1) Name the layers in the Internet protocol stack. Name one advantage and one disadvantage of implementing network protocols in different layers? (6 points)

Phy, mac, network, transport, application
Pros: easy to use, maintain, reuse
Cons: less efficient, harder to optimize/troubleshoot

2) Why is reflection both useful and harmful? (2 points)

Signals can be strengthened at some locations
Signals can be weakened at some locations and signals can change a lot even with small movement, less predictable.

3) Which modulations are robust against noise? What are issues with these modulations that are robust against noise. (4 points)

- Frequency modulation and phase modulation
- Frequency: waste bandwidth
- Phase: requires sync

4) What is hidden terminal problem? Someone suggests we can solve it by reducing carrier sense threshold. Is this a good solution? Why or why not? (4 points)

Two senders don’t carrier sense each other, but if they transmit together, they lead to collision.
No, reducing carrier sense threshold too much can allow nodes carrier sense farther away nodes, but fewer nodes can send concurrently, which can be overly conservative.
5) What is the benefit of collision detection in a MAC protocol? Does 802.11 use collision detection? Why or why not? (4 points)

Collision detection reduces the cost of collisions. No, 802.11 doesn’t use it because (i) hidden terminal and (ii) half duplex wireless nodes.

6) You are walking across UT campus and find WiFi handoff take a long time. Name two approaches to speed up the hand off. (4 points)

- Use active scanning instead of passive scanning
- If we know the channel the AP is likely to be on, scan that channel first. That info. can be learned based on location.

7) If RTS/CTS frame sizes are the same as data frame size, is RTS/CTS useful? Why or why not? (3 points)

No, then RTS collision is equally costly as data collision.

8) Consider a network with two single-hop flows using IEEE 802.11 DCF protocol. Can the aggregate throughput decrease if virtual carrier sensing is disabled? Why or why not? (4 points)

Yes, throughput can reduce when there are hidden terminals since RTS/CTS without virtual carrier sense no longer works.

9) Fill in each blank in the following statements with one of these words: node or neighbor (4 points)

In Link State routing, a router provides update information about each neighbor_____________________ to every node___________________________. In Distance Vector routing, a router provides update information about every node________________________to each neighbor__________________________.
10) For each of the following protocol features, indicate which protocol(s) among DSR, AODV, and DSDV has/have the corresponding features: (7 points)
   - Source routing: DSR
   - Distance vector routing: AODV, DSDV
   - Use destination sequence for route invalidation: AODV, DSDV
   - Scalable to large networks: AODV, DSDV
   - Performs best in high mobility: AODV
   - Guarantee loop free at all time: DSR
   - Support asymmetric links: DSR, DSDV

11) We use DSR/AODV for routing in ad hoc networks. As the ad hoc network gets larger, how to make the routing scalable? (4 points)

   Use geographical routing like GPSR

12) Determine the routing metric that minimizes total power consumption of the selected route, assuming the power consumption is proportional to the transmission time plus a constant. Feel free to introduce your notations. (4 points)

   ETT works since the energy consumption is proportional to the transmission time \(1/(p_f*p_r)\) \(1/R\), where \(p_f\) and \(p_r\) are forward and reverse delivery rates and \(R\) is data rate
Long Questions (60 points)

1) Consider A sends unicast data to node B. There is another node C that has data to send. They all use IEEE 802.11. Assume the background noise is $10^{-9}$ mW, attenuation factor is 4 (i.e., the propagation model is $P_r = P_t / d^4$), carrier sense threshold is $4 \times 10^{-9}$ mW, transmission power is 1 mW, minimum SINR for a packet to be received correctly is 10. Show intermediate steps. Simplify the solution to the simplest form and you do not need to compute the exact number. (20 points)
(i) What is the distance requirement for C not to transmit due to reception of RTS?
(ii) What is the distance requirement for C not to transmit due to reception of CTS (but not due to reception of RTS)?
(iii) What is the distance requirement for C not to transmit due to physical carrier sense (but not due to reception of RTS/CTS)?
(iv) What is the optimal capacity of link A to B when AB is 10 meters apart, BC is 100 meters apart, and AC is 95 meters apart?

(i) $\text{SNR} \geq 10 \Rightarrow \frac{P_t}{d^4} / 10^{-9} \geq 10 \Rightarrow d \leq 100 \text{ m within 100 meters away from A}$
(ii) Within 100 meters away from B but over 100 meters away from A
(iii) $\frac{P_t}{d^4} \geq 4 \times 10^{-9} \Rightarrow d \leq (10^9/4)^{1/4}$
   Within 125.7 meters from A but outside 100m from both A and B
(iv) $W \log_2(1 + \text{SNR}) = 20 \log_2(1 + \frac{P_t}{d^4} / 10^{-9}) = 20 \log_2(1 + 10^5) \text{ Mbps}$
2) 802.11a physical layer transmission rate = 36 Mbps, MAC layer data payload = 1452 bytes, MAC header = 28 bytes, ACK Frame Size = 14 bytes, RTS length = 20 bytes, CTS length = 14 bytes, Propagation Delay = 1μs, Slot Time = 9 μs, SIFS Time = 16μs, DIFS Time = 34μs, Physical layer overhead = 20μs (every frame has the same PHY overhead). Compute MAC layer throughput with and without RTS/CTS. Throughput is defined as the number of bits sent by the MAC layer in a given period of time. (10 points)

\[
\text{Time w/ RTS} = \text{DIFS} + \text{RTS} + \text{CTS} + \text{Data} + \text{ACK} + 3\times\text{SIFS} + 4\times\text{prop} \\
= 34 + \left(\frac{20\times8}{36}+20\right) + \left(\frac{14\times8}{36}+20\right)\times2 + \left(\frac{1452+28}{36} + 20\right) + 3\times16+4\times1
\]

\[
\text{Time wo/ RTS} = \text{Data} + \text{ACK} + \text{SIFS} + 2\times\text{prop} \\
= 34 + \left(\frac{1452+28}{36} + 20\right) + \left(\frac{14\times8}{36}+20\right) + 2\times1
\]

\[
\text{Tput} = 1452 \times 8 \div \text{Time}
\]

3) Consider the following network, when the link YZ changes from 1 to 6, how many messages does the network generate under link state and distance vector? For each message, describe which node sends to which node and the content of the message. (15 points)

Link state: Y (or Z) finds the link YZ changes to 6, it broadcasts the new link cost to the other two nodes. Every node runs Dijkstra algorithm to compute the shortest path. (If wireless, 1 message; if wireline, 2 messages).

Distance vector: Suppose Y detects the link change.
1) Y computes the new distance vector: \(D_y(z) = \min(c(y,z), c(y,x)+D_x(z)) = \min(6, 2 + 3) = 5\). \(D_y(x) = \min(c(y,x), c(y,z)+D_z(x)) = \min(2, 6+3) = 2\). So Y sends update \(D_y(z) = 5\).
2) After X receives the update, X computes \(D_x(y) = \min(c(x,y), c(x,z)+D_z(y)) = 2\); \(D_x(z) = \min(c(x,z), c(x,y)+D_y(z)) = \min(7, 2+5) = 7\). It sends update \(D_x(z) = 7\).
3) After Z receives the update, Z computes \(D_z(y) = \min(c(z,y), c(z,x)+D_x(y)) = 6\); \(D_z(x) = \min(c(z,x), c(z,y)+D_y(x)) = \min(7, 6+2) = 7\). It sends update \(D_z(y) = 6\) and \(D_z(x) = 7\).
4) After Y receives the update, Y computes \(D_y(x) = \min(c(y,x), c(y,z)+D_z(x)) = \min(2, 6+7) = 2\) and \(D_y(z) = \min(c(y,z), c(y,x)+D_x(z)) = \min(6, 2+7) = 6\). It sends update \(D_y(z) = 6\).
5) After X receives it, X computes \( D_x(y) = \min(c(x,y), c(x,z) + D_z(y)) = \min(2, 7+6) = 2. \) \( D_x(z) = \min(c(x,z), c(x,y) + D_y(z)) = \min(7, 2+6) = 7. \) If the selected next hop remains the same as before, it doesn’t send update.

6) After Z receives it, Z computes \( D_z(y) = \min(c(z,y), c(z,x) + D_x(y)) = \min(6, 7+2) = 6. \) \( D_z(x) = \min(c(z,x), c(z,y) + D_y(x)) = \min(7, 6+2) = 7. \) It doesn’t send update.

There are 6 updates using wireless broadcast and 12 updates using wireline unicast.

4) Which path will hop count, ETX, and ETT pick, respectively? Why? What are their corresponding throughput? The percentages are delivery rates. For simplicity, you can assume throughput = data rate * delivery rate on each link. All links interfere with each other and use WiFi to access the medium. (15 points)

Shortest path: L1, throughput = 1*0.3 = 0.3 Mbps

ETX: L4 – L5, throughput = \( \min(11*1, 11*0.9)/2 = 4.95 \) Mbps

ETT: L4 – L3, throughput = \( \min(11*1, 24*0.7)/2 = 5.5 \) Mbps
Extra Sheet