Network Security:
Classic protocol flaws

ENCS5322, NETWORK SECURITY PROTOCOLS

First Semester 2024-2025

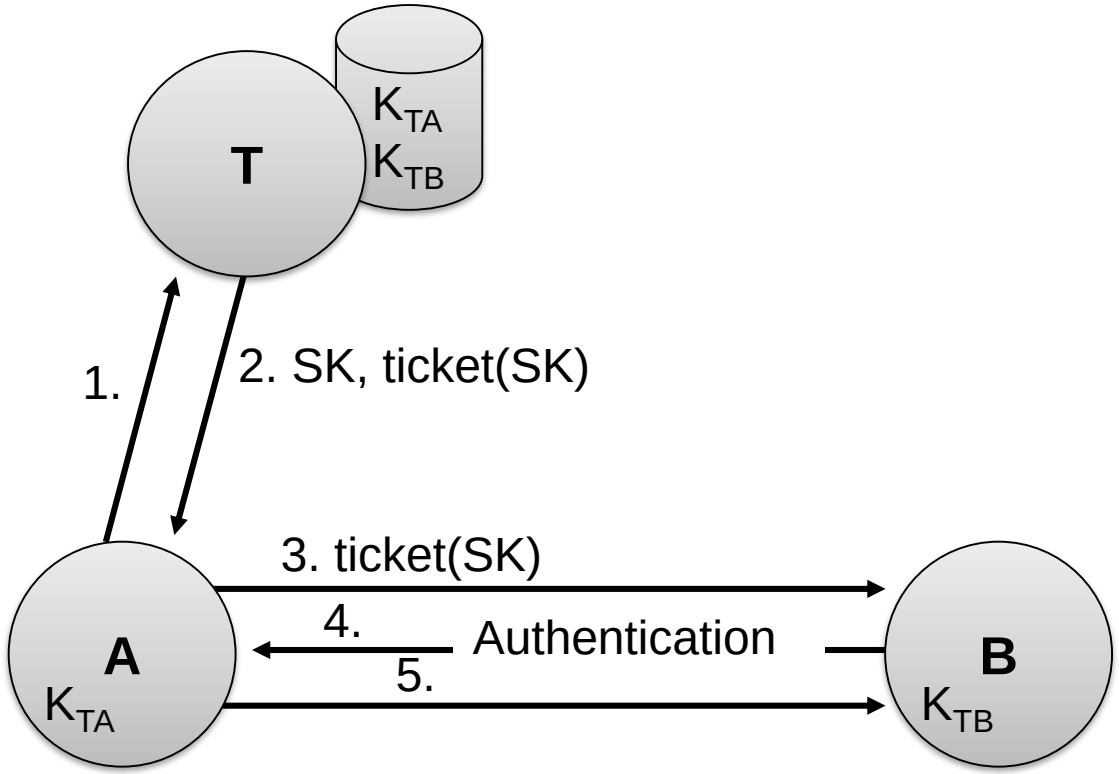
Outline

- Needham-Schroeder secret-key protocol
- Denning-Sacco protocol
- Needham-Schroeder public-key protocol
- Wide-mouth-frog protocol
- Encrypt and sign

These protocol are old designs or early research ideas that must not be used in practice. They are covered in security courses because they illustrate specific security flaws.

Needham-Schroeder secret-key protocol

- The first secret-key key-exchange protocol 1978; basis for Kerberos
- Trusted third party (T) shares a secret master key with each user
- Alice (A) asks T to create a session key SK for communication with Bob (B)



Needham-Schroeder secret-key protocol

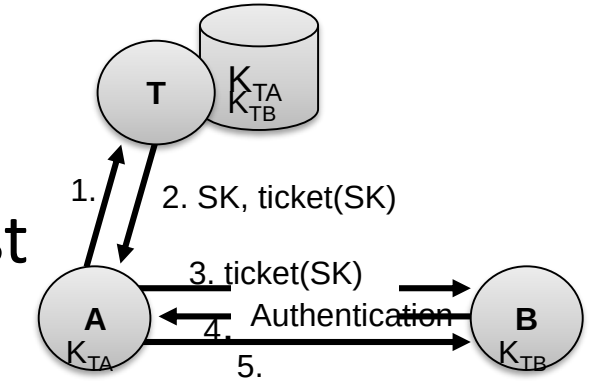
T creates a random session key SK and distributes it encrypted with A's and B's the master keys K_{TA}, K_{TB}

1. A → T: A, B, N_{A1}
2. T → A: $E_{TA}(N_{A1}, B, SK, ticket_{AB})$
3. A → B: $ticket_{AB}$, $E_{SK}(N_{A2})$
4. B → A: $E_{SK}(N_{A2}-1, N_B)$
5. A → B: $E_{SK}(N_B-1)$

$ticket_{AB} = E_{TB}(SK, A)$

// ticket request

// ticket grant



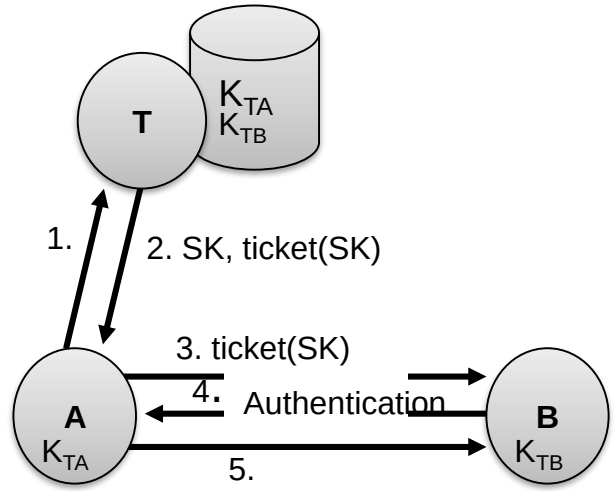
// authentication and

// key confirmation

// E must be authenticated encryption, e.g., encrypt then MAC

Needham-Schroeder analysis

1. A → T: A, B, N_{A1}
2. T → A: $E_{TA}(N_{A1}, B, SK, ticket_{AB})$ // $ticket_{AB} = E_{TB}(SK,A)$
3. A → B: $ticket_{AB}$, $E_{SK}(N_{A2})$
4. B → A: $E_{SK}(N_{A2}-1, N_B)$
5. A → B: $E_{SK}(N_B-1)$

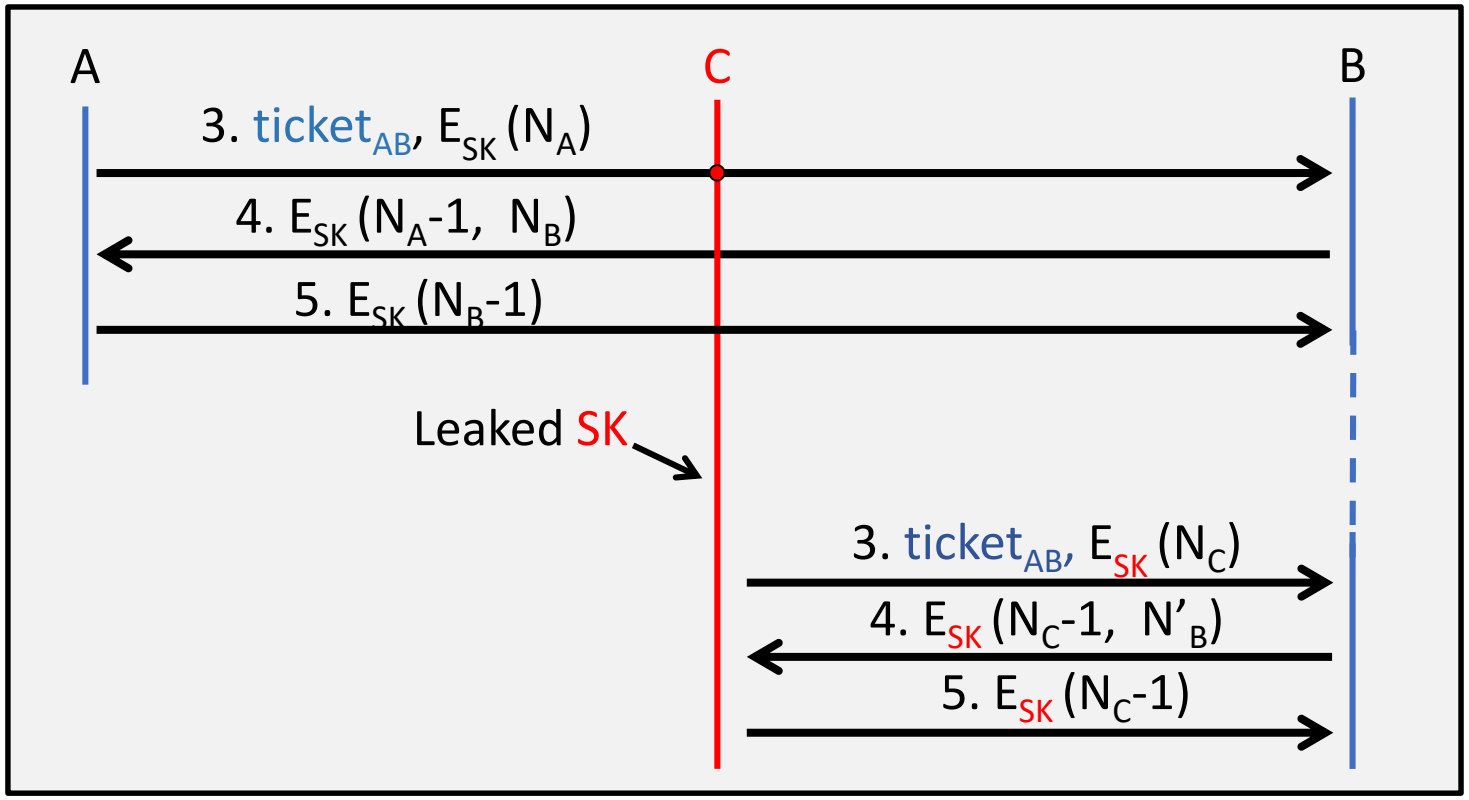


- T encrypts a session key under A's and B's master keys
- Master keys K_{TA} and K_{TB} must be strong secrets; weak passwords could can be cracked by trying to decrypt message 2 and the ticket
- Messages 4–5 provide key confirmation

- N_{A1} guarantees freshness of ticket and session key to A
- N_{A2} and N_B guarantee freshness of authenticators to A and B, respectively
- No freshness of the ticket to B…

Needham-Schroeder vulnerability

- Vulnerability discovered by Denning and Sacco 1981
  - B cannot check freshness of the ticket
- Assume attacker C has an old (sniffed) ticket, and that the old session key SK leaks. C pretends to be A:



Lesson: protocol designers should assume compromise of old short-term secrets

How to fix?
How fixed in Kerberos?

Denning-Sacco protocol

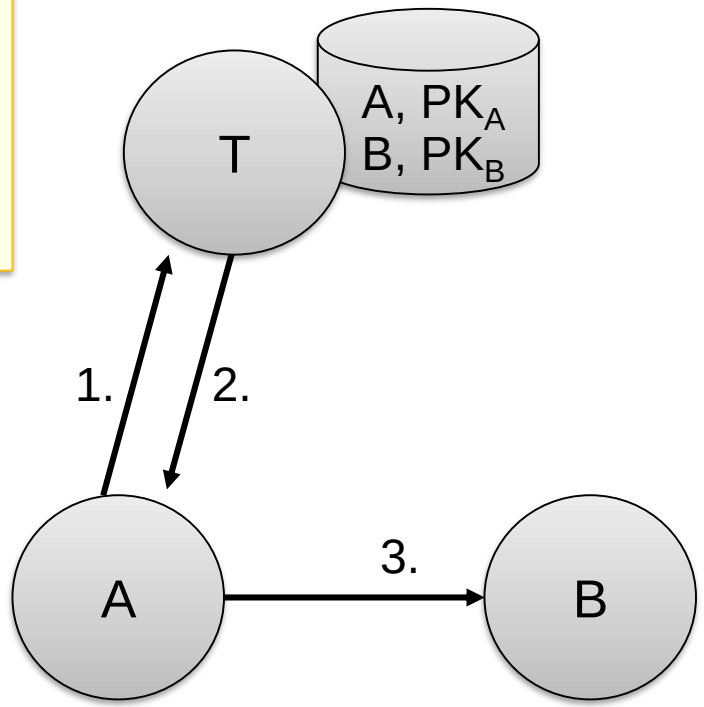
- Public-key key exchange 1981; flaw found in 1994
- A obtains certificates from trusted server T

1. A → T: A, B
2. T → A: $Cert_A$, $Cert_B$
3. A → B: $E_B(T_A, SK, S_A(T_A, SK))$, $Cert_A$, $Cert_B$

SK = session key selected by A

E_B = encryption with B's public key

$Cert_A = A, PK_A, S_T(A, PK_A)$



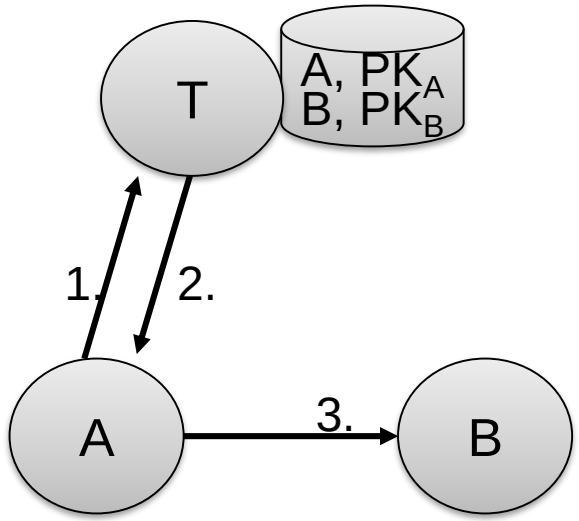
Denning-Sacco analysis

1. A → T: A, B
2. T → A: $Cert_A$, $Cert_B$
3. A → B: $E_B(T_A, SK, S_A(T_A, SK))$, $Cert_A$, $Cert_B$

SK = session key selected by A

E_B = encryption with B's public key

$Cert_A = A, PK_A, S_T(A, PK_A)$

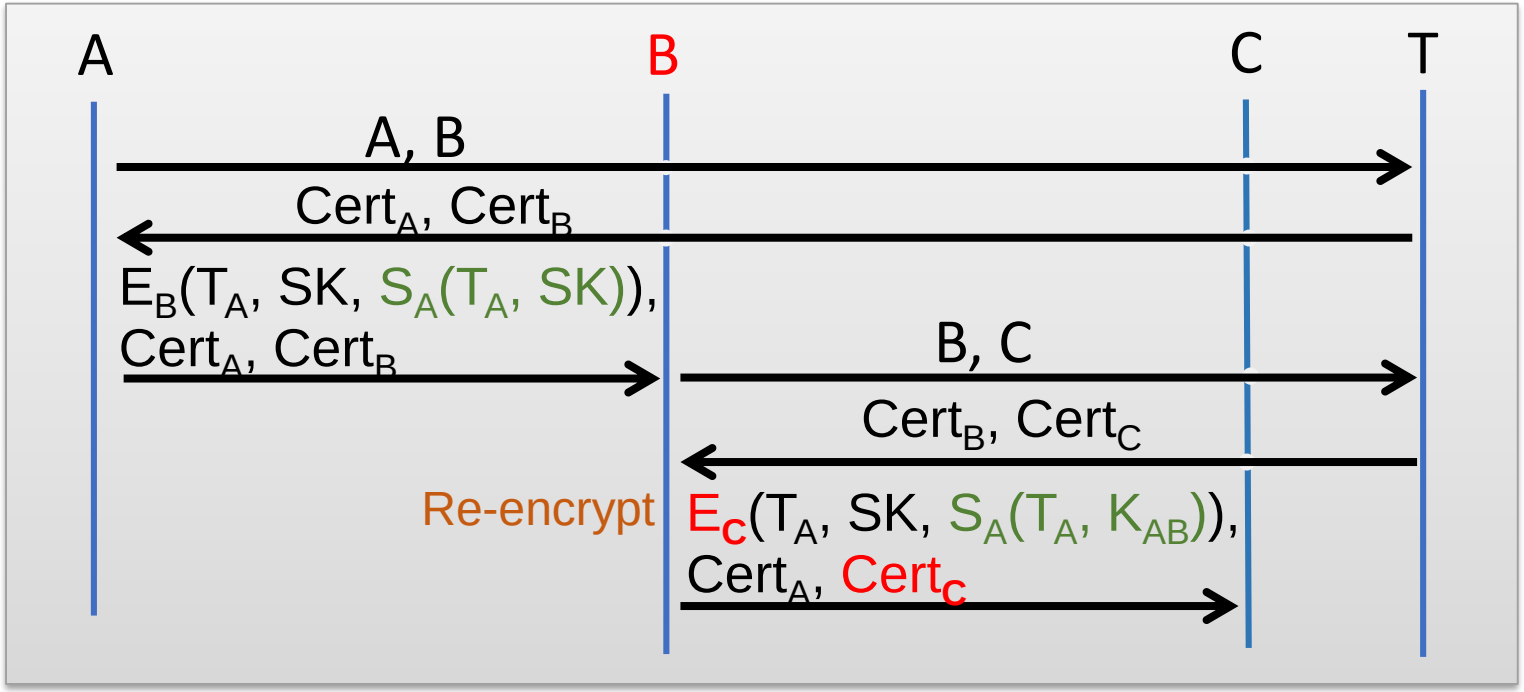


- Should use standard X.509 certificates with expiration time
- Public-key encryption for secrecy of SK → ok
- Timestamp for freshness of the session key → ok
- Public-key signature for authentication →

  what information exactly is authenticated?

Denning-Sacco vulnerability

- The signed part is missing some information: not bound to B's identity
  - Does it matter? Yes, because **B could be bad!**



Lesson: consider what is *not* authenticated

Lesson: protocols should withstand insider attacks where a legitimate user impersonates another

How to fix?

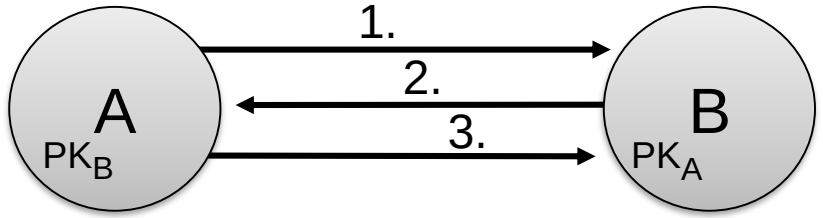
Compare with audience attribute in OpenID Connect identity token.

- Forwarding attack: B can re-encrypt and forward message 3 to others:
  C will think it shares SK with A, but also Bob knows it

Needham-Schroeder public-key protocol

- The first public-key protocol 1978; flaw found in 1995 [Lowe95]
- A and B know each other's public encryption keys (or certificates). Then, A and B exchange encrypted nonces:

1. $A \rightarrow B: E_B(N_A, A)$
2. $B \rightarrow A: E_A(N_A, N_B)$
3. $A \rightarrow B: E_B(N_B)$



N_A, N_B = secret nonces, used both for freshness and as key material

E_A, E_B = encryption with A's or B's public key

$SK = h(N_A, N_B)$

Needham-Schroeder analysis

1. A → B: $E_B(N_A, A)$
2. B → A: $E_A(N_A, N_B)$
3. A → B: $E_B(N_B)$

N_A, N_B = secret nonces, also serving as key material

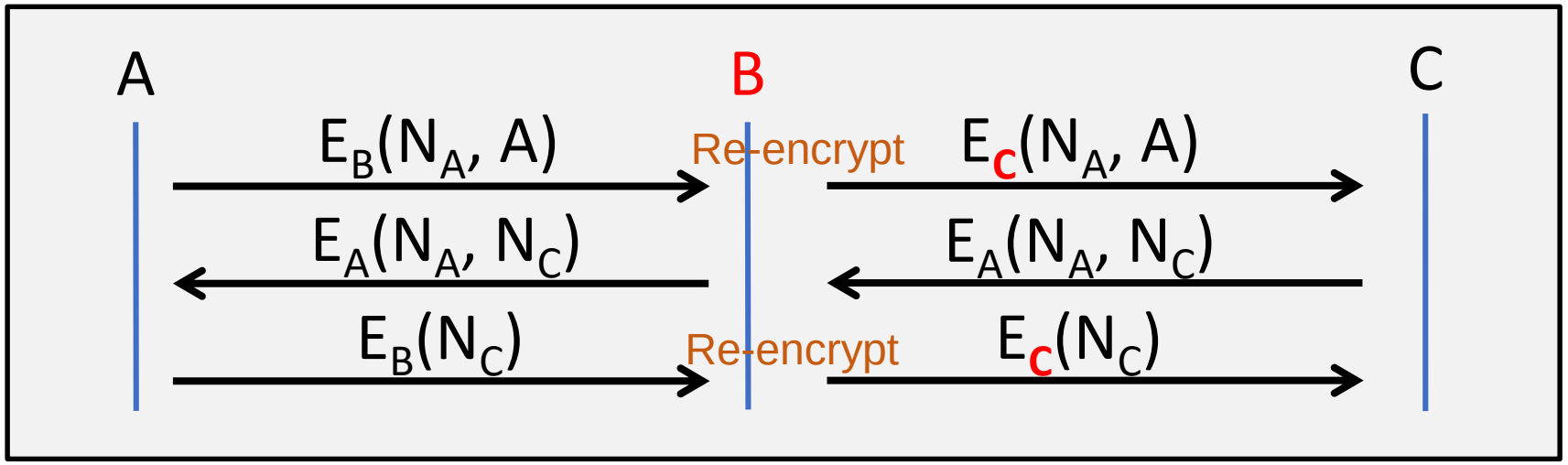
E_A, E_B = encryption with A's or B's public key

$SK = h(N_A, N_B)$

- Session key secret and fresh → ok
- Entity authentication → ok with authenticated encryption
- Key material bound to **A** but not to **B**

Needham-Schroeder public-key vulnerability

- A authenticates to B. B can forward the authentication to C:



How to fix?

- C thinks it shares SK with A, but also B knows SK
- Insider attack: legitimate user B impersonates another user A

Another lesson: Consider two or more parallel protocol executions and attacker forwarding messages between them (interleaving attack)

Wide-mouth-frog protocol

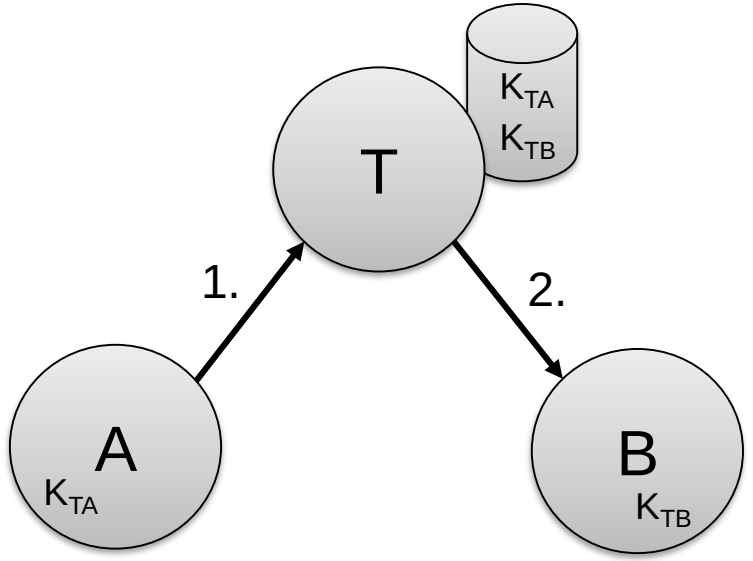
- Toy protocol with interesting flaws
- A and B share secret master keys with trusted server T.
  T distributes session keys:

1. $A \rightarrow T: A, E_{TA}(T_A, B, SK)$
2. $T \rightarrow B: E_{TB}(T_T, A, SK)$

E_{TA}, E_{TB} = encryption with A's and B's master keys

T_A, T_T = timestamps

SK = session key selected by A



Wide-mouth-frog analysis

1. A → T: A, $E_{TA}(T_A, B, SK)$
2. T → B: $E_{TB}(T_T, A, SK)$

E_{TA}, E_{TB} = symmetric encryption with A's and B's master keys

T_A, T_T = timestamps

SK = session key selected by A

- It requires a global clock.
- Server has access to all the keys.
- the session key SK is determined by user A.
- It can only replay the messages within the valid timestamp period.
- User A is not certain that user B exists.
- It is a stateful protocol

A Stateful Protocol is a type of network protocol in which the client sends a server request and expects some sort of response

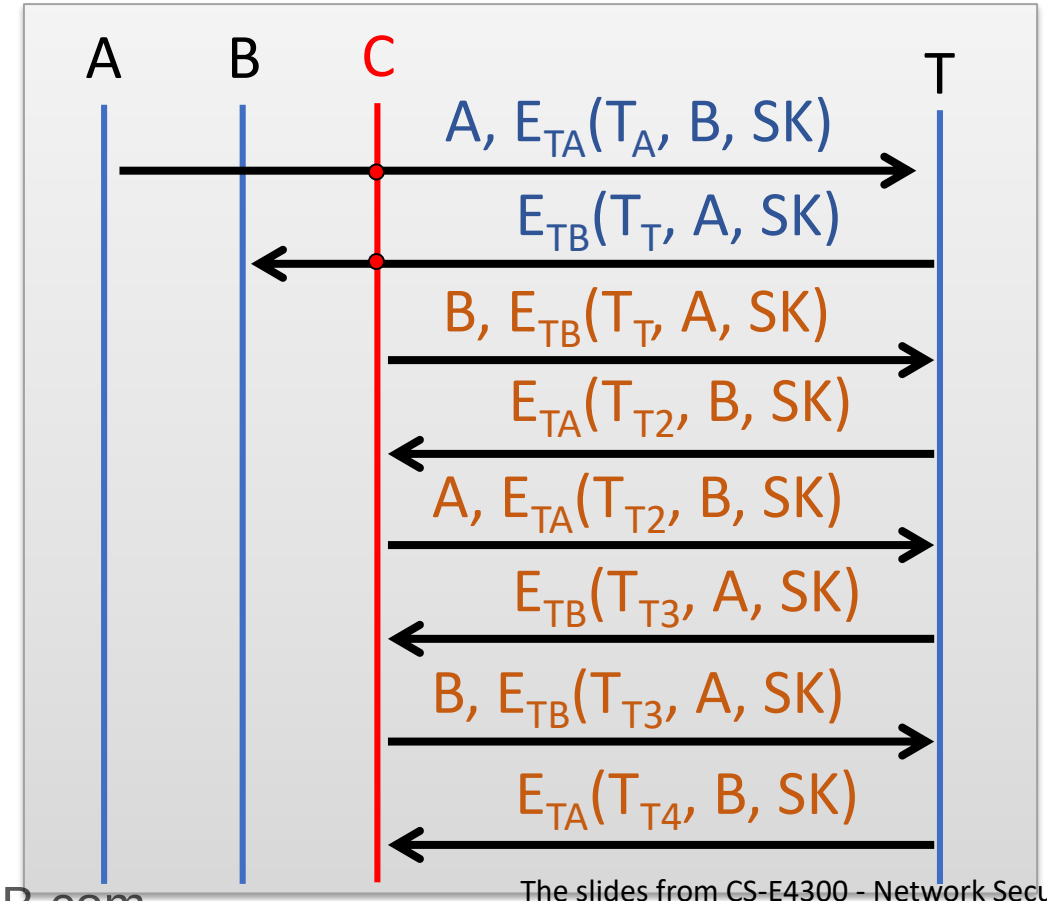
- Encryption must protect integrity

→ implement with a MAC or authenticated encryption

- Subtle issue with the timestamps and message formats…

Wide-mouth-frog vulnerability

- Messages **1** and **2** can be confused with each other → replay attack
- Attacker can refresh timestamps and keep sessions alive for ever



Lesson: Use type tags in all authenticated messages to avoid accidental similarities

Lesson: Don't allow unlimited refreshing of credentials or messages that should expire

How to fix?

Encrypt and sign

- **A** sends encrypted session key to **B**:

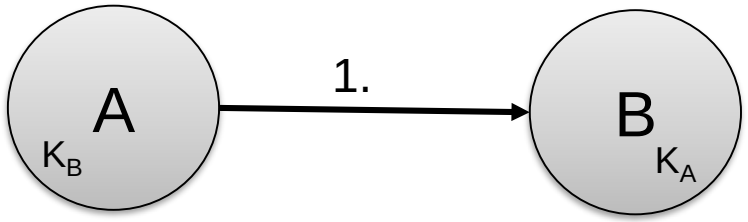
1. $A \rightarrow B$: $A, B, T_A, E_B(SK), S_A(A, B, T_A, E_B(SK))$

SK = session key selected by A

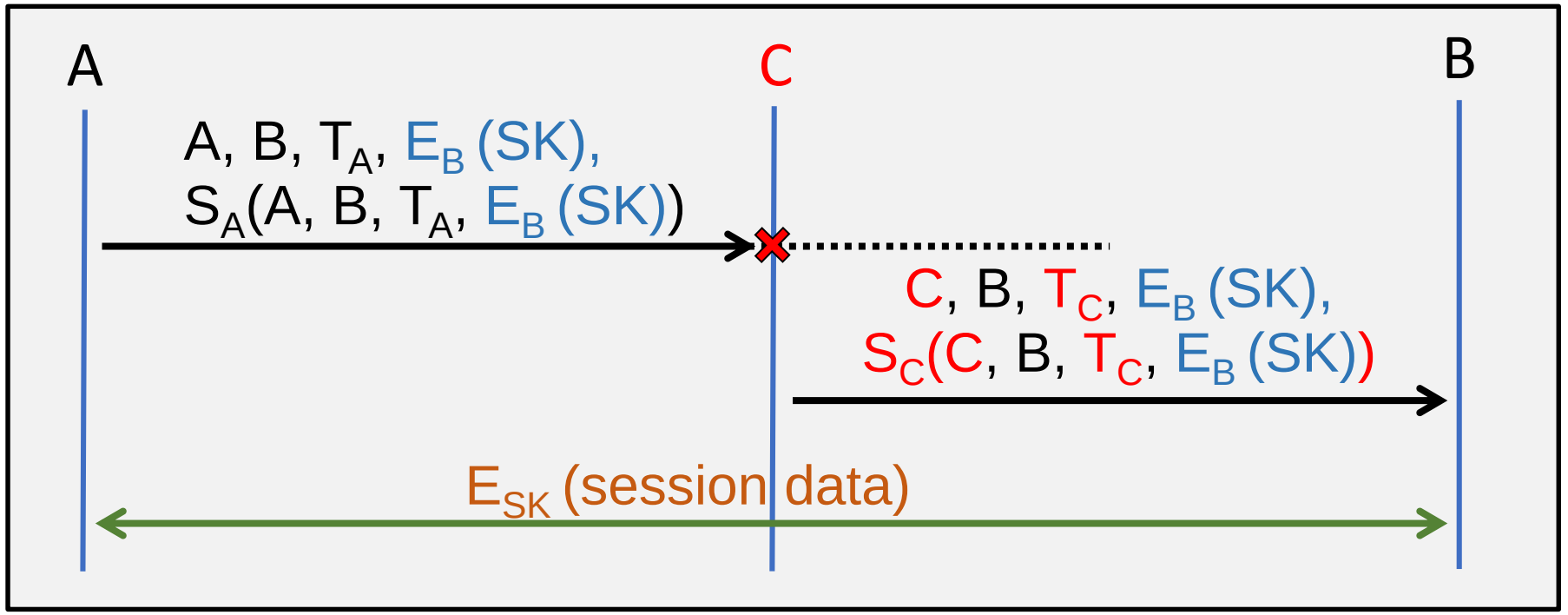
E_B = encryption with B's public key

S_A = A's public-key signature

T_A = timestamp



Encrypt and sign vulnerability



How to fix?

- C sniffs message 1, replaces the signature, and forwards the key as her own

→ Session between A and B, but B thinks it is between C and B

Lesson: In misbinding attacks, attacker causes confusion about who is communicating without learning any keys or secrets herself