Q1 *Coffee-Shop Attacks* (17 points)

Dr. Yang comes to MoonBucks and tries to connect to the network in the coffee shop. Dr. Yang and `http://www.piazza.com` are communicating through TCP. Mallory is an on-path attacker.

Q1.1 (5 points) Which of the following protocols are used when Dr. Yang first connects to the Wi-Fi network and visits `http://www.piazza.com`? Assume any caches are empty. Select all that apply.

☐ (A) CSRF

☐ (B) IP

☐ (C) DNS (or DNSSEC)

☐ (D) HTTP

☐ (E) DHCP

☐ (F) None of the above

Q1.2 (3 points) Suppose Mallory spoofs a packet with a valid, upcoming sequence number to inject the malicious message into the connection. Would this affect other messages in the connection?

◯ (G) Yes, because the malicious message replaces some legitimate message

◯ (H) Yes, because future messages will arrive out of order

◯ (I) No, because on-path attackers cannot inject packets into a TCP connection

◯ (J) No, because TCP connections are encrypted

◯ (K) ——

◯ (L) ——

Q1.3 (3 points) To establish a TCP connection, Dr. Yang first sends a SYN packet with Seq = 980 to the server and receives a SYN-ACK packet with Seq = 603; Ack = 981. What packet should Dr. Yang include in the next packet to complete the TCP handshake?

◯ (A) SYN-ACK packet with Seq = 981; Ack = 604

◯ (B) SYN-ACK packet with Seq = 604; Ack = 981

◯ (C) ACK packet with Seq = 981; Ack = 604

◯ (D) ACK packet with Seq = 604; Ack = 981

◯ (E) Nothing to send, because the TCP handshake is already finished.

◯ (F) ——

Q1.4 (3 points) Immediately after the TCP handshake, Mallory injects a valid RST packet to the server. Next, Mallory spoofs a SYN packet from Dr. Yang to the server with headers Seq $= X$. The server responds with a SYN-ACK packet with Seq $= Y$; Ack $= X + 1$. What is the destination of this packet?

- ◯ (G) Dr. Yang
- ◯ (H) The server
- ◯ (I) Mallory
- ◯ (J) None of the above
- ◯ (K) ——
- ◯ (L) ——

Q1.5 (3 points) Which of the following network attackers would be able to perform the same attacks as Mallory?

Clarification during exam: By "perform the same attacks," we mean "reliably perform the same attacks."

- ◯ (A) A MITM attacker between Dr. Yang and the server
- ◯ (B) An off-path attacker
- ◯ (C) All of the above
- ◯ (D) None of the above
- ◯ (E) ——
- ◯ (F) ——

Q2 *Pancake Query Protocol* **(19 points)**

EvanBot is already prepared for the winter break but realizes that there are no more pancakes and needs to order more! To speed up the ordering process, EvanBot crafts a custom Pancake Query Protocol (PQP) and needs to ensure that it is secure.

PQP runs directly over IP, and a PQP packet contains the following information:

- A packet type
- The pancake query data (either a request for an order, or the order itself)

For now, assume that the only packet type supported by PQP is the ORDER type. For example, EvanBot might send the following PQP packet:

- EvanBot ⟶ Restaurant: {Type: ORDER; Data: "I want 1 stack of blueberry pancakes!"}

For all parts, assume that EvanBot knows the IP address of the restaurant. All subparts of this question are independent.

Q2.1 (5 points) Which of the following statements are true about PQP? Select all that apply.

☐ (A) An off-path attacker can learn EvanBot's order

☐ (B) An off-path attacker can trick the restaurant into cooking unwanted pancakes for EvanBot

☐ (C) An on-path attacker can conduct a RST injection attack

☐ (D) An on-path attacker can learn EvanBot's order

☐ (E) EvanBot can be sure that the restaurant received the order

☐ (F) None of the above

Q2.2 (3 points) EvanBot adds an ACK packet type to PQP packets. After a restaurant receives an order, the restaurant sends an ACK packet acknowledging the order. If EvanBot does not receive the ACK, EvanBot re-sends the order until an ACK is received.

EvanBot tries to order 1 stack of pancakes from the restaurant and eventually receives an ACK. Assume that **no** network attackers are present. How many orders could the restaurant receive?

◯ (G) Exactly 0, because IP is unreliable.

◯ (H) Either 0 or 1, because IP is unreliable.

◯ (I) 0 or more, because IP is unreliable.

◯ (J) Exactly 1, because the restaurant ACKs any order it receives.

◯ (K) 1 or more, because EvanBot might try more than once.

◯ (L) 2 or more, because the restaurant may send multiple ACKs.

Q2.3 (4 points) Consider the following modification to PQP: To order, the client generates a random order ID and sends it in the PQP ORDER packet along with the order. The server sends back the order ID in the PQP ACK packet.

Can an off-path attacker trick the restaurant into accepting a spoofed order appearing to come from EvanBot? Briefly justify your answer (1–2 sentences).

○ (A) Yes

○ (B) No

○ (C) ——

○ (D) ——

○ (E) ——

○ (F) ——

Q2.4 (4 points) Which of the following modifications to PQP, if made individually, would prevent an off-path attacker from tricking the restaurant into accepting spoofed orders? Select all that apply.

☐ (G) The restaurant generates a random order ID and sends it back in the PQP ACK. The restaurant must receive a PQP ACK-ACK packet from EvanBot containing the order ID to confirm the order.

☐ (H) The restaurant sends a fixed time-to-live (TTL) to EvanBot in the PQP ACK. The restaurant must receive a final, empty PQP ACK packet from EvanBot within the TTL to confirm the order.

☐ (I) PQP runs over UDP instead of IP, and EvanBot chooses a random source port.

☐ (J) PQP runs over TCP instead of IP.

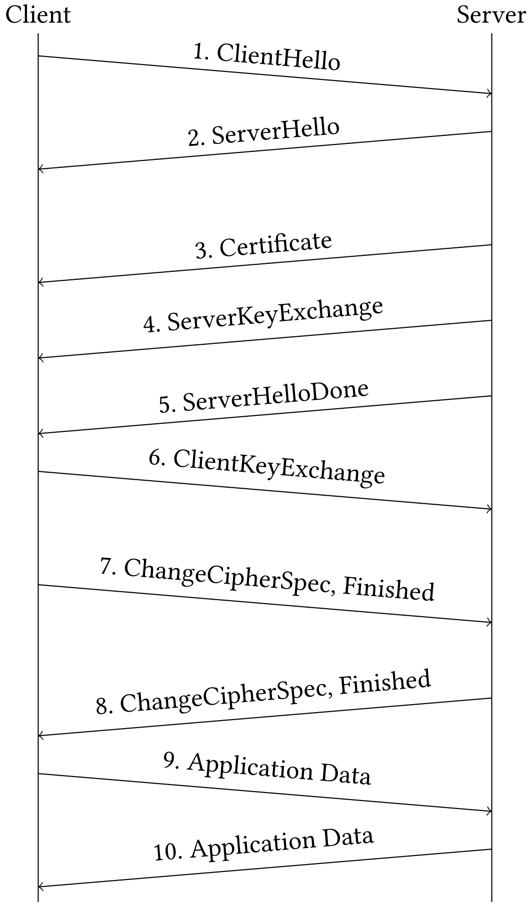
☐ (K) None of the above

☐ (L) ——

Q2.5 (3 points) EvanBot proposes an additional packet types for PQP: LISTORDERS. When a restaurant receives an LISTORDERS packet, it responds with a list of all orders that it has ever received from any customer. Name one security issue with this proposal and describe the steps an attacker should take to exploit this issue (1–2 sentence).

Recall the TLS handshake:

Q3 ***Mutuality*** **(18 points)**



1. Client sends 256-bit random number R_b and supported ciphers
2. Server sends 256-bit random number R_s and chosen cipher
3. Server sends certificate
4. DH: Server sends $\{g, p, g^a \bmod p\}_{K_{\text{server}}^{-1}}$
5. Server signals end of handshake
6. DH: Client sends $g^b \bmod p$
   RSA: Client sends $\{PS\}_{K_{\text{server}}}$

Client and server derive cipher keys C_b, C_s and integrity keys I_b, I_s from R_b, R_s, PS

7. Client sends MAC(dialog, I_b)
8. Server sends MAC(dialog, I_s)
9. Client data takes the form $\{M_1, \text{MAC}(M_1, I_b)\}_{C_b}$
10. Server data takes the form $\{M_2, \text{MAC}(M_2, I_s)\}_{C_s}$

In TLS, we verify the identity of the server, but not the client. How would we modify TLS to also verify the identity of the client?

Clarification during exam: All parts of this question refer to a modified TLS scheme designed to verify the identity of the client.

Q3.1 (3 points) Which of these additional values should the client send to the server?

◯ (A) A certificate with the client's public key, signed by the client's private key

◯ (B) A certificate with the client's public key, signed by the server's private key

◯ (C) A certificate with the client's private key, signed by a certificate authority's private key

◯ (D) A certificate with the client's public key, signed by a certificate authority's private key

◯ (E) ——

◯ (F) ——

Q3.2 (3 points) How should the client send the premaster secret in RSA TLS?

○ (G) Encrypted with the server's public key, signed by the client's private key

○ (H) Encrypted with the client's public key, signed by the server's private key

○ (I) Encrypted with the server's public key, signed by a certificate authority's private key

○ (J) Encrypted with the client's public key, signed by a certificate authority's private key

○ (K) ——

○ (L) ——

Q3.3 (3 points) EvanBot argues that the key exchange protocol in Diffie-Hellman TLS doesn't need to be changed to support client validation. Is EvanBot right?

○ (A) Yes, because only the client knows the secret a, so the server can be sure it's talking to the legitimate client

○ (B) Yes, because the server has already received and verified the client's certificate

○ (C) No, the client must additionally sign their part of the Diffie-Hellman exchange with the client's private key

○ (D) No, the client must additionally sign their part of the Diffie-Hellman exchange with the certificate authority's private key

○ (E) ——

○ (F) ——

Q3.4 (2 points) TRUE or FALSE: The server can be sure that they're talking to the client (and not an attacker impersonating the client) immediately after the client and server exchange certificates.

○ (G) True ○ (H) False ○ (I) —— ○ (J) —— ○ (K) —— ○ (L) ——

Q3.5 (3 points) At what step in the TLS handshake can both the client and server be sure that they have derived the same symmetric keys?

○ (A) Immediately after the TCP handshake, before the TLS handshake starts

○ (B) Immediately after the ClientHello and ServerHello are sent

○ (C) Immediately after the client and server exchange certificates

○ (D) Immediately after the client and server verify signatures

○ (E) Immediately after the MACs are exchanged and verified

○ (F) ——

Q3.6 (4 points) Which of these keys, if stolen individually, would allow the attacker to impersonate the client? Select all that apply.

- ☐ (G) Private key of a certificate authority
- ☐ (H) Private key of the client
- ☐ (I) Private key of the server
- ☐ (J) Public key of a certificate authority
- ☐ (K) None of the above
- ☐ (L) ——