5 pts

✔ **+ 5 pts** Correct

+ 0 pts Incorrect

+ 2 pts A correct and B incorrect

+ 3 pts B correct and A incorrect

3.2 **(no title)** **5** / 5 pts

✔ **+ 5 pts** Correct

+ 0 pts Incorrect

+ 2 pts A correct and B incorrect

+ 3 pts B correct and A incorrect

3.3 **(no title)** **5** / 5 pts

✔ **+ 5 pts** Correct

+ 0 pts Incorrect

+ 2 pts A correct and B incorrect

+ 3 pts B correct and A incorrect

3.4 **(no title)** **5** / 5 pts

+ 0 pts Incorrect

✔ **+ 5 pts** Correct

+ 2 pts A correct and B incorrect

+ 3 pts B correct and A incorrect

Question 4

Bandwidth, data rate, and SNR — **20** / 20 pts

4.1 (no title) — **5** / 5 pts

- ✔ **+ 5 pts** Correct
- **+ 0 pts** Incorrect

4.2 (no title) — **5** / 5 pts

- ✔ **+ 5 pts** Correct
- **+ 0 pts** Incorrect

4.3 (no title) — **5** / 5 pts

- **+ 0 pts** Incorrect
- ✔ **+ 5 pts** Correct

4.4 (no title) — **5** / 5 pts

- **+ 0 pts** Incorrect
- ✔ **+ 5 pts** Correct

Question 5

Internet concepts — **8** / 10 pts

5.1 (no title) — **4** / 5 pts

- **– 5 pts** Incorrect
- **– 0 pts** Correct
- ✔ **– 1 pt** One Option incorrect
- **– 2 pts** Two options incorrect
- **– 3 pts** Three options incorrect
- **– 4 pts** Four options incorrect
- **– 5 pts** Five options incorrect

5.2 (no title) — **4** / 5 pts

- **– 0 pts** Correct
- **– 5 pts** Incorrect
- ✔ **– 1 pt** One Option incorrect
- **– 2 pts** Two options incorrect
- **– 3 pts** Three options incorrect
- **– 4 pts** Four options incorrect
- **– 5 pts** Five options incorrect

Q1 Choose all that apply

32 Points

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

Q1.1

4 Points

Data rate is a function of the transmitted signal's ___

- [ ] center frequency
- [ ] time duration
- [x] bandwidth
- [ ] propagation delay

Q1.2

4 Points

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.

- [x] BW >= CF
- [x] BW = CF
- [x] BW <= CF
- [ ] BW > 2 × CF

Q1.3
4 Points

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):

- [ ] The received signal would contain only the frequencies of the transmitted signal.
- [ ] The received signal would contain the frequencies of the transmitted signal, plus some other frequencies from the reflections.
- [x] The received signal will contain frequencies that are shifted versions of the transmitted frequencies.
- [ ] Nothing can be said about the content of the received signal; it all depends on the pattern of the echoes.

Q1.4
4 Points

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 first 4 options). In this example, the statement that "total packet delivery time is dominated by transmit time" is ___(choose from last 2 options).

- [x] 1
- [ ] 2
- [ ] 3
- [ ] 4
- [x] False
- [ ] True

Q1.5
4 Points

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.

- [ ] 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
- [ ] FALSE, because the total time should be counted when the transmitter starts transmitting to when the same transmitter completes transmission.
- [ ] TRUE, because the receiver must wait for the first bit and the transmitter must wait for the last bit.
- [x] FALSE, because the propagation delay of the first bit is in parallel to the transmit time of the subsequent bits.

Q1.6
4 Points

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.

- [ ] If average La/r<1, then no packets will be waiting in the router queue
- [ ] If average La/r>1, then all packets need to be waiting in the router queue
- [x] When average La/r increases, the average waiting time in router queue will also increase
- [x] Average waiting time increase super linearly (faster than linearly) as La/r increases and approaches 1
- [ ] Average waiting time increases linearly as La/r increases and approaches 1

Q1.7
4 Points

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.

- [x] no less than
- [ ] less than
- [ ] can surely
- [x] might not

Q1.8
4 Points

Can the average queueing delay increase monotonically even though the average packet arrival rate is less than the router's packet processing rate (constant)?

- [x] Yes. Because when the queue is empty, the router is idled. Burst traffic may come later and increase the delay.
- [ ] Yes. Because the router's packet processing rate will decrease when the queue gets longer.
- [ ] No. There will be no packets remaining in the queue since the packet processing rate is greater.
- [ ] No. There might be few packets remaining in the queue, but the queueing delay will stay low.

Q2 Applications of Probability

18 Points

Q2.1 Statistical multiplexing

6 Points

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. ($\mathbf{Note}$: round to 4 decimal places)

0.0041

Q2.2 User satisfaction 1/2

6 Points

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.

60

Q2.3 User satisfaction 2/2

6 Points

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. ($\mathbf{Note}$: that average is a linear function but log is not and round to 4 decimal places)

6.0415

Q3 Throughput and Queuing Delay

20 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. (**Note**: Round your answer to 2 decimal places)

Q3.1

5 Points

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

0.90

0.20

Q3.2

5 Points

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

1

2

Q3.3
5 Points

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

0.30

4.50

Q3.4
5 Points

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

0.70

1.20

Q4 Bandwidth, data rate, and SNR

20 Points

Shannon's groundbreaking 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.

Q4.1

5 Points

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 $Q = 12milliWatt/m^2$. Also assume that noise power density at the receiver is $N = 0.02milliWatt/m^2$.($\mathbf{Note}$: Calculate the rate in Mbps. Please enter a numeric value only.)

67.50

Q4.2

5 Points

If the laptop intends to double its data rate, how close should it move to the WiFi base station? ($\mathbf{Note}$: Calculate the distance in metres. Please enter a numeric value only and round to 3 decimal places)

2.372

Q4.3

5 Points

If moving closer is not an option, what should the bandwidth be to triple its data rate? ($\mathbf{Note}$: Calculate BW in MHz. Please enter a numeric value only.)

60

Q4.4
5 Points

Alice wants to send a packet of size 1000 bits to Bob, and also wants the packet to reach within 0.1 seconds from the start of transmission. Bob is at a far away distance $3 \times 10^6 m$ 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 1000, and the wire is non-dispersive). Calculate the minimum bandwidth B_{min}Hz that will allow Alice to meet her intentions. You can use the Shannon equation from the previous question, and use $3 \times 10^8 m/s$ for speed of light. ($\mathbf{Note}$: Calculate the BW in Hz. Please enter a numeric value only and round to 3 decimal places)

1114.765

Q5 Internet concepts

10 Points

Q5.1

5 Points

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: (**Note**: The final answer is **comma-separated** & **no-spaces** cause starting letter. E.g., C,F,F,F,F,O,I) and -1pt 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.

O,F,F,I,O,C,C

Correct Answer: O,F,F,I,I,C,C

Q5.2
5 Points

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

- [x] The transport layer header is not read or modified, except at the source and the destination.
- [ ] 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.
- [x] The network layer at a Comcast router reads the network layer header but not the link layer header.
- [ ] The network layer at Youtube's server reads the network layer header and the link layer header.
- [ ] The network layer header is read at every device in the Internet.
- [ ] The application layer header is read at every device in the Internet.
- [x] Reducing the size of headers improves the goodput of the network.
- [x] Virtual circuits are one way to reduce the size of the headers.
- [ ] Typically, queueing delay is greater than transmission delay, which is greater than propagation delay.
- [ ] Typically, transmission delay is greater than propagation delay, which is greater than queueing delay.

Correct Answer:
The transport layer header is not read or modified, except at the source and the destination.,
The network layer at a Comcast router reads the network layer header but not the link layer header.,
Reducing the size of headers improves the goodput of the network.,
Virtual circuits are one way to reduce the size of the headers., T
ypically, queueing delay is greater than transmission delay, which is greater than propagation delay.