One-Time Verifier-Based Encrypted Key Exchange

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Summary

- Authenticated Key Exchange
- Password-Based Authentication
  - EKE and OKE
  - Security Results
- Enhanced Security against Corruption

Authenticated Key Exchange

Two parties (Alice and Bob) agree on a ***common*** secret key sk, in order to establish a secret channel

- Basic security notion: ***semantic security***
  - only the intended partners can compute the session key sk
- Formally:
  - the session key sk is indistinguishable from a random string r, to anybody else

Further Properties

- ***Mutual authentication***
  - They are both sure to **actually** share the secret with the people they think they do
- ***Forward-secrecy***
  - Even if a long-term secret data is corrupted, previously shared secrets are **still** protected

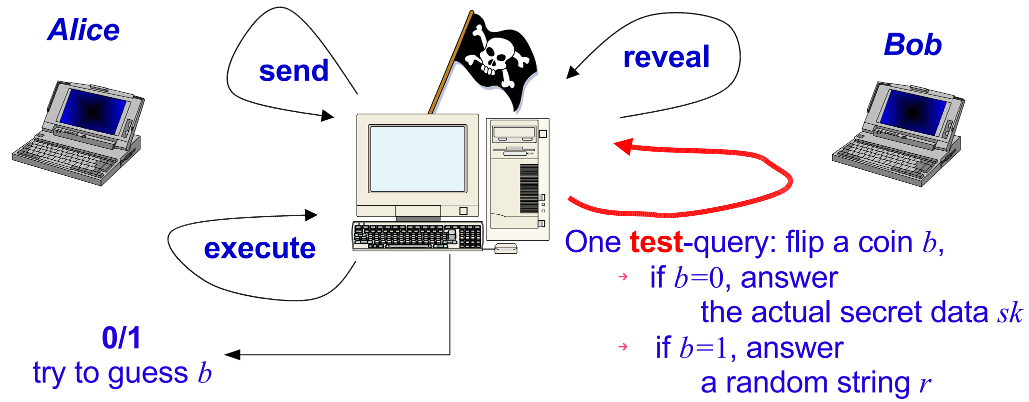
Passive/Active Adversaries

- ***Passive adversary***: *history* built using
  - the **execute**-queries → transcripts
  - the **reveal**-queries → session keys
- ***Active adversary***: *entire control of the network*
  - the **send**-queries

    active, adaptive adversary on concurrent executions
    - to send message to Alice or Bob
      (in place of Bob or Alice respectively)
    - to intercept, forward and/or modify messages

Semantic Security

As many **execute**, **send** and **reveal** queries as the adversary wants



Freshness

A_i and B_j: two instances of Alice and Bob

- the adversary asks a **reveal** to A_i
- the adversary asks the **test** to B_j

Freshness:

- the instance has accepted (holds a key!)
- neither the instance nor its partner has been asked for a **reveal** query

Foward Secrecy: Corrupt-Query

Forward Secrecy*: corruption of long term keys*
- the **corrupt**-queries → long-term key

FS-Freshness:

- the instance has accepted (holds a key!)
- neither the instance nor its partner has been asked for a **reveal** query
- (neither the instance) nor its partner has been asked for a **corrupt** query

⇒Diffie-Hellman provides the Forward Secrecy

Diffie-Hellman Key Exchange

G $= <g>$, cyclic group of prime order q

- Alice chooses a random $x \in \mathbf{Z}_q$,
  computes and sends $X = g^x$
- Bob chooses a random $y \in \mathbf{Z}_q$,
  computes and sends $Y = g^y$
- They can both compute the value

$$K = Y^x = X^y$$

Properties

- Without any authentication, no security is possible:
  man-in-the-middle attack

$\Rightarrow$ some authentication is required

- If flows are **authenticated** (MAC or Signature), it provides the forward secrecy under the **DDH Problem**
- If one derives the session key as $sk = \mathrm{H}(K, \ldots)$, in the random oracle model, the forward secrecy is relative to the **CDH Problem**

Password-based Authentication

Password (short – low-entropy secret – say 20 bits)

- exhaustive search is possible
- basic attack: **on-line exhaustive search**
  - the adversary guesses a password
  - tries to play the protocol with this guess
  - failure $\Rightarrow$ it erases the password from the list
  - and restarts…

after 2^{20} attempts, the adversary wins

Dictionary Attack

- The on-line exhaustive search
  - cannot be prevented
  - can be made less serious (delay, limitations, …)

We want it to be the best attack…

- The **off-line exhaustive search**
  - a few passive or active attacks
  - transcripts $\Rightarrow$ password, by an off-line check

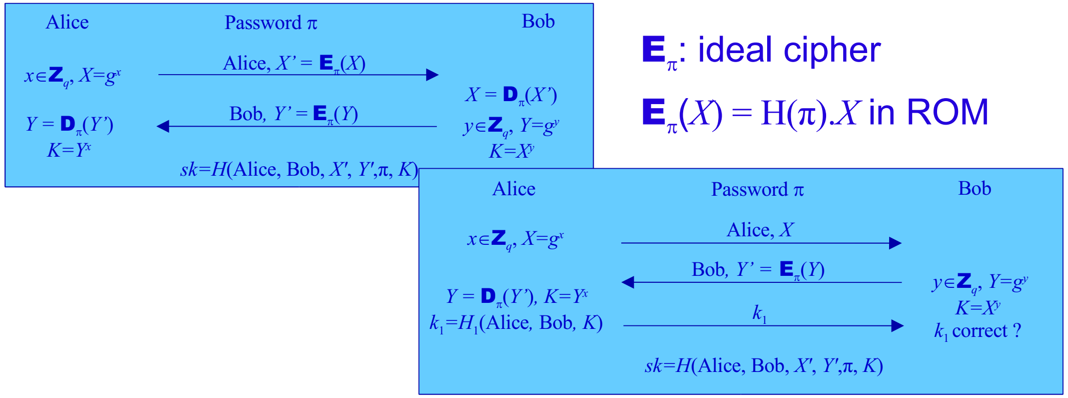
this is called dictionary attack

$\Rightarrow$ our GOAL: prevent dictionary attacks

Example: EKE

The most famous scheme: Encrypted Key Exchange

Either one or two flows are encrypted with the password



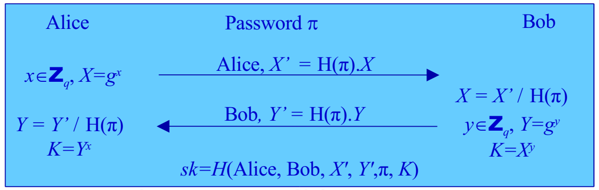
$\mathbf{E}_\pi$: ideal cipher

$\mathbf{E}_\pi(X) = \mathrm{H}(\pi).X$ in ROM

EKE - OKE

- OKE: Open Key Exchange
  - first flow sent in clear (open)
  - forward secrecy = CDH [MKe02: PAK]
- EKE: Encrypted Key Exchange
  - both flows encrypted
  - semantic security = CDH

EKE: Forward secrecy
= open problem
[MKe02: PAK]



Reasons...

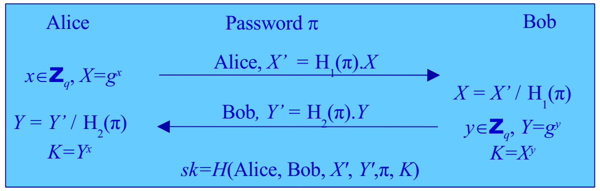
- Proof of semantic security:
  - sequence of indistinguishable games, such that at the end the simulation does not use the password

  ⇒ the password can be chosen at the very end to check whether or not the adversary had won
- In the forward-secrecy game:
  - the password has to be chosen when the **corrupt** query is asked, and then the adversary knows the password
  - he can ask **reveal** or **hash** queries on previous keys (when the password was unknown to the simulator)

⇒ consistency?... Decisional Oracle... ⇒ Gap Problem

EKE: Security Results

- Assumptions
  - two different masks with H_1 and H_2
  - random-oracle model for H, H_1, and H_2



Semantic security of EKE :

advantage $\leq 2\, q_s/N + 3q_h^{\,2}\, \mathrm{Succ}^{\mathrm{CDH}}(t') + \varepsilon$

Forward Secrecy of EKE :

advantage $\leq 2\, q_s/N + 4\, \mathrm{Succ}^{\mathrm{GDH}}(t',q_h) + \varepsilon$

$\mathrm{Succ}^{\mathrm{GDH}}(t,q)$ = Probability to solve the CDH problem, within time t, after q calls to a DDH oracle

Improved Security

- *Protecting against server corruptions*:
  verifier-based authentication
  - Alice knows a password π,
  - Bob just knows a verifier of the password $v = f(\pi)$,
    - v is the *actual* password,
    - then Alice proves her knowledge of $\pi = f^{-1}(v)$, in ZK

Improved Security (Con'd)

- *Protecting against client corruptions*:
  one-time password authentication
  - the *actual* password is $v_n = f^n(\pi)$
  - at the end the client sends,
    encrypted under the new session key, $v_{n-1} = f^{n-1}(\pi)$,
    which validity can be easily checked
  - the next password will be v_{n-1}