Information Security

Van K Nguyen - HUT

Key Management

Overview

- Key exchange
  - Session vs. interchange keys
  - Classical, public key methods
  - Key generation
- Cryptographic key infrastructure
  - Certificates
- Key storage
  - Key escrow
  - Key revocation

Notation

- $X \rightarrow Y : \{ Z \,||\, W \}\, k_{X,Y}$
  - 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
- $A \rightarrow T : \{ Z \}\, k_A \,||\, \{ W \}\, k_{A,T}$
  - 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)

Session key - Interchange key

- Alice wants to send a message *m* to Bob
  - Assume public key encryption
  - Alice know Bob's public key Z_B
- Proposed protocol
  - Alice generates a random cryptographic key k_s and uses it to encipher *m*
    - To be used for this message *only*
    - Called a *session key*
  - She enciphers k_s with Bob's public key Z_B
    - Z_B enciphers all session keys Alice uses to communicate with Bob
    - Called an *interchange key*
  - Alice sends Bob: $\{ m \} k_s \{ k_s \} Z_B$

Why session key?

- Limits amount of traffic enciphered with single key
  - Standard practice, to decrease the amount of traffic an attacker can obtain
- Prevents some attacks
  - Example: Alice will send Bob message that is either “BUY” or “SELL”. Eve computes possible ciphertexts { “BUY” } Z_B and { “SELL” } Z_B. Eve intercepts enciphered message, compares, and gets plaintext at once

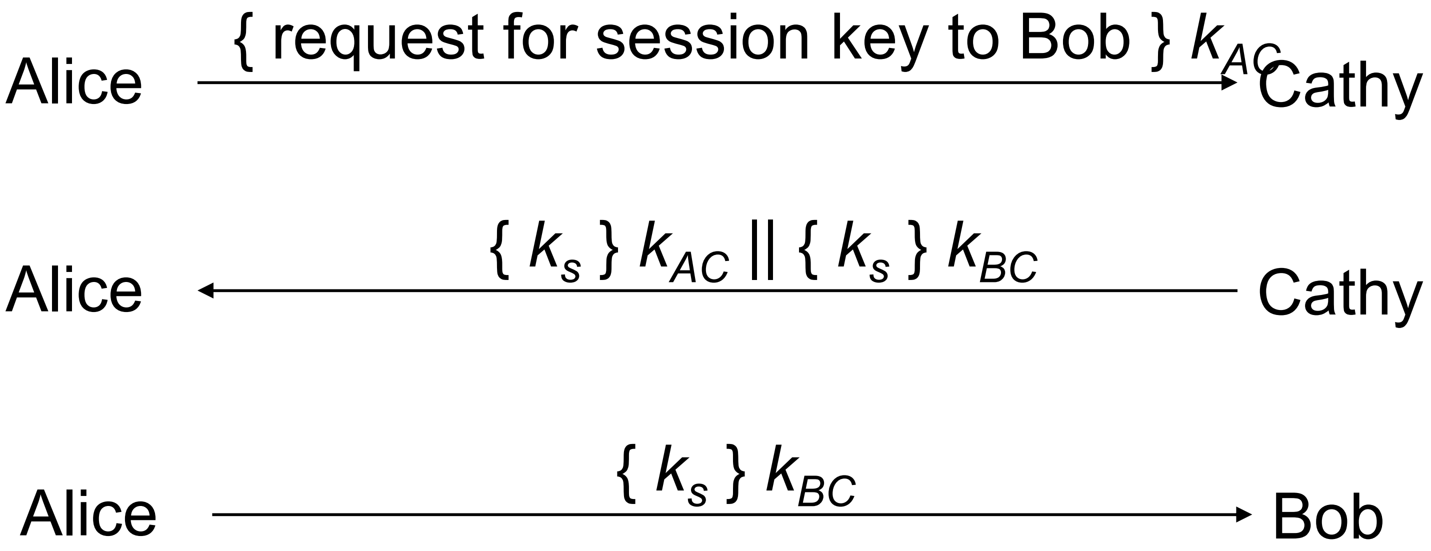
Key Exchange Algorithms

- Goal: Alice, Bob to get shared key (wo/ interchange key)
  - Key cannot be sent in clear
    - Attacker can listen in
    - Key can be sent enciphered, or derived from exchanged data plus data not known to an eavesdropper
  - Alice, Bob may use a trusted third party
  - All cryptosystems, protocols publicly known
    - Only secret data is the keys, ancillary information known only to Alice and Bob needed to derive keys
    - Anything transmitted is assumed known to attacker

Classical Key Exchange

- Bootstrap problem: how do Alice, Bob begin?
  - Alice can’t send it to Bob in the clear!
- Assume trusted third party, Cathy
  - Alice and Cathy share secret key k_{AC}
  - Bob and Cathy share secret key k_{BC}
  - Use this to exchange shared key k_s

Simple Protocol



Alice $\xrightarrow{\{ \text{ request for session key to Bob } \} \, k_{AC}}$ Cathy

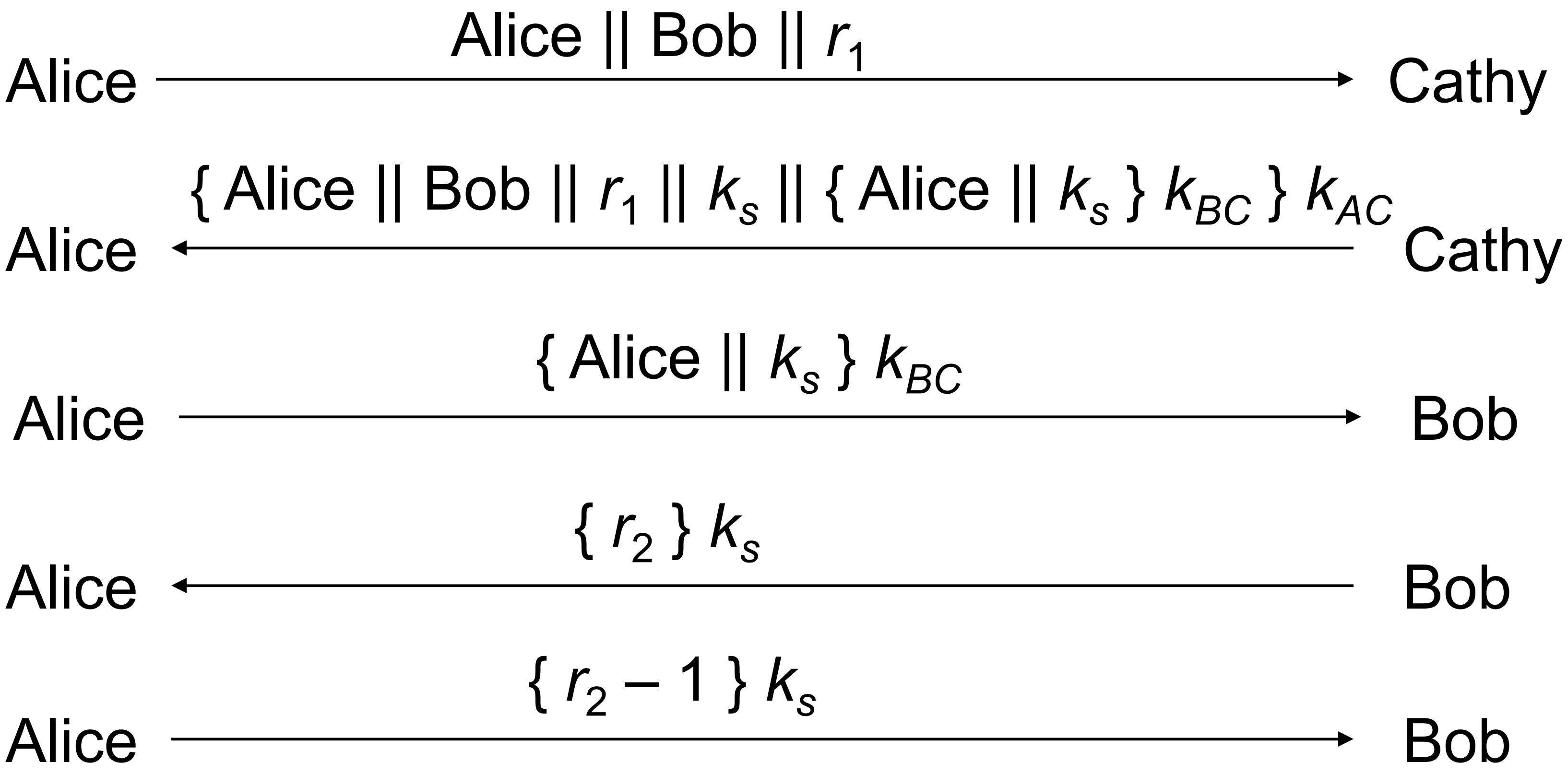
Alice $\xleftarrow{\{ k_s \} \, k_{AC} \, || \, \{ k_s \} \, k_{BC}}$ Cathy

Alice $\xrightarrow{\{ k_s \} \, k_{BC}}$ Bob

Problems

- How does Bob know he is talking to Alice?
    - Replay attack: Eve records message from Alice to Bob, later replays it; Bob may think he’s talking to Alice, but he isn’t
    - Session key reuse: Eve replays message from Alice to Bob, so Bob re-uses session key
        - Eve may fortunately get a session key dropped by Alice
- Protocols must provide authentication and defense against replay

Needham-Schroeder



$$\text{Alice} \xrightarrow{\text{Alice} \,||\, \text{Bob} \,||\, r_1} \text{Cathy}$$

$$\text{Alice} \xleftarrow{\{\, \text{Alice} \,||\, \text{Bob} \,||\, r_1 \,||\, k_s \,||\, \{\, \text{Alice} \,||\, k_s \,\}\, k_{BC} \,\}\, k_{AC}} \text{Cathy}$$

$$\text{Alice} \xrightarrow{\{\, \text{Alice} \,||\, k_s \,\}\, k_{BC}} \text{Bob}$$

$$\text{Alice} \xleftarrow{\{\, r_2 \,\}\, k_s} \text{Bob}$$

$$\text{Alice} \xrightarrow{\{\, r_2 - 1 \,\}\, k_s} \text{Bob}$$

Argument: Alice talking to Bob

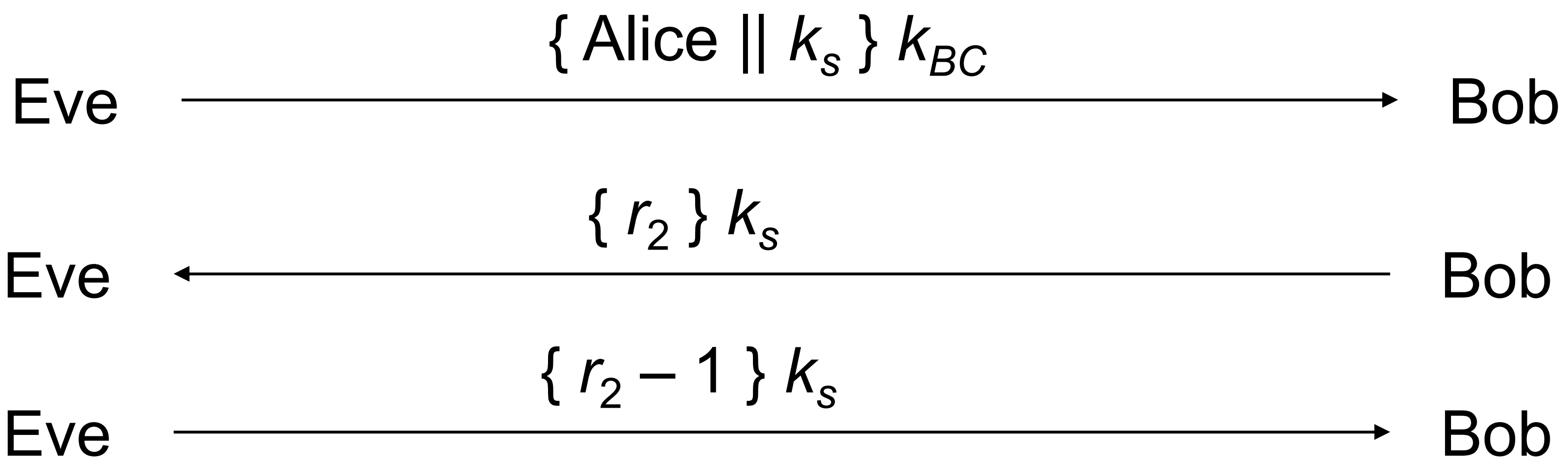
- Second message
  - Enciphered using key only she, Cathy knows
    - So Cathy enciphered it
  - Response to first message
    - As r_1 in it matches r_1 in first message
- Third message
  - Alice knows only Bob can read it
    - As only Bob can derive session key from message
  - Any messages enciphered with that key are from Bob

Argument: Bob talking to Alice

- Third message
  - Observe that: Enciphered using key only he and Cathy know
    - So Cathy enciphered it
  - Inside are the name Alice and the session key
    - Bob concludes that Cathy provided session key, saying Alice is the other party
- Fourth and Firth messages:
  - Use session key to determine if it is replay from Eve
    - If not, Alice will respond correctly in fifth message
    - If so, Eve can't decipher r_2 and so can't respond, or responds incorrectly

Denning-Sacco Problem

- Assumption: all keys are secret
- Question: suppose Eve can obtain session key. How does that affect protocol?
  - In what follows, by chance Eve knows k_s



Eve $\xrightarrow{\{ \text{Alice} \, || \, k_s \} \, k_{BC}}$ Bob

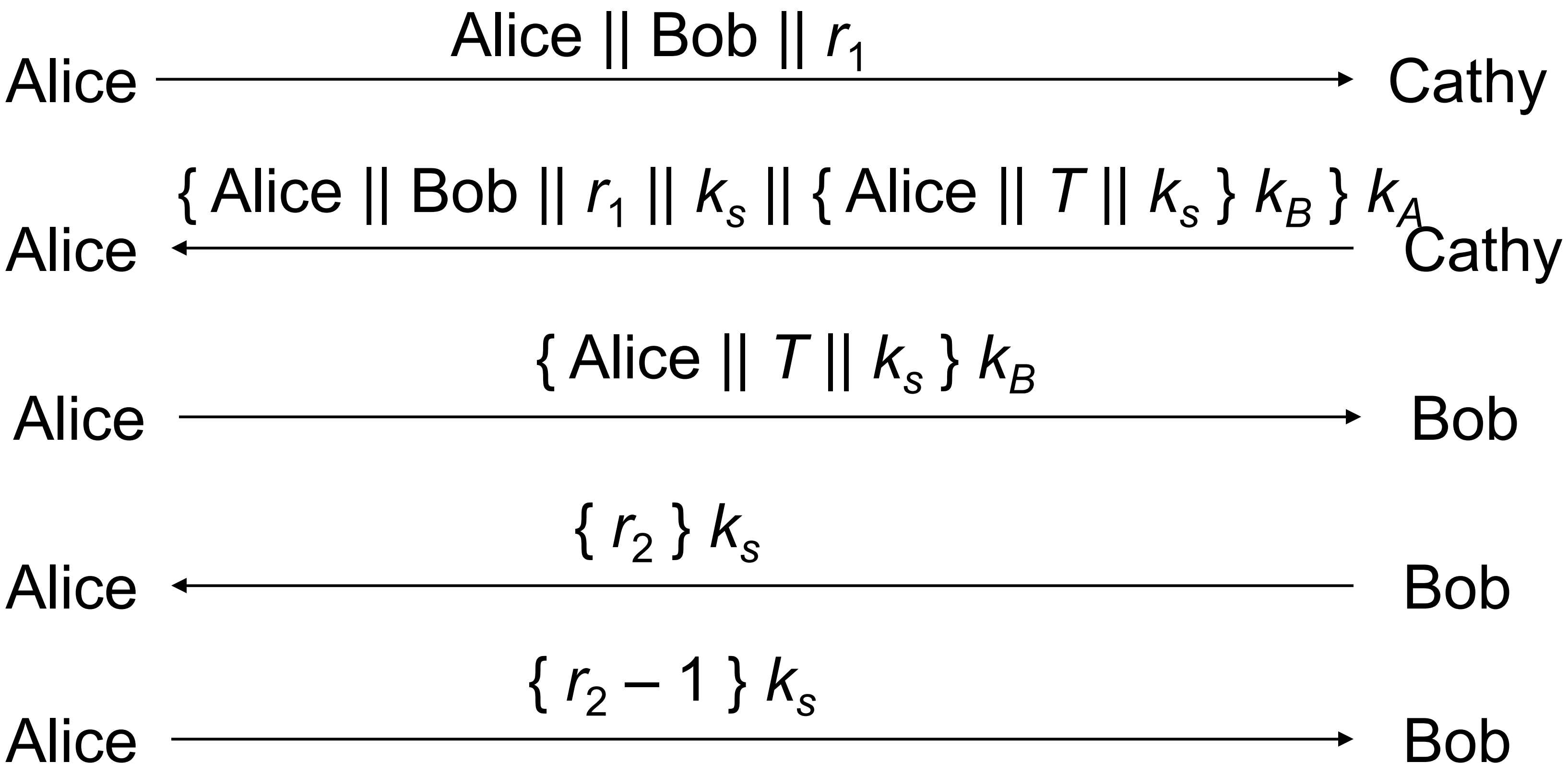
Eve $\xleftarrow{\{ r_2 \} \, k_s}$ Bob

Eve $\xrightarrow{\{ r_2 - 1 \} \, k_s}$ Bob

Solution

- In protocol above, Eve impersonates Alice
- Problem: replay in third step
  - First in previous slide
- Solution: use time stamp *T* to detect replay

Needham-Schroeder with Denning-Sacco Modification



$$\text{Alice} \xrightarrow{\text{Alice} \,||\, \text{Bob} \,||\, r_1} \text{Cathy}$$

$$\text{Alice} \xleftarrow{\{\, \text{Alice} \,||\, \text{Bob} \,||\, r_1 \,||\, k_s \,||\, \{\, \text{Alice} \,||\, T \,||\, k_s \,\}\, k_B \,\}\, k_A} \text{Cathy}$$

$$\text{Alice} \xrightarrow{\{\, \text{Alice} \,||\, T \,||\, k_s \,\}\, k_B} \text{Bob}$$

$$\text{Alice} \xleftarrow{\{\, r_2 \,\}\, k_s} \text{Bob}$$

$$\text{Alice} \xrightarrow{\{\, r_2 - 1 \,\}\, k_s} \text{Bob}$$

Still weakness, anyway

- If clocks not synchronized, may either reject valid messages or accept replays
  - Parties with either slow or fast clocks vulnerable to replay
  - Resetting clock does *not* eliminate vulnerability
- Use Otway-Rees protocol (Bishop's text)

Kerberos

- Authentication system
  - Based on Needham-Schroeder with Denning-Sacco modification
  - Central server plays role of trusted third party (“Cathy”)
- Ticket
  - Issuer vouches for identity of requester of service
- Authenticator
  - Identifies sender

Idea

- User *u* authenticates to Kerberos server
    - Obtains ticket $T_{u,TGS}$ for ticket granting service (TGS)
- User *u* wants to use service *s*:
    - User sends authenticator A_u, ticket $T_{u,TGS}$ to TGS asking for ticket for service
    - TGS sends ticket $T_{u,s}$ to user
    - User sends A_u, $T_{u,s}$ to server as request to use *s*
- Details in Bishop's text

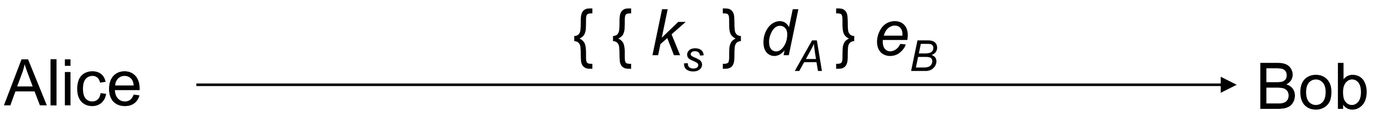
Public Key Key Exchange

- Here interchange keys known
  - e_A, e_B Alice and Bob’s public keys known to all
  - d_A, d_B Alice and Bob’s private keys known only to owner
- Simple protocol
  - k_s is desired session key

$$\text{Alice} \xrightarrow{\{\, k_s \,\}\, e_B} \text{Bob}$$

Problem and Solution

- Vulnerable to forgery or replay
  - Because e_B known to anyone, Bob has no assurance that Alice sent message
- Simple fix uses Alice's private key
  - k_s is desired session key

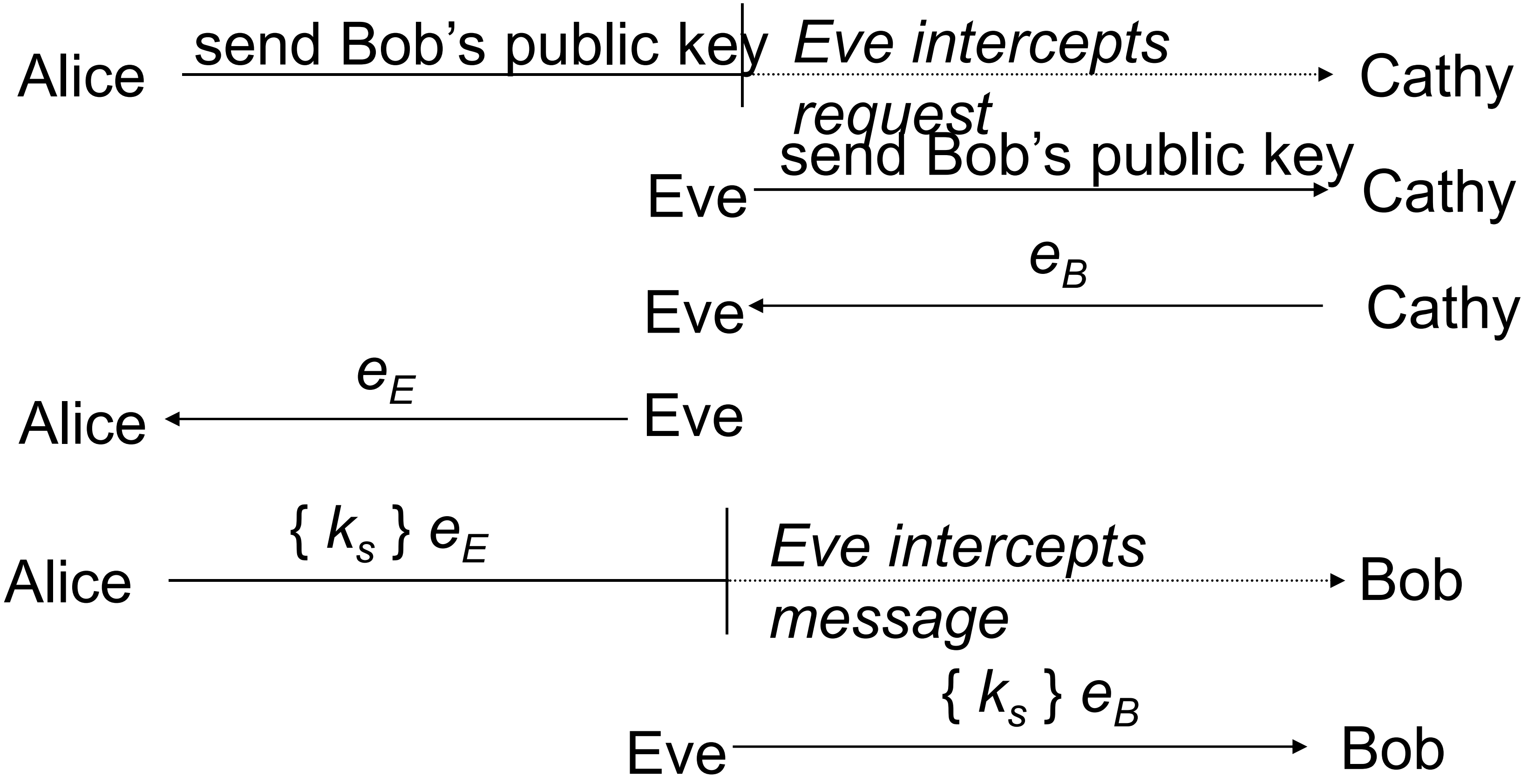


$$\text{Alice} \xrightarrow{\{\,\{\,k_s\,\}\,d_A\,\}\,e_B} \text{Bob}$$

Notes

- Can include message enciphered with k_s
- Assumes Bob has Alice's public key, and *vice versa*
  - If not, each must get it from public server
  - If keys not bound to identity of owner, attacker Eve can launch a *man-in-the-middle* attack (next slide; Cathy is public server providing public keys)
    - Solution to this (binding identity to keys) discussed later as public key infrastructure (PKI)

Man-in-the-Middle Attack



Alice — send Bob's public key — *Eve intercepts request* → Cathy

Eve — send Bob's public key → Cathy

Eve ← e_B — Cathy

Alice ← e_E — Eve

Alice — $\{ k_s \} e_E$ — *Eve intercepts message* → Bob

Eve — $\{ k_s \} e_B$ → Bob

Key Generation

- Goal: generate keys that are difficult to guess
- Problem statement: given a set of *K* potential keys, choose one randomly
  - Equivalent to selecting a random number between 0 and *K*–1 inclusive
- Why is this hard: generating random numbers
  - Actually, numbers are usually *pseudo-random*, that is, generated by an algorithm

What is “Random”?

- *Sequence of cryptographically random numbers*: a sequence of numbers n_1, n_2, … such that for any integer $k > 0$, an observer cannot predict n_k even if all of n_1, …, n_{k-1} are known
  - Best: physical source of randomness
    - Random pulses
    - Electromagnetic phenomena
    - Characteristics of computing environment such as disk latency
    - Ambient background noise

What is "Pseudorandom"?

- *Sequence of cryptographically pseudorandom numbers*: sequence of numbers intended to simulate a sequence of cryptographically random numbers but generated by an algorithm
  - Very difficult to do this well
    - Linear congruential generators [$n_k = (an_{k-1} + b) \bmod n$] broken
    - Polynomial congruential generators [$n_k = (a_j n_{k-1}^j + \ldots + a_1 n_{k-1}\ a_0) \bmod n$] broken too
    - Here, "broken" means next number in sequence can be determined

Best Pseudorandom Numbers

- *Strong mixing function*: function of 2 or more inputs with each bit of output depending on some nonlinear function of all input bits
  - Examples: DES, MD5, SHA-1
  - Use on UNIX-based systems:

    ```
    (date; ps gaux) | md5
    ```

    where "ps gaux" lists all information about all processes on system

Cryptographic Key Infrastructure

- Goal: bind identity to key
- Classical: not possible as all keys are shared
  - Use protocols to agree on a shared key (see earlier)
- Public key: bind identity to public key
  - Crucial as people will use key to communicate with principal whose identity is bound to key
  - Erroneous binding means no secrecy between principals
  - Assume principal identified by an acceptable name

Certificates

- Create token (message) containing
  - Identity of principal (here, Alice)
  - Corresponding public key
  - Timestamp (when issued)
  - Other information (perhaps identity of signer)

  signed by trusted authority (here, Cathy)

$$C_A = \{ e_A \mathbin{||} \text{Alice} \mathbin{||} T \} d_C$$

Use

- Bob gets Alice’s certificate
  - If he knows Cathy’s public key, he can decipher the certificate
    - When was certificate issued?
    - Is the principal Alice?
  - Now Bob has Alice’s public key
- Problem: Bob needs Cathy’s public key to validate certificate
  - Problem pushed “up” a level
  - Two approaches: Merkle’s tree, signature chains

Certificate Signature Chains

- Create certificate
  - Generate hash of certificate
  - Encipher hash with issuer’s private key
- Validate
  - Obtain issuer’s public key
  - Decipher enciphered hash
  - Recompute hash from certificate and compare
- Problem: getting issuer’s public key

X.509 Chains

- Some certificate components in X.509v3:
  - Version
  - Serial number
  - Signature algorithm identifier: hash algorithm
  - Issuer’s name; uniquely identifies issuer
  - Interval of validity
  - Subject’s name; uniquely identifies subject
  - Subject’s public key
  - Signature: enciphered hash

X.509 Certificate Validation

- Obtain issuer's public key
  - The one for the particular signature algorithm
- Decipher signature
  - Gives hash of certificate
- Recompute hash from certificate and compare
  - If they differ, there's a problem
- Check interval of validity
  - This confirms that certificate is current

Issuers

- *Certification Authority (CA)*: entity that issues certificates
  - Multiple issuers pose validation problem
  - Alice’s CA is Cathy; Bob’s CA is Don; how can Alice validate Bob’s certificate?
  - Have Cathy and Don cross-certify
    - Each issues certificate for the other

Validation and Cross-Certifying

- Certificates:
  - Cathy<<Alice>>
  - Dan<<Bob>
  - Cathy<<Dan>>
  - Dan<<Cathy>>
- Alice validates Bob’s certificate
  - Alice obtains Cathy<<Dan>>
  - Alice uses (known) public key of Cathy to validate Cathy<<Dan>>
  - Alice uses Cathy<<Dan>> to validate Dan<<Bob>>

Key Escrow

- *Key escrow system* allows authorized third party to recover key
  - Useful when keys belong to roles, such as system operator, rather than individuals
  - Business: recovery of backup keys
  - Law enforcement: recovery of keys that authorized parties require access to
- Goal: provide this without weakening cryptosystem
- Very controversial

Desirable Properties

- Escrow system should not depend on encipherment algorithm
- Privacy protection mechanisms must work from end to end and be part of user interface
- Requirements must map to key exchange protocol
- System supporting key escrow must require all parties to authenticate themselves
- If message to be observable for limited time, key escrow system must ensure keys valid for that period of time only

Components

- User security component
  - Does the encipherment, decipherment
  - Supports the key escrow component
- Key escrow component
  - Manages storage, use of data recovery keys
- Data recovery component
  - Does key recovery

Example: ESS, Clipper Chip

- Escrow Encryption Standard
  - Set of interlocking components
  - Designed to balance need for law enforcement access to enciphered traffic with citizens' right to privacy
- Clipper chip prepares per-message escrow information
  - Each chip numbered uniquely by UID
  - Special facility programs chip
- Key Escrow Decrypt Processor (KEDP)
  - Available to agencies authorized to read messages

Key Revocation

- Certificates invalidated *before* expiration
  - Usually due to compromised key
  - May be due to change in circumstance (*e.g.*, someone leaving company)
- Problems
  - Entity revoking certificate authorized to do so
  - Revocation information circulates to everyone fast enough
    - Network delays, infrastructure problems may delay information

CRLs

- *Certificate revocation list* lists certificates that are revoked
- X.509: only certificate issuer can revoke certificate
  - Added to CRL
- PGP: signers can revoke signatures; owners can revoke certificates, or allow others to do so
  - Revocation message placed in PGP packet and signed
  - Flag marks it as revocation message

Kiểm tra giữa kỳ

1. Gọi **M** = (**STT** mod 40)+ 5. Cho p=11, q=17 trong hệ RSA. Hãy thực hiện các công việc sau:
   - Xây dựng khoá công khai và bí mật của hệ (chú ý áp dụng thuật toán GCD mở rộng).
   - Tính MÃ của tin M
   - Nếu sử dụng hệ này để làm chữ ký, xác định chữ ký cho M nói trên (chú ý dùng giải thuật nhanh để tính lũy thừa đồng dư).
   - Nếu muốn gửi một thông báo M vừa có đảm bảo xác thực vừa có tính mật, cần thực hiện cụ thể thế nào?
2. Cho biết ý nghĩa, công dụng của vector khởi đầu (initial vector) trong các chế độ mã khối.
   - Cho bản rõ M=M1||M2. Sử dụng chế độ mã khối CBC với thuật toán DES, viết bản mật của tin trên theo M1,M2, IV và hàm $DES_K()$.
   - Tại sao nói chế độ ECB không nên dùng trong truyền tin bí mật, nhưng lại thích hợp để mật mã thông tin lưu trữ (trong các CSDL, các đĩa lưu …).