Q1: Select all true statements.

(a) The sliding window only moves when the left edge has been acknowledged.
(b) TCP uses a two-way handshake.

Solution: Wrong. It uses a three-way handshake.

(c) The TCP handshake includes communicating the receive window size to the sender, so that the receiver is not overwhelmed by traffic.

Solution: 
Q2: Select all true statements.

(a) There is no connection establishment in UDP.
(b) The UDP base header is smaller than the TCP base header.
(c) The objective of flow control is to not overwhelm the network.

Solution: Wrong. The objective of congestion control is to not overwhelm the network. The objective of flow control is to not overwhelm the hosts.

Q3: Select all true statements.

(a) A too low timeout value in TCP will result in excessive re-transmissions.
(b) During congestion avoidance in TCP, the successful acknowledgement of a segment results in the sender congestion window growing by one segment.

Solution: Wrong. In congestion avoidance, the sender congestion window grows with 1 segment per RTT.
(c) The Multiplicative-Increase-Multiplicative-Decrease (MIMD) approach described in the lecture slides always results in an unfair but efficient state.

Solution: Wrong. Might result in a fair state if the initial state was fair since it fluctuates along the equi-fairness line.

Q4: Select all true statements.

(a) In Additive-Increase-Multiplicative-Decrease (AIMD), as described in the lecture slides, an efficient state cannot be achieved since the congestion window is decreased more aggressively than increased.

Solution: Wrong. AIMD converges to fairness & efficiency.

(b) The ssthresh in TCP is used to estimate the achievable congestion window after a timeout.

(c) The sliding window can be advanced whenever a duplicate acknowledgement is received.

Solution: Wrong. The sliding window is only advanced once the first packet sent in this window is acknowledged.
Q5: The Maximum Segment Size (MSS) of TCP is equal to..

(a) .. the Maximum Transmission Unit (MTU) of IP packets (MSS = MTU)
(b) .. the MTU of IP minus both IP and TCP headers size (MSS = MTU - header(IP) - header(TCP))
(c) .. the MTU of IP plus IP, TCP and Application Layer headers size (MSS = MTU + header(IP) + header(TCP) + header(APP))
(d) .. the MTU of IP minus IP, TCP and Application Layer headers size (MSS = MTU - header(IP) - header(TCP) - header(APP))
(e) .. the MTU of IP minus IP header size plus TCP header size (MSS = MTU - header(IP) + header(TCP))

Solution:

Q6: Which of the following statements concerning *sockets* is/are true?

(a) UDP sockets type is SOCK_DGRAM while TCP sockets type is SOCK_STREAM
(b) A socket is a software abstraction by which an application process exchanges network messages with the MAC layer in the operating system
(c) For a SOCK_DGRAM, an operating system stores both local and remote IP address

(d) For a SOCK_STREAM, an operating system stores both local and remote port

(e) The socket ID is a part of the standard TCP header

Q7: Given a directed graph G(V,E), with |V| and |E| being the numbers of vertices and edges, how many variables do you need for the max-flow LP formulation discussed in class?

(a) O(|E|)
(b) O(|V|)
(c) O(|V| + |E|)
(d) O(|V|^2)

Solution:
Q8: For load balancing requests across many servers, what drawbacks does the “Query load on all responsive servers; pick least loaded” approach have? (Select all true statements).

(a) If there are multiple load balancers, they may make synchronized choices, causing overload at the chosen server.
(b) Querying load at every server can be inefficient across large pools of servers.
(c) Failure of a server results in its entire workload being shifted to another server.
(d) Unless we maintain state about which session was allocated to which server, ensuring session continuity is challenging.

Solution:

Q9: For the “Query load on k random servers; pick lesser loaded approach”, going from \( k = 1 \) to \( k = 2 \), the expected load on the most loaded server decreases __

(a) linearly (i.e., addition of a constant factor)
(b) multiplicatively (i.e., multiplied with a constant factor)
(c) logarithmically
(d) quadratically

Solution: Please see the algorithm slides for a graphical visualisation. The expected load on a server with \( k = 1 \) is \( O\left(\frac{ln(n)}{ln(ln(n))}\right) \), and for \( k \geq 2 \) is \( O\left(\frac{ln(ln(n))}{ln(k)}\right) \). So if you go \( k = 1 \) to \( k = 2 \), the improvement is a factor (disregarding constant multiplicative constants of the big-O notation): 

\[
\frac{ln(n)}{ln(ln(n))} = \frac{ln(n)}{ln(ln(n)) + ln(ln(n))} \rightarrow \text{which is a logarithmic factor.}
\]

From \( k = 1 \) to \( k = 2 \) the difference is:

\[
\frac{ln(ln(n))/ln(2)}{ln(ln(n))/ln(3)} = \frac{ln(2)}{ln(3)}
\]
Q10: For the “Query load on $k$ random servers; pick lesser loaded approach”, going from $k = 2$ to $k = 3$, the expected load on the most loaded server decreases _

(a) linearly (i.e., addition of a constant factor)
(b) multiplicatively (i.e., multiplied with a constant factor)
(c) logarithmically
(d) quadratically

**Solution:** See solution of previous question.

Q11: For the balls and bins analysis, if indicator variables $X_{ij}$ are used to denote collisions, being able to write the expectation of the number of collisions, $\mathbb{E}[\sum X_{ij}]$ as $\sum \mathbb{P}[X_{ij} = 1]$ requires that all $X_{ij}$ are independent of each other. True or false?

**Solution:** False. The linearity of expectation does not depend on independence of random variables.
Q12: With $m$ balls being thrown into $n$ bins (uniform independently at random), what is the probability that balls $i$ and $j$ land in the same bin?

(a) $1/n^2$
(b) $1/n$
(c) $1/m^2$
(d) $1/m$

Q13: After $n$ insertions into a Bloom filter with $m$ bits of memory using $k$ hash functions per insertion, what is the probability that a particular bit is still 0?

(a) $(1 - 1/mk)^{k+n}$
(b) \((1 - \frac{1}{m})^{kn}\)
(c) \((1 - \frac{1}{mk})^{n}\)
(d) \((1 - \frac{1}{k})^{mn}\)

Solution:

**Q14:** Which of the following statements about QUIC is/are true?

(a) Because QUIC builds on UDP it doesn’t need a handshake.

**Solution:** *Wrong.* QUIC still needs a handshake to establish encryption keys and protocol state. Though it reduces the number of RTTs for a handshake and can also offer 0-RTT session resumption.

(b) QUIC decreases the overhead for connection setup compared to TCP + TLS

**Solution:** *Correct.* QUIC needs 1RTT before it can send the first data on completely new connection while TCP+TLS need 2RTT (TLS 1.3) or 3RTT (TLS 1.2). When resuming a previous connection it can even directly send data (0RTT) while TCP+TLS1.3 need 1RTT to establish a TCP connection.

(c) QUIC can handle switching from WiFi to a cellular network without having to reestablish the connection.

**Solution:** *Correct.* QUIC uses connection IDs independent of the IP address instead of a 4-tuple like TCP to identify connections. This way packets using the connection ID are still valid, even if the source IP address changes.
Q15: Consider the below network below with traffic going from $s$ to $t$, with a fraction $\alpha$ going over the bottom route and the rest $(1-\alpha)$ going over the top route. The cost for a single unit of traffic to go over the bottom route is $2 \cdot \sqrt{x}$ and for the top route it is $\ln(1 + x)$ where $x$ is the fraction of traffic going over the respective routes.

$$\ln(1 + x)$$

$$2 \cdot \sqrt{x}$$

What is the total cost for a single infinitely-divisible unit of traffic to traverse the network?

(a) $2 \cdot \sqrt{\alpha} + \ln(2 - \alpha)$

(b) $2 \cdot \alpha^{\frac{3}{2}} + (1 - \alpha) \cdot \ln(2 - \alpha)$

(c) $\frac{2\sqrt{\alpha}}{\alpha} + \frac{\ln(2-\alpha)}{1-\alpha}$

**Solution:** The total cost is the cost of the incurred by traveling over the two links combined. The cost for a single link is the fraction of traffic going over that link multiplied by the cost of the link.

The bottom link has cost $\alpha \cdot 2 \cdot \sqrt{\alpha} = 2 \cdot \alpha^{\frac{3}{2}}$ since $\alpha$ is the amount of traffic and $2 \cdot \sqrt{\alpha}$ the cost for that link. The cost for the top link is $\ln(1 + (1-\alpha))$. The total cost is the sum of the costs of the two links, which gives us option (b).
\[(1 - \alpha) \cdot \ln(1 + (1 - \alpha)) = (1 - \alpha) \cdot \ln(2 - \alpha)\]

with an analogous explanation.

**Solution:**

**Q16:** Select all correct statements about multi-commodity-flows below;

UPDATE: it was pointed out that "all multi-commodity-flow problems" is too broad of a definition for the statements. In the question below it was intended as "Any multi-commodity flow problem which can be expressed in polynomial time into a set of linear constraints and a linear optimization goal, both composed of continuous variables".

(a) All multi-commodity-flow problems can be solved using linear programming.

**Solution:** Debatable based on the interpretation of "all"

(b) There is no known way to solve all multi-commodity-flow problems in polynomial time.

**Solution:** Debatable based on the interpretation of "all"
Q17: Select all correct statements about linear programs:

(a) Integer linear programs are harder to solve than linear programs.
(b) Integer linear programs are easier to solve than general linear programs.

Solution: Integer linear programs are NP-complete while general linear programs can be solved in polynomial time.

(c) Integer linear programs can be solved in polynomial time, but general linear programs cannot.

Solution: It’s the opposite way around, general linear programs can be solved in polynomial time while integer linear programs cannot. They are NP-complete.

Q18: Which of the following statements about distributed decision making are true:
(a) Adding an extra link to a network can increase the load on some other links.

(b) Actors acting selfishly always leads to non-optimal network utilization.

**Solution:** No, it is possible that selfish behavior is equal to optimal network utilization. I.e., a counter-example is a case in which there is only one choice – the selfish decision must be the same as the optimal decision, because there is only one.

(c) Game theory can be used to analyze the behaviour of actors in a co-operative setting.

**Solution:**