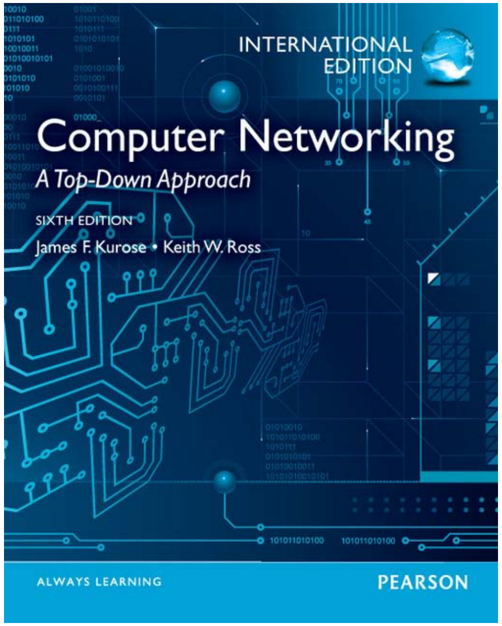
Chapter 8
Network Security



Chapter 8: Network Security

Chapter goals:

- understand principles of network security:
  - cryptography and its *many* uses beyond "confidentiality"
  - authentication
  - message integrity
- security in practice:
  - firewalls and intrusion detection systems
  - security in application, transport, network, link layers

Chapter 8 roadmap

8.1 What is network security?

8.2 Principles of cryptography

8.3 Message integrity

8.4 Securing e-mail

8.5 Operational security: firewalls and IDS

What is network security?

Confidentiality: only sender, intended receiver should “understand” message contents

- sender encrypts message
- receiver decrypts message

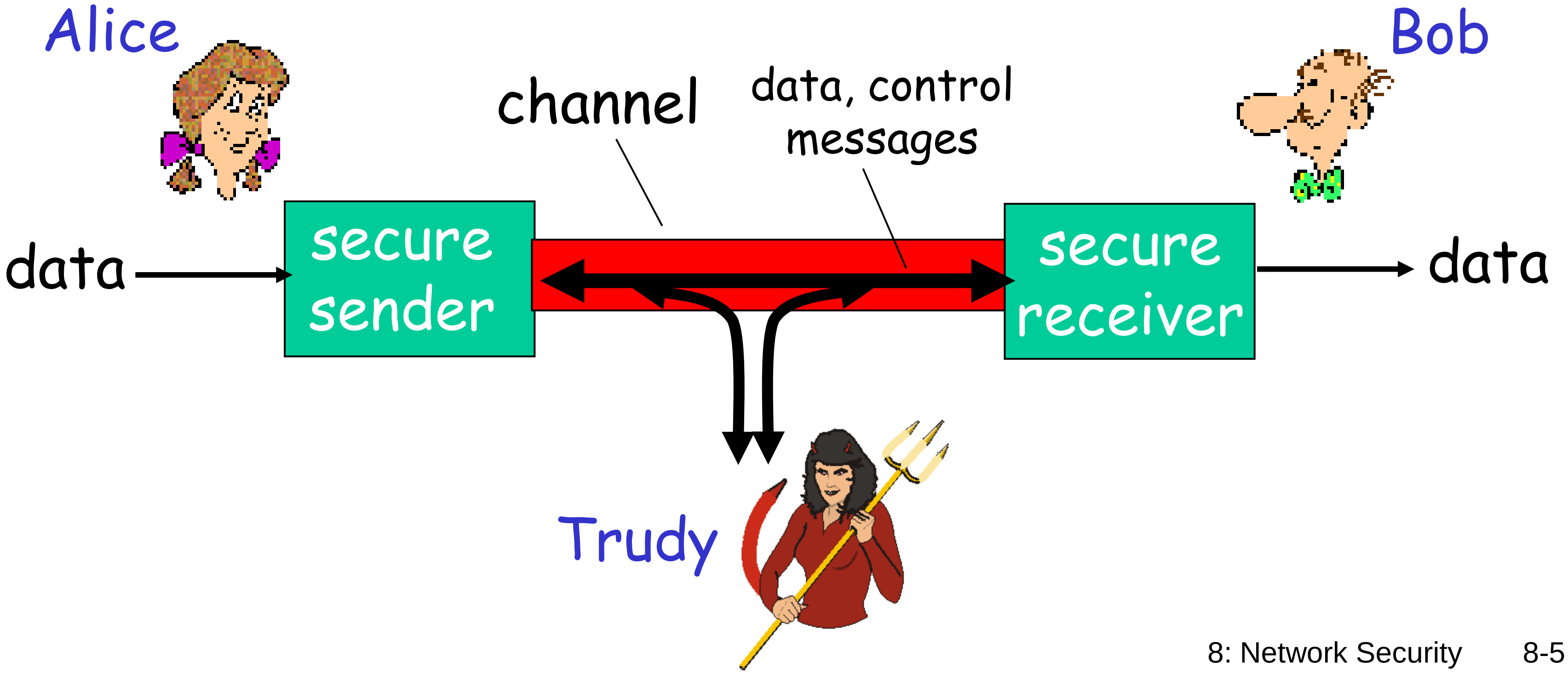
Authentication: sender, receiver want to confirm identity of each other

Message integrity: sender, receiver want to ensure message not altered (in transit, or afterwards) without detection

Access and availability: services must be accessible and available to users

Friends and enemies: Alice, Bob, Trudy

- well-known in network security world
- Bob, Alice (lovers!) want to communicate “securely”
- Trudy (intruder) may intercept, delete, add messages



There are bad guys (and girls) out there!

Q: What can a "bad guy" do?

A: a lot!

- *eavesdrop:* intercept messages
- actively *insert* messages into connection
- *impersonation:* can fake (spoof) source address in packet (or any field in packet)
- *hijacking:* "take over" ongoing connection by removing sender or receiver, inserting himself in place
- *denial of service*: prevent service from being used by others (e.g., by overloading resources)

more on this later ……

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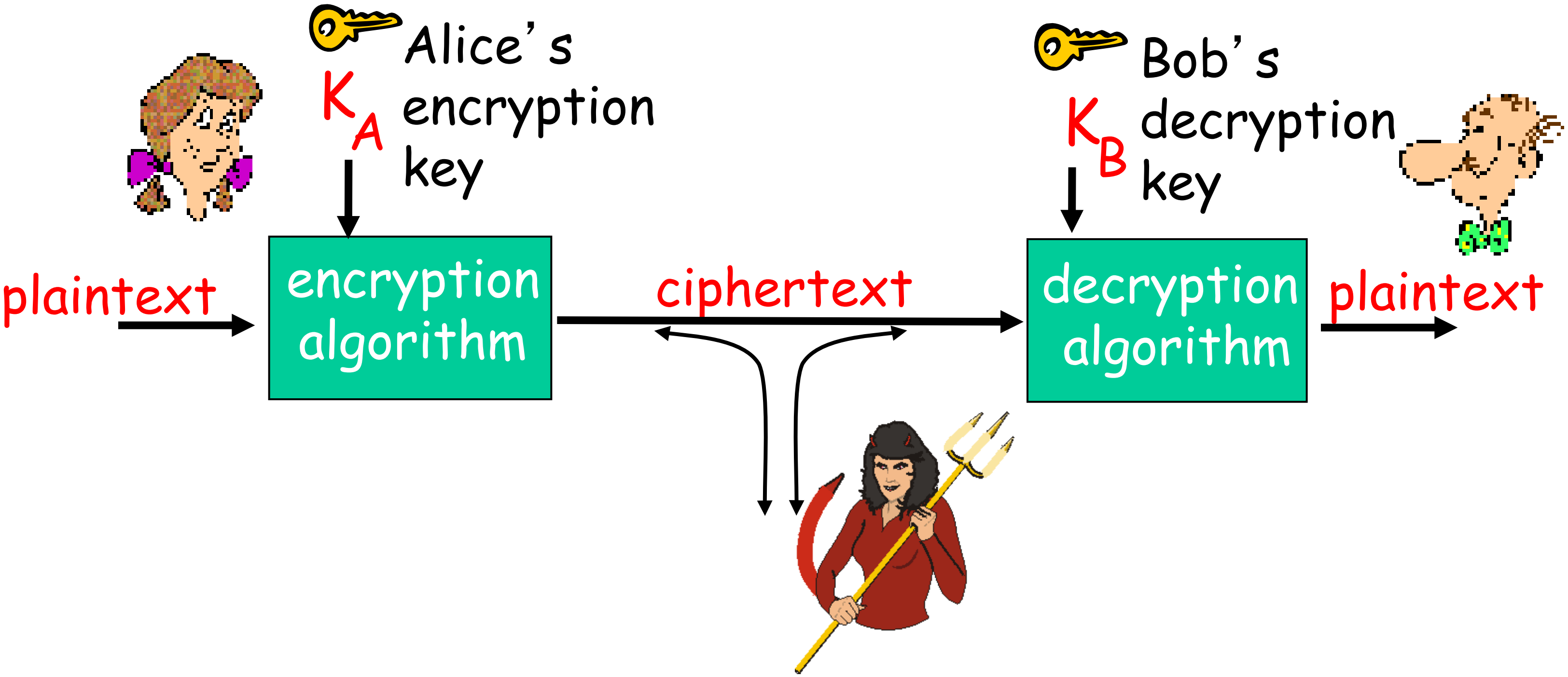
The language of cryptography



symmetric key crypto: sender, receiver keys *identical*

public-key crypto: encryption key *public*, decryption key *secret* (private)

Symmetric key cryptography

substitution cipher: substituting one thing for another

- monoalphabetic cipher: substitute one letter for another

```
 plaintext:  abcdefghijklmnopqrstuvwxyz

ciphertext:  mnbvcxzasdfghjklpoiuytrewq
```

E.g.:

```
Plaintext: bob. i love you. alice
ciphertext: nkn. s gktc wky. mgsbc
```

Exercise

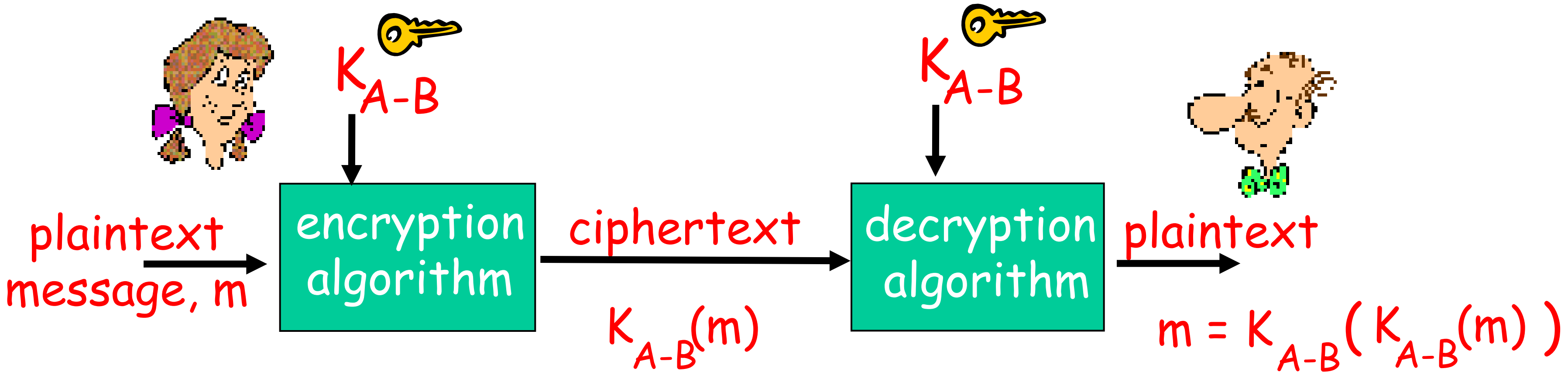
```
 plaintext:  abcdefghijklmnopqrstuvwxyz

ciphertext:  mnbvcxzasdfghjklpoiuytrewq
```

(a) Encode the message “This is an easy problem”

(b) Decode the message “rmij’ u uamu xyj.”

(c) How hard to break this simple cipher?

Symmetric key cryptography



symmetric key crypto: Bob and Alice share know same (symmetric) key: K_{A-B}

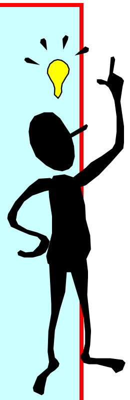
- e.g., key is knowing substitution pattern in mono alphabetic substitution cipher
- Q: how do Bob and Alice agree on key value?

Public key cryptography

symmetric key crypto

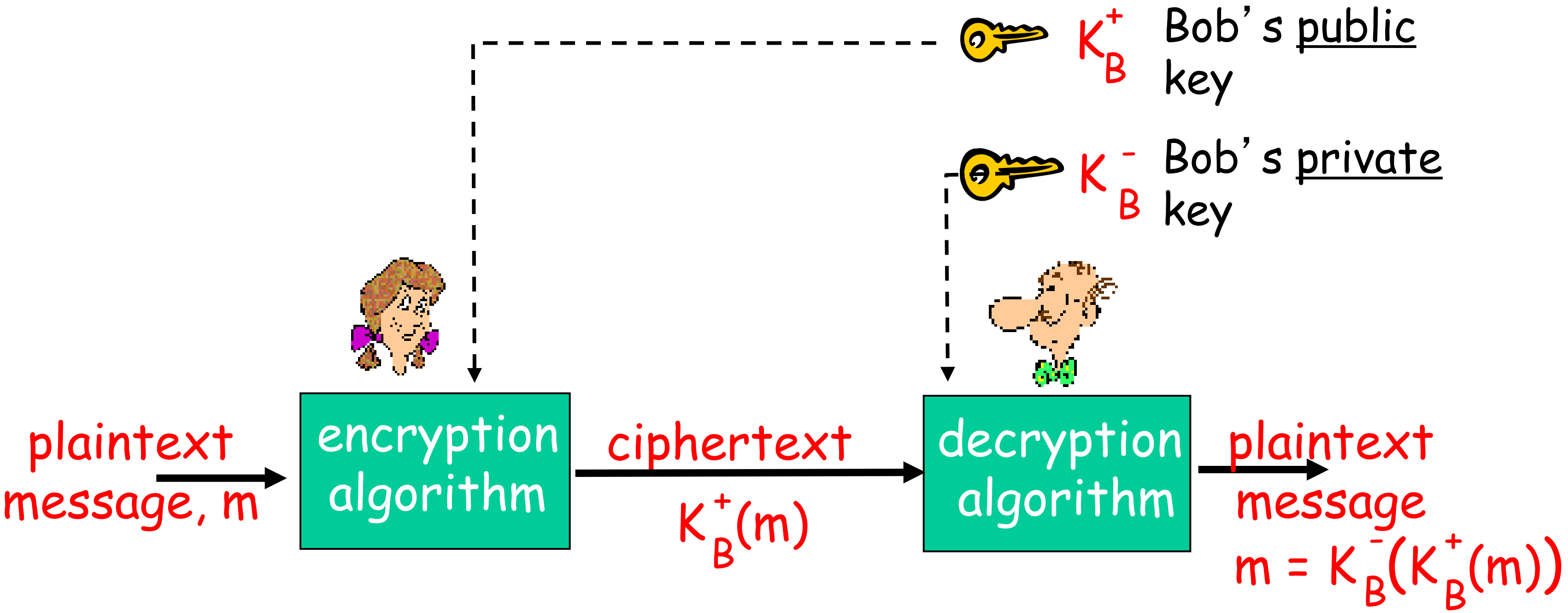
- requires sender, receiver know shared secret key
- Q: how to agree on key in first place (particularly if never “met”)?

public key cryptography



- radically different approach [Diffie-Hellman76, RSA78]
- sender, receiver do *not* share secret key
- *public* encryption key known to *all*
- *private* decryption key known only to receiver

Public key cryptography



K_B^+ Bob's public key

K_B^- Bob's private key

plaintext message, m

encryption algorithm

ciphertext

$K_B^+(m)$

decryption algorithm

plaintext message

$m = K_B^-(K_B^+(m))$

Public key encryption algorithms

Requirements:

① need $K_B^+(\cdot)$ and $K_B^-(\cdot)$ such that

$$K_B^-(K_B^+(m)) = m$$

② given public key K_B^+, it should be impossible to compute private key K_B^-

RSA: Rivest, Shamir, Adleman algorithm

RSA: Choosing keys

1. Choose two large prime numbers *p, q.* (e.g., 1024 bits each)

2. Compute $n = pq$, $z = (p-1)(q-1)$

3. Choose *e* (with $e<n$) that has no common factors with z. (*e, z* are “relatively prime”).

4. Choose *d* such that $ed-1$ is exactly divisible by *z*. (in other words: $ed \bmod z = 1$).

5. *Public* key is $\underbrace{(n,e)}_{K_B^+}$. *Private* key is $\underbrace{(n,d)}_{K_B^-}$.

RSA: Encryption, decryption

0. Given (n,e) and (n,d) as computed above

1. To encrypt bit pattern, m, compute
   $c = m^e \bmod n$ (i.e., remainder when m^e is divided by n)

2. To decrypt received bit pattern, c, compute
   $m = c^d \bmod n$ (i.e., remainder when c^d is divided by n)

Magic happens!

$$m = (\underbrace{m^e \bmod n}_{c})^d \bmod n$$

RSA example:

Bob chooses *p=5, q=7*. Then *n=35, z=24.*

e=5 (so *e, z* relatively prime).

d=29 (so *ed-1* exactly divisible by z.

	letter	m	m^e	$c = m^e \bmod n$
encrypt:	l	12	1524832	17

	c	c^d	$m = c^d \bmod n$	letter
decrypt:	17	481968572106750915091411825223071697	12	l

RSA: Why is that $m = (m^e \bmod n)^d \bmod n$

Useful number theory result: If p,q prime and $n = pq$, then:

$$x^y \bmod n = x^{y \bmod (p-1)(q-1)} \bmod n$$

$$(m^e \bmod n)^d \bmod n = m^{ed} \bmod n$$

$$= m^{ed \bmod (p-1)(q-1)} \bmod n$$

(using number theory result above)

$$= m^1 \bmod n$$

(since we chose *ed* to be divisible by *(p-1)(q-1)* with remainder 1)

$$= m$$

RSA: another important property

The following property will be *very* useful later:

$$\underbrace{K_B^-(K_B^+(m))}_{\substack{\text{use public key}\\ \text{first, followed}\\ \text{by private key}}} = m = \underbrace{K_B^+(K_B^-(m))}_{\substack{\text{use private key}\\ \text{first, followed}\\ \text{by public key}}}$$

Result is the same!

Exercise

- Using RSA, choose p=3, q=11, and encode the word “hello.” Apply the decryption algorithm to the encrypted version to recover the original plaintext message.

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Message Integrity

Bob receives msg from Alice, wants to ensure:

- message originally came from Alice
- message not changed since sent by Alice

Cryptographic Hash:

- takes input m, produces fixed length value, H(m)
  - e.g., as in Internet checksum
- computationally infeasible to find two different messages, x, y such that H(x) = H(y)
  - equivalently: given m = H(x), (x unknown), can not determine x.
  - note: Internet checksum *fails* this requirement!

Internet checksum: poor crypto hash function

Internet checksum has some properties of hash function:

ü produces fixed length digest (16-bit sum) of message

ü is many-to-one

But given message with given hash value, it is easy to find another message with same hash value:

message	ASCII format
I O U 1	49 4F 55 31
0 0 . 9	30 30 2E 39
9 B O B	39 42 4F 42
	B2 C1 D2 AC

message	ASCII format
I O U 9	49 4F 55 39
0 0 . 1	30 30 2E 31
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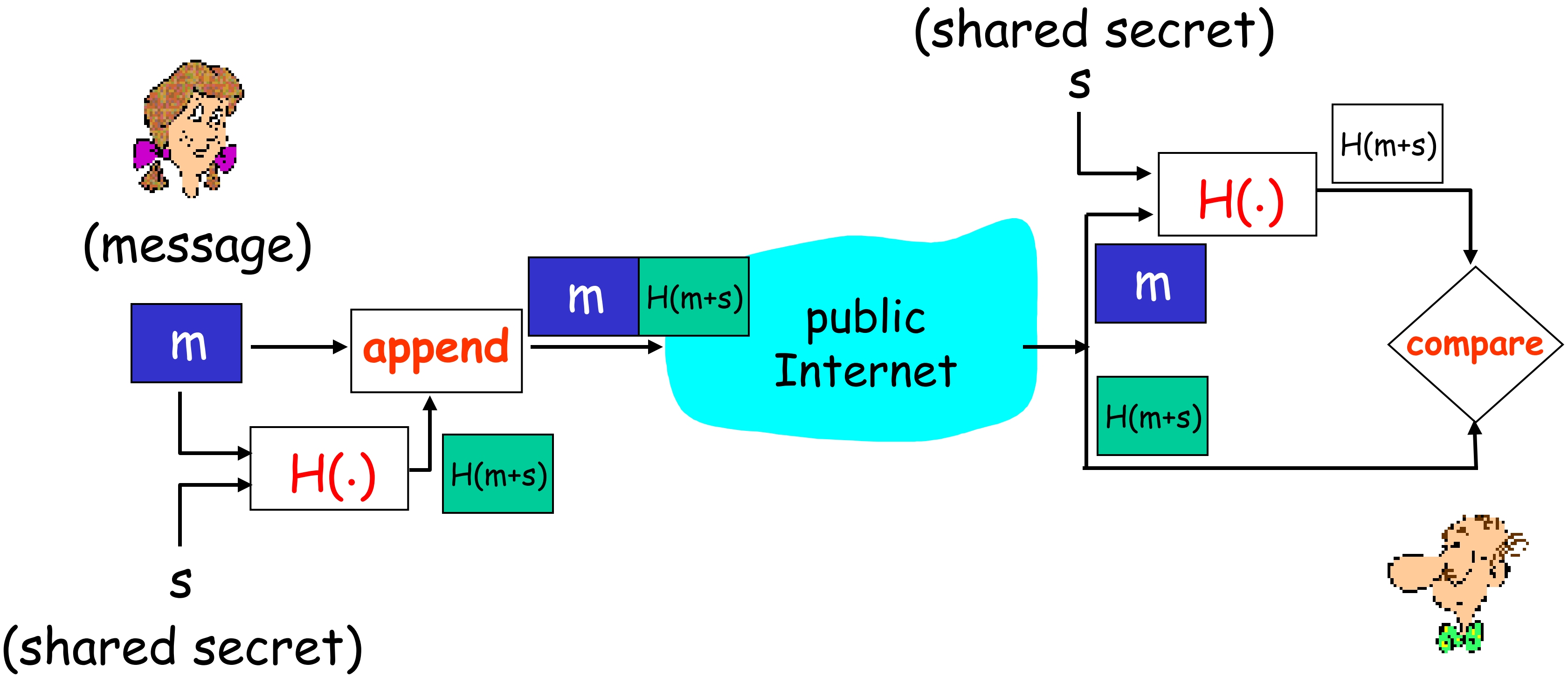
	B2 C1 D2 AC

different messages but identical checksums!

Message Authentication Code



Digital Signatures

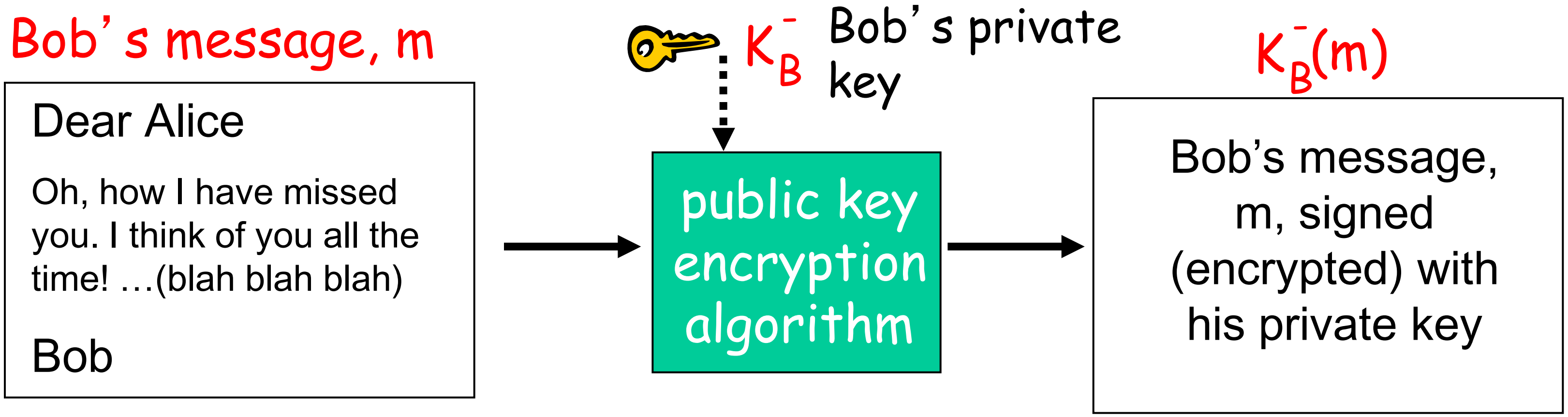
cryptographic technique analogous to hand-written signatures.

- sender (Bob) digitally signs document, establishing he is document owner/creator.
- verifiable, nonforgeable: recipient (Alice) can prove to someone that Bob, and no one else (including Alice), must have signed document

Digital Signatures

simple digital signature for message m:

r Bob “signs” m by encrypting with his private key K_B^-, creating “signed” message, $K_B^-(m)$



Bob’s message, m

Dear Alice

Oh, how I have missed you. I think of you all the time! …(blah blah blah)

Bob

K_B^- Bob’s private key

public key encryption algorithm

$K_B^-(m)$

Bob’s message, m, signed (encrypted) with his private key

Digital Signatures (more)

r suppose Alice receives msg m, digital signature $K_B^-(m)$

r Alice verifies m signed by Bob by applying Bob's public key K_B^+ to $K_B^-(m)$ then checks $K_B^+(K_B^-(m)) = m$.

r if $K_B^+(K_B^-(m)) = m$, whoever signed m must have used Bob's private key.

Alice thus verifies that:

ü Bob signed m.

ü No one else signed m.

ü Bob signed m and not m'.

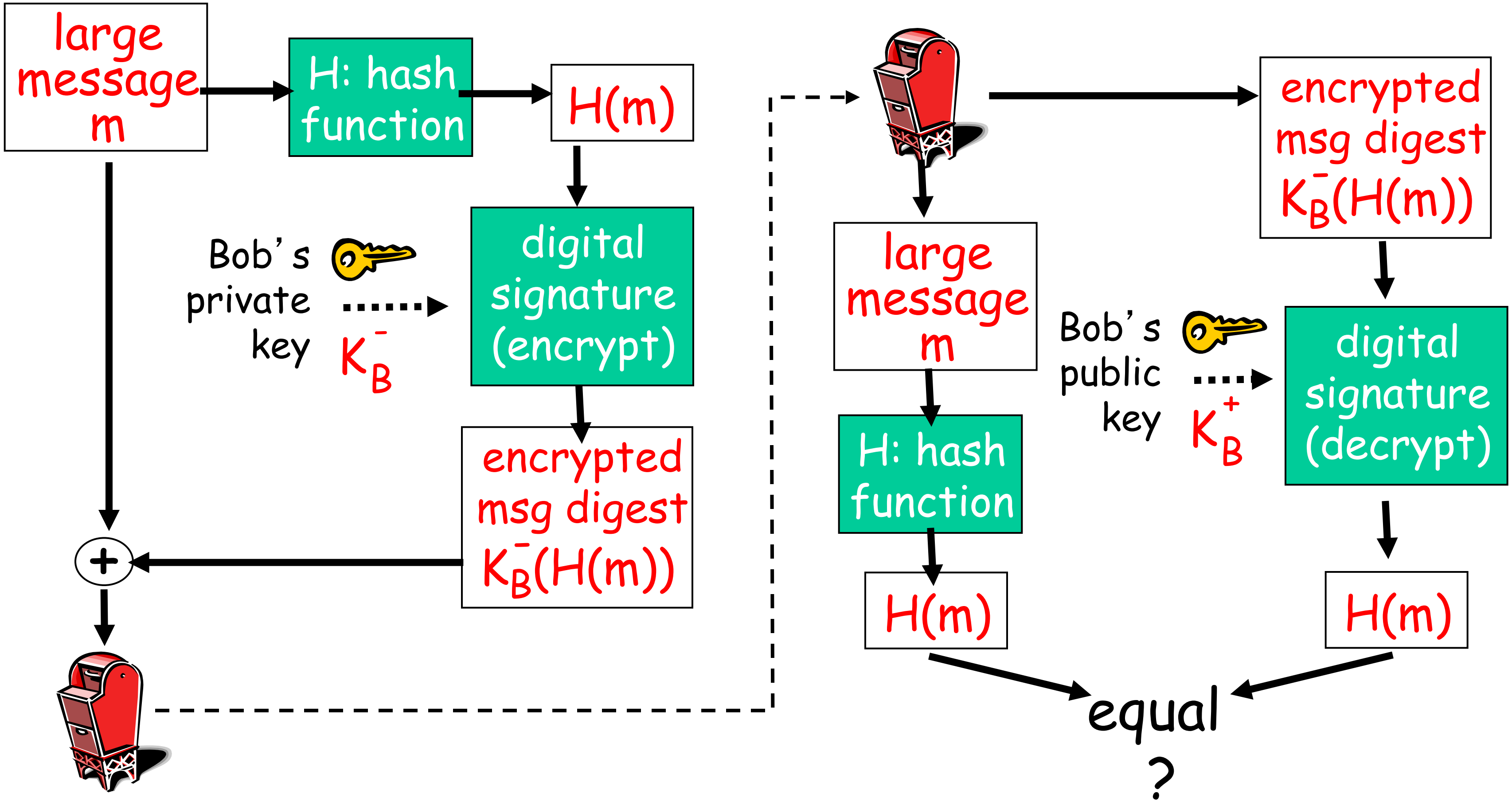
non-repudiation:

✓ Alice can take m, and signature $K_B^-(m)$ to court and prove that Bob signed m.

Digital signature = signed MAC

Bob sends digitally signed message:

Alice verifies signature and integrity of digitally signed message:



large message m

H: hash function

H(m)

Bob's private key K_B^-

digital signature (encrypt)

encrypted msg digest $K_B^-(H(m))$

+

large message m

H: hash function

H(m)

encrypted msg digest $K_B^-(H(m))$

Bob's public key K_B^+

digital signature (decrypt)

H(m)

equal ?

Public Key Certification

public key problem:

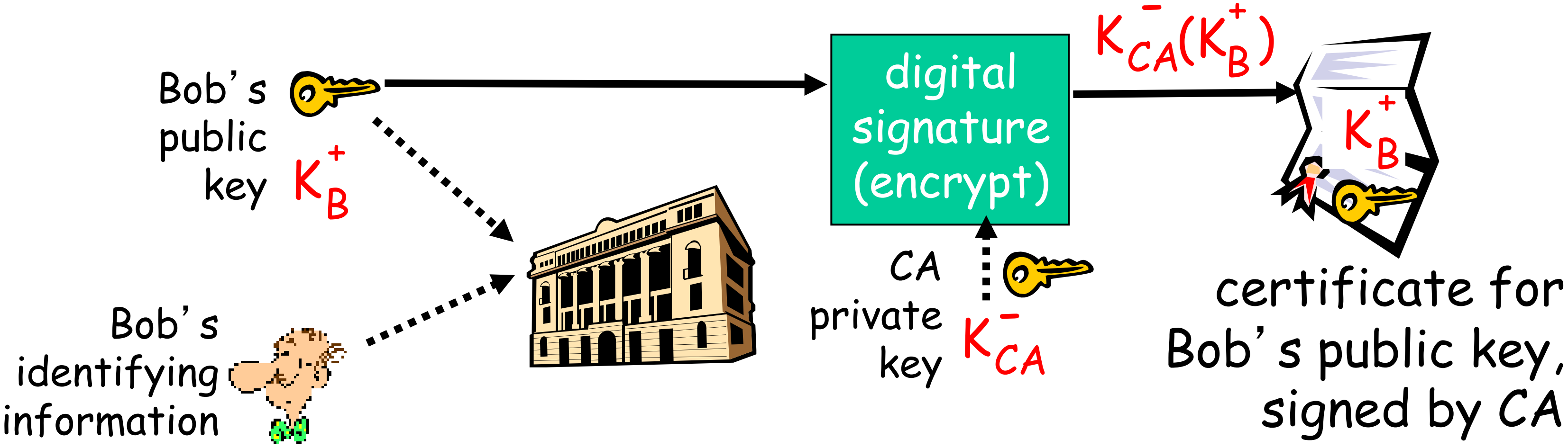
- When Alice obtains Bob's public key (from web site, e-mail, diskette), how does she *know* it is Bob's public key, not Trudy's?

solution:

- trusted certification authority (CA)

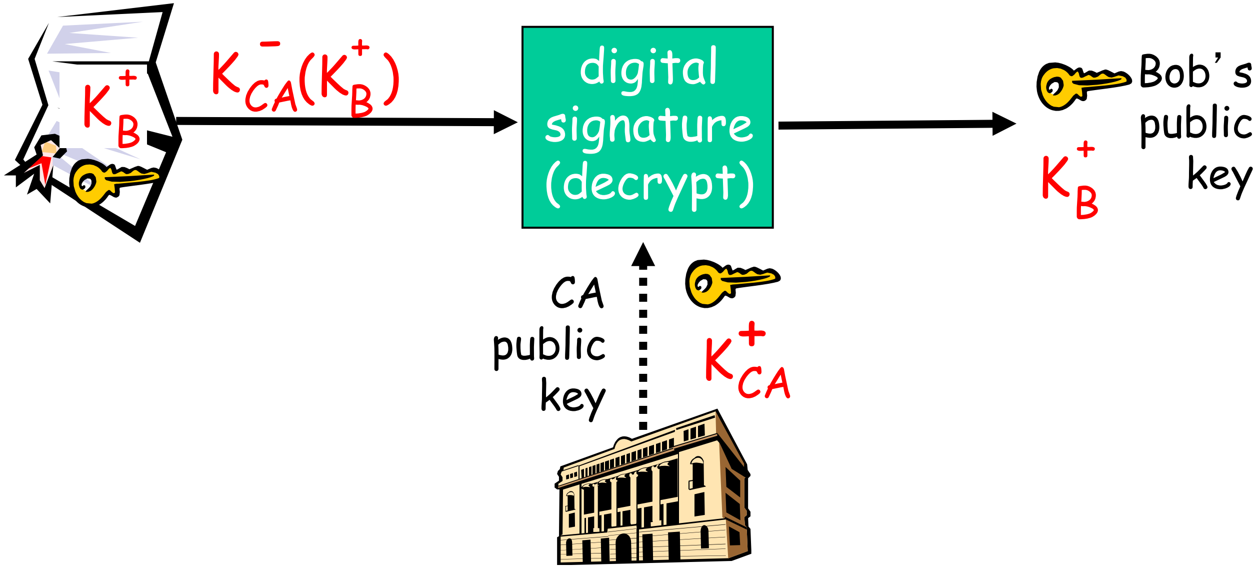
Certification Authorities

- Certification Authority (CA): binds public key to particular entity, E.
- E registers its public key with CA.
  - E provides "proof of identity" to CA.
  - CA creates certificate binding E to its public key.
  - certificate containing E's public key digitally signed by CA: CA says "This is E's public key."


Bob's public key
K_B^+
Bob's identifying information
digital signature (encrypt)
$K_{CA}^-(K_B^+)$
K_B^+
CA private key
K_{CA}^-
certificate for Bob's public key, signed by CA

Certification Authorities

- when Alice wants Bob's public key:
  - gets Bob's certificate (Bob or elsewhere).
  - apply CA's public key to Bob's certificate, get Bob's public key



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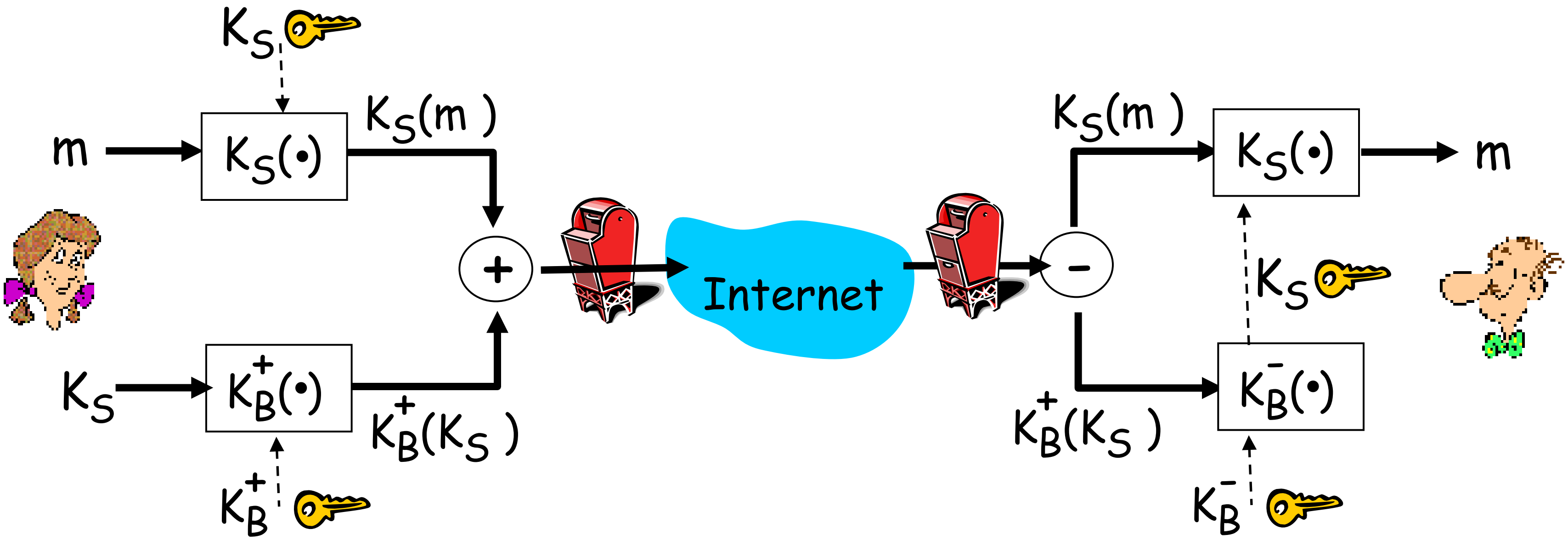
Secure e-mail

- Alice wants to send confidential e-mail, m, to Bob.

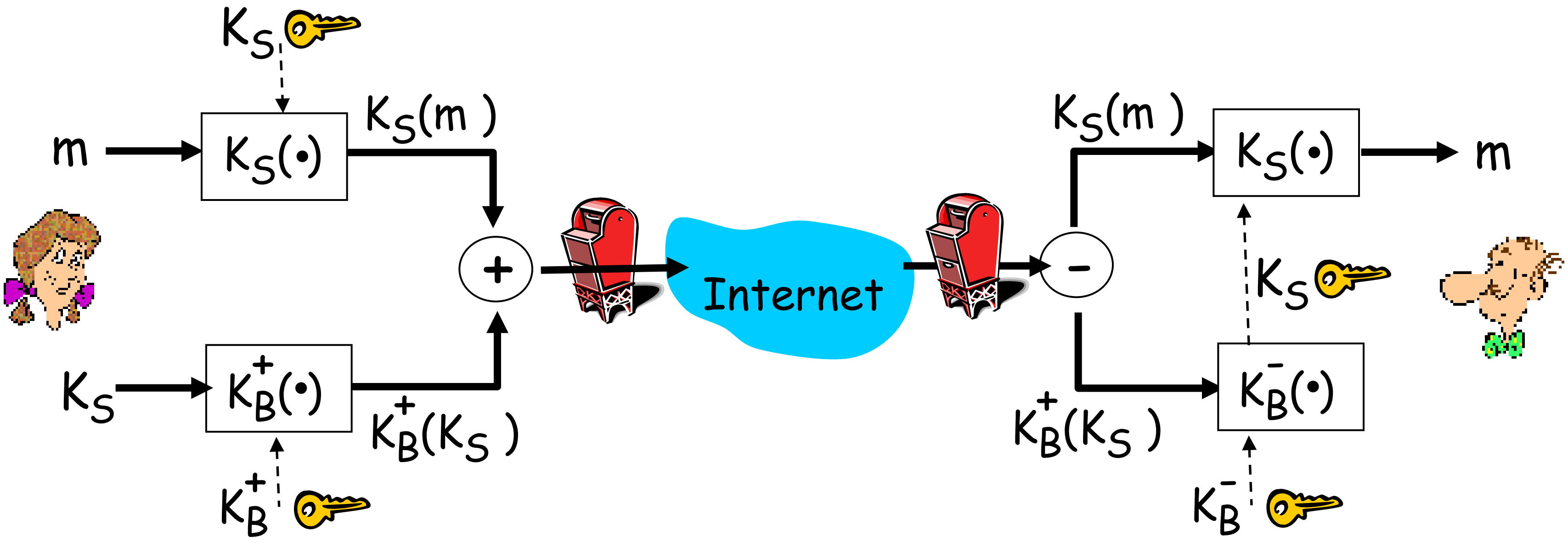


Alice:

- generates random *symmetric* private key, K_S.
- encrypts message with K_S (for efficiency)
- also encrypts K_S with Bob's public key.
- sends both $K_S(m)$ and $K_B(K_S)$ to Bob.

Secure e-mail

- Alice wants to send confidential e-mail, m, to Bob.

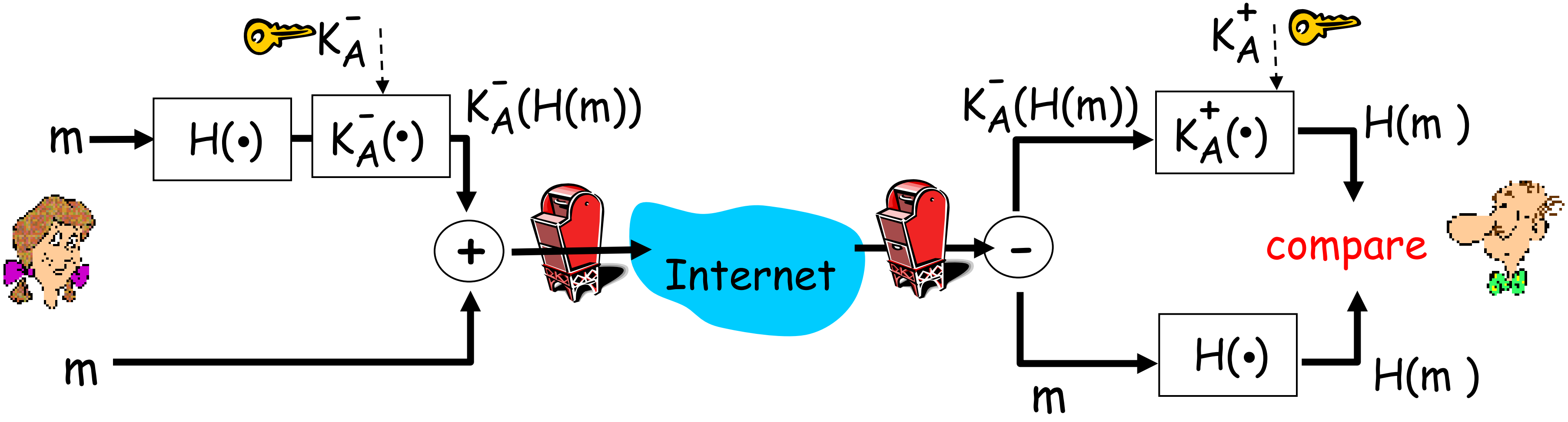


Bob:

- uses his private key to decrypt and recover K_S
- uses K_S to decrypt $K_S(m)$ to recover m

Secure e-mail (continued)

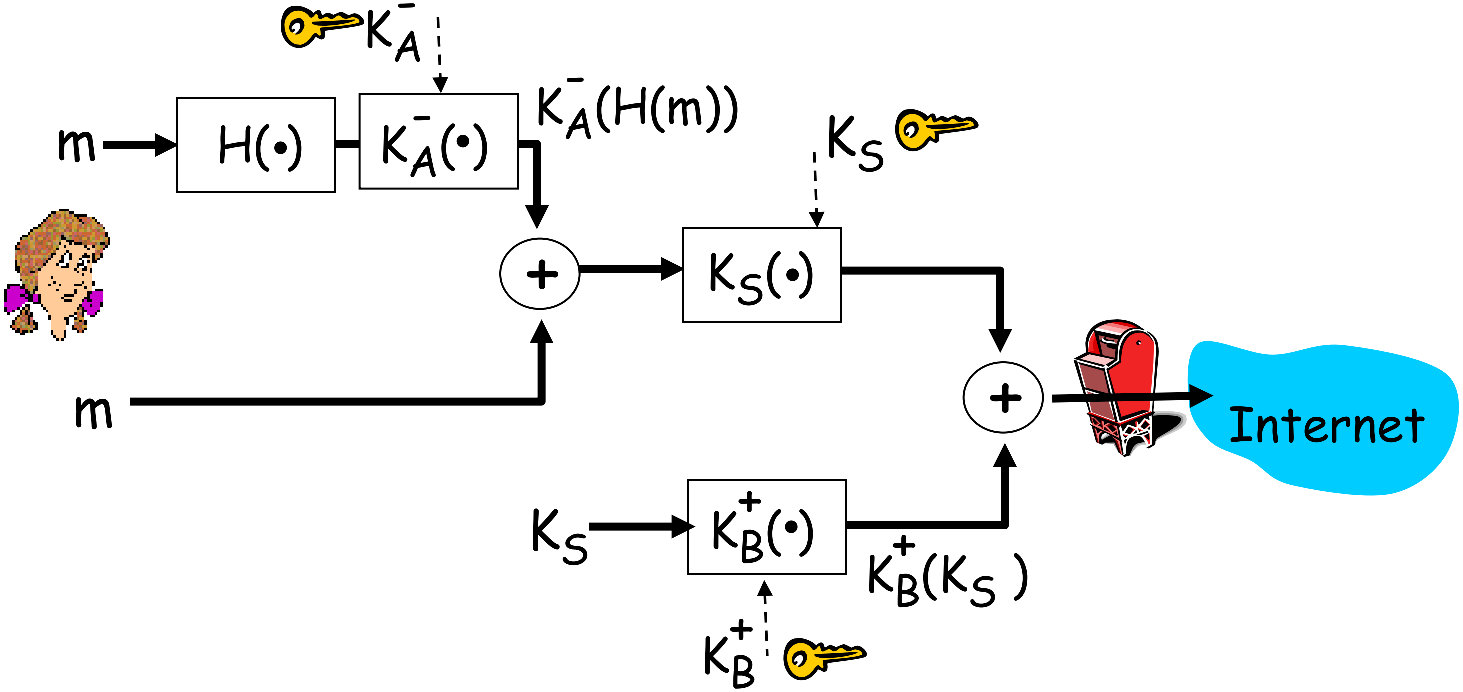
- Alice wants to provide sender authentication message integrity.



- Alice digitally signs message.
- sends both message (in the clear) and digital signature.

Secure e-mail (continued)

- Alice wants to provide secrecy, sender authentication, message integrity.



Alice uses three keys: her private key, Bob's public key, newly created symmetric key

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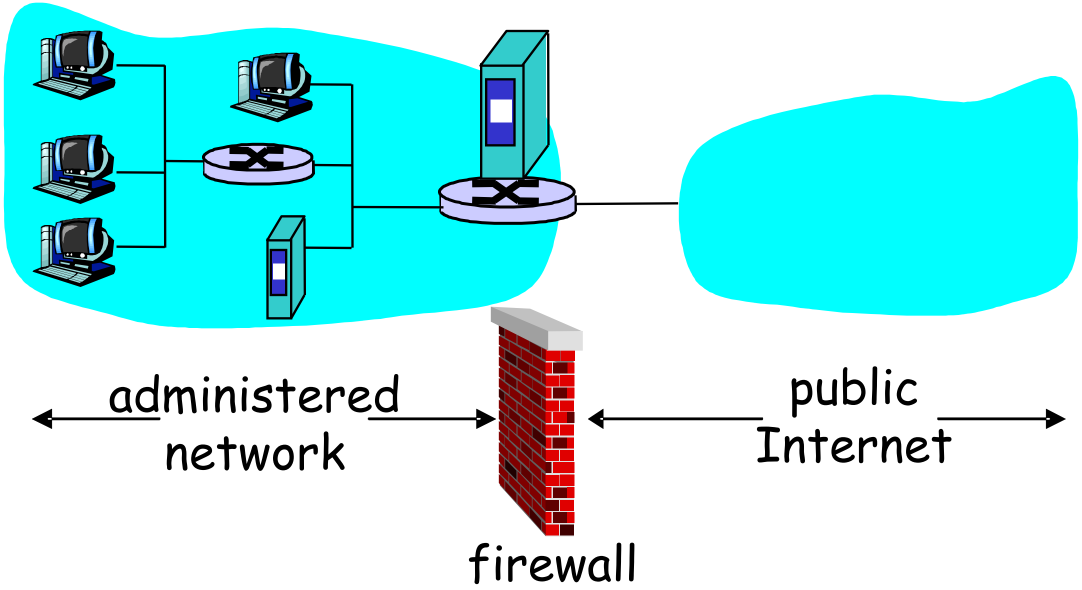
Firewalls

firewall

isolates organization's internal net from larger Internet, allowing some packets to pass, blocking others.



Firewalls: Why

prevent denial of service attacks:

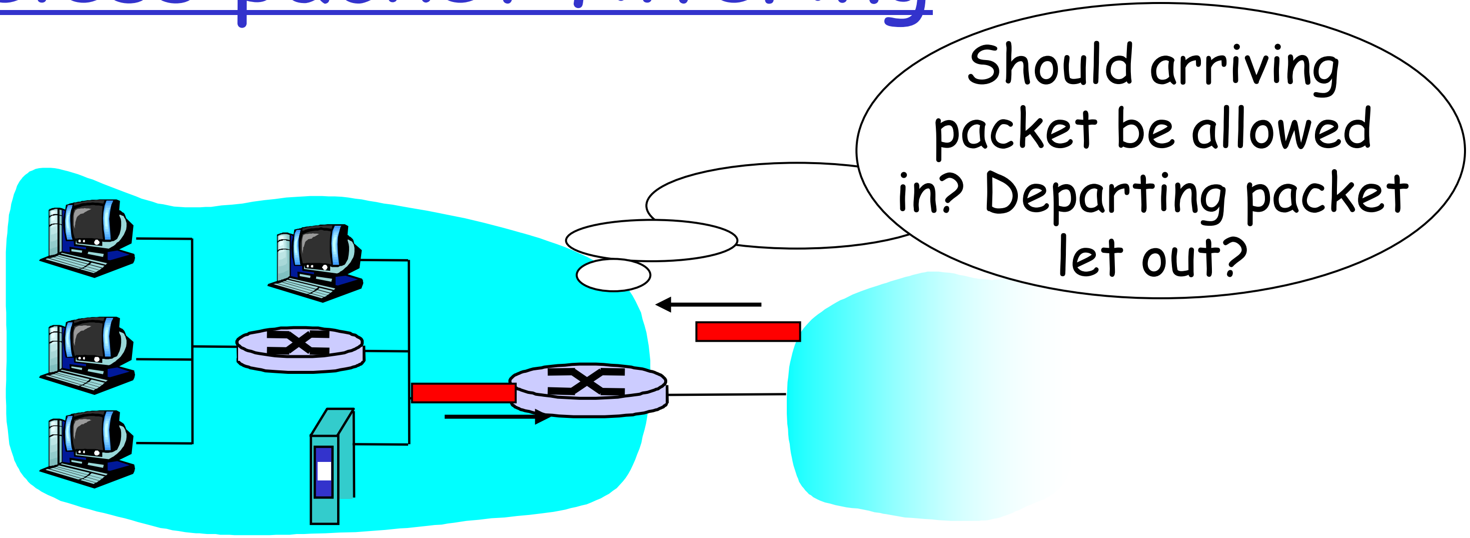
- SYN flooding: attacker establishes many bogus TCP connections, no resources left for "real" connections

prevent illegal modification/access of internal data.

- e.g., attacker replaces CIA's homepage with something else

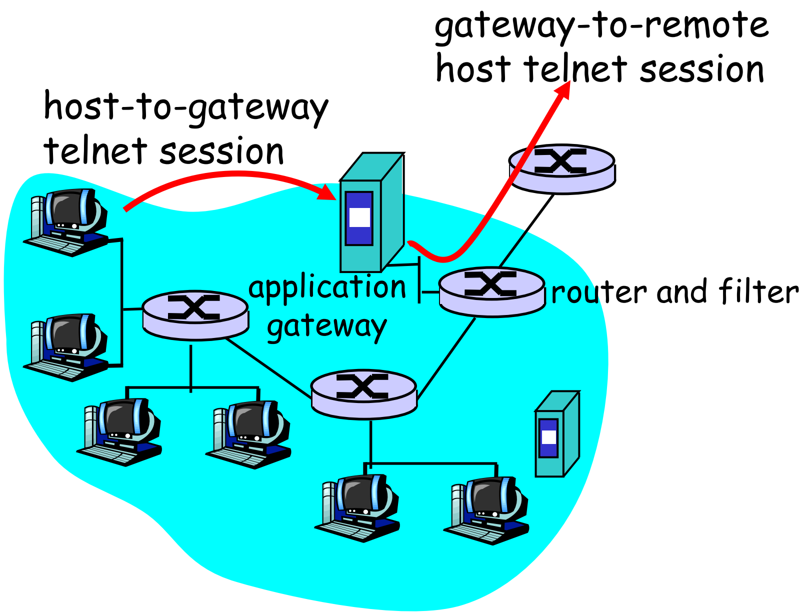
allow only authorized access to inside network (set of authenticated users/hosts)

Stateless packet filtering


Should arriving packet be allowed in? Departing packet let out?

- internal network connected to Internet via router firewall
- router filters packet-by-packet, decision to forward/drop packet based on:
  - source IP address, destination IP address
  - TCP/UDP source and destination port numbers
  - ICMP message type
  - TCP SYN and ACK bits

Application gateways



gateway-to-remote host telnet session
host-to-gateway telnet session
application gateway
router and filter

- filters packets on application data as well as on IP/TCP/UDP fields.
- example: allow select internal users to telnet outside.

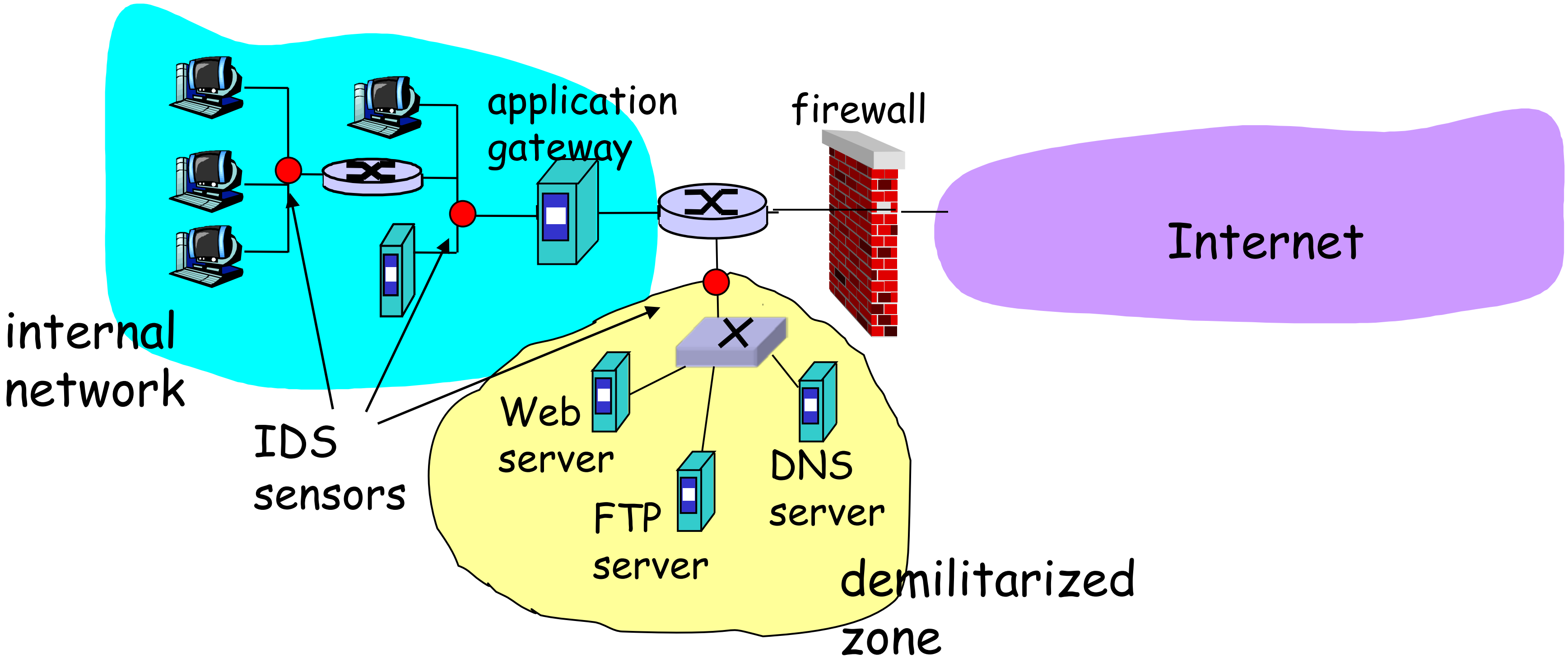
1. require all telnet users to telnet through gateway.
2. for authorized users, gateway sets up telnet connection to dest host. Gateway relays data between 2 connections
3. router filter blocks all telnet connections not originating from gateway.

Intrusion detection systems

- packet filtering:
  - operates on TCP/IP headers only
  - no correlation check among sessions
- *IDS: intrusion detection system*
  - *deep packet inspection:* look at packet contents (e.g., check character strings in packet against database of known virus, attack strings)
  - examine correlation among multiple packets
    - port scanning
    - network mapping
    - DoS attack

Intrusion detection systems

- multiple IDSs: different types of checking at different locations



Network Security (summary)

Basic techniques…...

- cryptography (symmetric and public)
- message integrity
- digital signature

…. used in many different security scenarios

- secure email

Operational Security: firewalls and IDS