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Security Protocols

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CYBER CHALLENGE
CyberChallenge.IT

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Cyber Security National Lab

Outline

1 Motivation

2 Basic notions

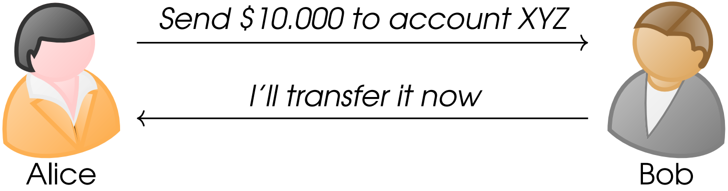
3 Needham-Schroeder Public Key Authentication Protocol

4 Needham-Schroeder Shared-Key Protocol

5 Kerberos

Motivation

Example: Securing an e-banking application.



Send $10.000 to account XYZ

I'll transfer it now

Alice

Bob

- How does *Bob* know the message originated from *Alice*?
- How does *Bob* know *Alice* just said it?

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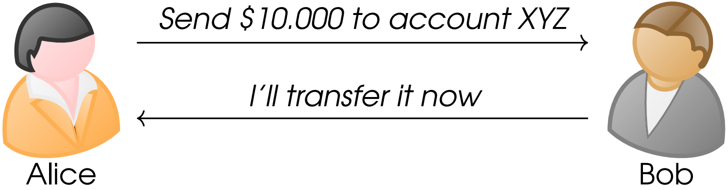

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Motivation – top down (II)

Other examples:

- Securing a sensor network.
- A micropayment scheme for a parking company.
- An access control system for area-wide ski lifts.

How would you build distributed algorithms for doing this?

Solutions involve protocols like: IPSec, SSH, PGP, SSL, Kerberos, etc.

We will focus on underlying ideas.

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- A protocol consists of a set of rules (conventions) that determine the exchange of messages between two or more principals.
  In short, a distributed algorithm with emphasis on communication.
- Security (or cryptographic) protocols use cryptographic mechanisms to achieve security objectives.
  Examples: Entity or message authentication, key establishment, integrity, timeliness, fair exchange, non-repudiation, ...
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Messages

- Message constructors are:
  Names: A, B or *Alice*, *Bob*, ...
  Keys: K and inverse keys K^{-1}
  Encryption: $\{M\}_K$; Example: encryption with A's public key: $\{M\}_{K_A}$
  Signing: $\{M\}_{K^{-1}}$; Example: signing with A's private key: $\{M\}_{K_A^{-1}}$
  Symmetric keys: $\{M\}_{K_{AB}}$
  Nonces: N_A, fresh data items used for challenge/response.
  Timestamps: T, denote time, e.g., used for key expiration.
  Message concatenation: $\{M_1, M_2\}$, $M_1 || M_2$, or $[M_1, M_2]$.
- Example: $\{A, T_A, K_{AB}\}_{K_B}$

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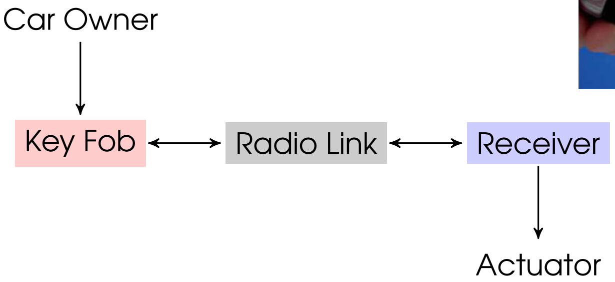

Car Owner

Key Fob

Radio Link

Receiver

Actuator

Security Goal (1st attempt)

Receiver sends unlock command to Actuator *only if* Car Owner *previously* pressed unlock button on Key Fob.

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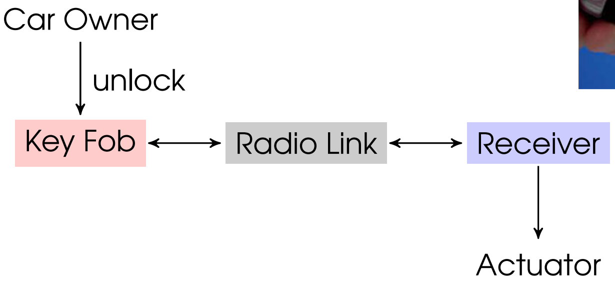

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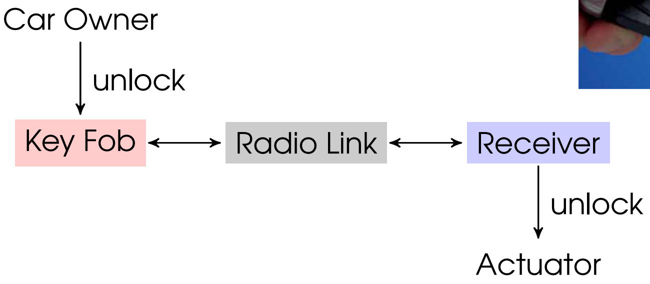

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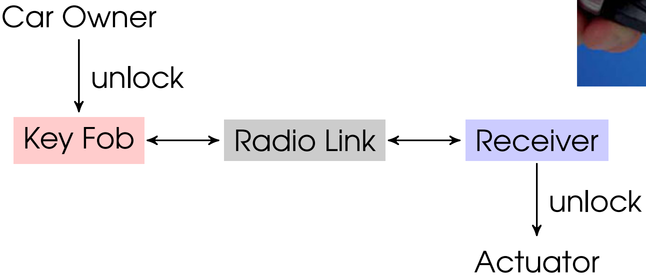

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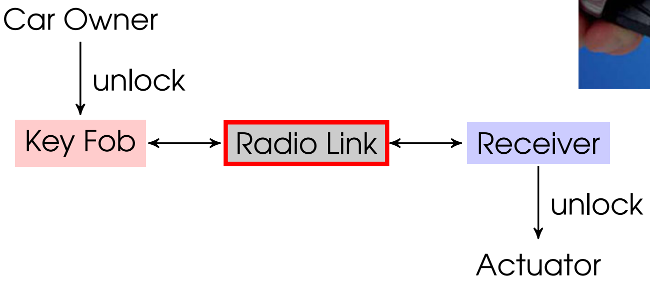

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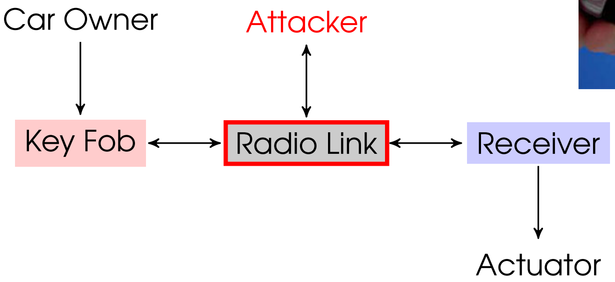

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Key Fob

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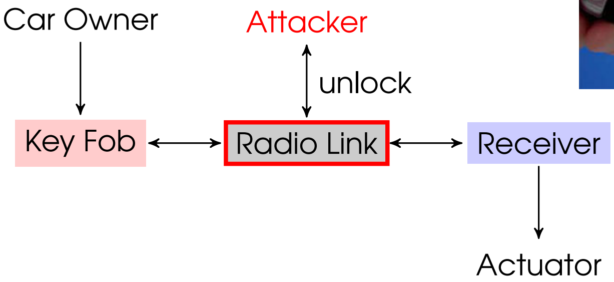

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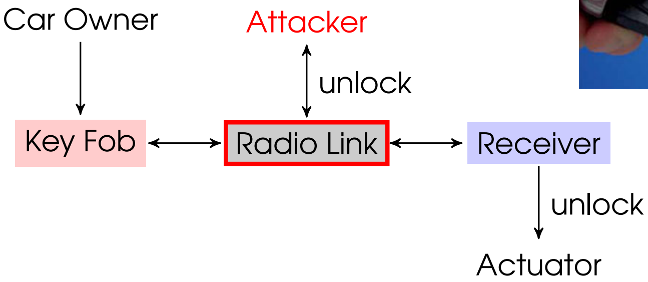

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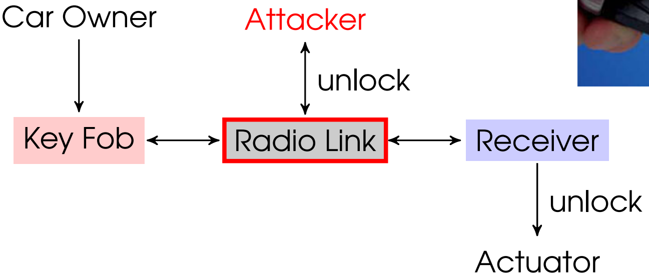

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Remote Keyless System Protocol (1st attempt)

Assume Serial Number (SN)
is a secret shared between KF and R.

KF sends SN to R:

$$1.\ KF \rightarrow R : unlock, SN$$

- Bad idea: Attacker can easily overhear SN and *replay* it subsequently.
- Problems:
  - Secrecy of SN compromised.
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Remote Keyless System Protocol (2nd attempt)

Idea: protect secrecy of SN

KF encrypts request with shared key (K) and sends the results to R.

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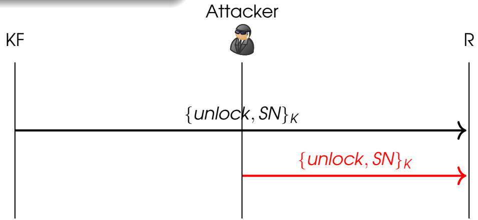
- Secrecy of SN ensured but attack possible anyway.
- R can check authenticity of request; but this is not enough...



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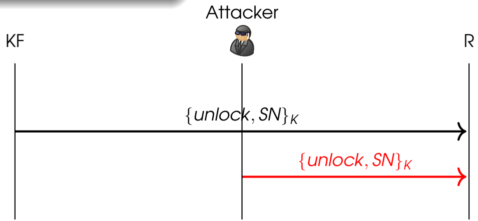

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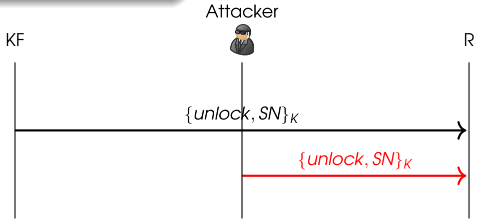

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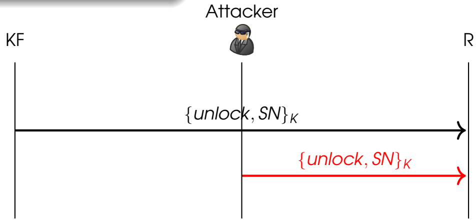

Security Goal: Freshness Requirement

The property:

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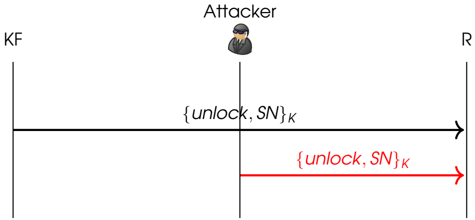

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Yet, the protocol suffers from a *replay attack*.

Security Goal (revised)

Receiver sends unlock command to Actuator *only if* Car Owner *recently* pressed unlock button on Key Fob.

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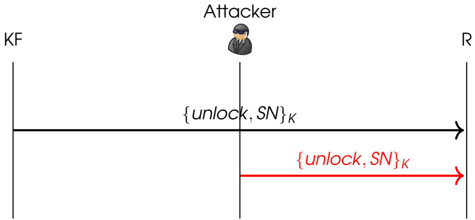

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Remote Keyless System Protocol (3rd attempt)

KF encrypts a timestamp with shared key K and sends result to R.

$$1.\ KF \rightarrow R : \{unlock, T\}_K$$

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- No need to send SN since KF can be identified by shared key.
- Timestamp prevents replay attack, but it requires synchronized clocks on KF and R.

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Remote Keyless System Protocol (4th attempt)

Receiver (R) sends Key Fob (KF) a challenge (a nonce, N) and KF sends back N encrypted with shared key (K).

1. $KF \rightarrow R : hello$
2. $R \rightarrow KF : N$
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Remote Keyless System Protocol (4th attempt)

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- The usage of the nonce prevents replay attacks.
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Alice & Bob Notation

- Fundamental events are communication between principals:

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\begin{array}{ll}
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2. & B \rightarrow A : \{B, A\}_K
\end{array}
$$

- *A* and *B* name roles.
  Can be instantiated by any principal playing in the role.
- Communication is asynchronous
- Sender/receiver names "$A \rightarrow B$" are not part of the message.
- Protocol specifies actions of principals.
  Equivalently, protocol defines a set of event sequences (traces).

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  Equivalently, protocol defines a set of event sequences (traces).

Alice & Bob Notation

- Fundamental events are communication between principals:

$$\begin{array}{ll} 1. & A \rightarrow B : \{A, T_A, K\}_{K_B} \\ 2. & B \rightarrow A : \{B, A\}_K \end{array}$$

- *A* and *B* name roles.
  Can be instantiated by any principal playing in the role.
- Communication is asynchronous
- Sender/receiver names "$A \rightarrow B$" are not part of the message.
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Assumptions and Goals

Assumptions (for principals):

- Principals know their private keys and public keys of others
- Principals can generate/check nonces and timestamps, encrypt and decrypt with known keys
- (Honest) Principals correctly implement the protocol
- The attacker controls the network, but cannot break crypto.

Goals: What the protocol should achieve. E.g.,

- Authenticate messages, binding them to their originator.
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How do we model the attacker? Possibilities:

- He knows the protocol but cannot break crypto. (Standard)
- He is passive but overhears all communications.
- He is active and can intercept and generate messages.
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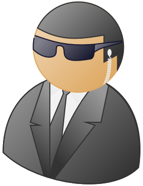

- The attacker is active. Namely:
  - He can intercept and read all messages.
  - He can decompose messages into their parts.
    But cryptography is secure: decryption requires inverse keys.
  - He can build new messages with the different constructors.
  - He can send messages at any time.
- Sometimes called the Dolev-Yao attacker model.
- Strongest possible assumptions about the attacker

⟹

correct protocols function in the largest range of environments.

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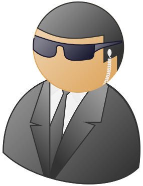

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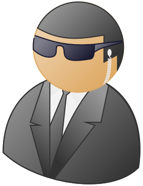

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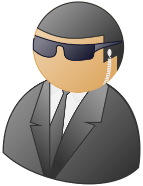

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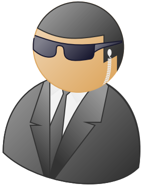

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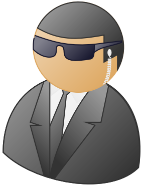

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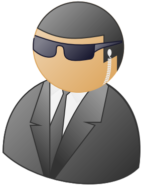

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Kinds of attack

- Replay (or freshness) attack: reuse parts of previous messages.
- Man-in-the-middle (or parallel sessions) attack: $A \leftrightarrow \mathcal{M} \leftrightarrow B$.
- Reflection attack send transmitted information back to originator.
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Outline

1 Motivation

2 Basic notions

3 Needham-Schroeder Public Key Authentication Protocol

4 Needham-Schroeder Shared-Key Protocol

5 Kerberos

NSPK Protocol

1. $A \rightarrow B : \{A, N_A\}_{K_B}$
2. $B \rightarrow A : \{N_A, N_B\}_{K_A}$
3. $A \rightarrow B : \{N_B\}_{K_B}$

- **Goal:** mutual (entity) authentication.
- Correctness argument (informal).
  1. This is Alice and I have chosen a nonce N_{Alice}.
  2. Here is your Nonce N_{Alice}. Since I could read it, I must be Bob. I also have a challenge N_{Bob} for you.
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- Recall principals can be involved in multiple runs. Goal should hold in all interleaved protocol runs.

Protocol proposed in 1970s and used for decades.

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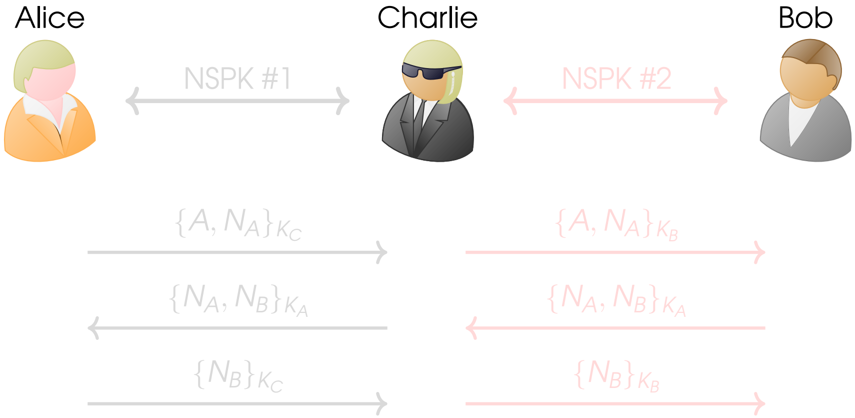

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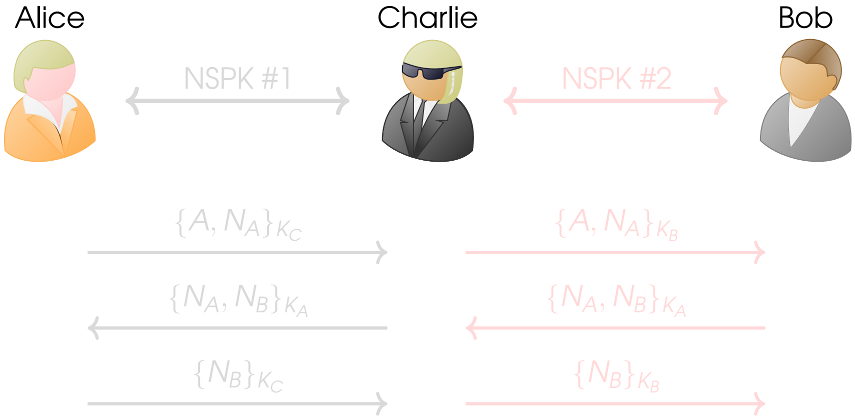

Alice

Charlie

Bob

NSPK #1

NSPK #2

$\{A, N_A\}_{K_C}$

$\{A, N_A\}_{K_B}$

$\{N_A, N_B\}_{K_A}$

$\{N_A, N_B\}_{K_A}$

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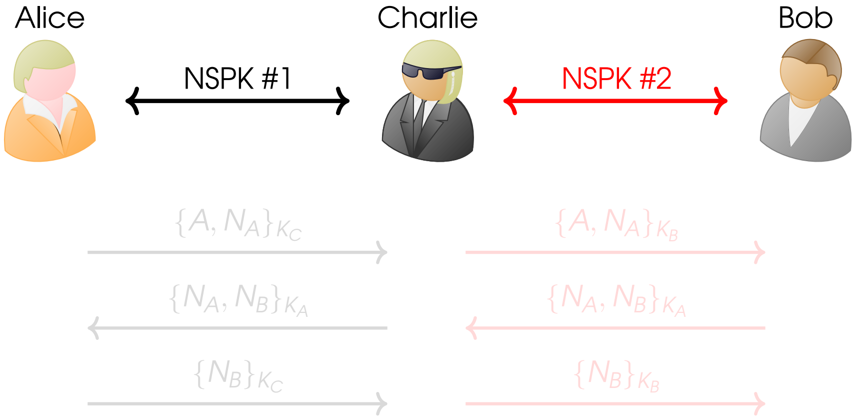

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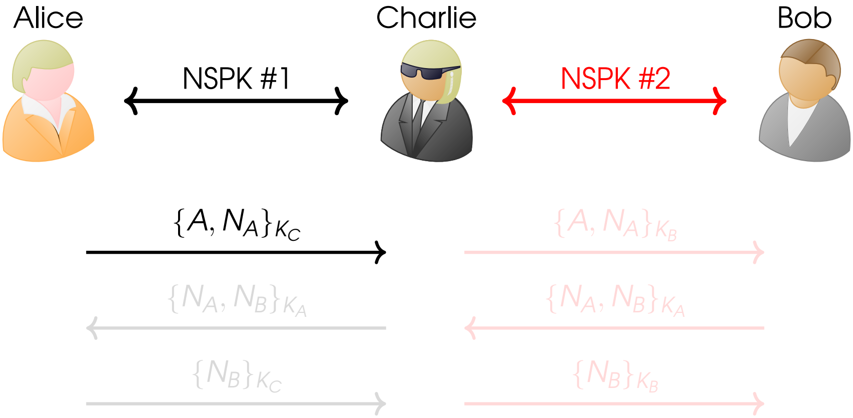

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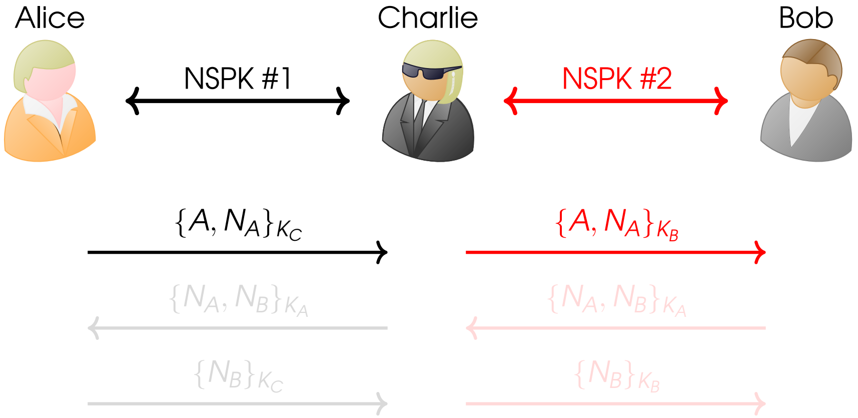

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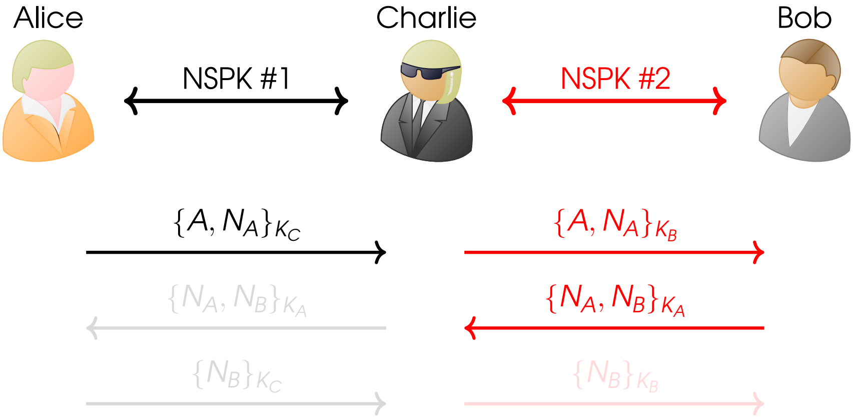

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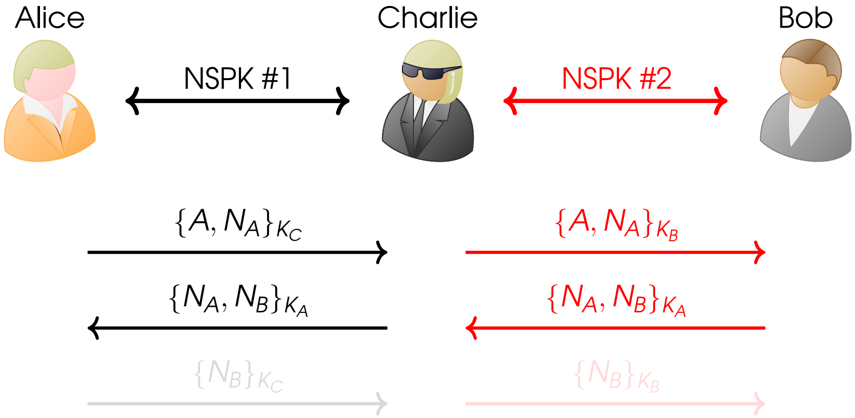

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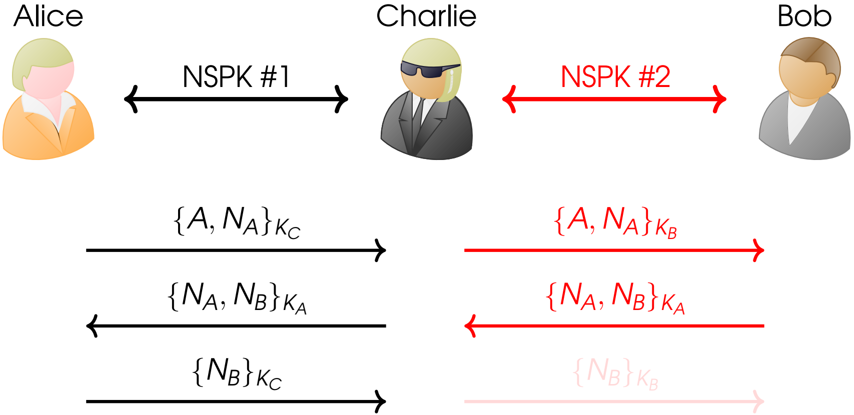

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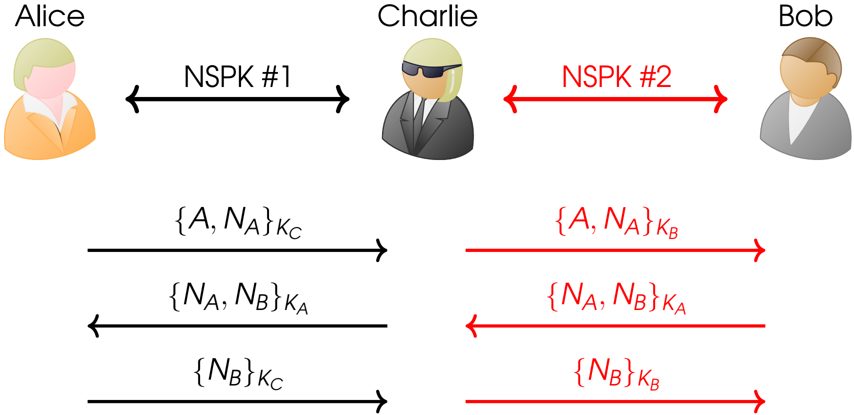

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NSPK #1

NSPK #2

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← $\{N_A, N_B\}_{K_A}$ ← $\{N_A, N_B\}_{K_A}$

$\{N_B\}_{K_C}$ → $\{N_B\}_{K_B}$ →

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NSPK Protocol with Lowe's Fix

How can we protect against the previous attack?

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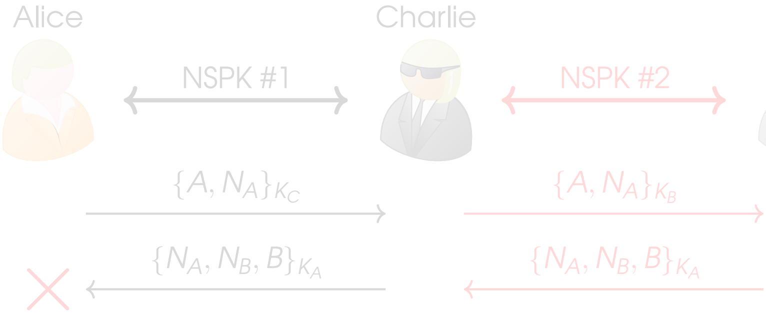

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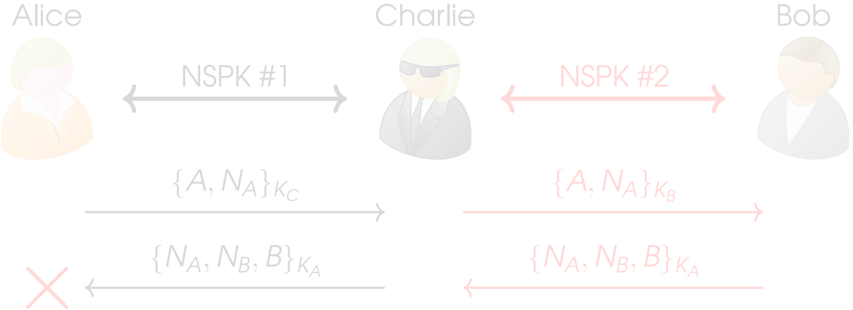

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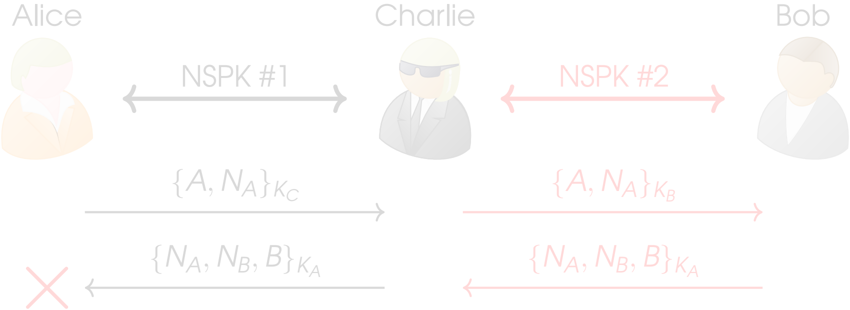

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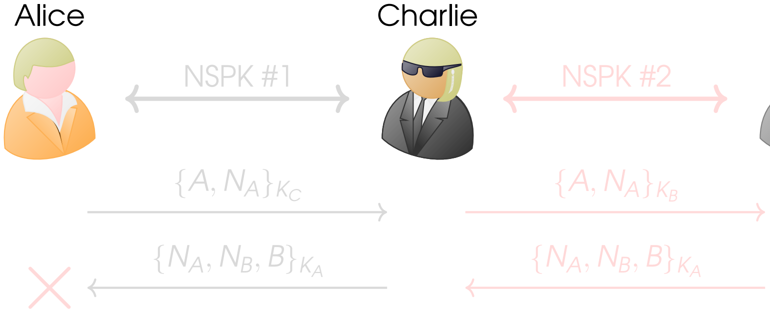

Alice

Charlie

Bob

NSPK #1

NSPK #2

$\{A, N_A\}_{K_C}$

$\{A, N_A\}_{K_B}$

$\{N_A, N_B, B\}_{K_A}$

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NSPK Protocol with Lowe´s Fix

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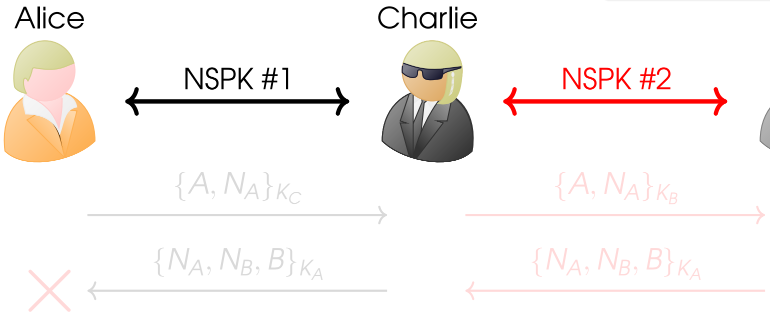

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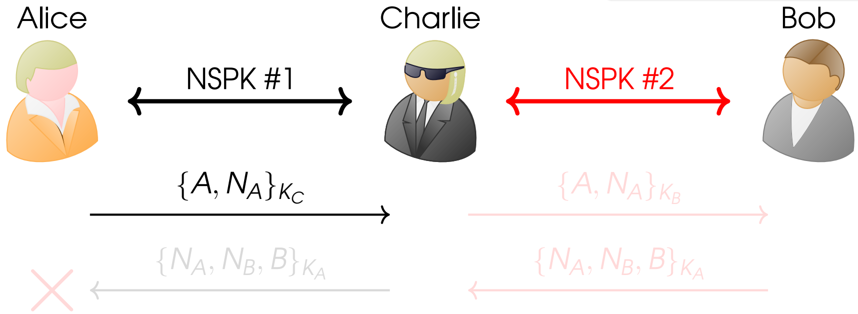

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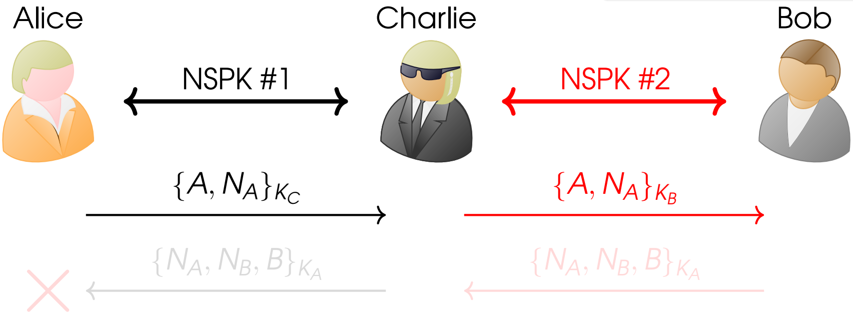

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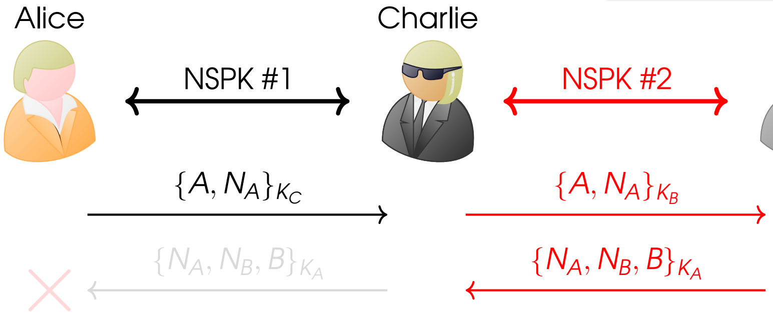

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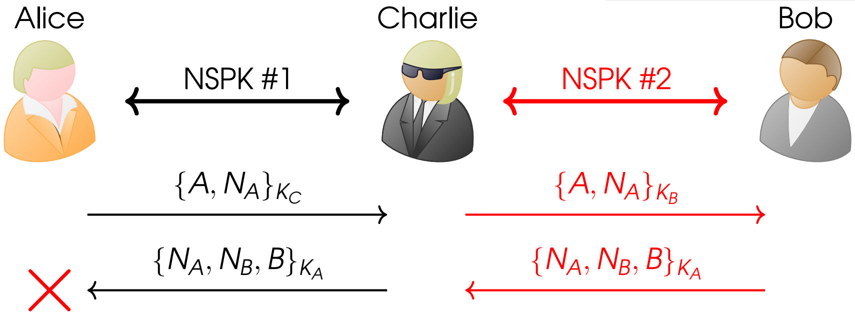


Outline

1 Motivation

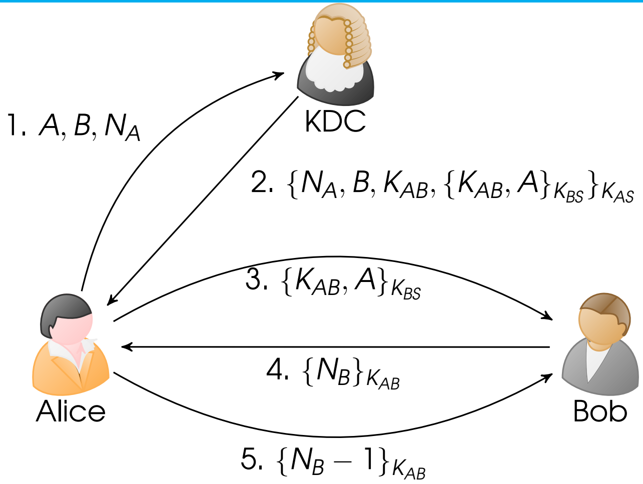
2 Basic notions

3 Needham-Schroeder Public Key Authentication Protocol

4 **Needham-Schroeder Shared-Key Protocol**

5 Kerberos

Needham-Schroeder Shared-Key Protocol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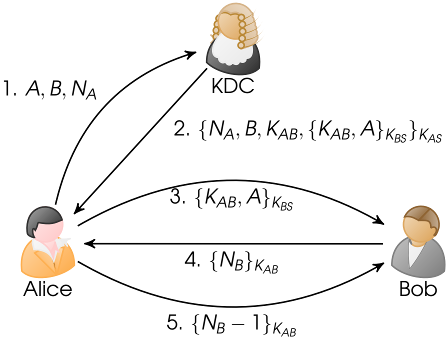
Alice
Bob

Security Goal: Authenticated key exchange.

Weakness of NSSK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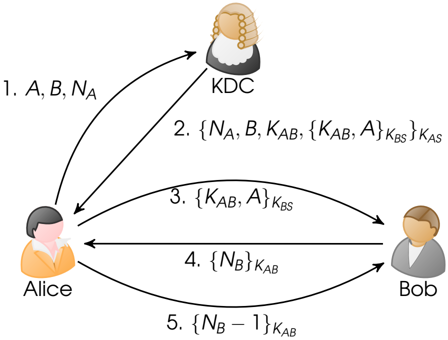
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Kerberos

- Protocol for authentication/access control for client/server applications.
- In Greek mythology, Kerberos is 3-headed dog guarding entrance to Hades. Modern Kerberos intended to have three components to guard a network’s gate: authentication, accounting, and audit.
  Last two heads never implemented.
- Developed as part of Project Athena (MIT, 1980’s).
  - Version V (1993) now standard.
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Kerberos Authentication Protocol: Aims (1/2)

(Taken from `https://www.kerberos.org/software/tutorial.html`)

- The user's password must never travel over the network;
- The user's password must never be stored in any form on the client machine: it must be immediately discarded after being used;
- The user's password should never be stored in an unencrypted form even in the authentication server database;
- Single Sign-On: The user is asked to enter a password only once per work session. Therefore users can transparently access all the services they are authorized for without having to re-enter the password during this session;

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- Authentication information resides on the authentication server only. The application servers must not contain the authentication information for their users. This is essential for obtaining the following results:
  - The administrator can disable the account of any user by acting in a single location without having to act on the several application servers;
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  - Timestamps instead of nonces to assure freshness of session keys.
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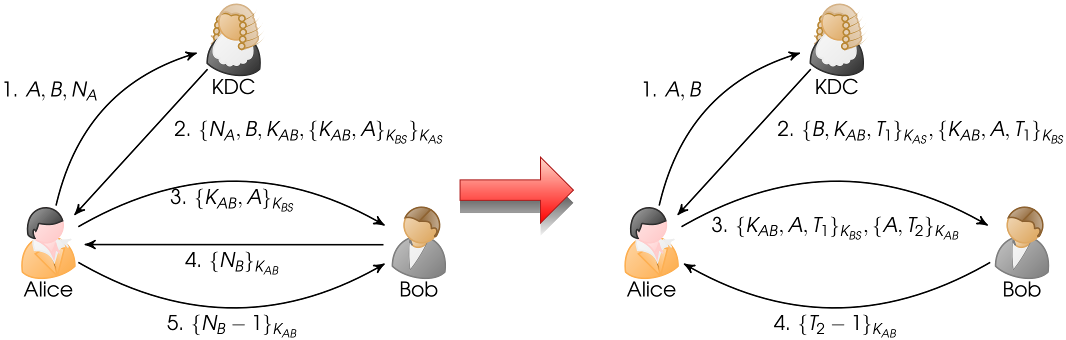
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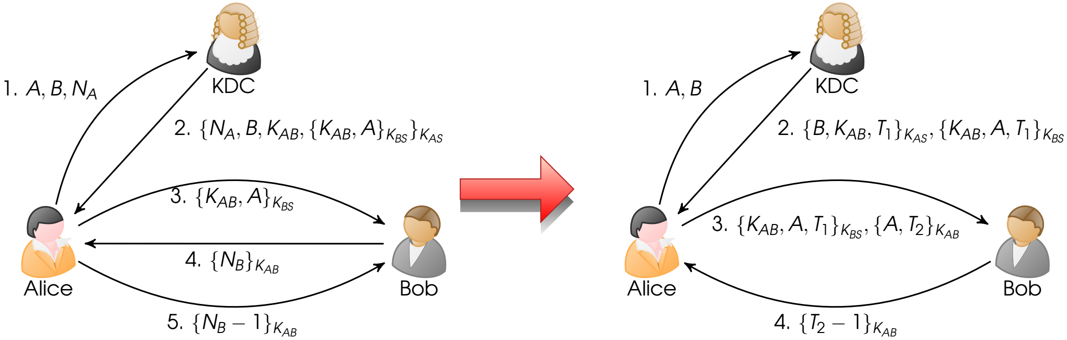

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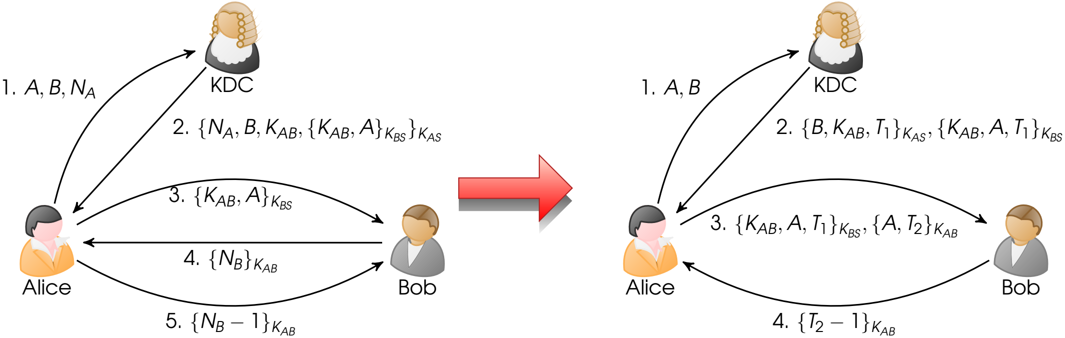

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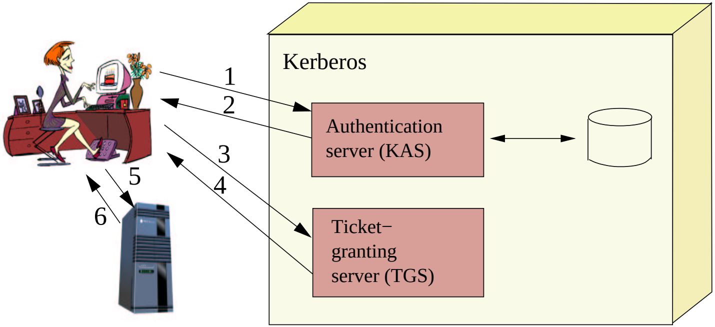
Kerberos IV: protocol



Authentication	messages 1 and 2.	Once per user login session.
Authorization	messages 3 and 4.	Once per type of service.
Service	messages 5 and 6.	Once per service session.

We present the three parts below (slightly simplified).

Authentication phase

1. $A \rightarrow KAS \quad : \quad A, TGS$
2. $KAS \rightarrow A \quad : \quad \{K_{A,TGS}, TGS, T_1\}_{K_{AS}}, \underbrace{\{A, TGS, K_{A,TGS}, T_1\}_{K_{KAS,TGS}}}_{AuthTicket}$

- *A* logs onto workstation and requests network resources.
- KAS accesses database and sends *A* a session key $K_{A,TGS}$ and an encrypted ticket *AuthTicket*.
- $K_{A,TGS}$ has lifetime of several hours (depending on application).
- K_{AS} is derived from the user's password, i.e. $K_{AS} = h(Password_A \| A)$.
- Both user and server keys must be registered in database.
- *A* types password on client to decrypt results. The ticket and session key are saved. The user's password is forgotten. *A* is logged out when $K_{A,TGS}$ expires.

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Authorization phase

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Before *A*'s first access of network resource *B*:

- *A* presents *AuthTicket* from message 2 to TGS together with a new *authenticator*, with short (seconds) lifetime.
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  - Role of authenticator? Short validity prevent replay attacks.
  - Servers store recent authenticators to prevent immediate replay.
- TGS issues *A* a new session key K_{AB} (lifetime of few minutes) and a new ticket *ServTicket*. K_{BS} is key shared between TGS and network resource.

Authorization phase

$$3.\ A \rightarrow TGS:\quad \underbrace{\{A,\ TGS,\ K_{A,TGS},\ T_1\}_{K_{KAS,TGS}}}_{\textit{AuthTicket}},\ \underbrace{\{A,\ T_2\}_{K_{A,TGS}}}_{\textit{authenticator}},\ B$$

$$4.\ TGS \rightarrow A:\quad \{K_{AB}, B, T_3\}_{K_{A,TGS}},\ \underbrace{\{A,\ B,\ K_{AB},\ T_3\}_{K_{BS}}}_{\textit{ServTicket}}$$

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Service phase

$$5.\ A \rightarrow B: \quad \underbrace{\{A,\ B,\ K_{AB},\ \mathcal{T}_3\}_{K_{BS}}}_{\textit{ServTicket}},\ \underbrace{\{A, \mathcal{T}_4\}_{K_{AB}}}_{\textit{authenticator}}$$

$$6.\ B \rightarrow A: \quad \{\mathcal{T}_4 + 1\}_{K_{AB}}$$

For *A* to access network resource *B*:

- *A* presents K_{AB} from 4 to *B* along with new *authenticator*.

  In practice, other information for server might be sent too.

- *B* replies, authenticating service.

Service phase

$$5.\ A \to B: \quad \underbrace{\{A,\ B,\ K_{AB},\ T_3\}_{K_{BS}}}_{\text{ServTicket}},\ \underbrace{\{A, T_4\}_{K_{AB}}}_{\text{authenticator}}$$

$$6.\ B \to A: \quad \{T_4 + 1\}_{K_{AB}}$$

For *A* to access network resource *B*:

- *A* presents K_{AB} from 4 to *B* along with new *authenticator*.

  In practice, other information for server might be sent too.
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