Key Establishment

EECE 412

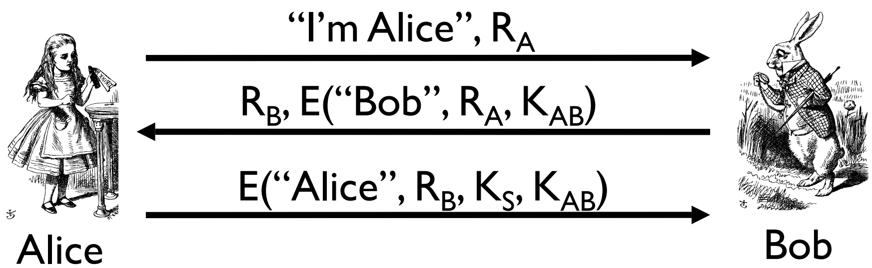
"The security of a cryptosystem must not depend on keeping secret the crypto-algorithm. The security depends only on keeping secret the key"

Auguste Kerckhoff von Nieuwenhof

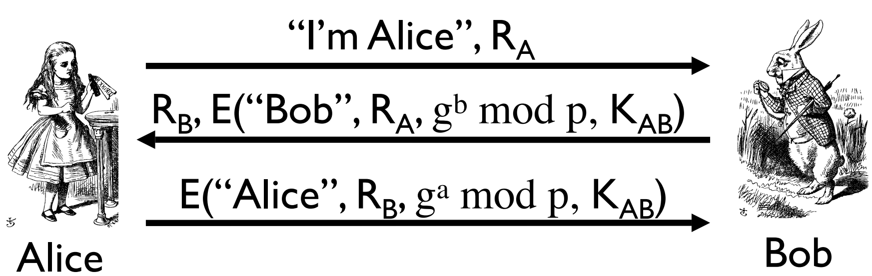
Dutch linguist

1883

session key with mutual authentication using symmetric key



FPS session key with mutual authentication using symmetric key



Outline

1. Diffie-Hellman key exchange (4.4)
2. mutual authentication in networks (9.1-9.3.3)
3. perfect forward secrecy (9.3.4, 9.3.5)

Notation

- $X \rightarrow Y : \{ Z \mid\mid W \} k_{X,Y}$
  - X sends Y the message produced by concatenating Z and W enciphered by key $k_{X,Y}$, which is shared by users X and Y
- $A \rightarrow T : \{ Z \} k_A \mid\mid \{ W \} k_{A,T}$
  - A sends T a message consisting of the concatenation of Z enciphered using k_A, A's key, and W enciphered using $k_{A,T}$, the key shared by A and T
- r_1, r_2 nonces ("nonrepeating" random numbers)

Diffie-Hellman Key Exchange

important trivia

- Invented by Williamson (GCHQ) and, independently, by D and H (Stanford)
- A "key exchange" algorithm
  - Used to establish a shared symmetric key
- Not for encrypting or signing
- Security rests on difficulty of **discrete log** problem: given g, p, and $g^k \bmod p$ find k

how it works

- Let p be prime, let g be a **generator**
  - For any $x \in \{1,2,\ldots,p-1\}$ there is n s.t. $x = g^n \bmod p$

1. Alice selects secret value a
2. Bob selects secret value b
3. Alice sends $g^a \bmod p$ to Bob
4. Bob sends $g^b \bmod p$ to Alice
5. Both compute shared secret $g^{ab} \bmod p$

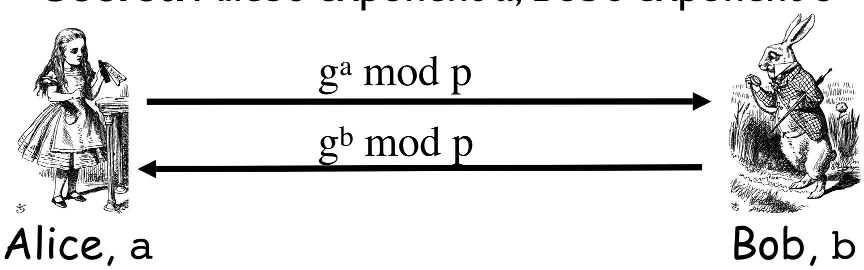
- Shared secret can be used as symmetric key

why it's hard to attack

- Suppose that Bob and Alice use $g^{ab} \bmod p$ as a symmetric key
- Trudy can see $g^a \bmod p$ and $g^b \bmod p$
- Note $g^a g^b \bmod p = g^{a+b} \bmod p \neq g^{ab} \bmod p$
- If Trudy can find a or b, system is broken
- If Trudy can solve **discrete log** problem, then she can find a or b

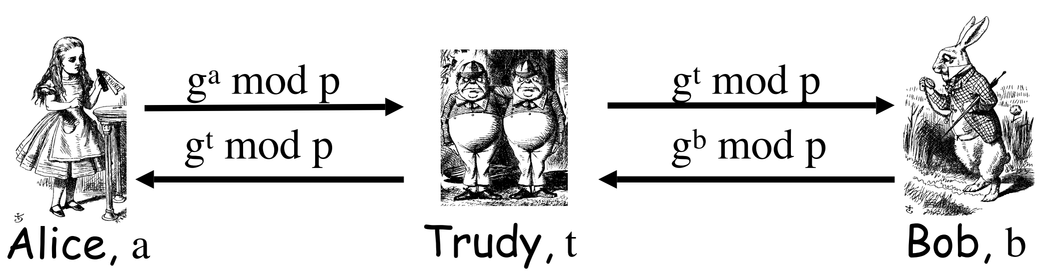
the protocol

- **Public:** g and p
- **Secret:** Alice's exponent a, Bob's exponent b



- Alice computes $(g^b)^a = g^{ba} = g^{ab} \bmod p$
- Bob computes $(g^a)^b = g^{ab} \bmod p$
- Could use $K = g^{ab} \bmod p$ as symmetric key

Man-in-the-Middle Attack



- Trudy shares secret $g^{at} \bmod p$ with Alice
- Trudy shares secret $g^{bt} \bmod p$ with Bob
- Alice and Bob don't know Trudy exists!

how to prevent MiM attack?

- Encrypt DH exchange with symmetric key
- Encrypt DH exchange with public key
- Sign DH values with private key
- Other?

You **MUST** be aware of MiM attack on Diffie-Hellman

Authentication Protocols

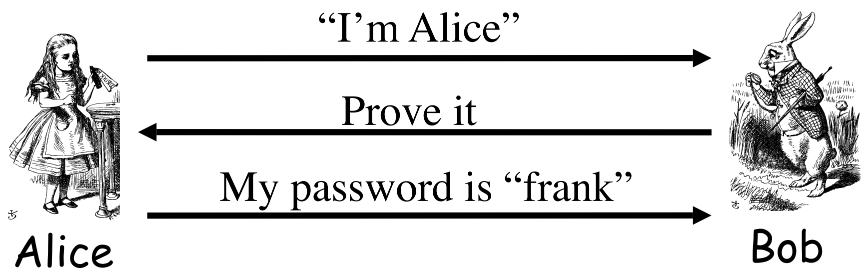
basics

- Alice must prove her identity to Bob
  - Alice and Bob can be humans or computers
- May also require Bob to prove he's Bob (mutual authentication)
- May also need to establish a session key
- May have other requirements, such as
  - Use only public keys
  - Use only symmetric keys
  - Use only a hash function
  - Anonymity, plausible deniability, etc., etc.

why authentication can be hard?

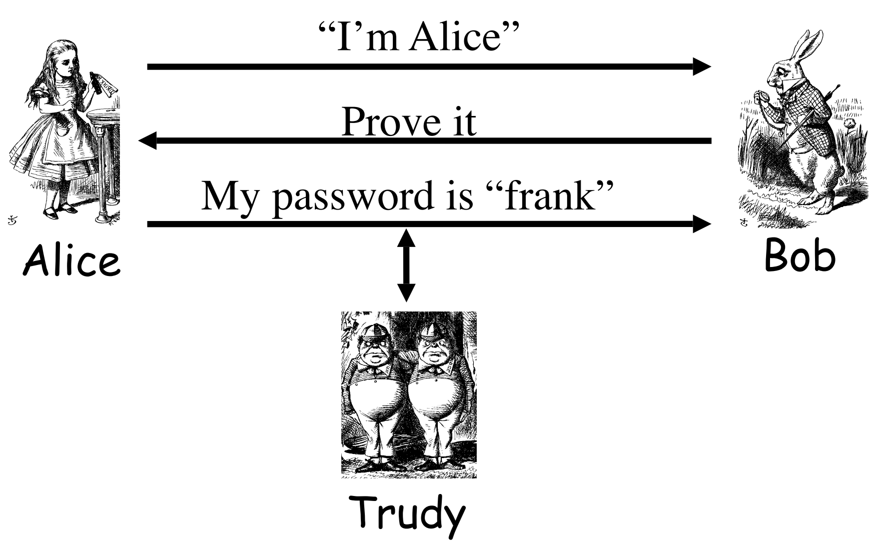
- relatively simple on a stand-alone computer
  - "Secure path" is the primary issue
  - main concern is an attack on authentication software
- much more complex over a network
  - attacker can passively observe messages
  - attacker can replay messages
  - active attacks may be possible (insert, delete, change messages)

simple authentication

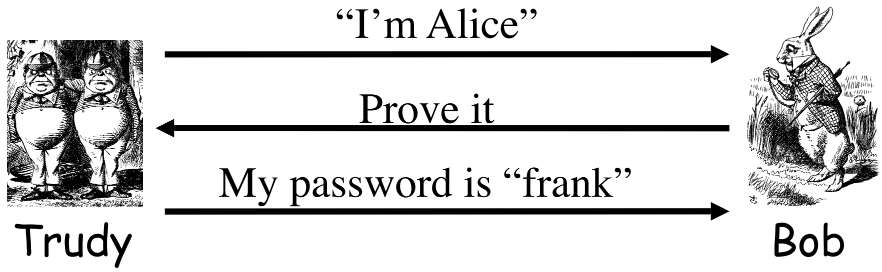


- Simple and may be OK for standalone system
- But insecure for networked system
  - Subject to a replay attack (next 2 slides)
  - Bob must know Alice's password

authentication attack

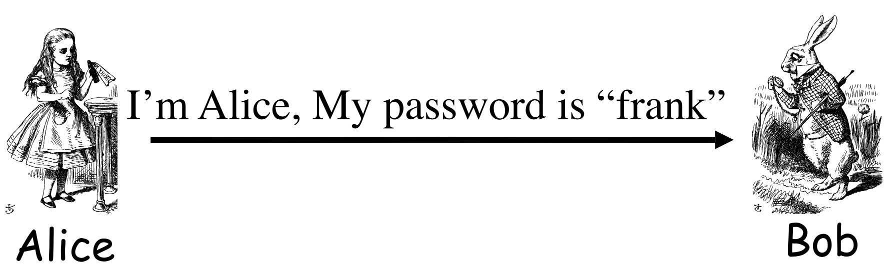


Authentication Attack



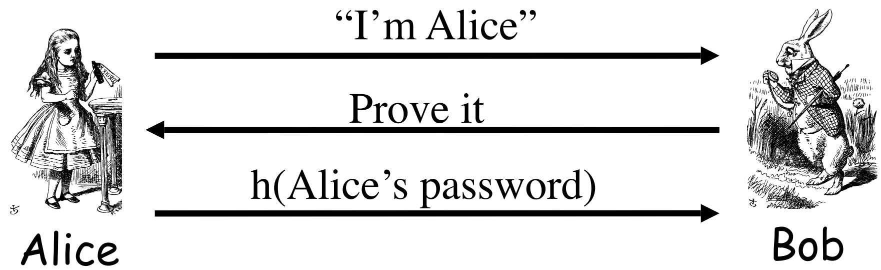
- This is a **replay** attack
- How can we prevent a replay?

Simple Authentication



- More efficient…
- But same problem as previous version

Better Authentication



- Better since it hides Alice's password
  - From both Bob and attackers
- But still subject to replay

challenge-response

- To prevent replay, challenge-response used
- Suppose Bob wants to authenticate Alice
  - Challenge sent from Bob to Alice
  - Only Alice can provide the correct response
  - Challenge chosen so that replay is not possible
- How to accomplish this?
  - Password is something only Alice should know…

simple challenge-response

"I'm Alice" →

← Nonce

h(Alice's password, Nonce) →

Alice — Bob

- Nonce is the **challenge**
- The hash is the **response**
- Nonce prevents replay, insures freshness
- Password is something Alice knows
- Note that Bob must know Alice's password

general challenge-response

"I'm Alice" →

← Nonce

Something that could only be from Alice (and Bob can verify) →

Alice — Bob

- What can we use to achieve this?
- Hashed pwd works, crypto might be better

symmetric key notation

- Encrypt plaintext P with key K

  C = E(P,K)

- Decrypt ciphertext C with key K

  P = D(C,K)

- Here, we are concerned with attacks on **protocols**, not directly on the crypto
- We assume that crypto algorithm is secure

authentication with symmetric key

- Alice and Bob share symmetric key K_{AB}
- key K_{AB} known only to Alice and Bob
- authenticate by proving knowledge of shared symmetric key
- how to accomplish this?
  - must not reveal key
  - must not allow replay attack

authentication with symmetric key

"I'm Alice" →

← R

$E(R, K_{AB})$ →

Alice, K_{AB}

Bob, K_{AB}

- Secure method for Bob to authenticate Alice
- Alice does not authenticate Bob
- Can we achieve mutual authentication?

mutual authentication?

"I'm Alice", R →

← $E(R, K_{AB})$

$E(R, K_{AB})$ →

Alice

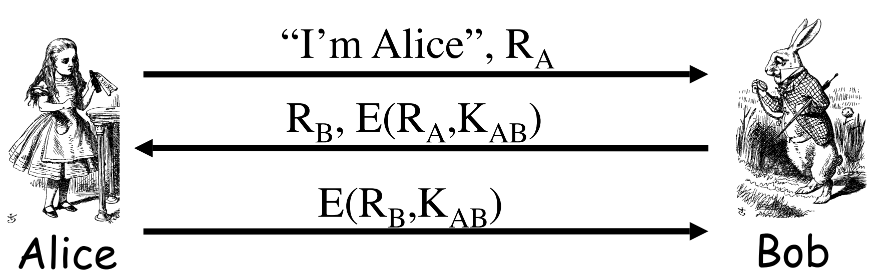
Bob

- What's wrong with this picture?
- "Alice" could be Trudy (or anybody else)!

Mutual Authentication

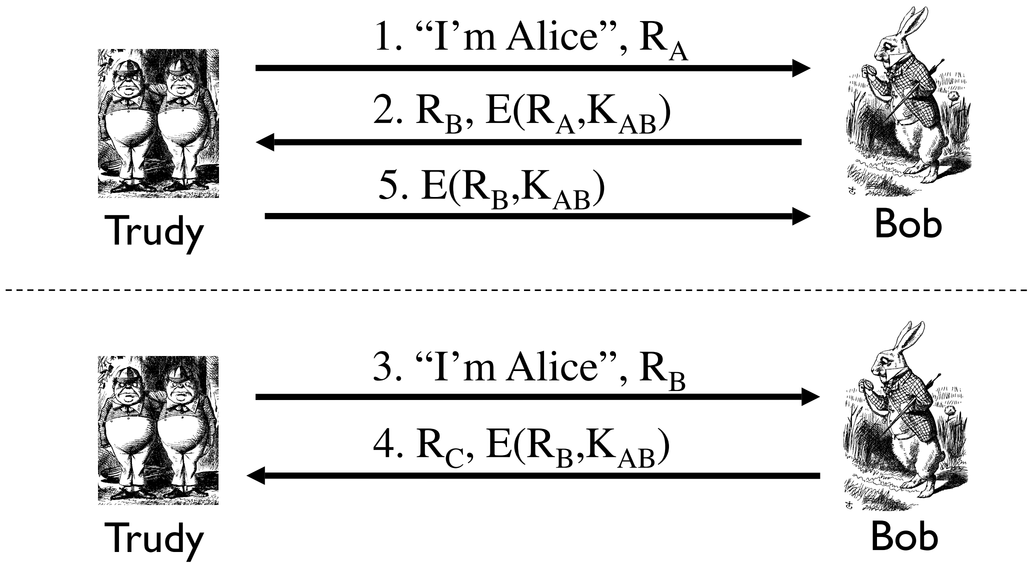
- Since we have a secure one-way authentication protocol…
- The obvious thing to do is to use the protocol twice
    - Once for Bob to authenticate Alice
    - Once for Alice to authenticate Bob
- This has to work…

Mutual Authentication



- This provides mutual authentication
- Is it secure? See the next slide…

mutual authentication attack



Mutual Authentication

- Our one-way authentication protocol **not** secure for mutual authentication
- Protocols are subtle!
- The "obvious" thing may not be secure
- Also, if assumptions or environment changes, protocol may not work
  - This is a common source of security failure
  - For example, Internet protocols

mutual authentication with symmetric key

“I’m Alice”, R_A

R_B, E(“Bob”, R_A, K_{AB})

E(“Alice”, R_B, K_{AB})

Alice

Bob

- Do these “insignificant” changes help?
- Yes!

session key with mutual authentication using symmetric key

“I’m Alice”, R_A

R_B, E(“Bob”, R_A, K_{AB})

E(“Alice”, R_B, K_S, K_{AB})

Alice

Bob

Perfect Forward Secrecy

Perfect Forward Secrecy

- The concern…
  - Alice encrypts message with shared key K_{AB} and sends ciphertext to Bob
  - Trudy records ciphertext and later attacks Alice's (or Bob's) computer to find K_{AB}
  - Then Trudy decrypts recorded messages

Perfect forward secrecy (PFS): Trudy cannot later decrypt recorded ciphertext

  - Even if Trudy gets key K_{AB} or other secret(s)
- Is PFS possible?

Perfect Forward Secrecy

- For perfect forward secrecy, Alice and Bob cannot use K_{AB} to encrypt
- Instead they must use a **session key** K_S and forget it after it's used
- Problem: How can Alice and Bob agree on session key K_S and insure PFS?

naïve session key protocol

$E(K_S, K_{AB})$ →

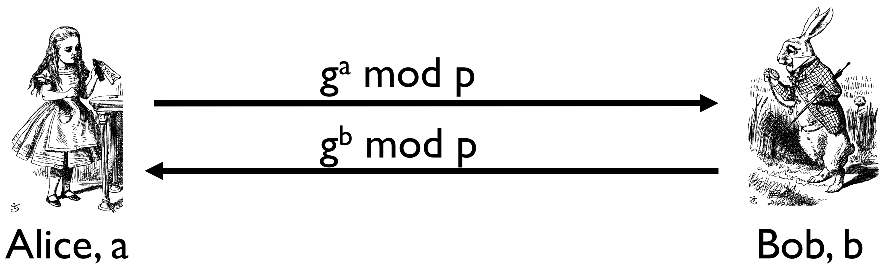
$E(messages, K_S)$ ↔

Alice, K_{AB} Bob, K_{AB}

- Trudy could also record $E(K_S,K_{AB})$
- If Trudy gets K_{AB}, she gets K_S

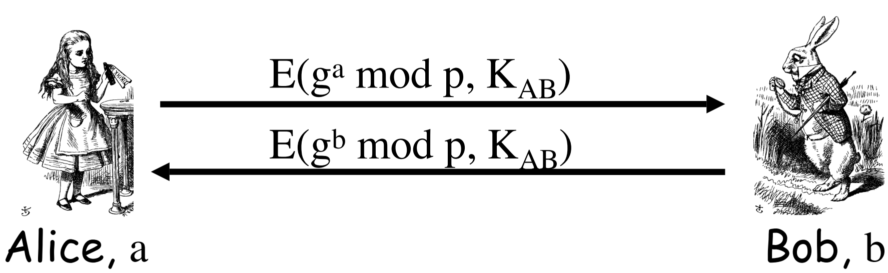
perfect forward secrecy

- Can use **Diffie-Hellman** for PFS
- Recall Diffie-Hellman: public g and p



- But Diffie-Hellman is subject to MiM
- How to get PFS and prevent MiM?

PFS session key via DH

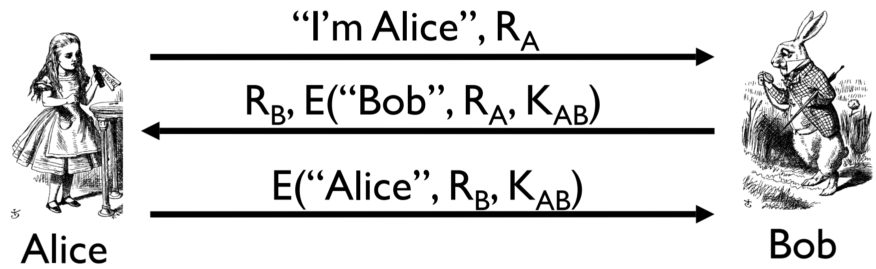


- Session key $K_S = g^{ab}$ mod p
- Alice forgets a, Bob forgets b

Ephemeral Diffie-Hellman

- Not even Alice and Bob can later recover K_S
- Other ways to do PFS?

mutual authentication with symmetric key



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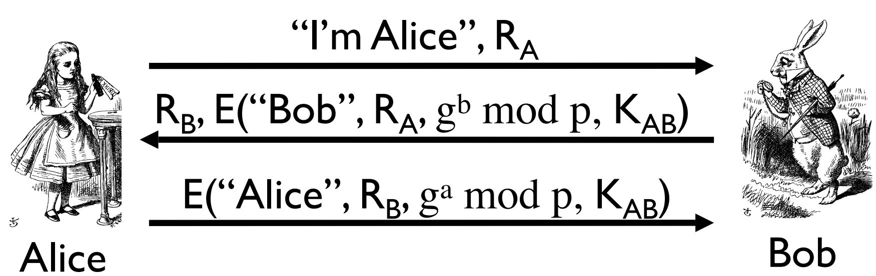
FPS session key with mutual authentication using symmetric key



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