Authentication II

ECE 4156/6156 Hardware-Oriented Security and Trust

Spring 2025

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Reading Assignment

- Take good notes during this lecture!
- Introduction to Modern Cryptography, 3rd Edition, Chapter 11
- Introduction to Modern Cryptography, 2nd Edition, Chapter 10
- R. Needham and M. Schroeder, "Using Encryption for Authentication in Large Networks of Computers," Communications of the ACM, Volume 21, Number 12, Dec. 1978, pp. 993-999
- G. Lowe, "An attack on the Needham-Schroeder public-key authentication protocol," Information Processing Letters, Volume 56, Issue 3, Nov. 1995, pp. 131-133.

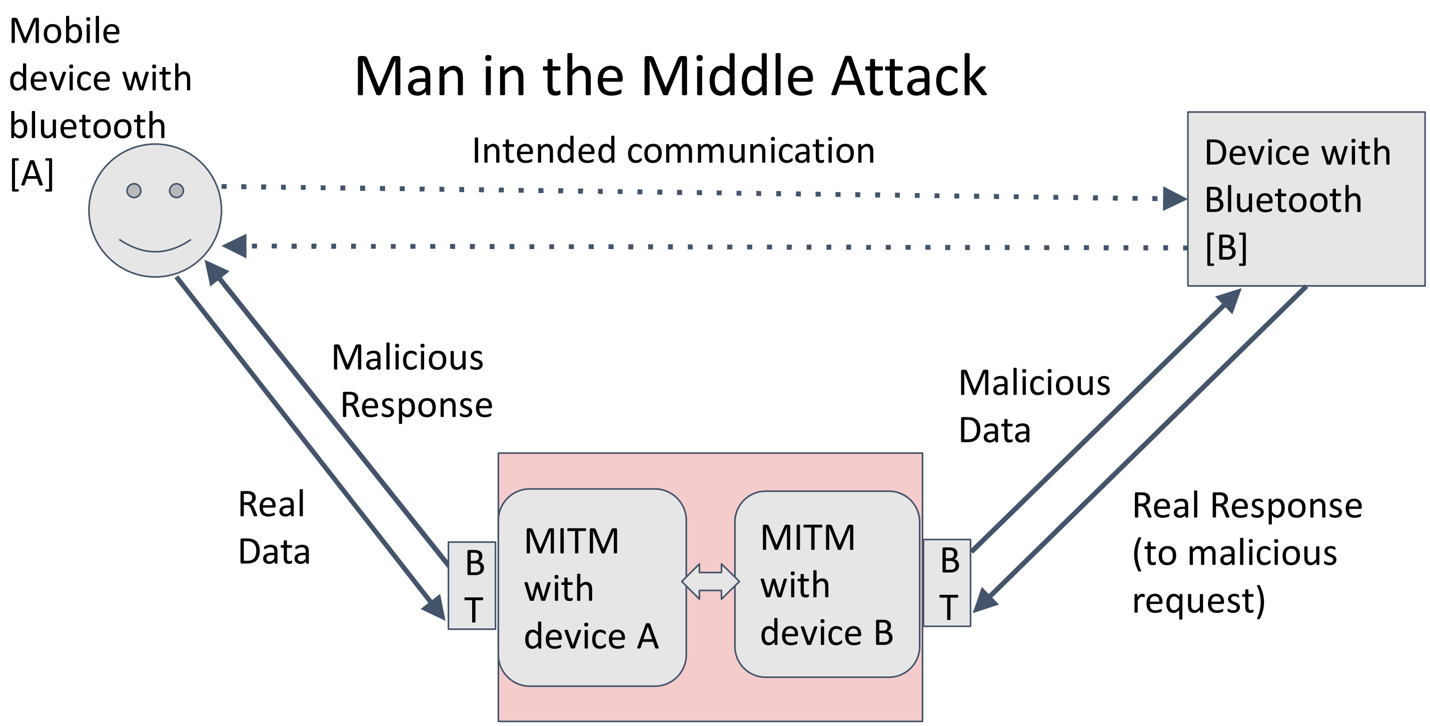
Protocols

- A protocol is a series of steps involving two or more parties designed to accomplish a task.
  - Everyone involved in the protocol must know the protocol and all of the steps to follow in advance
  - Everyone involved in the protocol must agree to follow it
  - The protocol must be unambiguous, the steps must be well defined, and there must be no change of misunderstanding
  - The protocol must be complete, i.e., there must be a specified action for every possible situation

First Attempt to Communicate Securely

- Alice and Bob agree on a cryptosystem
- Alice and Bob agree on a symmetric key
- Alice takes her plaintext message and encrypts it using the encryption algorithm and the key, creating a ciphertext message
- Alice sends the ciphertext to Bob
- Bob decrypts the ciphertext message with the same algorithm and key and reads it

Threat Scenario



Number used only Once (NONCE)

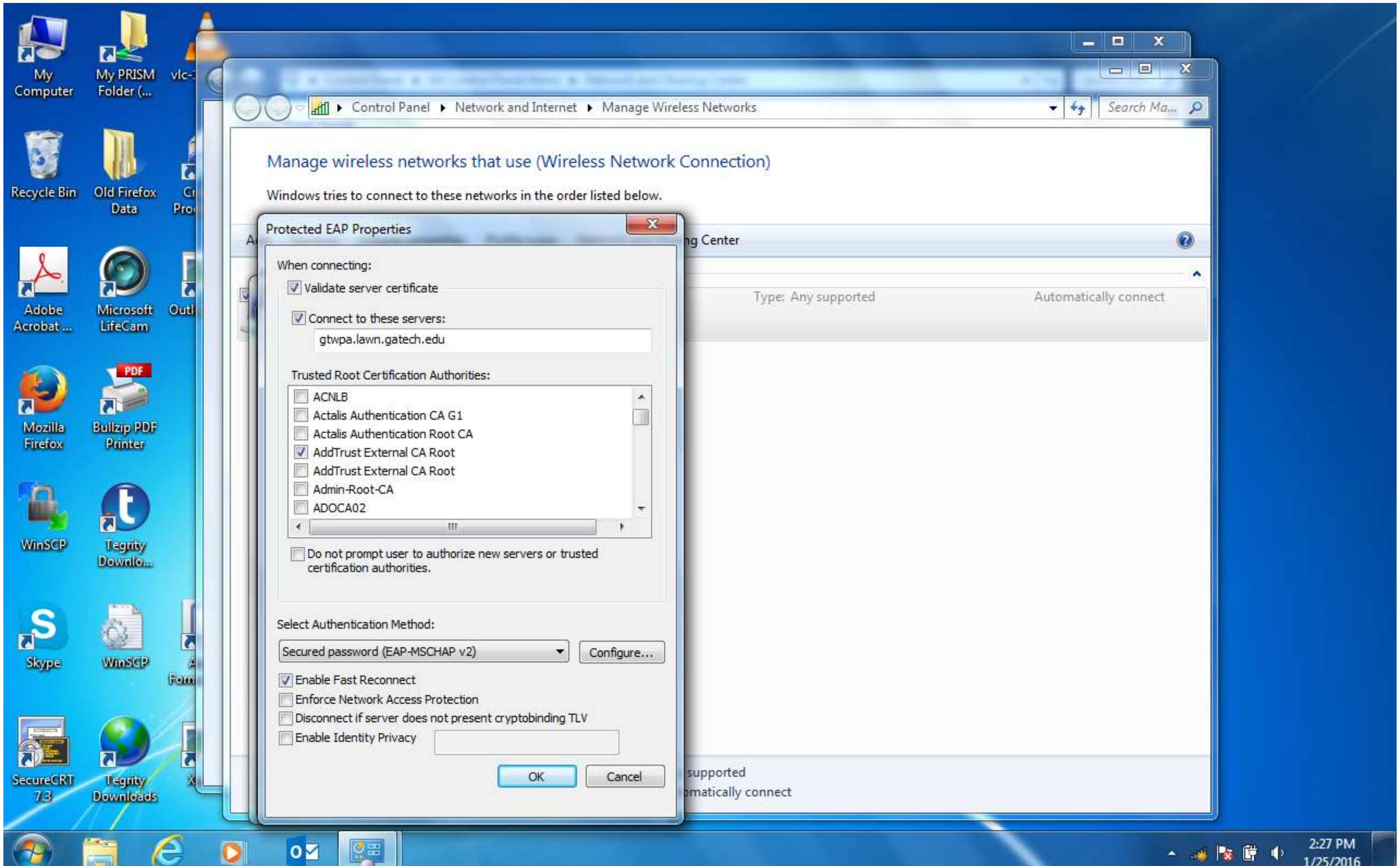
- Authentication with asymmetric cryptography
  - Server sends Alice a random number (a “nonce”) in plaintext
  - Alice encrypts the nonce with her private key and sends it back to the server along with her name
  - The server uses Alice’s public key to decrypt the message and verify that the nonce sent by Alice is correct
  - Now the server can proceed with the next steps, e.g., by sending Alice a session key (e.g., a 128-bit AES key) encrypted with Alice’s public key

Actually…

- The previous slide presented one-way authentication, e.g., Alice authenticated herself to the server
- What about communication pretending to be from the server but really from another entity?
- Two-way authentication
  - Server authenticates Alice
  - Alice authenticates the server
  - Then the next steps proceed…

A Second Attempt to Communicate Securely

- A public key cryptosystem infrastructure is made widely available
- Alice obtain’s Bob’s public key from the infrastructure
  - E.g., using a Certificate Authority (CA) or a Trusted Third Party (TTP)
- Alice encrypts her message using Bob’s public key and sends the message to Bob
- Bob then decrypts Alice’s message using his private key


Control Panel ▸ Network and Internet ▸ Manage Wireless Networks
Search Ma...
Manage wireless networks that use (Wireless Network Connection)
Windows tries to connect to these networks in the order listed below.
Protected EAP Properties
When connecting:
Validate server certificate
Connect to these servers:
gtwpa.lawn.gatech.edu
Trusted Root Certification Authorities:
ACNLB
Actalis Authentication CA G1
Actalis Authentication Root CA
AddTrust External CA Root
AddTrust External CA Root
Admin-Root-CA
ADOCA02
Do not prompt user to authorize new servers or trusted certification authorities.
Select Authentication Method:
Secured password (EAP-MSCHAP v2)
Configure...
Enable Fast Reconnect
Enforce Network Access Protection
Disconnect if server does not present cryptobinding TLV
Enable Identity Privacy
OK
Cancel
Type: Any supported
Automatically connect
My Computer
My PRISM Folder (...
Recycle Bin
Old Firefox Data
Adobe Acrobat ...
Microsoft LifeCam
Mozilla Firefox
Bullzip PDF Printer
WinSCP
Tegrity Downlo...
Skype
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SecureCRT 7.3
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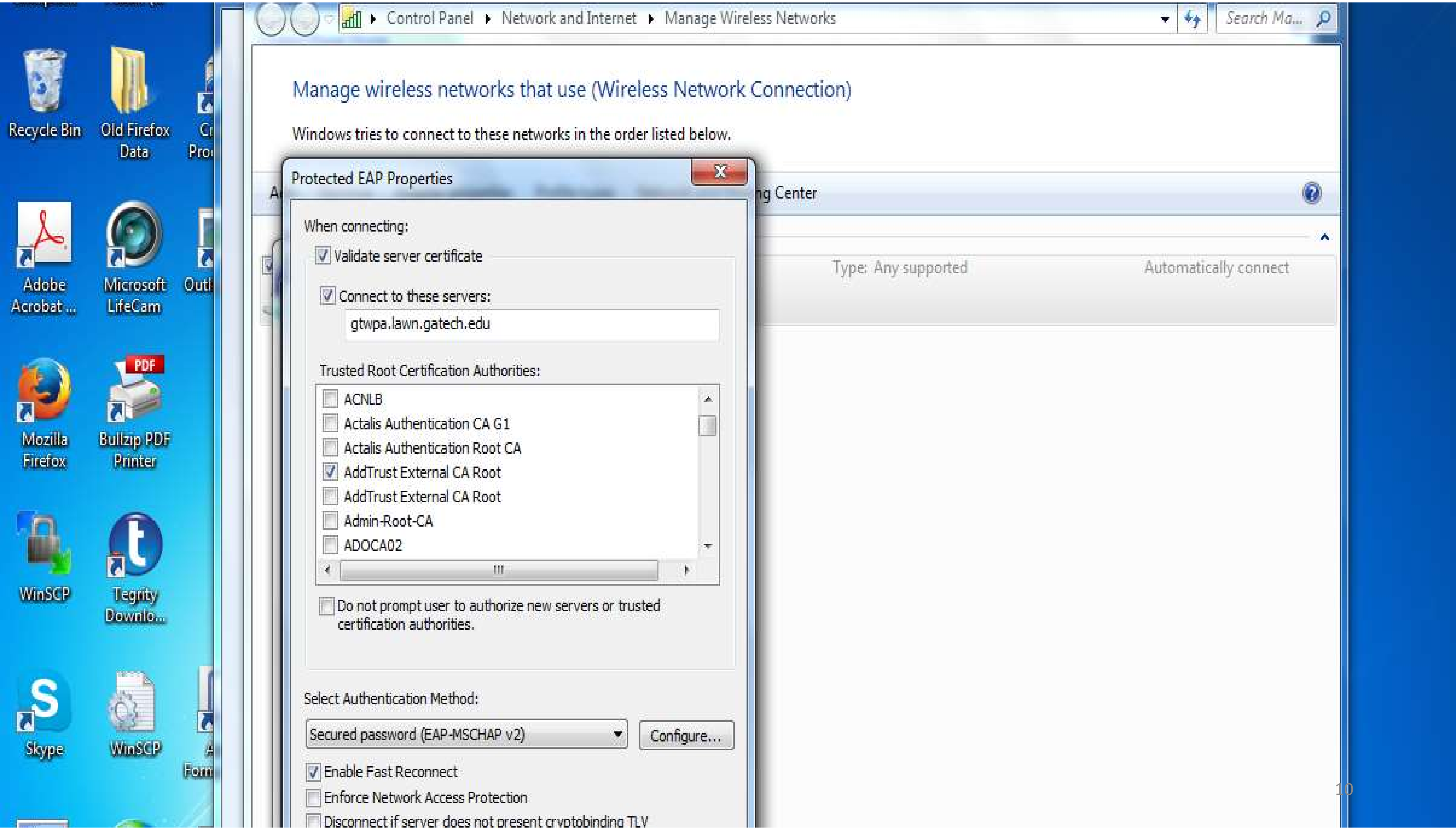
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Automatically connect
Recycle Bin
Old Firefox Data
Adobe Acrobat ...
Microsoft LifeCam
Mozilla Firefox
Bullzip PDF Printer
WinSCP
Tegrity Downlo...
Skype
WinSCP

Needham-Schroeder (1978)

- Alice to Trent: A, B, N_A (NOTE: Trent is a Trusted Third Party or TTP!)
- Trent to Alice: $E_{K_A}(N_A, B, K, E_{K_B}(K, A))$
- Alice to Bob: $E_{K_B}(K, A)$
- Bob to Alice: $E_K(N_B)$
- Alice to Bob: $E_K(N_B\text{-}1)$

Kerberos

- Alice sends Trent her identity and Bob's: A,B
- Trent generates key K and adds a timestamp T plus a lifetime L; he then encrypts two messages as follows and sends them to Alice
  - $E_A(T,L,K,B)$; $E_B(T,L,K,A)$
- Alice then uses K to send Bob her identity and timestamp, plus Trent's message
  - $E_K(A,T)$; $E_B(T,L,K,A)$
- Bob creates a message consisting of the timestamp plus one, encrypts it in K, and sends it to Alice
  - $E_K(T+1)$

An Attack on Needham-Schroeder

- Mallory obtains an old session key K
- Mallory to Bob: $E_B(K,A)$
- Bob to Alice: $E_K(N_B)$
  - Mallory intercepts this message and decrypts it with K
- Mallory to Bob: $E_K(N_B\text{-}1)$

RECALL!
Alice to Trent: A, B, N_A
Trent to Alice: $E_{K_A}(N_A,B,K,E_{K_B}(K,A))$
Alice to Bob: $E_{K_B}(K,A)$
Bob to Alice: $E_K(N_B)$
Alice to Bob: $E_K(N_B\text{-}1)$

Public-Key Needham-Schroeder

- Alice to Trent: A, B
- Trent to Alice: $E_{T_{priv}}(B_{pub}, B)$
- Alice to Bob: $E_{B_{pub}}(N_A, A)$
- Bob to Trent: B, A
- Trent to Bob: $E_{T_{priv}}(A_{pub}, A)$
- Bob to Alice: $E_{A_{pub}}(N_A, N_B)$
- Alice to Bob: $E_{B_{pub}}(N_B)$

An Attack on Public-Key Needham-Schroeder

- Assumption: Alice talks to Mallory
- 1.1 Alice to Trent: A, M
- 1.2 Trent to Alice: $E_{T_{priv}}(M_{pub}, M)$
- 1.3 Alice to Mallory: $E_{M_{pub}}(N_A, A)$
- 2.3 Mallory(Alice) to Bob: $E_{B_{pub}}(N_A, A)$
- 2.4 Bob to Trent: B, A
- 2.5 Trent to Bob: $E_{T_{priv}}(A_{pub}, A)$
- 2.6 Bob to Mallory(Alice): $E_{A_{pub}}(N_A, N_B)$
- 1.4 Mallory to Trent: M, A
- 1.5 Trent to Mallory: $E_{T_{priv}}(A_{pub}, A)$
- 1.6 Mallory to Alice: $E_{A_{pub}}(N_A, N_B)$
- 1.7 Alice to Mallory: $E_{M_{pub}}(N_B)$
- 2.7 Mallory(Alice) to Bob: $E_{B_{pub}}(N_B)$

RECALL!

1.1 Alice to Trent: A, M
1.2 Trent to Alice: $E_{T_{priv}}(M_{pub}, M)$
1.3 Alice to Mallory: $E_{M_{pub}}(N_A, A)$
1.4 Mallory to Trent: M, A
1.5 Trent to Mallory: $E_{T_{priv}}(A_{pub}, A)$
1.6 Mallory to Alice: $E_{A_{pub}}(N_A, N_M)$
1.7 Alice to Mallory: $E_{M_{pub}}(N_M)$

2.1 Alice to Trent: A, B
2.2 Trent to Alice: $E_{T_{priv}}(B_{pub}, B)$
2.3 Alice to Bob: $E_{B_{pub}}(N_A, A)$
2.4 Bob to Trent: B, A
2.5 Trent to Bob: $E_{T_{priv}}(A_{pub}, A)$
2.6 Bob to Alice: $E_{A_{pub}}(N_A, N_B)$
2.7 Alice to Bob: $E_{B_{pub}}(N_B)$

Solution to PK Needham-Schroeder Attack

- Include identities with nonces!
- 2.6 Bob to Mallory(Alice): $E_{A_{pub}}(B, N_A, N_B)$
    - 1.3 Alice to Mallory: $E_{M_{pub}}(N_A, A)$
    - 2.3 Mallory(Alice) to Bob: $E_{B_{pub}}(N_A, A)$
    - 2.6 Bob to Mallory(Alice): $E_{A_{pub}}(B, N_A, N_B)$
    - 1.6 Mallory to Alice: $E_{A_{pub}}(B, N_A, N_B)$
    - 1.7 Alice does not proceed

Recall!

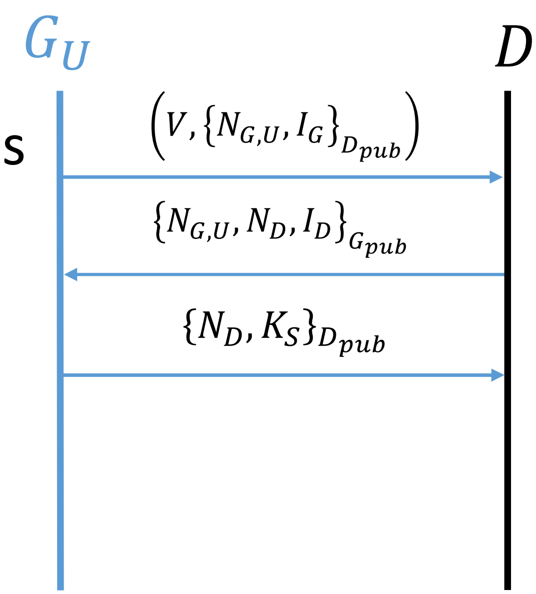
- 1.3 Alice to Mallory: $E_{M_{pub}}(N_A, A)$
- 2.3 Mallory(Alice) to Bob: $E_{B_{pub}}(N_A, A)$
- 2.6 Bob to Mallory(Alice): $E_{A_{pub}}(N_A, N_B)$
- 1.6 Mallory to Alice: $E_{A_{pub}}(N_A, N_B)$
- 1.7 Alice to Mallory: $E_{M_{pub}}(N_B)$
- 2.7 Mallory(Alice) to Bob: $E_{B_{pub}}(N_B)$

Notation

- D: target device
- G_U: updating organization
- (G_{pub}, G_{prv}): updating organization key pair
- (D_{pub}, D_{prv}): device key pair
- N_G, N_D: organization and device nonces
- I_G, I_D: organization and device identifiers
- V: incoming update version number
- K_s: symmetric key
- U: update image
- H: hash of the update image
- H_U : update hashes sent by G_U
- $\{M\}_{D_{pub}}$: message M is encrypted using key D_{pub}
  - Notation is common to both symmetric and asymmetric encryption
- $(G \rightarrow D : M)$: organization G sends M to device D
- $(G \leftarrow D : M)$: device D sends M to organization G

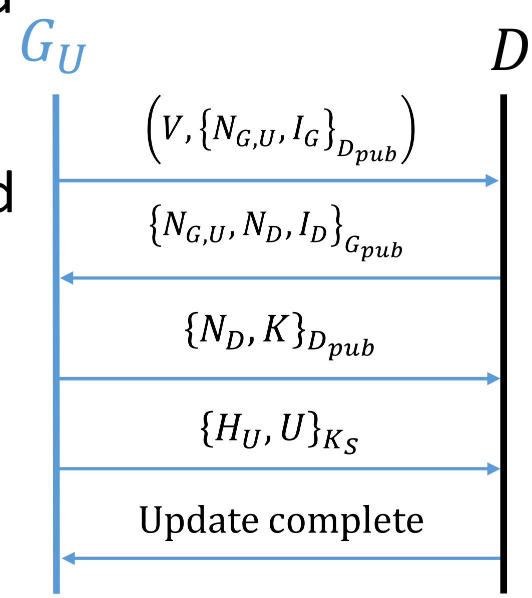
Authentication Phase Using Public Key Crypto

1. Organization nonce N_G and identifier I_G sent to device
2. Device retrieves N_G, and appends its own nonce and identifier N_D and I_D
3. Finally, organization responds with N_D and symmetric key K_S



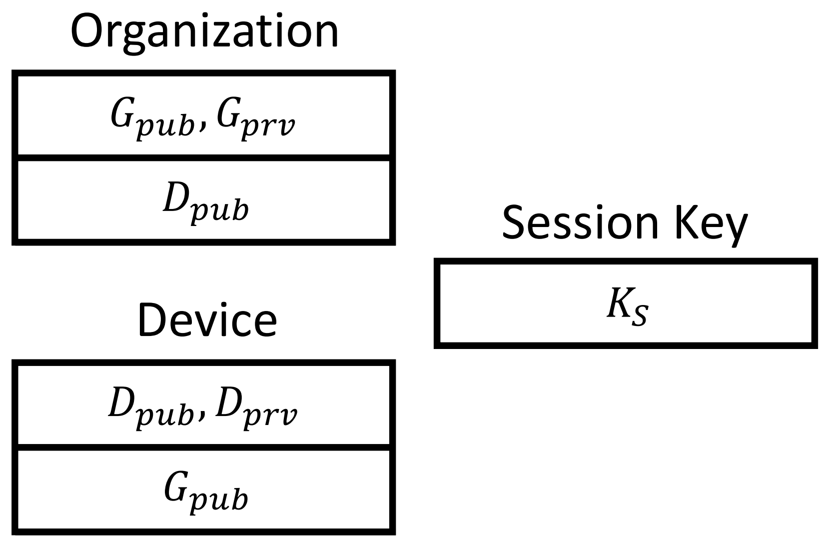
Update Phase Using Symmetric Key Crypto

4. Organization sends update U and hash of the update H_U using the and symmetric key K_S
5. Device decrypts the message and checks that the (keyless) hash value H_U is obtained on the update U
6. Finally, D sends an encrypted message indicating that the update is complete



Long Term Asymmetric Keys, Short Term Symmetric Session Key

- New symmetric session key generated by updating organization on every update
  - Shared during authentication phase
- Advantages
  - Decryption of update code faster than asymmetric
  - Higher security
- Disadvantages
  - Device has a higher implementation overhead in order to support asymmetric as well as symmetric crypto

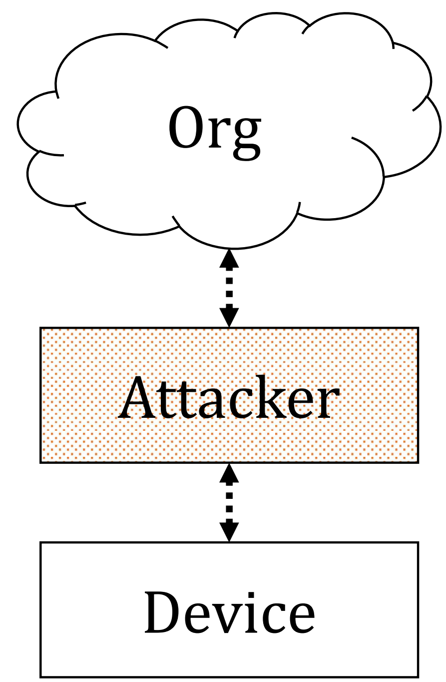


Security Analysis

1. Man in the middle
2. Replay attack
3. Organization spoofing

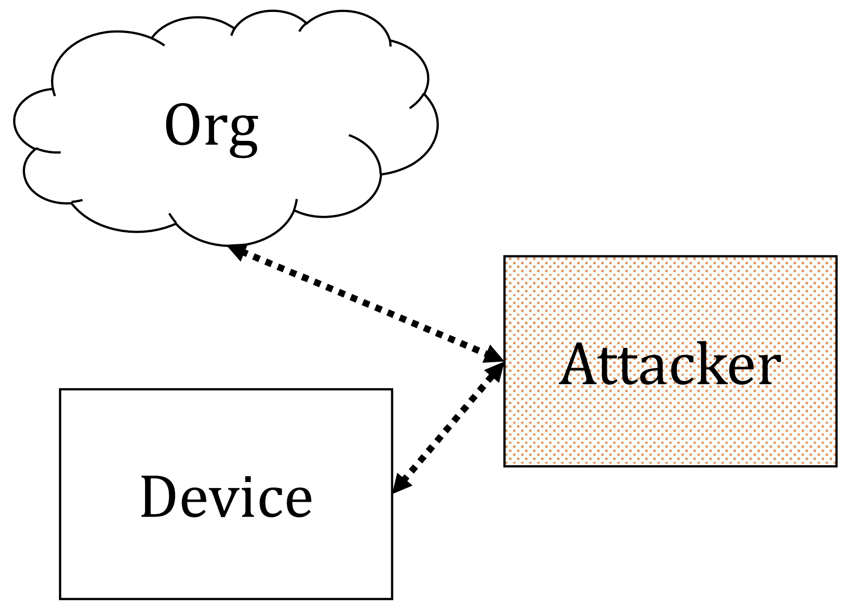
Man in the Middle

- Attacker tries to place himself between the updating organization and the device
- Attack fails because
    1. Authentication requires possession of private key
    2. All communication is encrypted
- Note that the assumption is that the public keys are correct



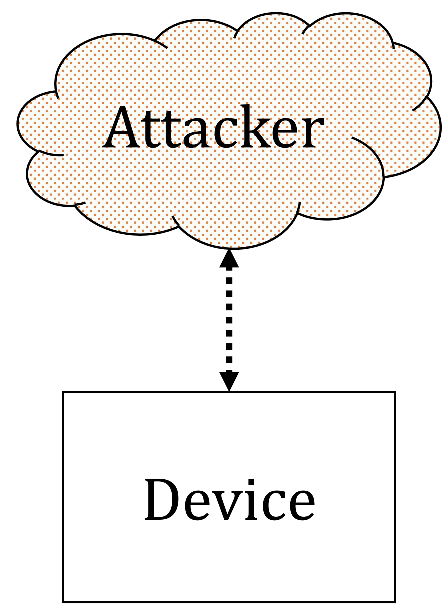
Replay Attack

- Attacker saves previous authentication and replays it
- Replay will be denied
  - Nonce used prevents successful replay



Organization Spoofing

- Attacker claims to be the updating organization
  - Pushes out malicious update
- Authentication will fail
  - Organization public key statically stored on Device
- Device will deny the update



Lessons Learned

- Do not try to be too clever; do not remove important pieces
    - Names
    - Random numbers
    - Timestamps
- Focus on what has worked in the past and has not yet been broken; optimizing a protocol will often break it
- What is your communications need?
    - Client-server
    - Many to many
- Time synchronization can be a big issue
- Recovery