Information Security

Session key - Key management

Overview

- Key exchange
  - Session vs. interchange keys
  - Classical, public key methods
- 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: $\{ m \} k_s \{ k_s \} Z_B$

Session key - Interchange key

- session key
  - cryptographic key associated with the communication itself
  - Uses to encipher data only. Does not authenticate the principals
- Interchange key
  - a cryptographic key associated with a principal to a communication
  - Can be used to authenticate the principals

Why session key?

- Limits amount of traffic enciphered with single key
  - Standard practice, to decrease the amount of traffic an attacker can obtain
- Guarantees the freshness of the keys

Key Exchange Algorithms

- Goal: Alice, Bob to get shared session 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

Session key creation using symmetric cryptography

Simple protocol

1. Protocol details
   1. A → B: ID_A
   2. B → A: $(ID_B||K_S)K_{AB}$
   3. A: decrypts $(ID_B||K_S)K_{AB}$ and derives K_S
2. Any security risk?
   1. Attacker derives an old session key used in the past
   2. He reuses the cipher text in step 2 and impersonates B
   3. A commmunicates with the attacker using old key K_S

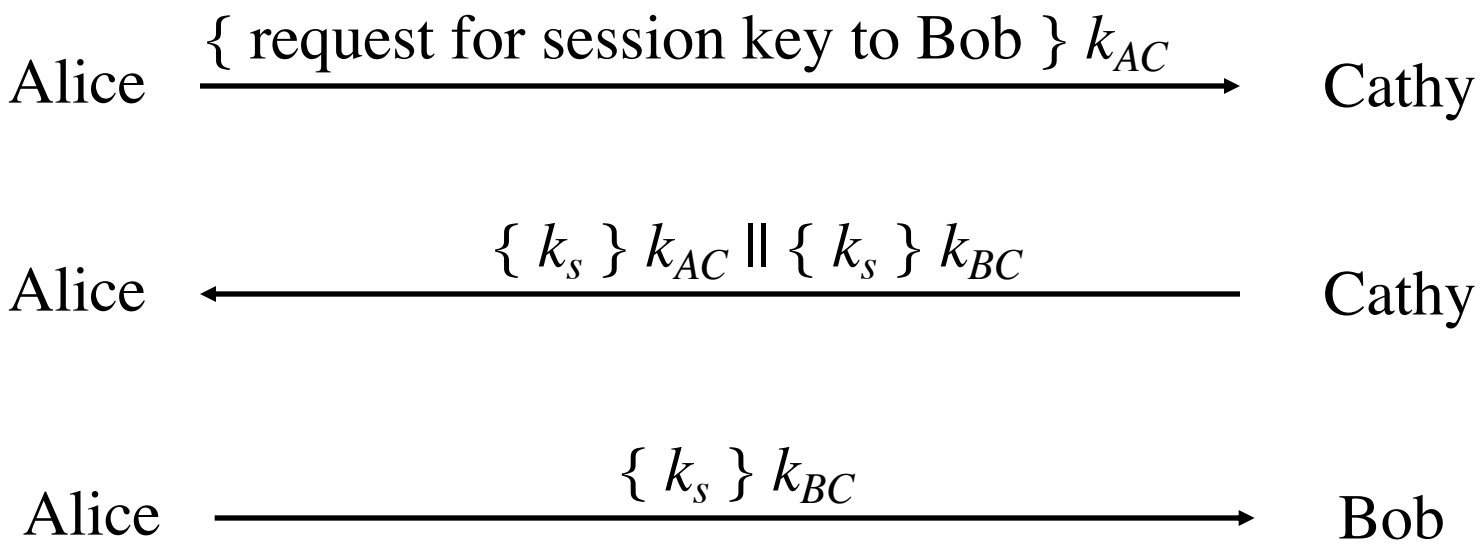
Simple protocol

- A modification against key-reuse attack
  - A→ B: $ID_A||R_1$
  - B→ A:$\left(ID_B||K_S||R_1||R_2\right)K_M$
  - A→ B: $(R_2)K_S$
  - B: decrypts $(R_2)K_S$ and checks the value of R_2
- The weakness of the centralized key management?

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

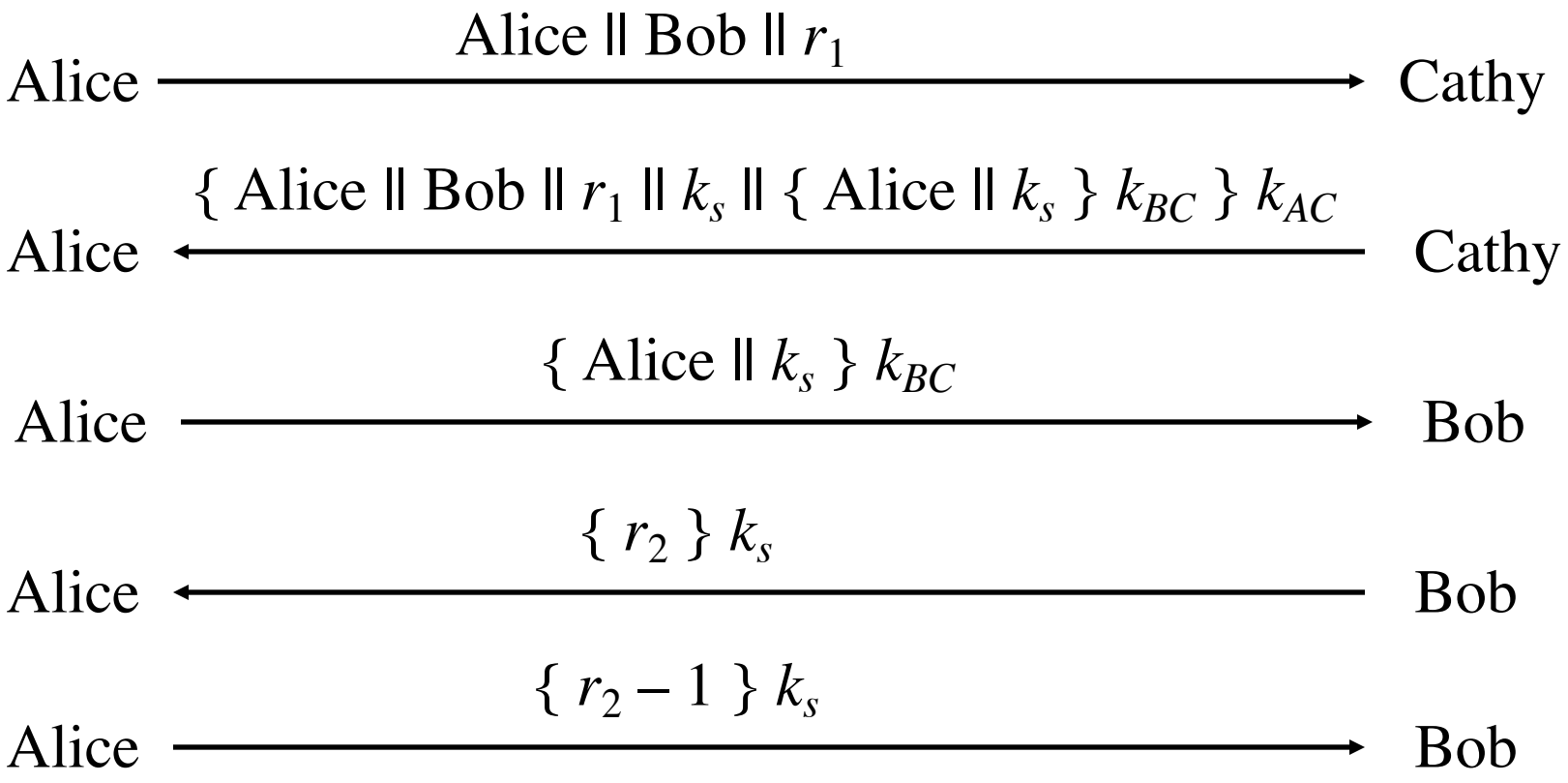
Simple Protocol



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



Argument: Alice talking to Bob

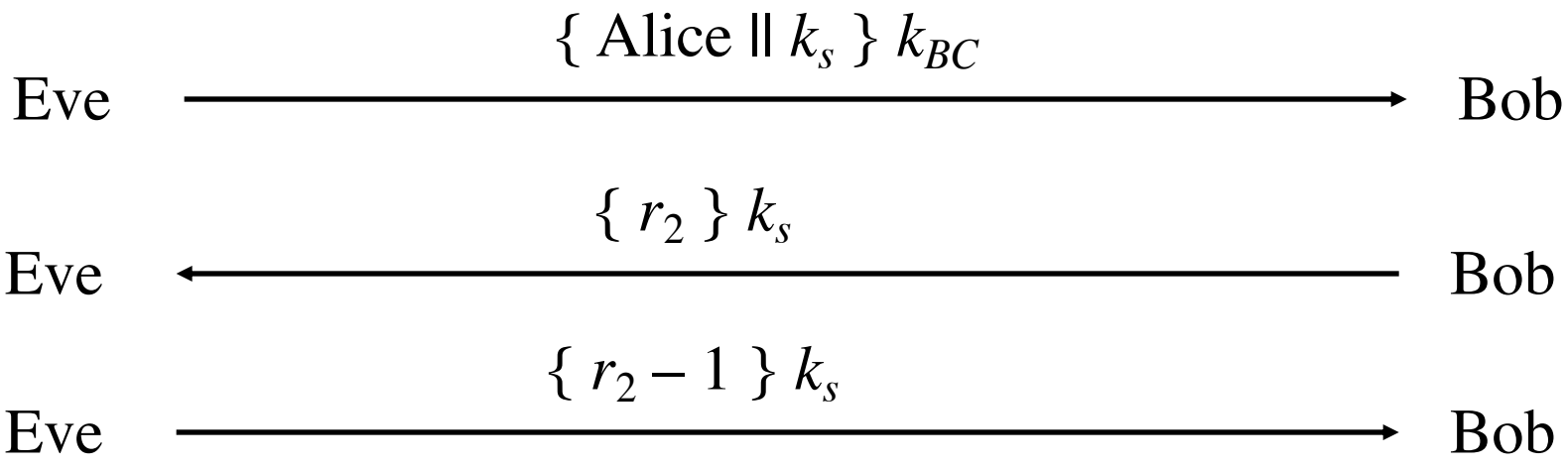
- Second message
  - Enciphered using key only she, Cathy knows
    - So Cathy enciphered it
  - Response to first message
    - As r_1 in it matches r_1 in first message
- Third message
  - Alice knows only Bob can read it
    - As only Bob can derive session key from message
  - Any messages enciphered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

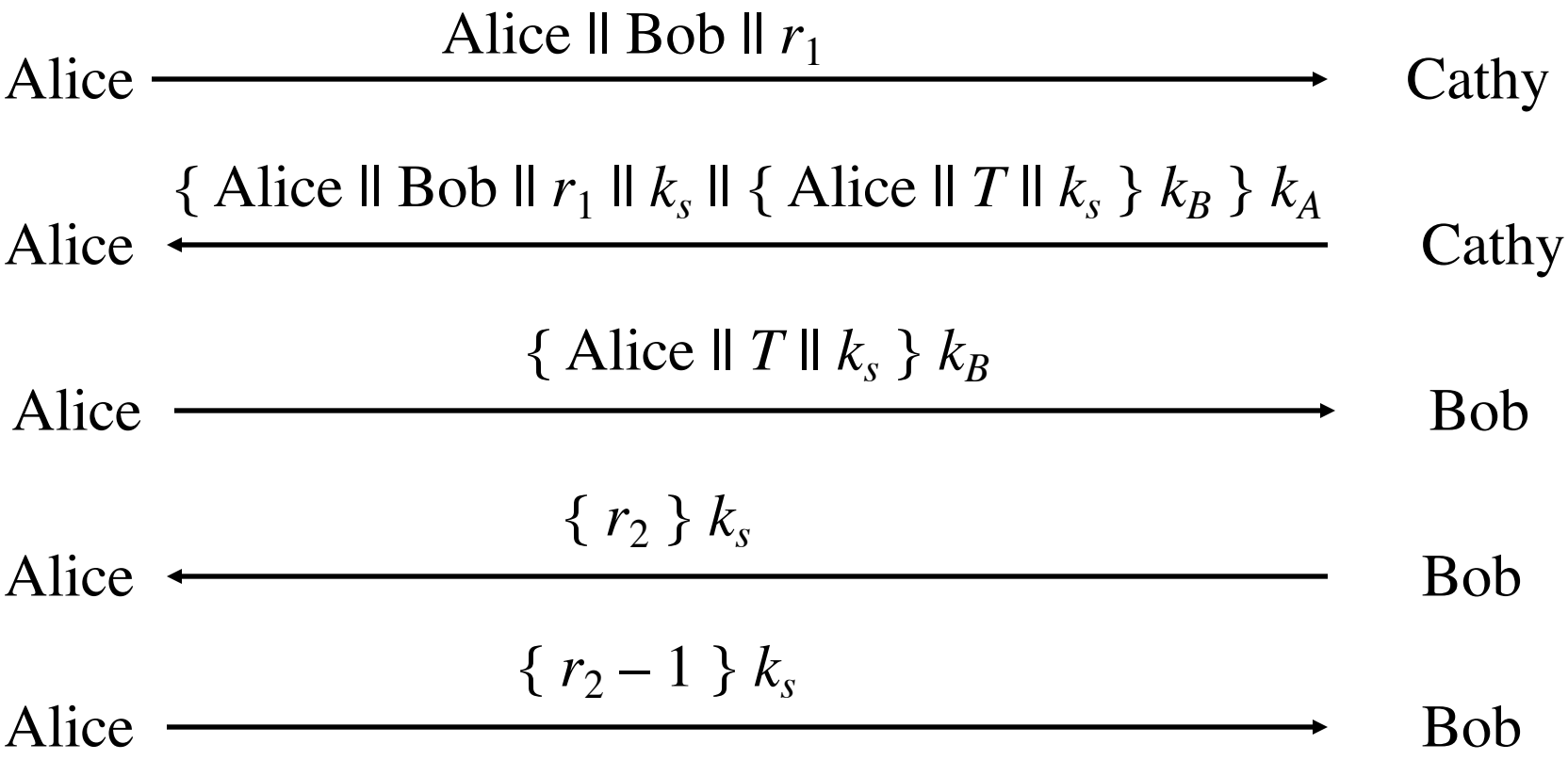
- Assumption: all keys are secret
- Question: suppose Eve can obtain session key. How does that affect protocol?
  - In what follows, by chance Eve knows k_s



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



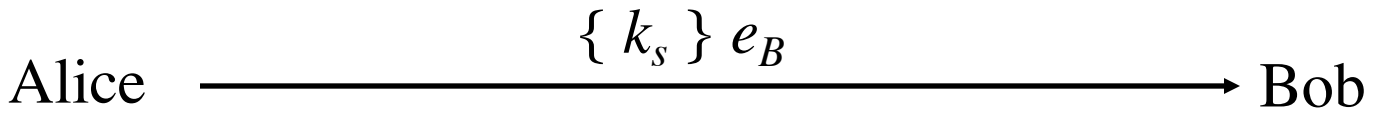
Still weakness, anyway

- 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)

Session key creation using asymmetric cryptography

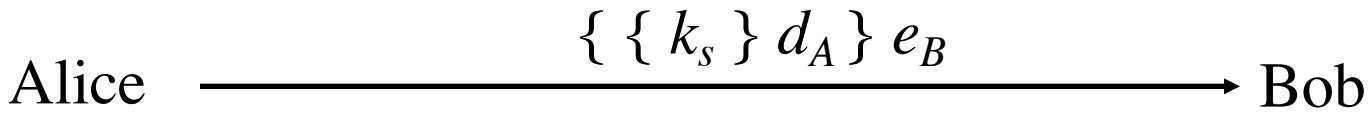
Public Key Key Exchange

- 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



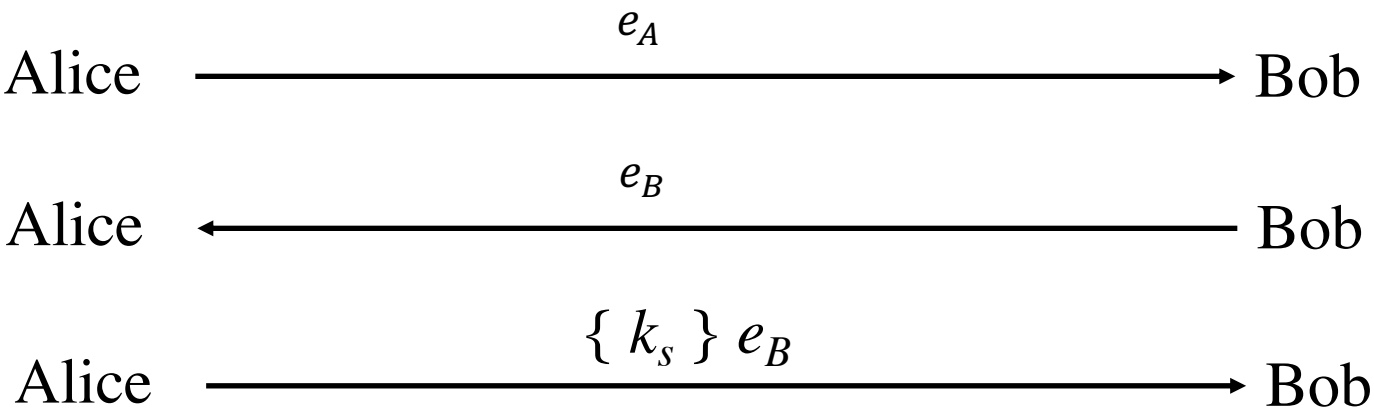
Problem and Solution

- 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

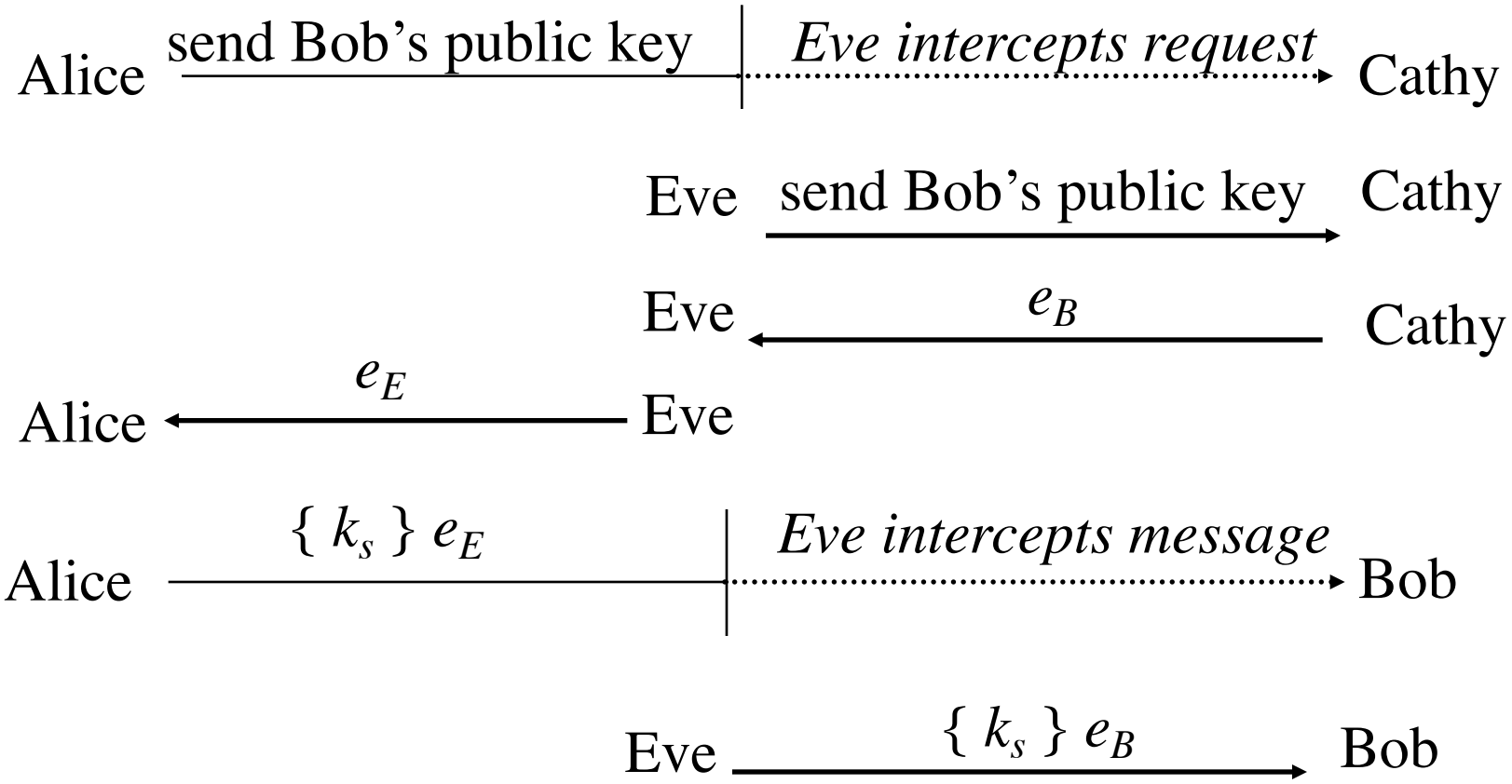


Bob and Alice do not know the other's public key in advance

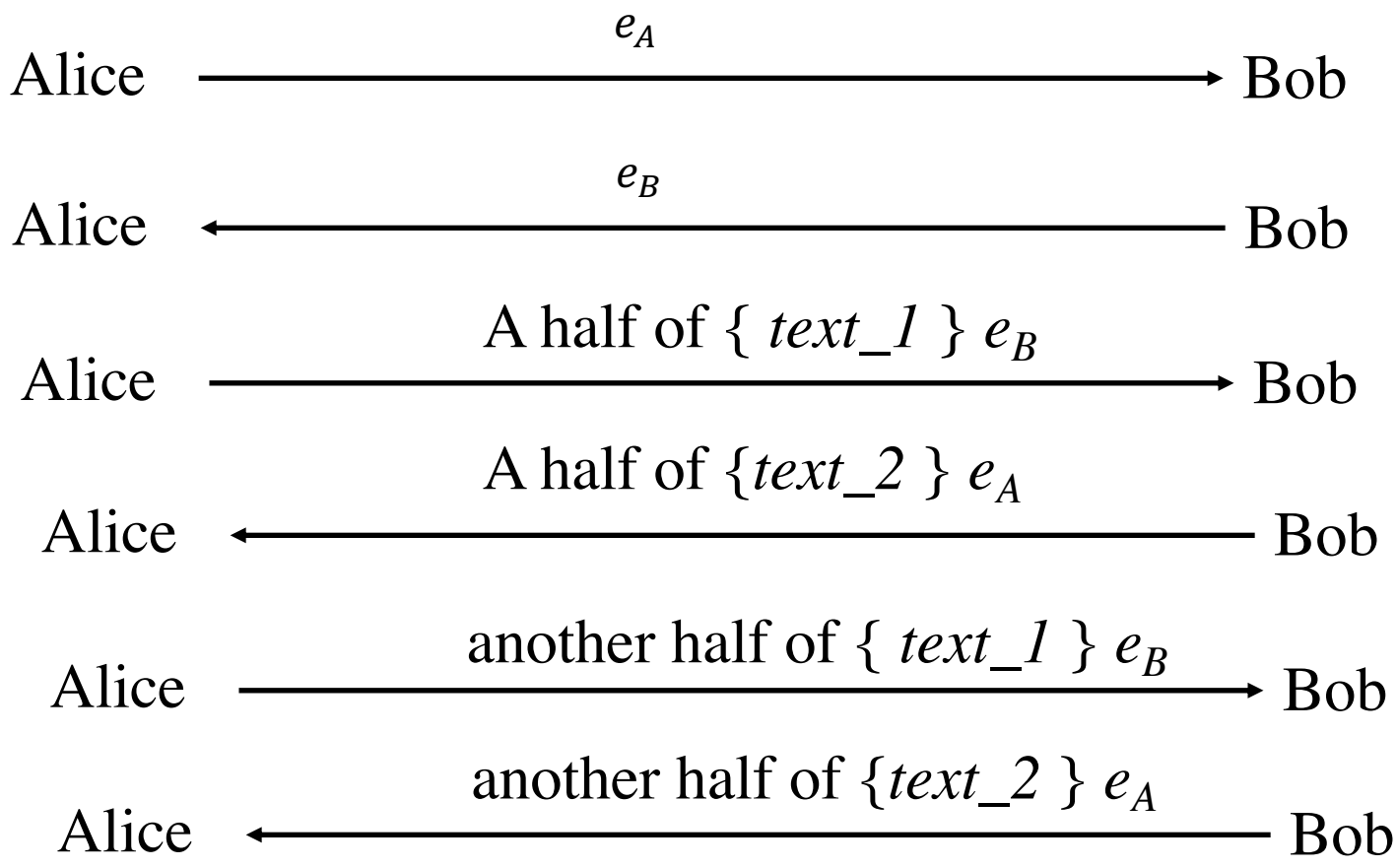
- Simple public key exchange protocol



Man-in-the-Middle Attack



Solution for Man-in-the-Middle Attack



Using a trusted third party

- PKA (Public Key Authority)
  - Keys: (e_{PKA}, d_{PKA})
  - PKA know the public key of A (e_A) and B (e_B)
  - A and B know the public key of PKA: e_{PKA}
- Simple protocol
  1. A → PKA: Alice || Bob
  2. PKA → A: $\{Bob||e_B\}d_{KPA}$
  3. A → B: $\{r_1\}e_B$
  4. B → PKA: Alice || Bob
  5. PKA → B: $\{Alice||e_A\}d_{KPA}$
  6. B → A: $\{r_1\}e_A$
- Any security risk?

Using a trusted third party

- An improvement against key reuse attack
  1. A → PKA: Alice || Bob || T_1 (T_1: timestamp)
  2. PKA → A: $\{Bob||e_B\}d_{KPA}$
  3. A → B: $\{r_1\}e_B$
  4. B → PKA: Alice || Bob || T_2 (T_2: timestamp)
  5. PKA → B: $\{Alice||e_A\}d_{KPA}$
  6. B → A: $\{r_1\}e_A$

Cryptographic Key Infrastructure

- Goal: bind identity to key
- Classical cryptography: not possible as all keys are shared
  - Use protocols to agree on a shared key (see earlier)
- Public key cryptography: 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 (e_A)
  - Timestamp (when issued) (T)
  - Other information (perhaps identity of signer)

  signed by trusted authority (here, Cathy)

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

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 Dan; how can Alice validate Bob's certificate?
  - Have Cathy and Dan 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
  - To ensure that the entity revoking the key is authorized to to so
  - To ensure timeliness of the revocation throughout the infrastructure
    - 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

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