Introduction to Cryptography

Part 3: real world applications

Jean-Sébastien Coron

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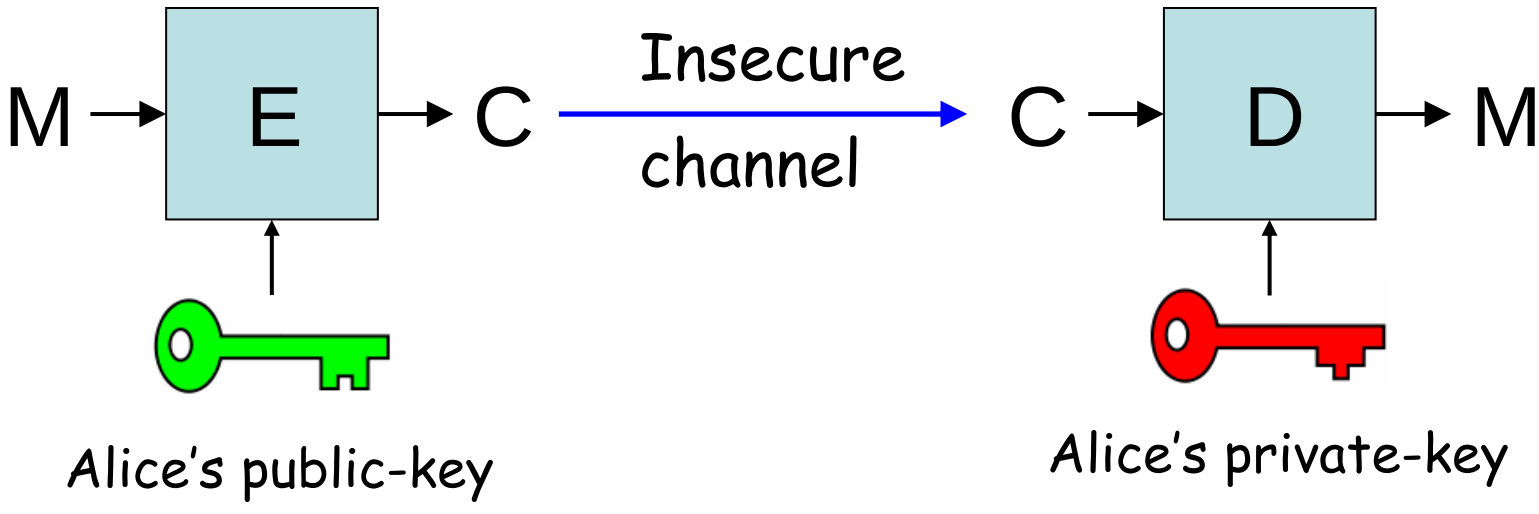
Public-key encryption

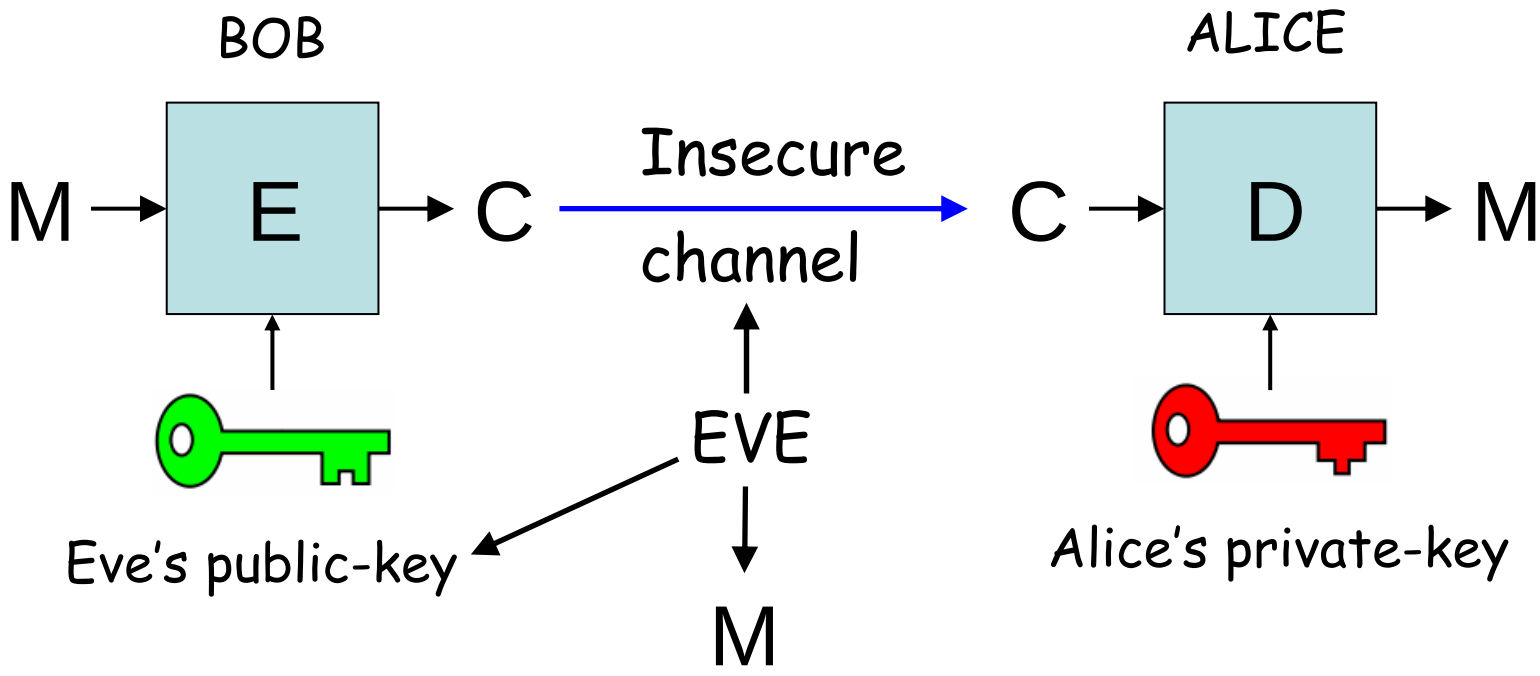
BOB

ALICE



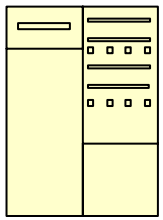
Authentication

- Public-keys need to be authenticated
  - Bob needs to be sure that the public-key belongs to Alice.
  - Otherwise, impersonation attack



Public-key Infrastructure

- A central authority binds public-keys to identities.
  - Public-key is stored in a certificate



Central authority

2) Alice authenticates and send PK_{Alice}

3) Certificate (ID_{Alice}, PK_{Alice})

1) Alice generates PK_{Alice} and SK_{Alice}

Public-key certificate

- Certificate:
  - the signature of the certificate authority binds together a public-key with an identity.
  - Bob can be sure that the public-key belongs to Alice by checking the signature using the CA public-key.
  - The CA is trusted by all participants.

Certificate Authority

- CA issues PK certificates that attest that the PK in the certificate belongs to the identity in the certificate
  - CA must verify user's identity before issuing certificate
  - If the CA's private key is compromised, security is lost.
- Largest providers of certificates
  - Verisign, Geotrust

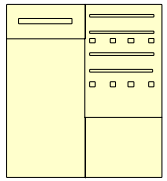
Public-key certificate

- A public-key certificate may include
  - user's public-key
  - name (person, computer, or company)
  - validity period.
  - location (URL) of a revocation center.
  - digital signature of the certificate, produced by the CA's private key.

Certificate revocation

- Certificate revocation when
  - Private-key is compromised
  - Identity/PK binding incorrect.
- A user should always check the validity of a certificate
  - CA can maintain a Certificate Revocation List (CRL)
  - Must be up to date and readily available

PKI encryption



CA authority

7. Certificate OK

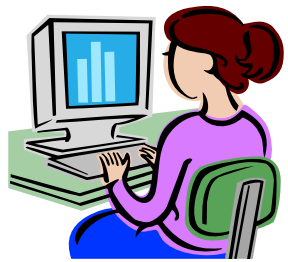
6. Bob verifies certificate. Bob checks for revocation

2. Alice authenticates and sends PK_{Alice}

3. Certificate (ID_{Alice}, PK_{Alice})

4. Bob requests Alice's certificate

5. Alice sends certificate



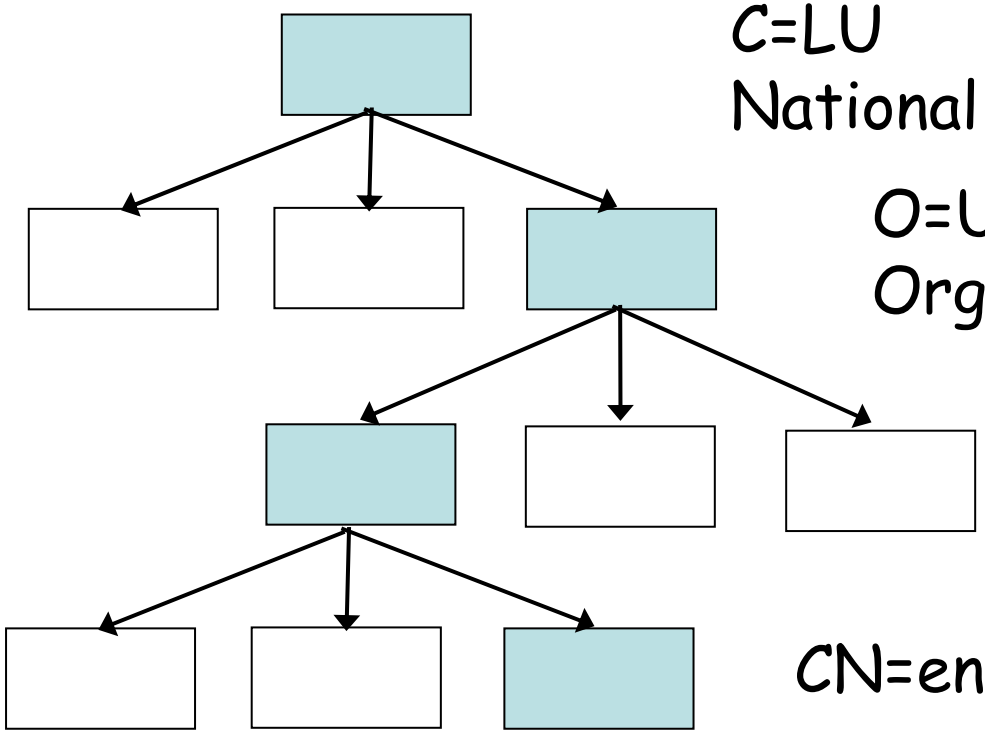
8. Bob send secure email using PK_{Alice}

1. Alice generates PK_{Alice}/SK_{Alice}

Hierarchy of certificates

- Bob may not know Alice's CA
  - The CA may be Alice's employer, and Bob may work for a different company.
- Alice's certificate can include her CA's public-key signed by a higher level CA_2
  - This CA_2 may be recognized by Bob
- This leads to a hierarchy of certificates

Certificate Hierarchy



C=LU
National CA, root certificate

O=University of Luxembourg
Organizational CA

OU=CS Department
Departmental CA

CN=end user

Certificate Standard

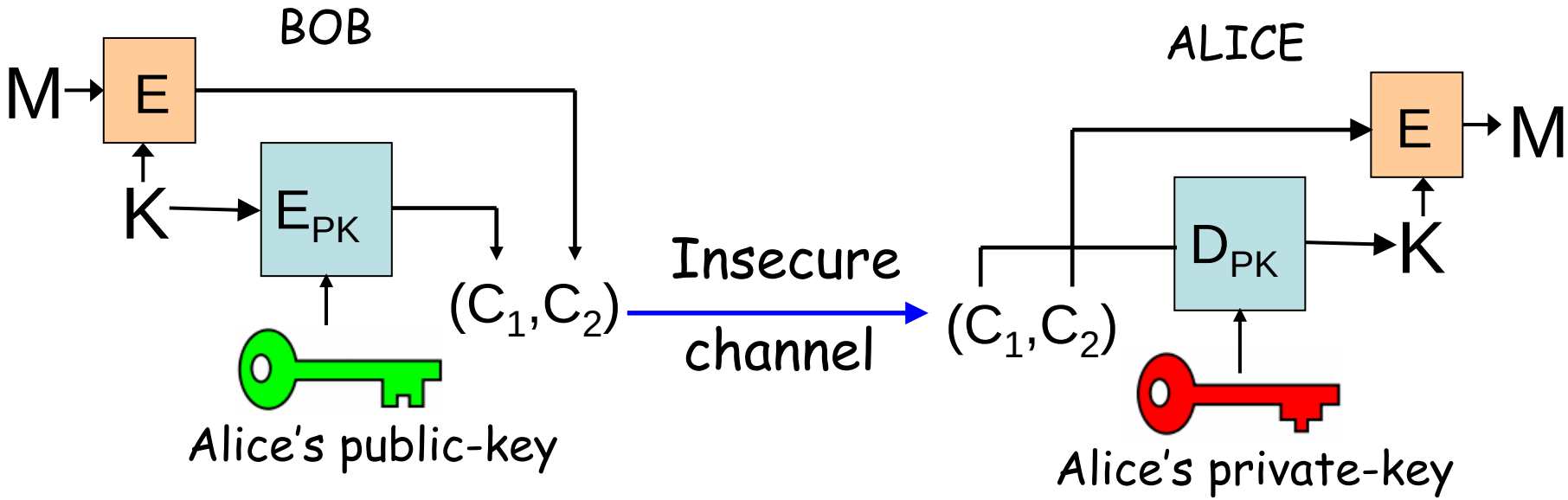
- X509
  - Most common certificate standard
  - Specifies certificate format and certificate validation path.
  - Assumes a hierarchy of CA
  - Root certificate is implicitly trusted
  - Specifies certificate revocation list (CRL) implementation

Root certificate

- Unsigned public-key certificate located at the top of a certificate chain.
  - Typically in X509 standard
  - Implicitly trusted
- Included in web browsers
  - Used for SSL/TLS connections
  - One needs to trust the browser's publisher to include correct root certificates.
  - Single point of failure
- In practice, hierarchy is flat.

PGP

- PGP (Pretty Good Privacy)
  - Software that provides email encryption and signature (and more).
  - First version by P. Zimmermann in 1991.
  - Uses PK encryption to encrypt a shared key, which is used to encrypt the message.

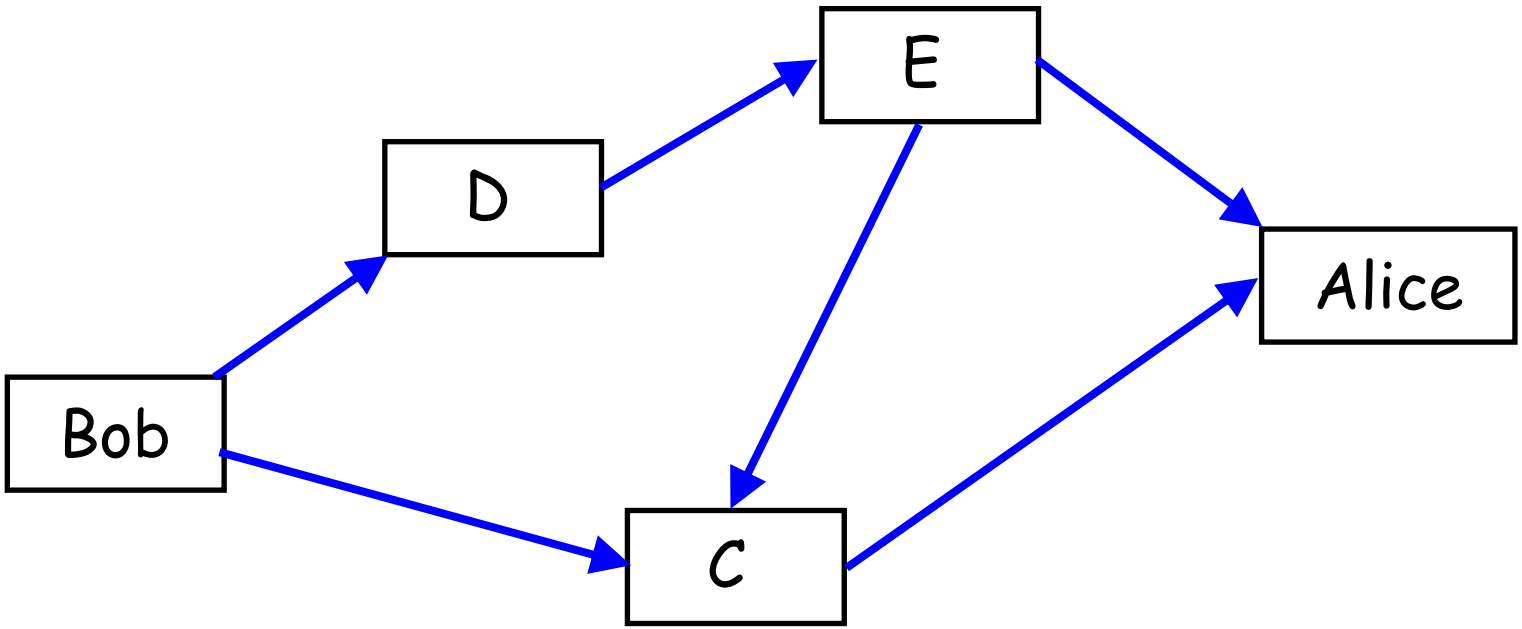


PGP

- Digital signature
  - When sending a message m, Bob can sign m with his private key.
  - Alice checks the signature with Bob's PK, so that Alice is convinced that m was sent by Bob and received unaltered.
  - RSA signature or DSA signature.
  - Used by default with encryption, but can be used for plaintext as well

PGP Web of trust

- Any party can sign the (PK,ID) of another.
- Decentralized web of trust



OpenPGP and GnuPG

- OpenPGP
  - Standard for PGP encryption since 1997.
  - Avoids patented algorithms
- GNU Privacy Guard (GnuPG)
  - developed by Free Software Foundation and freely available with source code.
  - Supports ElGamal, DSA, RSA, AES, 3DES, Blowfish, Twofish, CAST5, MD5, SHA-1, RIPE-MD-160 and TIGER.

SSL

- Used to provide secure web-browsing.
  - SSL 3.0 similar to TLS 1.0
  - ensures confidentiality, integrity and authenticity over the Internet.
- Generally, only the server is authenticated
  - Mutual authentication requires a PKI for the client.

SSL

- Three steps
  - Negotiation for algorithms used.
  - Certificate verification and PK encryption for session key.
  - Symmetric encryption for traffic encryption.

Cipher suite negotiation

- Client sends a ClientHello message to specify supported algorithms
  - For example, RSA, AES and HMAC-SHA-1
- Server sends a ServerHello message to specify its choice of algorithm.
  - Server adapts to client capabilities.

SSL: second phase

- Server sends certificate to client.
  - Generally, X509 certificate
- Server can request client certificate for mutual authentication
  - Rarely used in practice
- Client and Server establish a « master secret »
  - by PK encryption of a random seed by the client (generally RSA)
  - or possibly by Diffie-Hellman key exchange (rarely used)

SSL second phase (2)

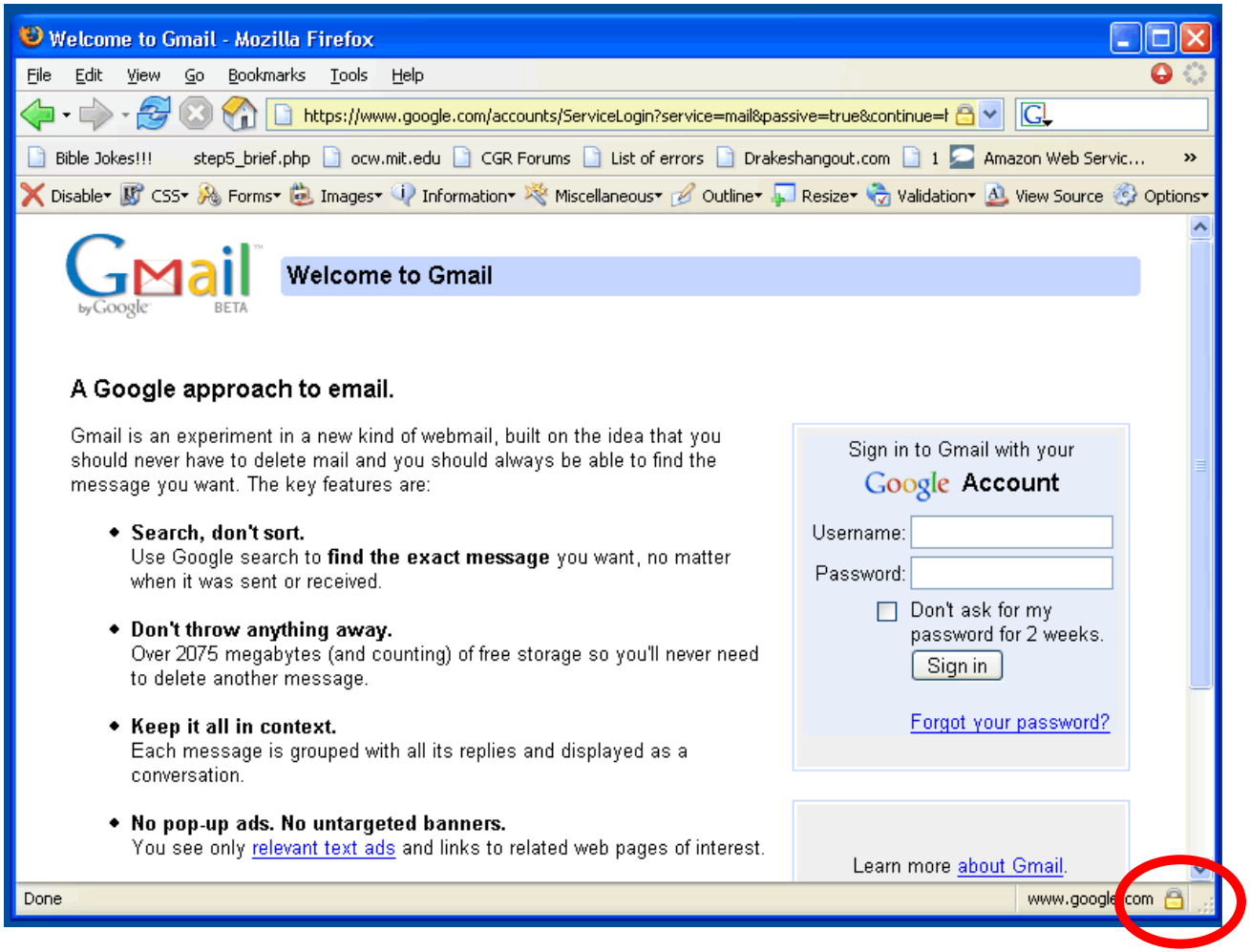
- Server authenticated by proof of possession of private key
  - Ability to decrypt client data.
  - Both sides share the same « master secret »
- Client/server finish
  - Authenticate all previously exchanged data with MACs

SSL: third phase

- Traffic encryption
  - Using symmetric cipher
  - Some early implementations of SSL used 40-bit keys because of US government restrictions on crypto export
  - Now relaxed export restrictions. Modern implementations use 128 bit keys for symmetric key.
- Integrity protection via MACs

Applications of SSL

- Mainly used to secure HTTP => HTTPS



Credit card via https

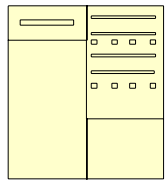
- https only protects the credit card number during transit between the user's computer and the server
  - Does not protect against an attack on the server
- Attack on the server usually easier than interception in transit.
  - Credit card number often saved in a database in merchant site
  - Attacks generally concentrate on the server and database

Identity-Based encryption

- Principle
  - Allows a party to encrypt a message using the recipient's identity as the public-key
  - The corresponding private key is provided by a central authority
- History
  - Concept invented by Shamir in 1984
  - First realization by Boneh and Franklin in 2001

IBE

- Bob sends an email to Alice using his identity as the public-key



Key server

2. Alice authenticates

3. Private-key for Alice

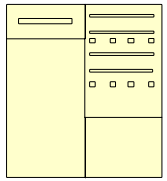
1. Bob encrypts with public-key **alice@a.com**

Bob send secure email

IBE

- Principle
  - Bob encrypts his email using Alice's email adress alice@a.com as the public key
  - Alice receives the message. She contacts the key server, authenticates, and receives her private key.
  - Alice uses her private-key to decrypt the message
  - This private-key can be used to decrypt any future message sent to Alice by Bob or any other user.

Difference with conventional PKI



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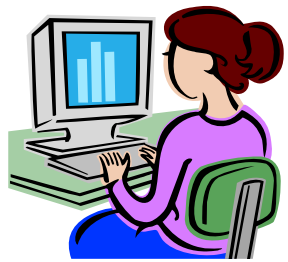

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Adantages of IBE

- Simplification compared to PKI
  - No need to distribute PK certificates
  - Users can use their email adress as PK
  - Recipient does not have to be online to present PK certificate.
  - Sender does not have to be online to check validity of certificate
  - Bob can send an email to Alice even if Alice has not yet registered in the system

Boneh-Franklin

- First efficient IBE, proposed by Boneh and Franklin at Crypto 2001
  - Most famous IBE scheme to date.
  - Based on the bilinear pairing operation on an Elliptic-Curve.
  - Provably secure encryption scheme
  - IBCS#1 standard, published by Voltage Security.

Applications of IBE

- Email encryption
  - A company hosts the Private-Key generator (PKG) and distributes private-keys to its employees.
  - Employees can communicate securely between themselves, using their email address as their public-key
  - Nobody expect the mail recipient (and the PKG) can decipher the communications
  - Private-keys can also be distributed outside the company

Revocation of Public-keys

- Key-revocation in IBE is simple
  - Bob encrypts his email to Alice using the public-key « **alice@company.com ¦¦ current-year** »
  - Alice can only decrypt if she has obtained the private-key for the corresponding year.
  - With « **alice@company.com ¦¦ current-date** » instead, Alice must obtain a new private-key every day
  - Key revocation: the PKG simply stops issuing private-keys to Alice if Alice leaves the company. Then she can no longer read her email
- Encrypting into the future
  - With « **alice@company.com ¦¦ future-date** »

Conclusion

- Public-key Infrastructure
  - Necessary to authenticate public-keys
  - Difficult to set up and maintain
    - Certificate Revocation List
  - Used for PGP encryption and SSL/TLS.
- IBE could be an alternative
  - But central authority can decrypt everything.