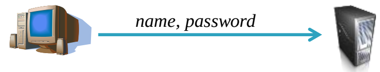
Key Establishment and Remote Authentication

Content

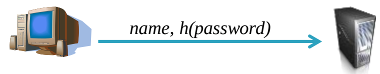
- Remote authentication
- Key establishment (and authentication)
- We look at two main key establishment problems:
  - A and B share a long term key and want to negotiate a session key.
  - A wants to have a shared key with B. Both trust a third party C.

Remote Authentication

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



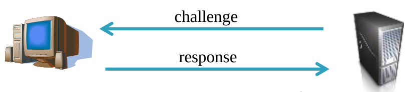
- Variant: Send name and the hash of the password



- **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 ”Web Security”

Key Establishment and Authentication

Different keys

- **Long term keys** – 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

Authenticated Key Exchange Protocol 2

- Bellare and Rogaway, 1994
- No trusted third party involved
- A and B shares 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

$$A \xrightarrow{n_A} B$$

$$A \xleftarrow{B, A, n_A, n_B, h_K(B, A, n_A, n_B)} B$$

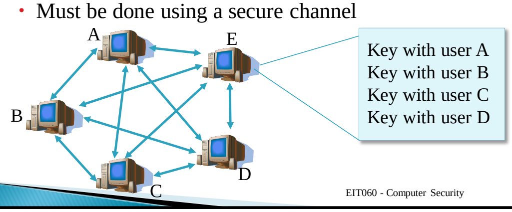
$$A \xrightarrow{A, n_B, h_K(A, n_B)} B$$

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

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



Diffie-Hellman Protocol

- Diffie and Hellman
- 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

$$A \xrightarrow{y_a = g^a \bmod p} B$$

$$A \xleftarrow{y_b = g^b \bmod p} B$$

$k = y_b^a \bmod p$ $k = y_a^b \bmod p$

Based on the DLP problem (discrete logarithm problem)

Problem with Diffie-Hellman

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

A M B

$$A \xrightarrow{g^a \bmod p} M \qquad M \xrightarrow{g^z \bmod p} B$$

$$A \xleftarrow{g^x \bmod p} M \qquad M \xleftarrow{g^b \bmod p} B$$

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

$k = g^{bz} \bmod p \longleftrightarrow k = g^{bz} \bmod p$

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.

$$A \xrightarrow{g^a} B$$

$$A \xleftarrow{g^b, eK(sS_b(g^b, g^a))} B$$

$$A \xrightarrow{eK(sS_a(g^a, g^b))} B$$

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

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

A PKI (Public Key Infrastructure) is needed

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*

$$A \xrightarrow{eP(K_s)} B$$

$$A \xleftrightarrow{eK_s(data)} B$$

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

Offline dictionary attack additionally needs to break K_a

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

$$A \xrightarrow{eP(K_a)} B$$

$$A \xleftarrow{eP(eK_a(K_s))} B$$

$$A \xleftrightarrow{eK_s(data)} B$$

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:** Obtain, from S, secret key shared between A and B
  - K_{ab}: session key created by S, for use between A and B
- First attempt:

Trusted third party

S A B

B

$eK_{as}(K_{ab}), eK_{bs}(K_{ab})$

$eK_{bs}(K_{ab})$

Problem?

Needham-Schroeder Protocol

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

Trusted third party

S A B

A, B, n_a

$eK_{as}(n_a, B, K_{ab}, eK_{bs}(K_{ab}, A))$

A knows fresh key is generated by *S* and is to be used with *B*.

$eK_{bs}(K_{ab}, A)$

B knows key is to be used with *A*.
A knows only *B* can know the key K_{ab}

$eK_{ab}(n_b)$

$eK_{ab}(n_b - 1)$

B checks so that the one she is talking to is actually *A*

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

M B

Replays old message with known K_{ab}

$eK_{bs}(K_{ab}, A)$

$eK_{ab}(n_b)$

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

$eK_{ab}(n_b - 1)$

Solution: Include lifetimes for tickets

Kerberos

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

Core protocol:

S A B

A, B, n_a

$eK_{as}(K_{ab}, n_a, L, B), \overbrace{eK_{bs}(K_{ab}, A, L)}^{\text{Ticket to } B}$

S authenticates to *A* by returning n_a encrypted.

$\overbrace{eK_{bs}(K_{ab}, A, L)}^{\text{Ticket to } B}\overbrace{eK_{ab}(A, T_a)}^{\text{Authenticator}}$

1. *B* receives K_{ab}
2. *B* checks lifetime (L) of ticket
3. *B* authenticates *A* by checking that identity is same in both ticket and authenticator

$eK_{ab}(T_a)$

B authenticates himself to *A*.

Lifetime will prevent replay of broken K_{ab}

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

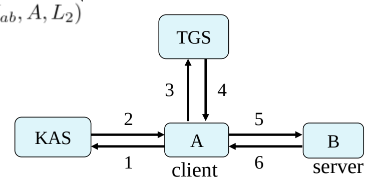
2: $eK_{as}(K_{a,tgs}, n_a, L_1, TGS), \overbrace{eK_{tgs}(K_{a,tgs}, A, L_1)}^{TGT}$

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



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