CSE 3400 - Introduction to Computer & Network Security
(aka: Introduction to Cybersecurity)

Lecture 8

Shared Key Protocols – Part I

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From Textbook Slides by Prof. Amir Herzberg

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Outline

- Modeling cryptography protocols.
- Session or record protocols.
- Entity authentication protocols.

Modeling Cryptographic Protocols

- A protocol is a set of PPT (efficient) functions
  - Each receiving (state, input), outputting (state, output)
  - Two (or more) parties, each has its own state
- Including *Init, In,* [and if needed *Wakeup*] functions
  - And task-specific functions, e.g., *Send*
- Adversary can invoke any function, handle outputs
- The execution process is a series of function invocations based on which the protocol proceeds.
- Our discussion (from here) is mostly informal
  - Definitions of protocols, execution, goals are hard
  - Focus on shared-key, two-party protocols, MitM adversary
  - Record protocol: message authentication (+confidentiality?)

Record Protocols

Secure communication between two parties using shared keys.

Two-party, shared-key **Record protocol**

- Parties/peers: *Alice* (sender), *Bob* (receiver)
  - Simplest – yet applied – protocol
  - Simplify: only-authentication, Alice sends to Bob
    - Goal: Bob outputs *m* only if Alice had *Send(m)*
  - $Init(k)$: shared key, unknown to adversary

- Let's design the protocol !

Design of Two-party, shared-key Record protocol

- Design: define the protocol functions
  - $Init(k)$ [Initialize Alice/Bob with secret key *k*]
    - $\{s.k \leftarrow k;\ \}$
    - Save received key k in state-variable $s.k$ (part of s)
  - $Send(m)$: party asked to send m to peer
      - Code even simpler if both can send, receive
      - E.g., Alice instructed to send message *m* to Bob
    - $\{Output\ x \leftarrow\ (m, MAC_k(m))\ ;\ \}$
  - $In((m, \sigma))$: Party receives (m, σ) from adversary
    - $\{Output\ m$ if $(\sigma = MAC_k(m))\ ;\}$
    - Output the message only if validated Ok
- Define adversary capabilities; access and computational.

Design of Two-party, shared-key Record protocol

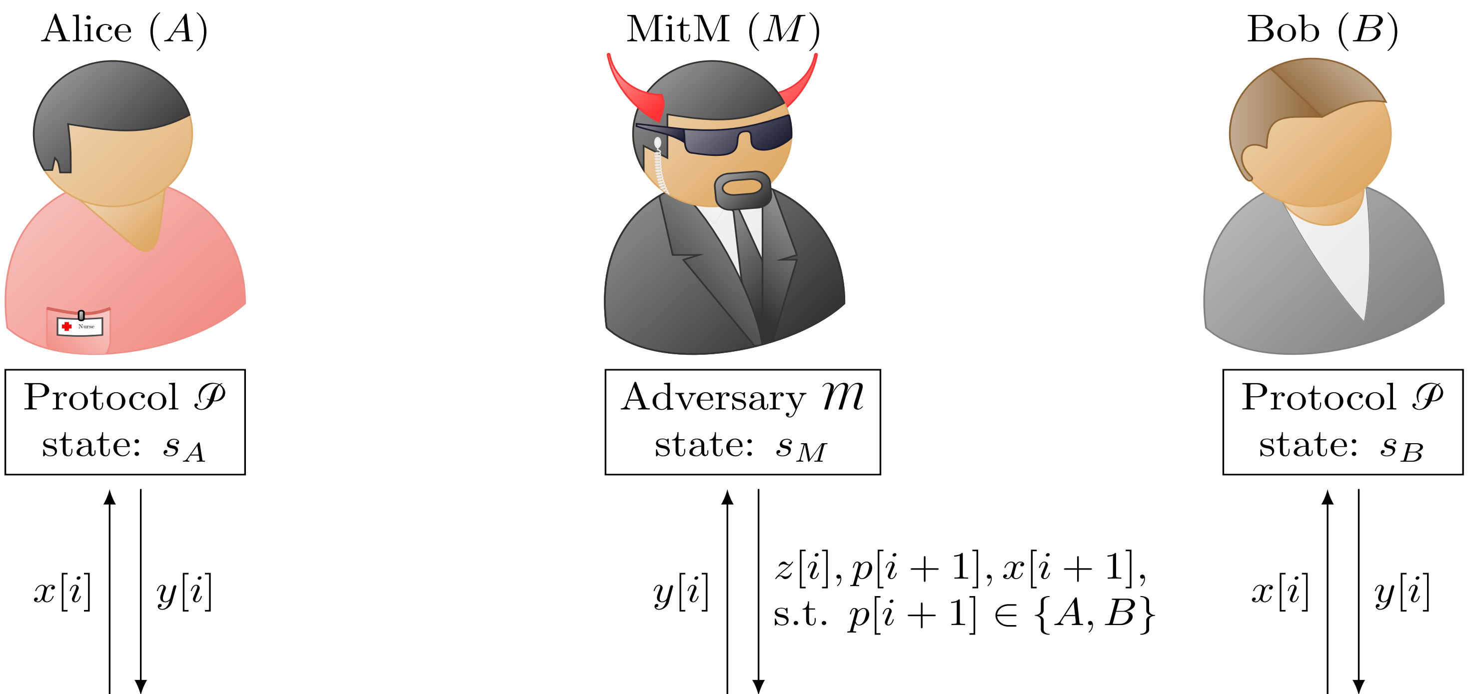
Two-party, shared-key **Record protocol**

- Design has many simplifications, easily avoided:
  - Only message authentication
    - No confidentiality!
  - Only ensure same message was sent
    - Allow duplication, out-of-order, `stale' messages, losses
  - Also: no retransmissions, compression, …
- To add confidentiality: use encryption

Two-party record protocol with Confidentiality

- $Init(k)$ [Initialize Alice/Bob with secret key *k*]
  - $\{s \leftarrow (k_E = F_k(`E`), k_A = F_k(`A`))$
- $Send(m)$: Alice sends message *m* (to Bob)
  - $\{Output\ x = (E_{k_E}(m), MAC_{k_A}(E_{k_E}(m)))$; }
- $In((c,\sigma))$: Bob receives (c,σ) from adversary
  - $\{Output\ D_k(c)$ if $(\sigma = MAC_{k_A}(c))$;}
- Ok! (but still allows dups/re-ordering, etc.)

Execution Process – Record Protocol

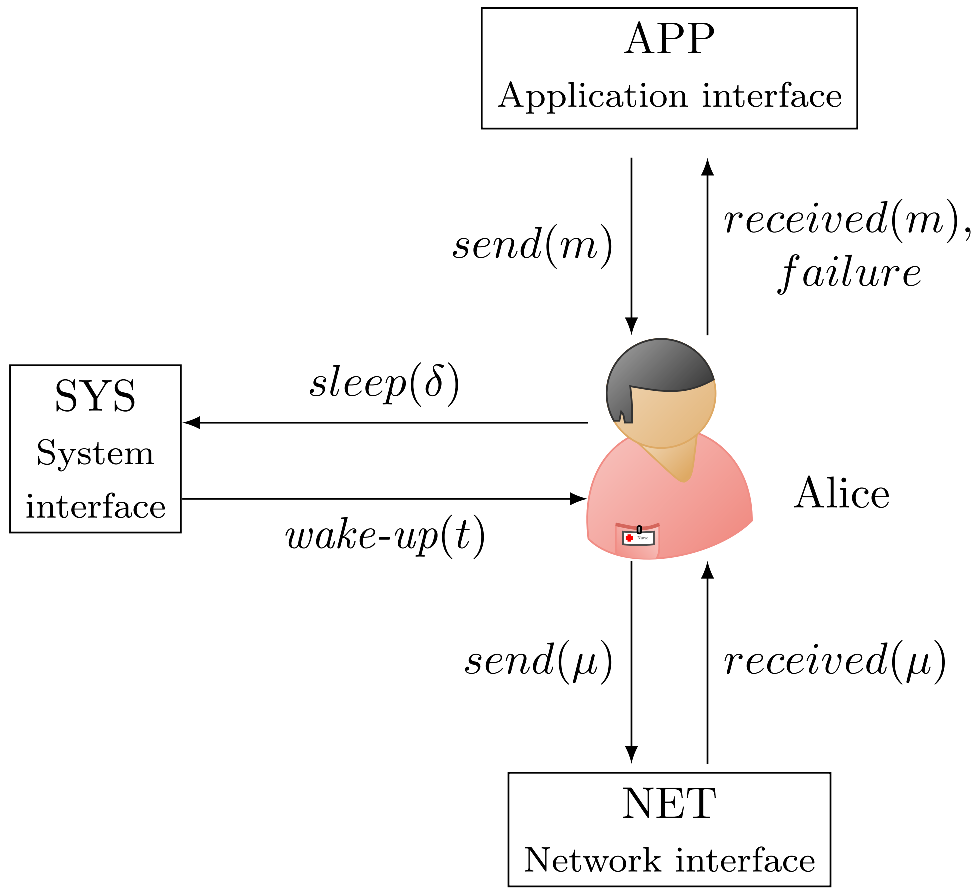


$Exec(\mathcal{P}, \mathcal{M}, 1^l)$:

1: $(s_A, s_B]) \leftarrow \mathcal{P}(\text{'Init'}, 1^l)$; ▷ Initialize Alice ($A$) and Bob ($B$)
2: $(s_M, (1^t, x[1], p[1]) \leftarrow \mathcal{M}(\text{'Init'}, 1^l)$; ▷ Initialize MitM ($M$)
3: **for** $i = 1$ to t **do**
4: $\quad (s_{p[i]}\ , y[i]) \leftarrow \mathcal{P}(s_{p[i]}, x[i])$; ▷ Party p event
5: $\quad (s_M,\ (z[i], p[i+1],\ x[i+1]) \leftarrow \mathcal{M}(s_M, y[i])$; ▷ MitM event.
6: **Return** t and $(x[i], y[i], p[i], z[i])$, for $i = 1$ to t;

Figure 5.1: Execution process $Exec(\mathcal{P}, \mathcal{M}, 1^l)$ for two benign parties Alice (A) and Bob (B) running shared-key protocol (algorithm) $\mathcal{P}$, *MitM* adversary (M) running algorithm $\mathcal{M}$, and security parameter 1^l.

Labels and Interfaces



Bob has similar interfaces.

Defining Security of Record Protocols

The existential-unforgeability advantage $\varepsilon^{EUF-Session}(\mathcal{P}, \mathcal{M}, 1^l)$ *of adversary* $\mathcal{M}$ *against session/record protocol* $\mathcal{P}$ *is defined as:*

$$\varepsilon^{EUF-Session}(\mathcal{P}, \mathcal{M}, 1^l) \equiv \equiv \Pr\left(\begin{array}{l} T \xleftarrow{\$} Exec(\mathcal{P}, \mathcal{M}, 1^l); \\ M^{rcv}(T) \textit{ is not a prefix of } M^{sent}(T) \end{array} \right) \tag{5.1}$$

Where the probability is taken over the random coin tosses of $\mathcal{M}$ *and* $\mathcal{P}$ *during the execution resulting in transcript* T*, and where* $M^{sent}(T)$*,* $M^{rcv}(T)$ *are defined as above.*

A session/record protocol $\mathcal{P}$ *is* existentially unforgeable *if for all PPT algorithms* $\mathcal{M}$*, the* advantage *of* $\mathcal{M}$ *against* $\mathcal{P}$ *is negligible, i.e.:* $\varepsilon^{EUF-Session}(\mathcal{P}, \mathcal{M}, 1^l) \in NEGL(l)$.

Entity Authentication Protocols

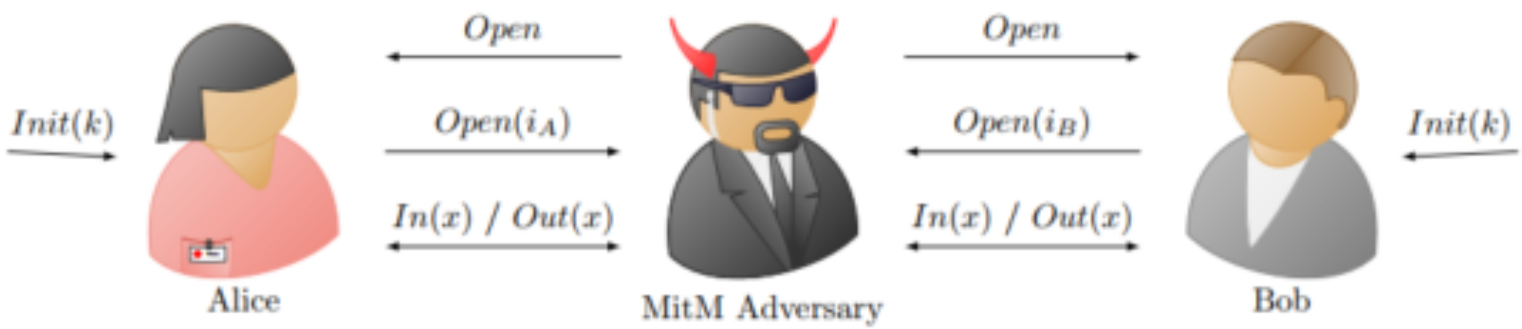
Ensure the identity of an entity (or a peer) involved in communication.

Mutual Authentication Protocols

- Our focus.
- In mutual authentication, each party authenticates herself to the other.
  - Alice knows that she is communicating with Bob, and vice versa
- This requires, at least, one exchange of messages.
  - A message from Alice and a response form Bob (or vice versa).
- Such a flow is called a ***handshake***.

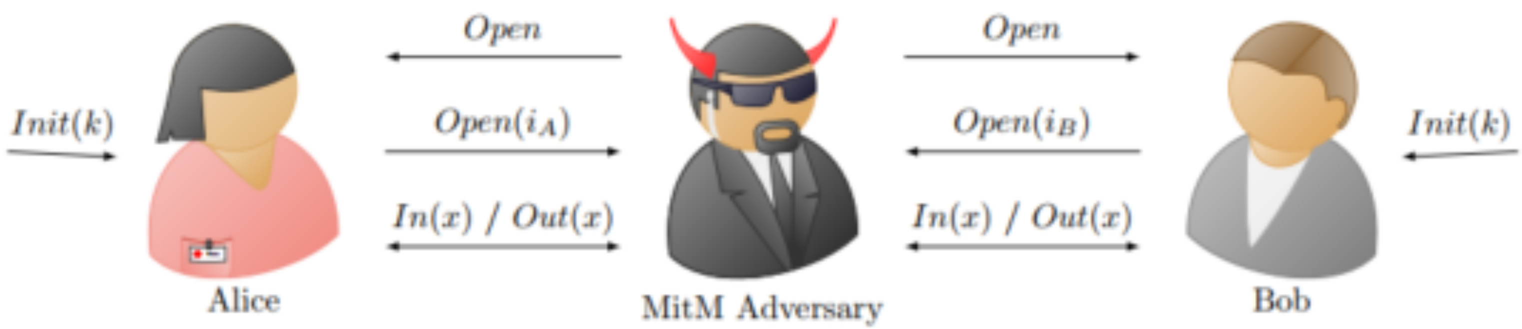
Handshake Entity-Authentication protocol

- A protocol to open **sessions** between parties
  - Each party assigns its own unique ID to each session
  - And map peer's-IDs to its own IDs
    - Alice maps Bob's i_B to its identifier $ID_A(i_B)$
    - Bob maps Alice's i_A to its identifier $ID_B(i_A)$
- 'Matching' goal: $i_A = ID_A\big(ID_B(i_A)\big)\,, i_B = ID_B\big(ID_A(i_B)\big)$
- Allow concurrent sessions and both to open
  - Simplify: no timeout / failures / close, ignore session protocol, …



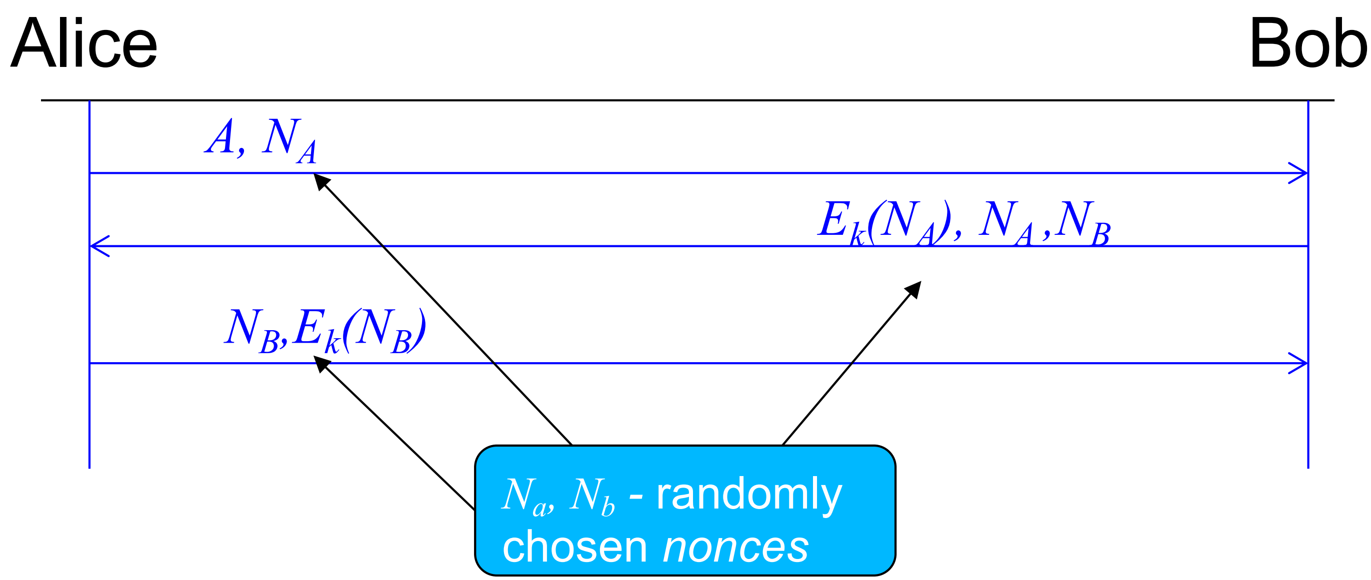
Handshake Entity-Authentication protocol

- Protocol functions
  - $Init(k)$ [Initialize Alice/Bob with secret key *k*]
  - $Open$: instruct Alice/Bob to open session
  - $In(x)$: party receives x from channel (via MitM)
- Protocol outputs
  - $Open(i)$: party opened session i
  - $Out(x)$: party asks to send x to peer



Example : IBM's SNA Handshake

- First dominant networking technology
- Handshake uses encryption with shared key k

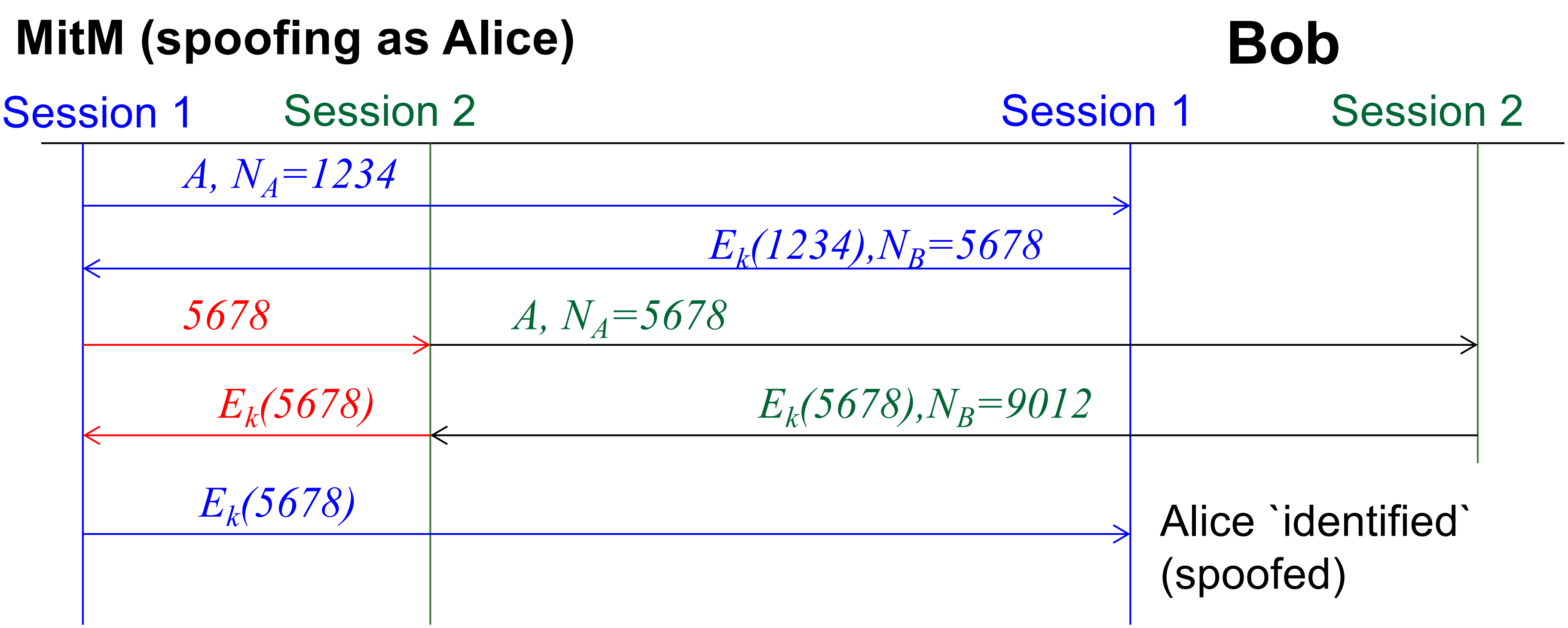


Insecure !! Why ?

SNA (Systems Network Architecture): IBM's proprietary network architecture, dominated market @ [1975-1990s], mainly in banking, government.

Attack on SNA's Handshake

- MitM opens two sessions with Bob… sending N_b to Bob in 2nd connection to get $E_k(N_b)$
  - SNA is secure for sequential mutual authentication handshakes but not concurrent.



Fixing Mutual Authentication

- Encryption does not ensure authenticity
  - Use MAC to authenticate messages
  - Although, a block cipher is a PRP, and a PRP is a PRF, and a PRF is a MAC, but domain is limited!
- Prevent redirection
  - Identify party in challenge
  - Better: use separate keys for each direction
- Prevent replay and reorder
  - Identify flow and connection
  - Prevent use of old challenge: randomness, time or state
- Do not provide the adversary with an oracle access!
  - Do not compute values from Adversary
  - Include self-chosen nonce in the protected reply

Two-Party Handshake Protocol (2PP)

Alice

Bob

- A, N_A
- N_B, $Mac_k(2 \,||\, A \leftarrow B \,||\, N_A \,||\, N_B)$
- $Mac_k(3 \,||\, A \rightarrow B \,||\, N_A \,||\, N_B)$

- ✓ Use MAC rather than encryption to authenticate
- ✓ Prevent redirection: include identities (A,B)
- ✓ Prevent replay and reorder:
  - Nonces (N_A,N_B)
  - Separate 2nd and 3rd flows: 3 vs. 2 input blocks
- Secure against arbitrary attacks [proved formally in the literature]

Covered Material From the Textbook

- Chapter 5
  - Sections 5.1 and 5.2

Thank You!