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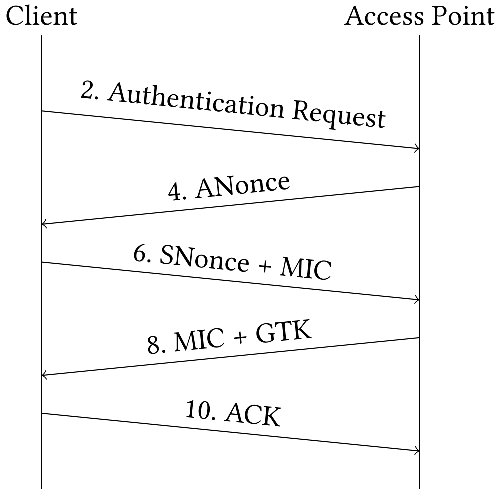
CS 161
Computer Security

Exam Prep 9

Q1 *I am Inevitable (SP22 Final Q10)* **(20 points)**

Recall the WPA 4-way handshake from lecture:



1. Client and AP derive the PSK from SSID and password.

3. AP randomly chooses ANonce.

5. Client randomly chooses SNonce and derives PTK.

7. AP derives PTK and verifies the MIC.

9. Client verifies the MIC.

For each method of client-AP authentication, select all things that the given adversary would be able to do. Assume that:

- The attacker does not know the WPA-PSK password but that they know that client's and AP's MAC addresses.
- For rogue AP attacks, there exists a client that knows the password that attempts to connect to the rogue AP attacker.
- The AMAC is the Access Point's MAC address and the SMAC is the Client's MAC address.

Q1.1 (5 points) The client and AP perform the WPA 4-way handshake with the following modifications:

- $\mathsf{PTK} = F(\mathsf{ANonce}, \mathsf{SNonce}, \mathsf{AMAC}, \mathsf{SMAC}, \mathsf{PSK})$, where F is a secure key derivation function
- $\mathsf{MIC} = \mathsf{PTK}$

■ An on-path attacker that observes a successful handshake can decrypt subsequent WPA messages without learning the value of the PSK.

□ An on-path attacker that observes a successful handshake can trick the AP into completing a new handshake without learning the value of the PSK.

□ An on-path attacker that observes a successful handshake can learn the PSK without brute force.

□ A rogue AP attacker can learn the PSK without brute force.

■ A rogue AP attacker can only learn the PSK if they use brute force.

□ None of the above

Solution: Because the MIC is the value of the PTK, it is trivial to decrypt subsequent communications. However, replay attacks are not possible since the ANonce is chosen by the AP, so the attacker can't trick the AP into completing a new handshake.

Additionally, because all the information needed to brute-force the PSK is sent in the clear (ANonce, SNonce, and MICs), brute-force attacks are possible by the rogue AP. However, there is no way of learning the PSK given the PTK with any method other than brute-force.

Q1.2 (5 points) The client and AP perform the WPA 4-way handshake with the following modifications:

- $\mathsf{PTK} = F(\mathsf{ANonce}, \mathsf{SNonce}, \mathsf{AMAC}, \mathsf{SMAC})$, where F is a secure key derivation function
- $\mathsf{MIC} = \mathsf{HMAC}(\mathsf{PTK}, \text{Dialogue})$

■ An on-path attacker that observes a successful handshake can decrypt subsequent WPA messages without learning the value of the PSK.

■ An on-path attacker that observes a successful handshake can trick the AP into completing a new handshake without learning the value of the PSK.

□ An on-path attacker that observes a successful handshake can learn the PSK without brute force.

□ A rogue AP attacker can learn the PSK without brute force.

□ A rogue AP attacker can only learn the PSK if they use brute force.

□ None of the above

Solution: Because the PSK isn't actually incorporated into this handshake, it is trivial for an attacker to derive the PTK to decrypt subsequent messages, and it is easy for them to form a new handshake with the AP.

Q1.3 (5 points) The client and AP perform the WPA 4-way handshake with the following modifications:

- Authentication: Client sends $\mathsf{H}(\mathsf{PSK})$ to AP, where H is a secure cryptographic hash.
- Verification: AP compares $\mathsf{H}(\mathsf{PSK})$ and to the value it received.
- AP sends: $\mathsf{Enc}(\mathsf{PSK}, \mathsf{PTK})$ to client, where Enc is an IND-CPA secure encryption algorithm.

□ An on-path attacker that observes a successful handshake can decrypt subsequent WPA messages without learning the value of the PSK.

■ An on-path attacker that observes a successful handshake can trick the AP into completing a new handshake without learning the value of the PSK.

□ An on-path attacker that observes a successful handshake can learn the PSK without brute force.

□ A rogue AP attacker can learn the PSK without brute force.

■ A rogue AP attacker can only learn the PSK if they use brute force.

□ None of the above

Solution: Assuming that an on-path attacker doesn't know the PSK, they can't brute-force the PTK since it's encrypted using the PSK and thus can't decrypt subsequent communications without learning the PSK. However, there are no nonces involved in the handshake, so it is possible to replay $\mathsf{Enc}(\mathsf{PSK}, \mathsf{PSK})$ to trick the AP into completing a new handshake.

Because the PSK is encrypted with itself, the on-path attacker and rogue AP aren't able to learn its value without brute force. However, if brute force is allowed, it is easy to guess a value of PSK and attempt to decrypt the ciphertext to see if the decrypted value is equal to the guessed PSK.

Q1.4 (5 points) The client and AP perform the WPA 4-way handshake with the following modifications:

- Authentication: Client conducts a Diffie-Hellman exchange with the AP to derive a shared key K.
- Client sends: $\mathsf{Enc}(K, \mathsf{PSK})$ to the AP.
- Verification: Check if $\mathsf{Dec}(K, \text{Ciphertext})$ equals the PSK
- Upon verification, AP sends: $\mathsf{Enc}(\mathsf{K}, \mathsf{PTK})$, where PTK is a random value, and sends it to the client.
- Assume that Enc is an IND-CPA secure encryption algorithm.

□ An on-path attacker that observes a successful handshake can decrypt subsequent WPA messages without learning the value of the PSK.

□ An on-path attacker that observes a successful handshake can trick the AP into completing a new handshake without learning the value of the PSK.

□ An on-path attacker that observes a successful handshake can learn the PSK without brute force.

■ A rogue AP attacker can learn the PSK without brute force.

□ A rogue AP attacker can only learn the PSK if they use offline brute force.

□ None of the above

Solution: Unlike the previous question, Diffie-Hellman defends against replay attacks since the AP would choose a new private Diffie-Hellman component for each handshake. However, a rogue AP learns the value of K, and is thus able to learn the value of the PSK by decrypting $\mathsf{Enc}(K, \mathsf{PSK})$ using K.

Q2 *Coffee-Shop Attacks (SU21 Final Q4)* (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.

Q2.1 (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.

□ CSRF	■ HTTP	□ None of the above
■ IP	■ DHCP	

Solution:

A: False. CSRF is not a protocol, but a web attack.

B: True. IP is used to send messages across the internet and is used by TCP, which is used by HTTP.

D: True. HTTP is the application protocol being used.

E: True. DHCP is used to receive the initial network configuration for the client.

Q2.2 (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?

● Yes, because the malicious message replaces some legitimate message

○ Yes, because future messages will arrive out of order

○ No, because on-path attackers cannot inject packets into a TCP connection

○ No, because TCP connections are encrypted

Solution: When the server receives the original TCP packet whose sequence number was used by Mallory, the server will ignore it, thinking that it has already received its data and that it was retransmitted.

Q2.3 (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?

○ SYN-ACK packet with Seq $= 981$; Ack $= 604$

○ SYN-ACK packet with Seq $= 604$; Ack $= 981$

● ACK packet with Seq $= 981$; Ack $= 604$

○ ACK packet with Seq $= 604$; Ack $= 981$

○ Nothing to send, because the TCP handshake is already finished.

Solution: This is the third step of the 3-way handshake, when the client sends an ACK packet to acknowledge the server's SYN-ACK packet.

Q2.4 (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?

● Dr. Yang

○ Mallory

○ The server

○ None of the above

Solution: The server uses the source as the destination for the SYN-ACK packet. Because Mallory spoofed the packet from the client, the response is sent to the client.

Q2.5 (3 points) Which of the following network attackers would be able to **reliably** perform the same attacks as Mallory?

● A MITM attacker between Dr. Yang and the server

○ All of the above

○ An off-path attacker

○ None of the above

Solution: A MITM attacker has all the capabilities of an on-path attacker, so it would be able to perform Mallory's attacks. An off-path attacker would be unable to guess the sequence numbers and would be unable to perform Mallory's attacks.