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EITA25 Computer Security (Datasäkerhet)
Key Establishment

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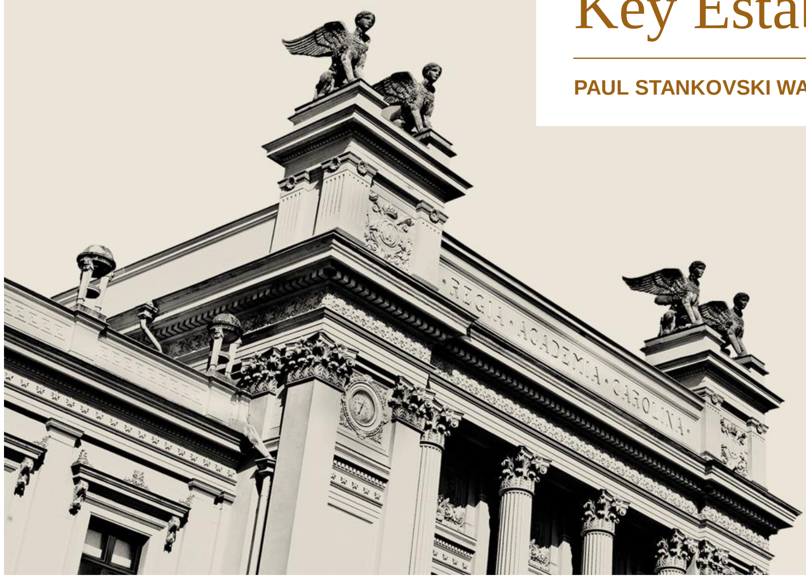


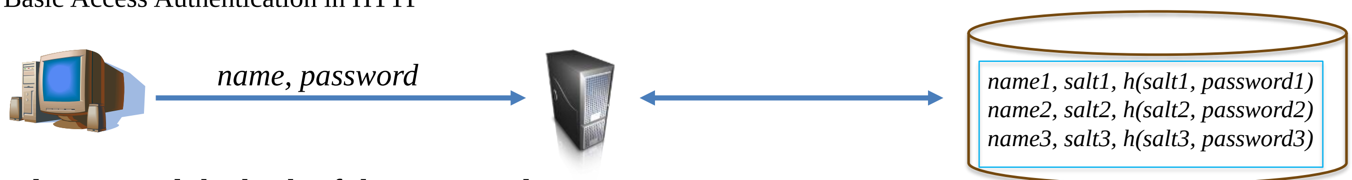
Remote Authentication and Key Establishment

Content

- Remote authentication
- Key establishment (and authentication)
- We look at two main key establishment problems:
  - A and B share a long term key and want to negotiate a session key.
  - A wants to have a shared key with B. Both trust a third party C.

Remote Authentication

- Authentication over a network
- Trivial variant: Send name and password just as in OS login
  - Used by Basic Access Authentication in HTTP

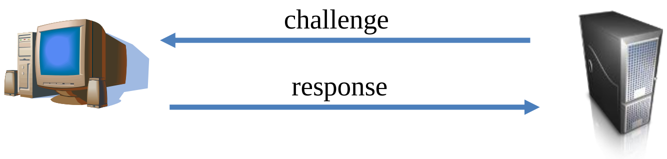


- Variant: Send name and the hash of the password

- **Replay attack**: Resending an eavesdropped hash will authenticate anyone with the hash
- Do the two methods differ in security in any way?

Avoid Sending Password

- Challenge response protocol
  - Server sends challenge, client sends response
  - Response depends on challenge



- **Example 1**: Encrypt challenge using (hash of) password as key
  - NTLM uses block cipher DES
- **Example 2**: Use a hash function including both challenge and password
  - Digest Access Authentication in HTTP uses a variant of this
- **Replay attack:** If same challenge is used twice, an attacker can replay an eavesdropped response to get authenticated
  - Solution 1: challenge is a ”number used once”, *a* ***nonce***
  - Solution 2: (part of) challenge is a time stamp
- More details in the course ”EITF05 Web Security”

Key Establishment and Authentication

Different keys

- **Long term keys (Permanent key)** – Rarely or never changed. Use sparingly.
- **Session keys** – Often changed. If lost or broken, only current session is affected.
  - Each key is used to encrypt a limited amount of data
  - Asymmetric long term keys can be used to negotiate symmetric keys.

Slow encryption → fast encryption

  - Key is not valid for a long time → **key freshness**
- Common to separate keys depending on application
  - Symmetric: One for encryption, one for message authentication
  - Asymmetric: Different key pairs for encryption and digital signatures

- We want to know *who* we are establishing keys with so authentication is included
  - Mutual vs. Unilateral authentication

Key Establishment

- Key Establishment divided into
  - **Key Transport** – one party creates/obtains secret key and securely transfers it to the other party
    - » Also called key distribution
  - **Key Agreement** – Both parties contribute to the generation of the secret key
- Other terms
  - **(Implicit) Key Authentication** – One party knows that no one besides a specifically identified second party may gain access to a secret key
  - **Key Confirmation** – One party is assured that the second party has possession of a secret key
    - » but identity of the other party may not be known
  - **Explicit Key Authentication** – Both implicit key authentication and key confirmation

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Authenticated Key Exchange Protocol 2

- Bellare and Rogaway, 1994
- No trusted third party involved
- A and B share two common *symmetric* keys, *K* and *K'* and wish to negotiate a session key.
- *h* and *h'* are keyed hash functions (MACs), *n* is a nonce (number used once)

A → B: n_A

B → A: $B, A, n_A, n_B, h_K\left(B, A, n_A, n_B\right)$

A → B: $A, n_B, h_K\left(A, n_B\right)$

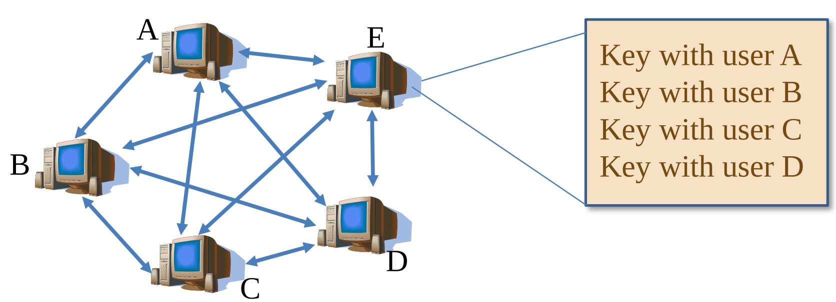
A: $k = h'_{K'}(n_B)$

B: $k = h'_{K'}(n_B)$

Protocol provides (implicit) key authentication and mutual entity authentication

Pre-shared Keys

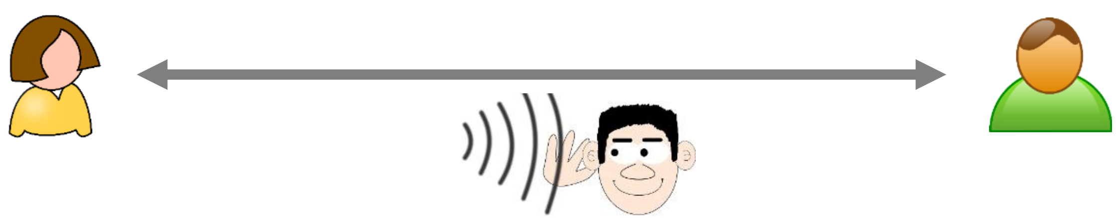
- Consider a system of n users, everyone having pre-shared key with each other
- There are $n(n-1)/2$ different keys
- Some problems:
  - Each user needs to securely store $n-1$ keys
  - Distribution of pre-shared keys require distribution of about n^2 keys
    - » Must be done using a secure channel



Without Pre-Shared Secret

Can two parties agree on a key without having a previously established secret?

Assume anyone can eavesdrop on the communication while they agree on the key!



Diffie-Hellman Protocol

- Diffie and Hellman (and Merkle), 1976
- Ellis and Cocks, GCHQ, 1969
- Key agreement protocol
- A and B do not share any secret (long term key) in advance
- p is a large prime, g is element of large order in multiplicative group mod p.

A		B
	$y_a = g^a \bmod p$ →	
$k = y_b^a \bmod p$	← $y_b = g^b \bmod p$	$k = y_a^b \bmod p$

Based on the DLP problem (discrete logarithm problem)

This works against eavesdroppers, but what about active attackers?

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Problem with Diffie-Hellman

- No key authentication!
  - No party knows with whom they share the secret
- **Man-in-the-middle attack**

A — M — B

A → M: $g^a \bmod p$

M → A: $g^x \bmod p$

M → B: $g^z \bmod p$

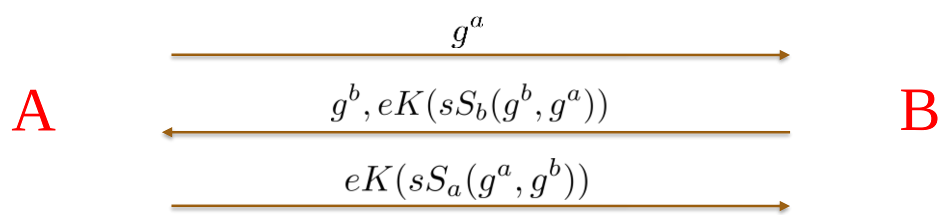
B → M: $g^b \bmod p$

$k = g^{ax} \bmod p$ ⟷ $k = g^{ax} \bmod p$

$k' = g^{bz} \bmod p$ ⟷ $k' = g^{bz} \bmod p$

Station-to-Station (STS) Protocol

- Authentication added to Diffie-Hellman
- S_x is x's signature key and sS_x is the signature produced by S_x.



As before, $eK = g^{ab} \bmod p$

Provides *mutual entity authentication* and *explicit key authentication*

A PKI (Public Key Infrastructure) is needed

Agree on a Key, Another Variant

- Encrypt a key using receiver's public key (consider RSA)

Certificate

A

B

Generate key k

$encKey = k^e \bmod n$

$k = encKey^d \bmod n.$

Why do we encrypt keys?
We could just encrypt data using recipients public key.

1. A may not have a certificate
2. Asymmetric encryption is very slooow

Again, a PKI is needed!

Which One is Best?

- Diffie-Hellman with PKI or
  RSA with PKI?

- Answer: Diffie-Hellman!

- **Perfect Forward Secrecy (PFS):**

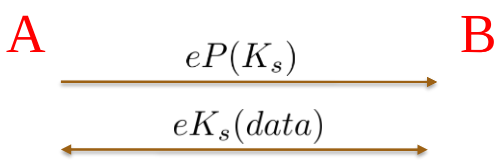
If a long-term key is stolen or compromised, previous session keys are not compromised!

  - Diffie-Hellman with signed messages: No key material encrypted → PFS
  - Session key encryption with public key: Session key can be decrypted and eavesdropped traffic can be decrypted → No PFS

Password-based Protocols

- Long-term keys need to be stored on clients
- A password can represent a key
- Convenient for human interaction – Easier to remember a password
- P is password, eP is encryption with password (mapped to encryption key), K_s is session key, eK_s is encryption with session key

Simple protocol:



Problem: Offline dictionary attacks or brute-force attacks on password using data redundancy possible.

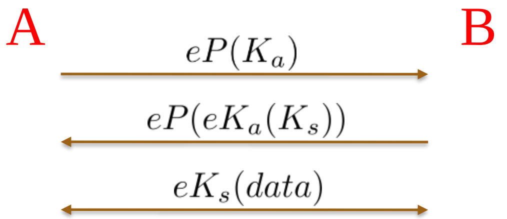
Passwords are often badly chosen

Password-based Protocols

- Encrypted Key Exchange (EKE) *(Bellovin and Merrit 1992)*
- Use a temporary public key K_a encrypted with password to encrypt session key

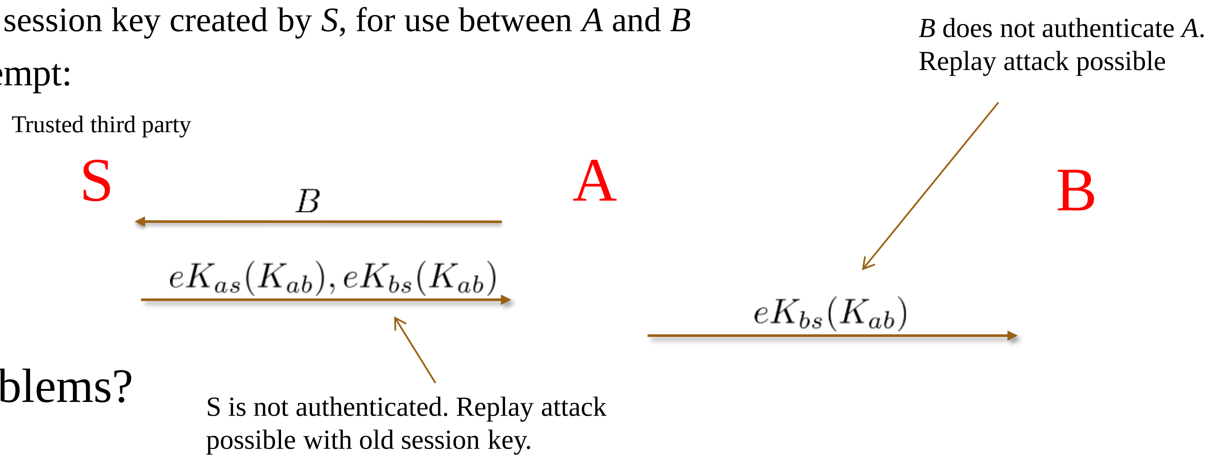
Eavesdropper can see $eP(K_a)$
and $eP(eK_a(K_s))$

Guess P' gives K_a' and $eK_a(K_s)'$, now either
1. Brute-force K_s and check if $eK_a'(K_s') = eK_a(K_s)'$
OR
2. Find private key corresponding to K_a'



Using a Trusted Third Party

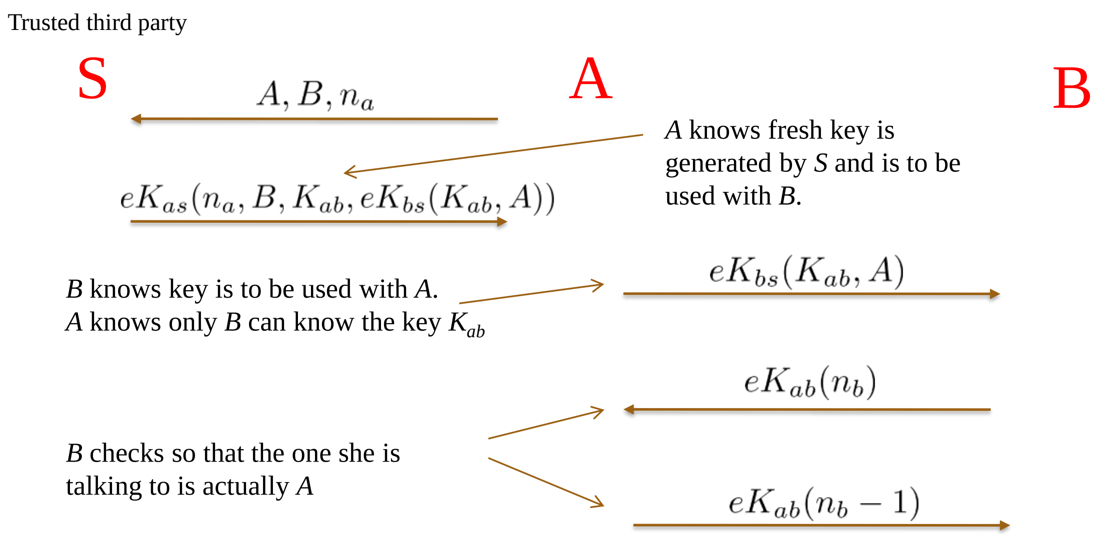
- *A* and *B* each share a secret key with server *S*.
  - K_{as}: secret key shared between *A* and *S* (long term)
  - K_{bs}: secret key shared between *B* and *S* (long term)
- **Goal:** From *S*, obtain secret key shared between *A* and *B*
  - K_{ab}: session key created by *S*, for use between *A* and *B*
- First attempt:



Problems?

Needham-Schroeder Protocol

- Key transport protocol, 1978
- n_a, n_b: Nonces generated by *A* and *B*. Used to prevent replay attacks

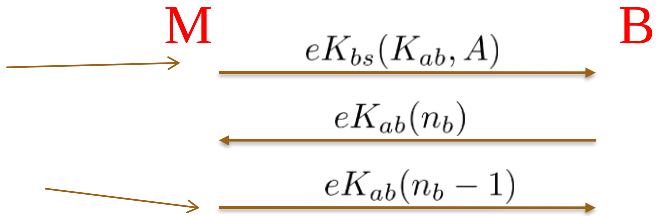


Problem with Needham-Schroeder

- *B* does not know if K_{ab} is fresh or not!
- What if we can break one session key?
- Then replay attack is possible (Denning – Sacco 1981)
- Assume adversary *M* breaks K_{ab}, and enter protocol at message 3

Replays old message with known K_{ab}

M can answer the challenge since K_{ab} is known

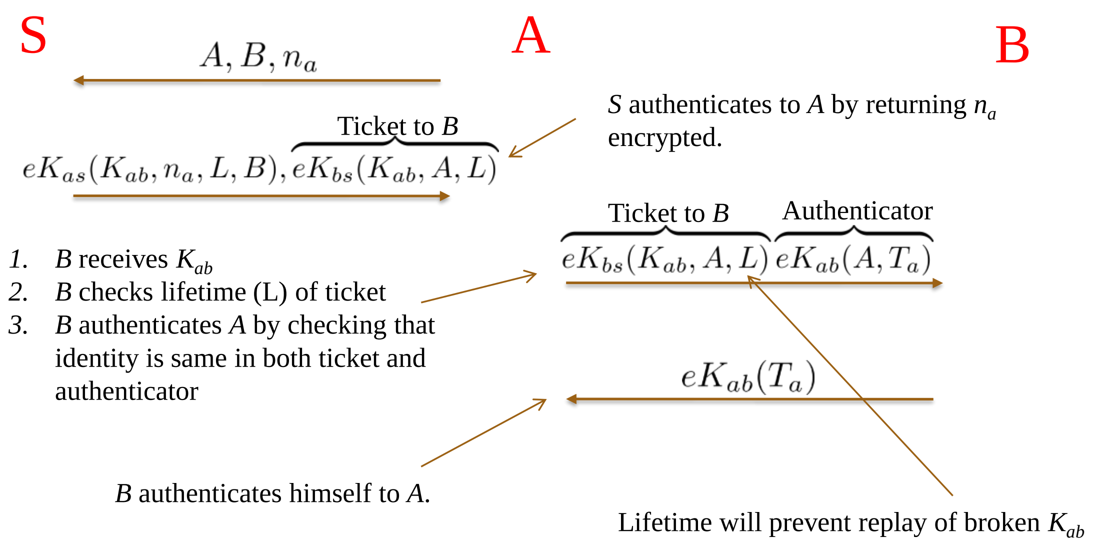


Solution: Include lifetimes for session keys

Kerberos

- Basically Needham-Schroeder with timestamps and limited lifetimes for session keys

Core protocol:



Kerberos

- A Kerberos Authentication Server (KAS) is used together with one or several Ticket Granting Servers TGS.
- A principal is a user or a server.
- KAS authenticates principals at login and issues Ticket Granting Tickets (TGTs), which enable principals to obtain other tickets from TGSs.
- TGSs issues tickets that give principals access to network services demanding authentication.
- Kerberos 4 uses DES as symmetric cipher, Kerberos 5 can use other algorithms
- Users authenticate using passwords

Kerberos

1: A, TGS, n_a

2: $eK_{as}(K_{a,tgs}, n_a, L_1, TGS), \overbrace{eK_{tgs}(K_{a,tgs}, A, L_1)}^{TGT}$

3: $\overbrace{eK_{tgs}(K_{a,tgs}, A, L_1)}^{TGT}, \overbrace{eK_{a,tgs}(A, T_a)}^{Authenticator}, B, n'_a$

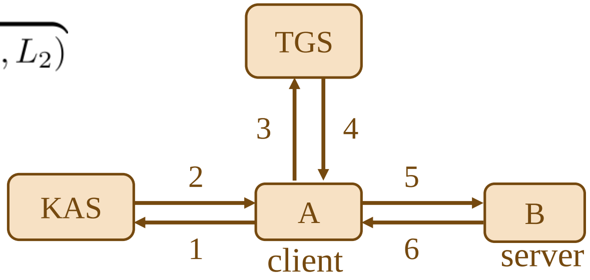
4: $eK_{a,tgs}(K_{ab}, n'_a, L_2, B), \overbrace{eK_{bs}(K_{ab}, A, L_2)}^{Ticket_B}$

5: $\overbrace{eK_{bs}(K_{ab}, A, L_2)}^{Ticket_B}, \overbrace{eK_{ab}(A, T'_a)}^{Authenticator}$

6: $eK_{ab}(T'_a)$

KAS and TGS know each other's keys

A cache protects authenticators from being used twice



Kerberos

- Revocation – access rights are revoked by updating KAS, TGS databases. However, issued tickets are valid until they expire.
- A realm has a KAS, one or more TGSs and a set of servers. It is possible to get tickets for other realms. KAS_x and KAS_y must share keys.
- Limitations of Kerberos:
  - synchronous clocks.
  - servers must be on-line, trust in servers.
  - password attacks still possible, implementation errors.
- Secure protocol is not enough, implementation also has to be secure

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