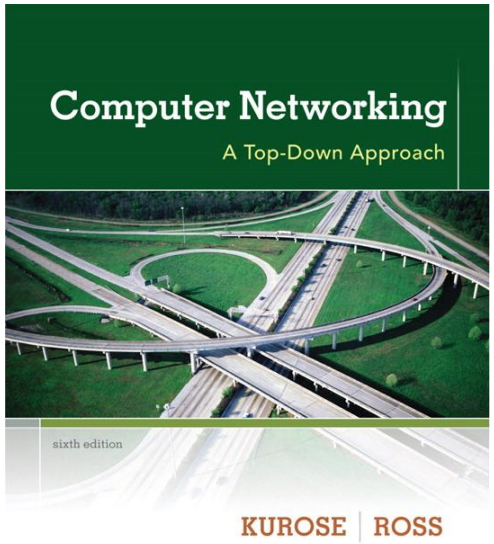
Computer Networking

谢 逸

中山大学 • 数据科学与计算机学院

2018. Spring

Chapter 8 Security



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Thanks and enjoy! JFK/KWR

Computer Networking: A Top Down Approach

6th edition

Jim Kurose, Keith Ross

Addison-Wesley
March 2012

Chapter 8 roadmap

8.1 What is network security?

8.2 Principles of cryptography

8.3 Message integrity, authentication

8.4 Securing e-mail

8.5 Securing TCP connections: SSL

8.6 Network layer security: IPsec

8.7 Securing wireless LANs

8.8 Operational security: firewalls and IDS

What is network security?

confidentiality: **only sender, intended receiver should "understand" message contents**

- **sender encrypts message**
- **receiver decrypts message**

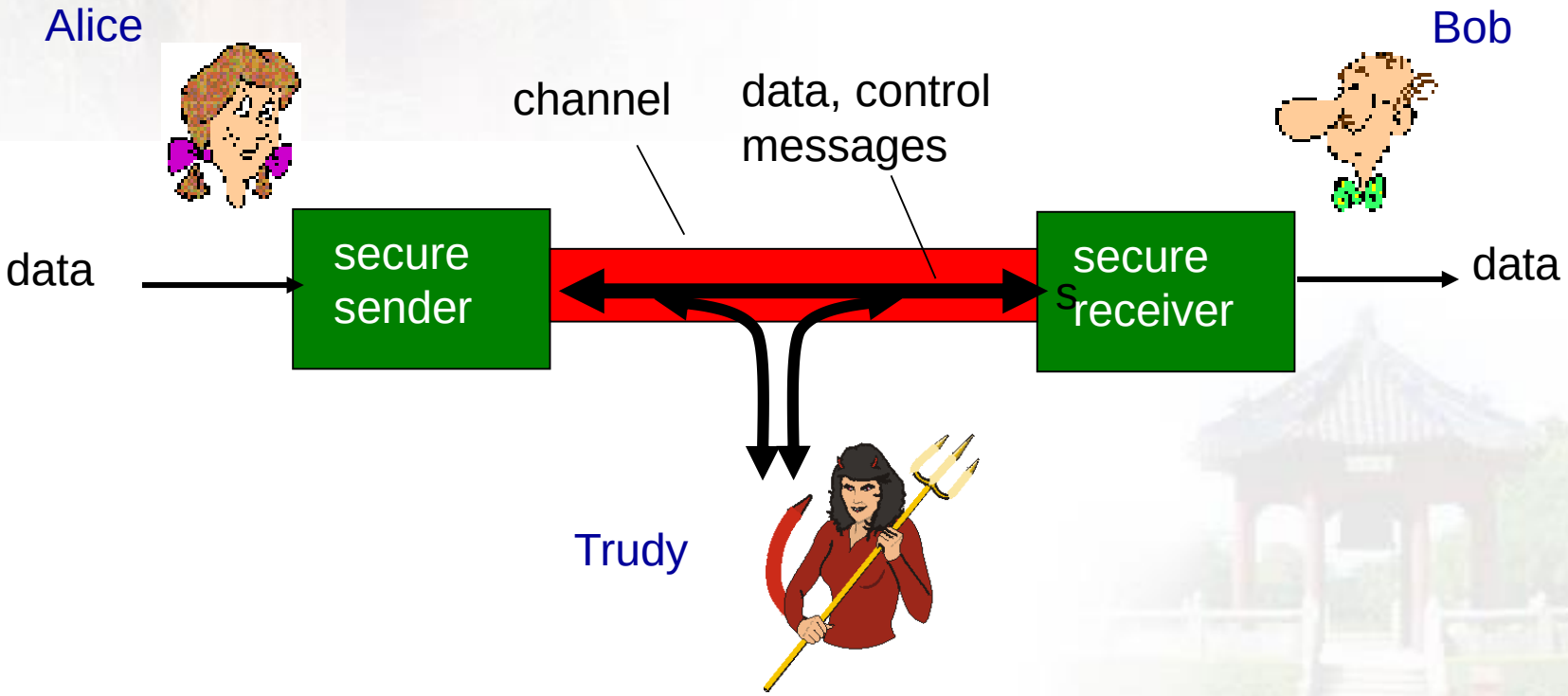
authentication: **sender, receiver want to confirm identity of each other**

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! See section 1.6

- *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)

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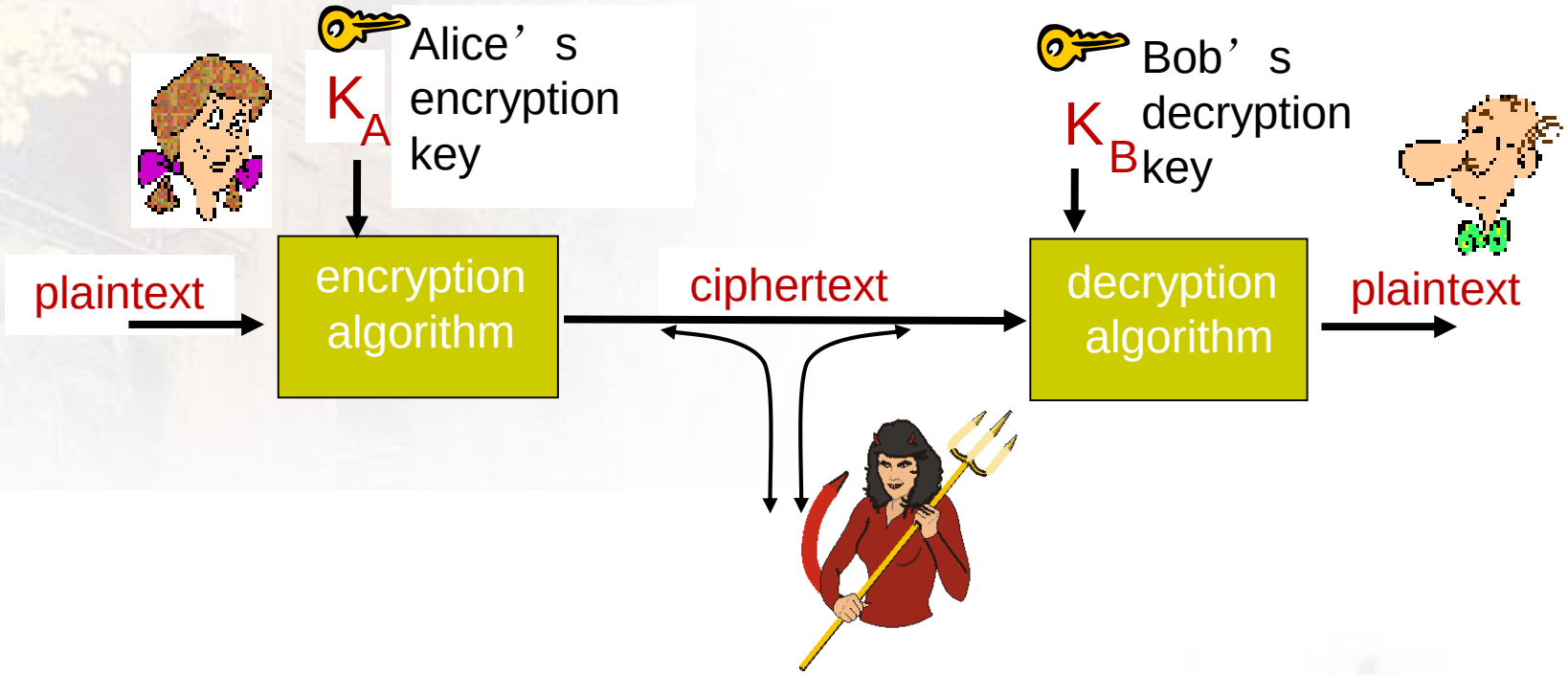
The language of cryptography



m plaintext message

$K_A(m)$ ciphertext, encrypted with key K_A

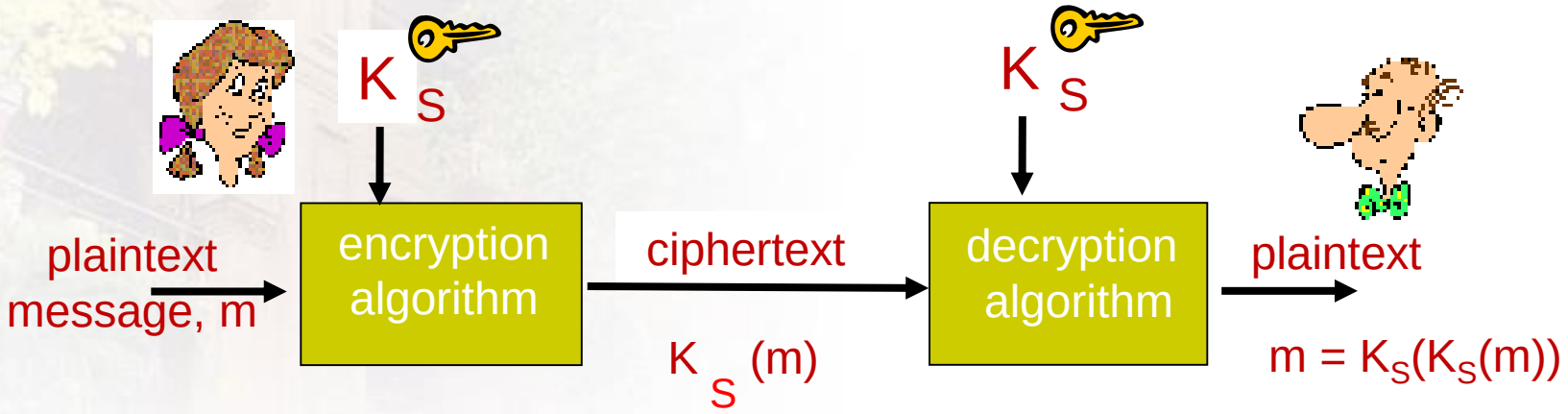
$m = K_B(K_A(m))$

Breaking an encryption scheme

- **cipher-text only attack:**
  Trudy has ciphertext she can analyze
- **two approaches:**
  - brute force: search through all keys
  - statistical analysis

- **known-plaintext attack:**
  Trudy has plaintext corresponding to ciphertext
  - e.g., in monoalphabetic cipher, Trudy determines pairings for a,l,i,c,e,b,o,
- **chosen-plaintext attack:**
  Trudy can get ciphertext for chosen plaintext

Symmetric key cryptography



symmetric key crypto: Bob and Alice share same (symmetric) key: K_S

- **e.g., key is knowing substitution pattern in mono alphabetic substitution cipher**

Q: how do Bob and Alice agree on key value?

Symmetric key crypto: DES

DES: Data Encryption Standard

- US encryption standard [NIST 1993]
- 56-bit symmetric key, 64-bit plaintext input
- block cipher with cipher block chaining
- how secure is DES?
  - DES Challenge: 56-bit-key-encrypted phrase decrypted (brute force) in less than a day
  - no known good analytic attack
- making DES more secure:
  - 3DES: encrypt 3 times with 3 different keys

AES: Advanced Encryption Standard

- symmetric-key NIST standard, replacied DES (Nov 2001)
- processes data in 128 bit blocks
- 128, 192, or 256 bit keys
- brute force decryption (try each key) taking 1 sec on DES, takes 149 trillion years for AES

Public Key Cryptography

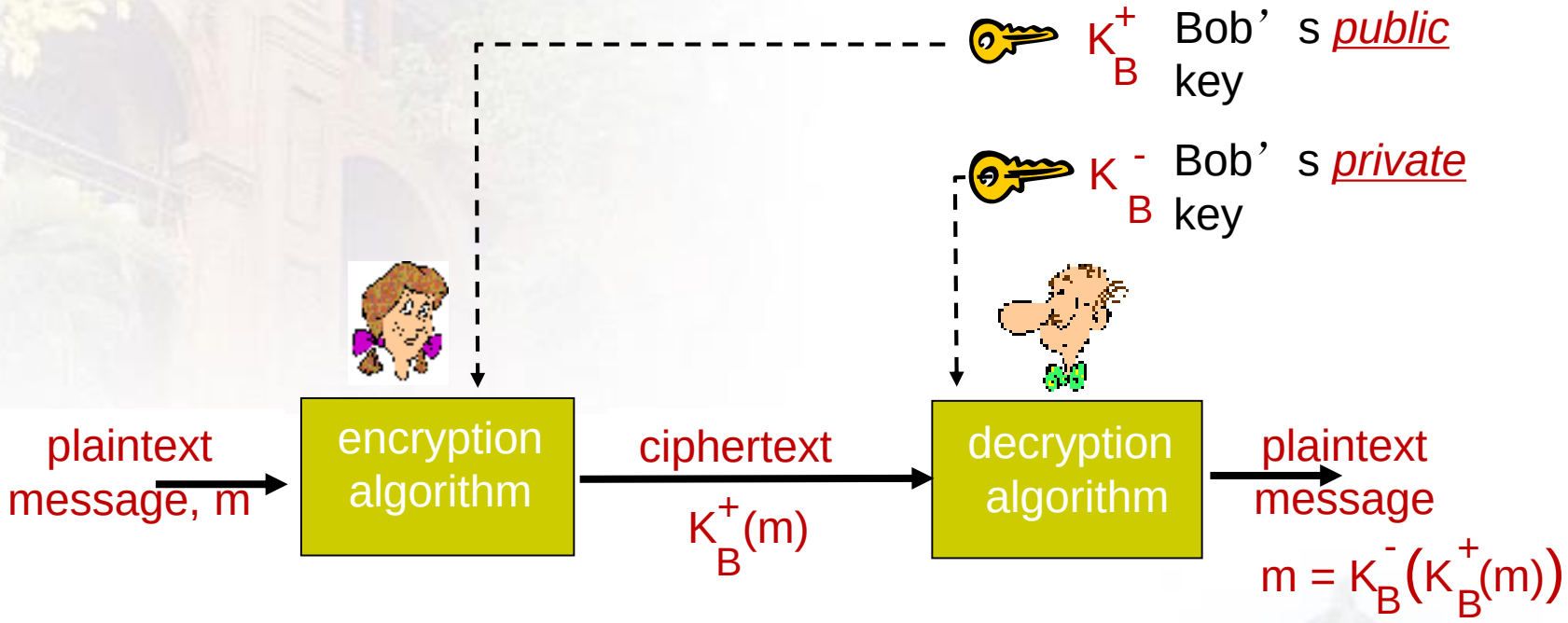
symmetric key crypto

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

public key crypto

- 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



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, Adelson algorithm

RSA: another important property

The following property will be *very* useful later:

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

result is the same!

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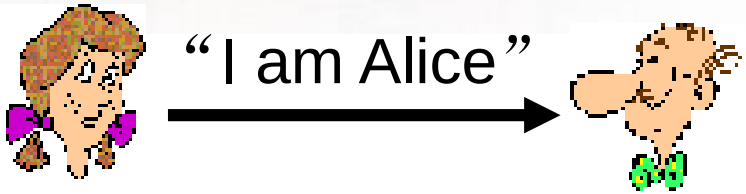
Authentication

Goal: **Bob wants Alice to "prove" her identity to him**

Protocol ap1.0: Alice says "I am Alice"

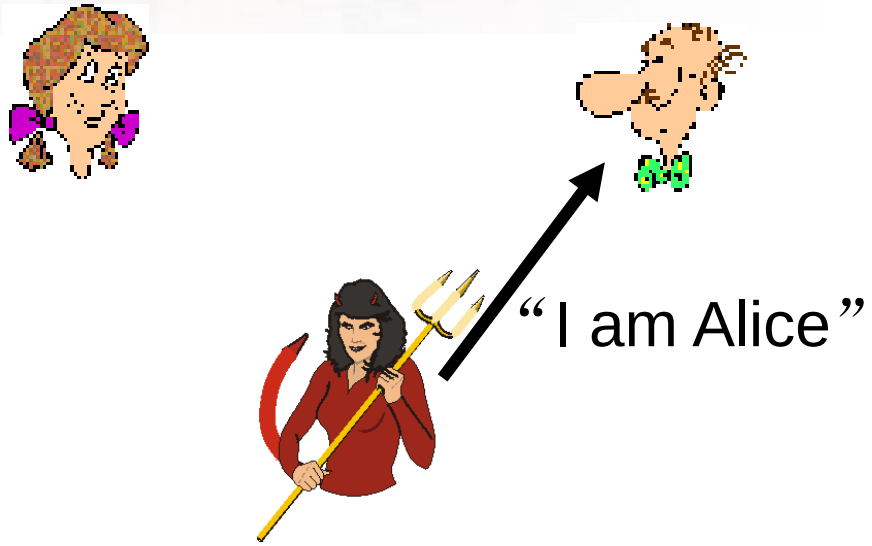


Failure scenario??

Authentication

Goal: Bob wants Alice to "prove" her identity to him

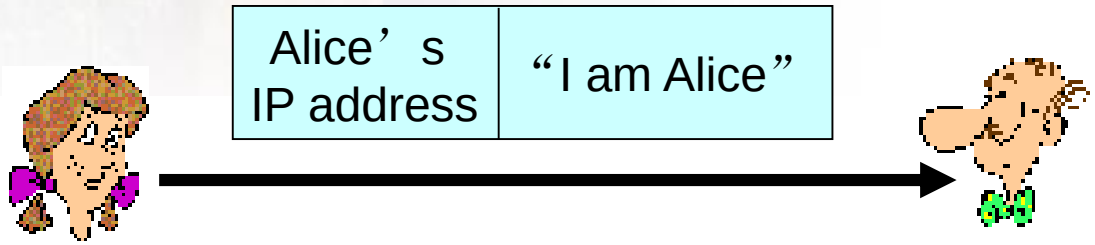
Protocol ap1.0: Alice says "I am Alice"



in a network,
Bob can not "see"
Alice, so Trudy simply
declares
herself to be Alice

Authentication: another try

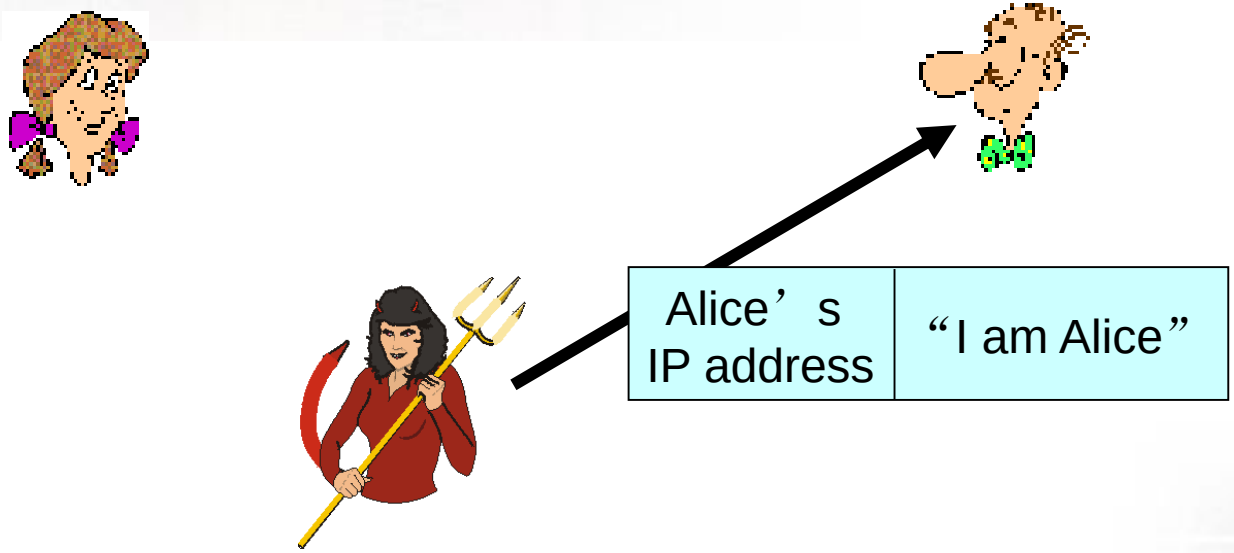
Protocol ap2.0: Alice says "I am Alice" in an IP packet containing her source IP address



Failure scenario??

Authentication: another try

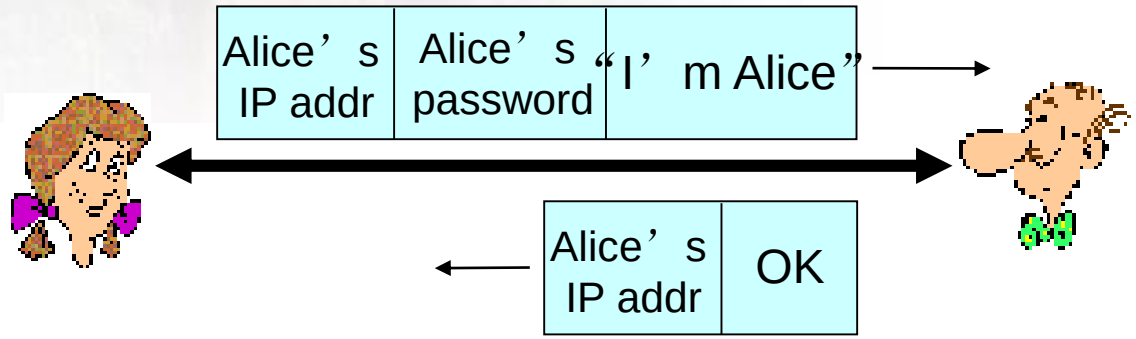
Protocol ap2.0: Alice says "I am Alice" in an IP packet containing her source IP address



Trudy can create a packet "spoofing" Alice's address

Authentication: another try

Protocol ap3.0: Alice says "I am Alice" and sends her secret password to "prove" it.



Failure scenario??

Authentication: another try

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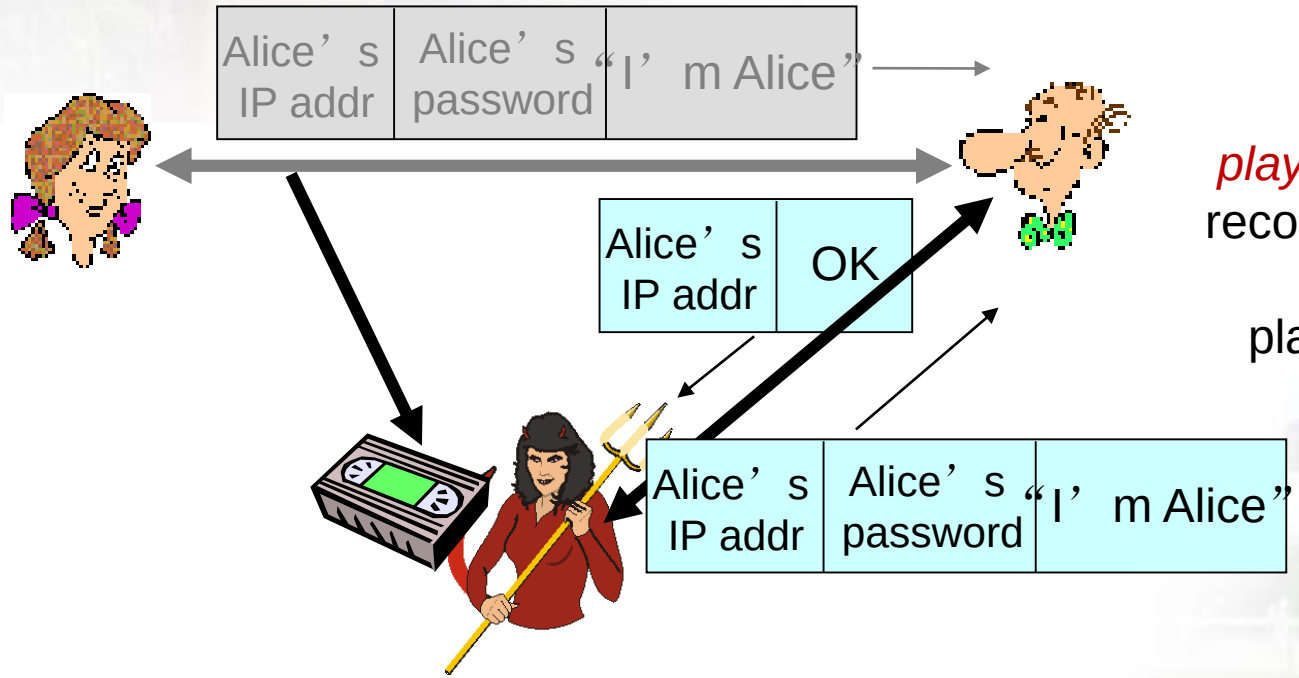
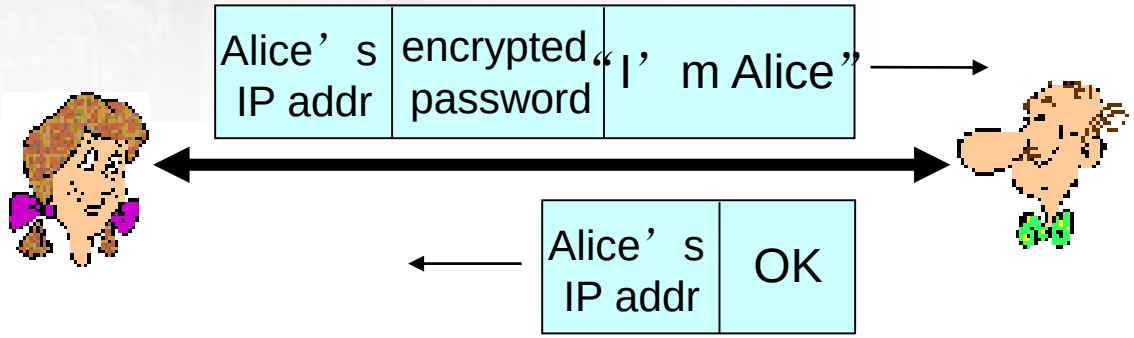


playback attack: Trudy records Alice's packet and later plays it back to Bob

Authentication: yet another try

Protocol ap3.1: Alice says "I am Alice" and sends her *encrypted* secret password to "prove" it.



Failure scenario??

Authentication: yet another try

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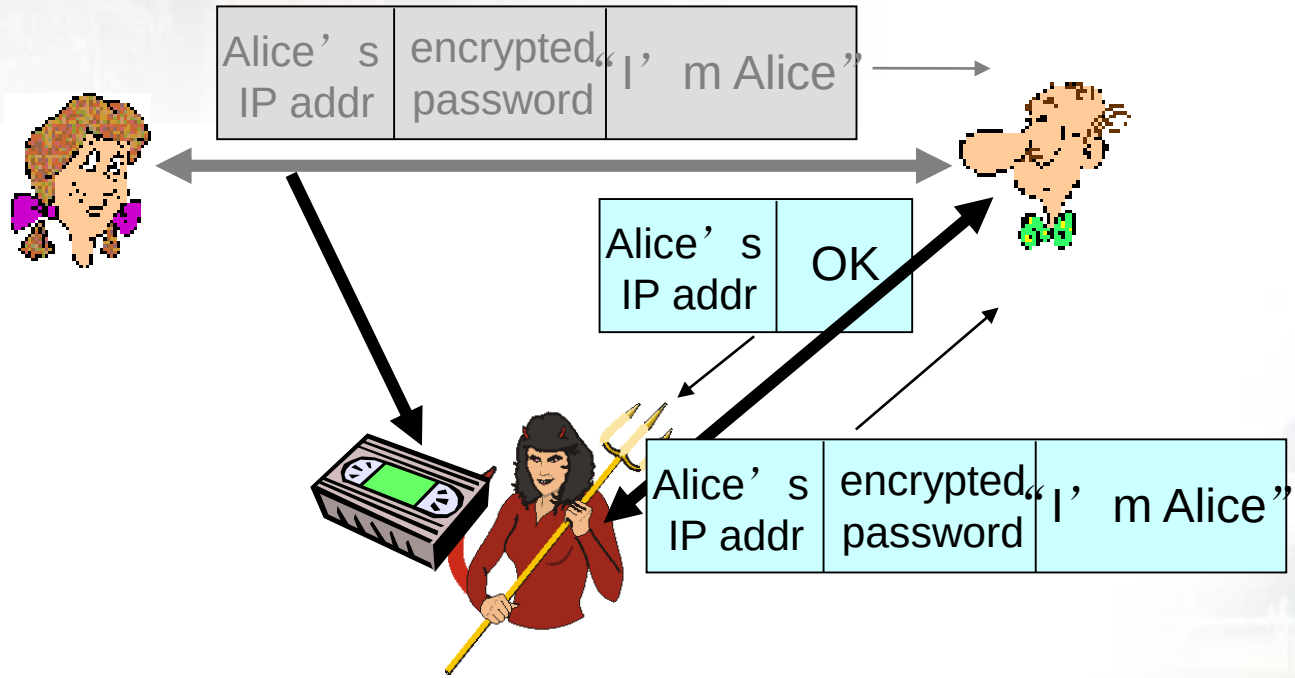


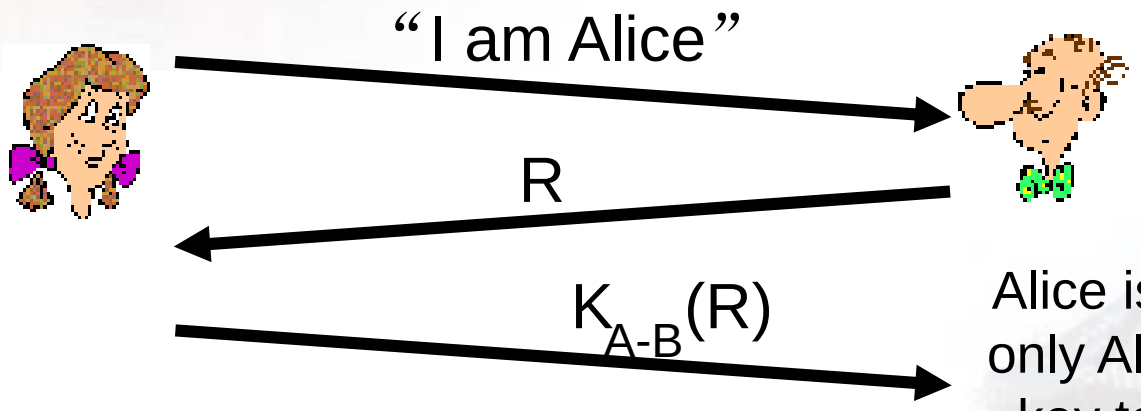
record and playback *still* works!

Authentication: yet another try

Goal: avoid playback attack

nonce: number (R) used only *once-in-a-lifetime*

ap4.0: to prove Alice "live", Bob sends Alice *nonce*, R. Alice must return R, encrypted with shared secret key



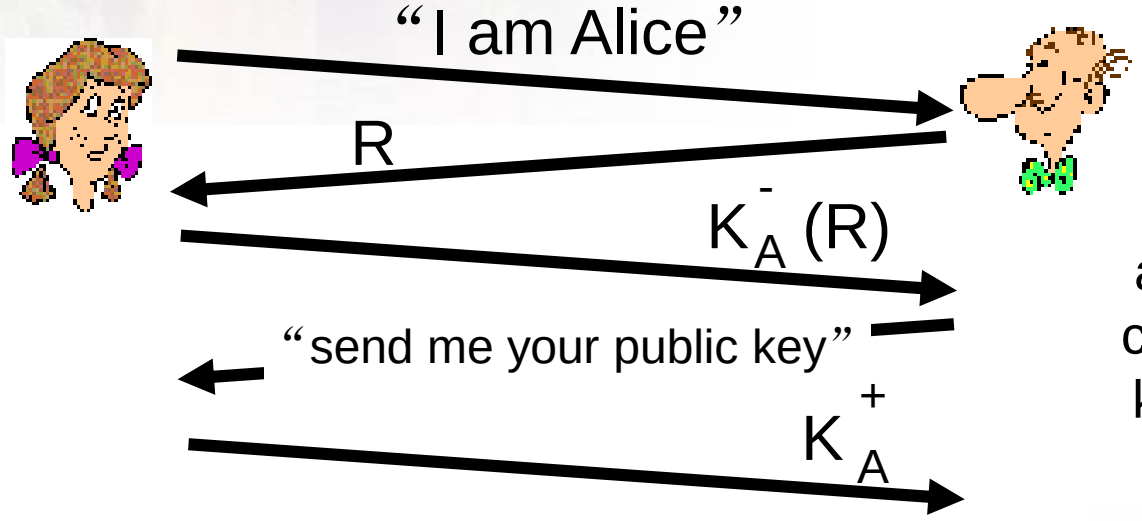
Failures, drawbacks?

Authentication: ap5.0

ap4.0 requires shared symmetric key

- **can we authenticate using public key techniques?**

ap5.0: **use nonce, public key cryptography**



Bob computes

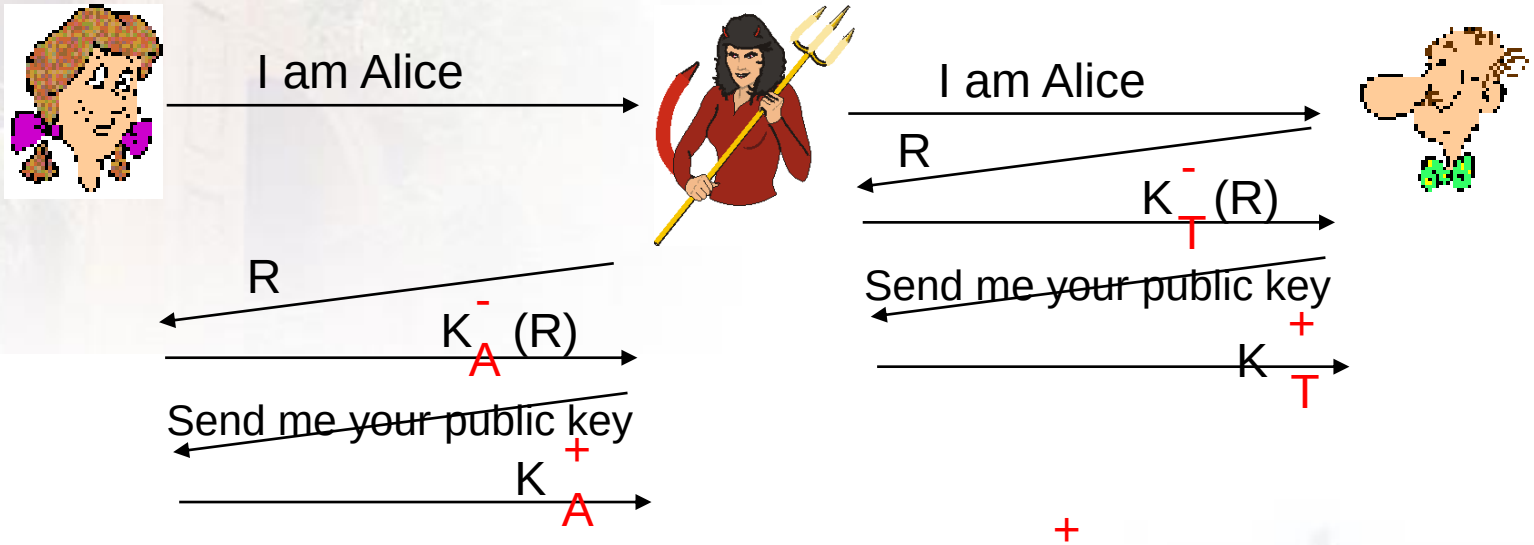
$K_A^+(K_A^-(R)) = R$

and knows only Alice could have the private key, that encrypted R such that

$K_A^+(K_A^-(R)) = R$

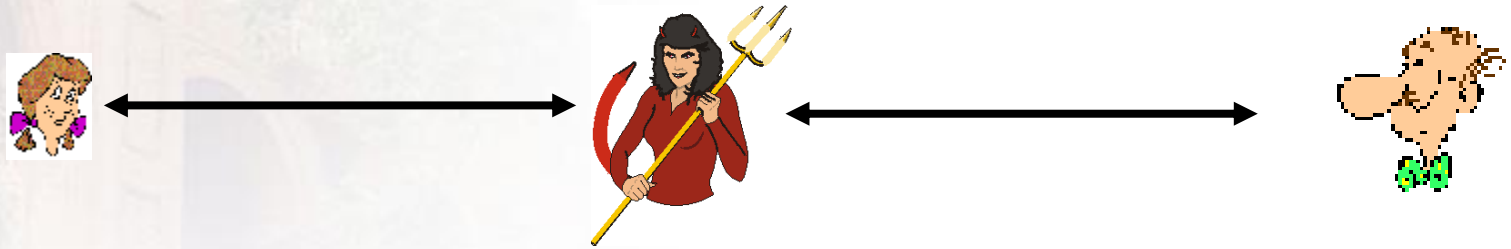
ap5.0: security hole

man (or woman) in the middle attack: **Trudy poses as Alice (to Bob) and as Bob (to Alice)**



ap5.0: security hole

man (or woman) in the middle attack: Trudy poses as Alice (to Bob) and as Bob (to Alice)



difficult to detect:

- Bob receives everything that Alice sends, and vice versa. (e.g., so Bob, Alice can meet one week later and recall conversation!)
- problem is that Trudy receives all messages as well!

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Digital signatures

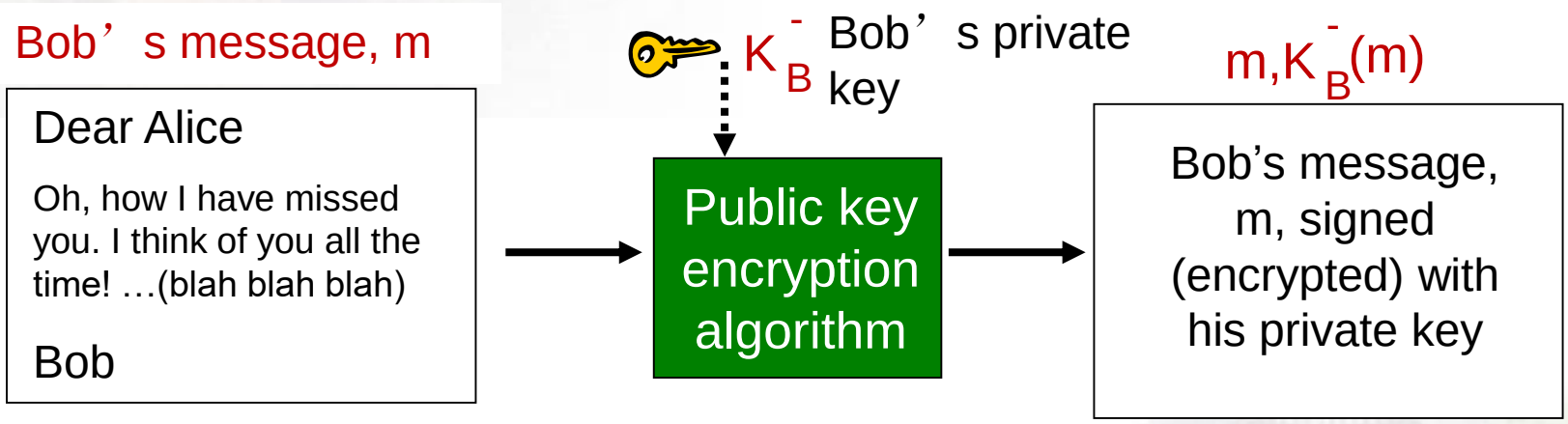
cryptographic technique analogous to hand-written signatures:

- **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:

- **Bob signs m by encrypting with his private key K_B^-, creating "signed" message, $K_B^-(m)$**



Digital signatures

- suppose Alice receives msg m, with signature: m, $K_B^-(m)$
- Alice verifies m signed by Bob by applying Bob's public key K_B^+ to $K_B^-(m)$ then checks $K_B^+(K_B^-(m)) = m$.
- If $K_B^+(K_B^-(m)) = m$, whoever signed m must have used Bob's private key.

Alice thus verifies that:

- ✓ **Bob signed m**
- ✓ **no one else signed m**
- ✓ **Bob signed m and not m '**

non-repudiation:

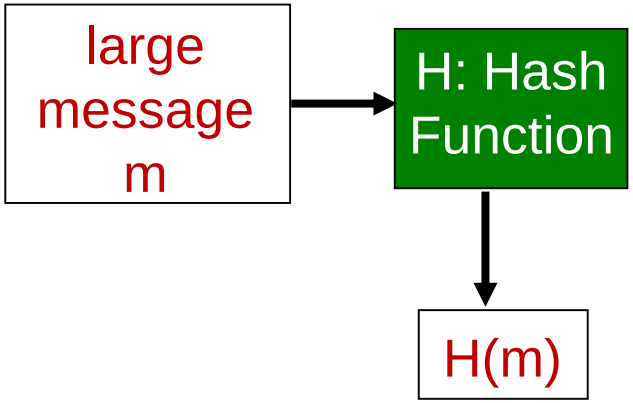
- ✓ **Alice can take m, and signature $K_B^-(m)$ to court and prove that Bob signed m**

Message digests

computationally expensive to public-key-encrypt long messages

goal: fixed-length, easy-to-compute digital "fingerprint"

- apply hash function H to *m*, get fixed size message digest, *H(m)*.

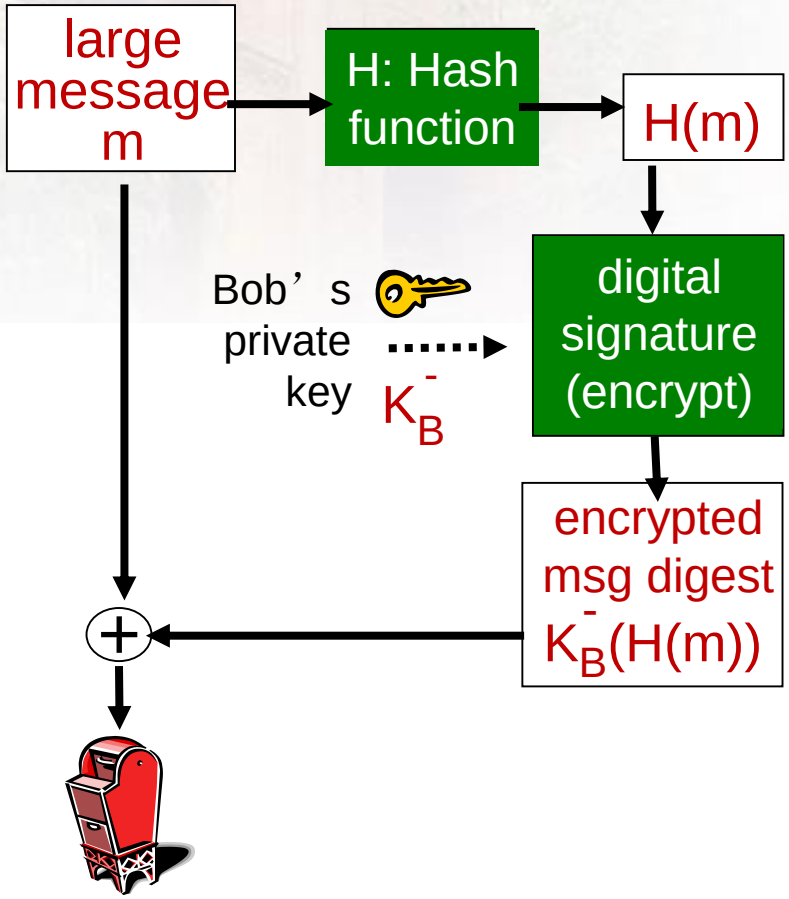


Hash function properties:

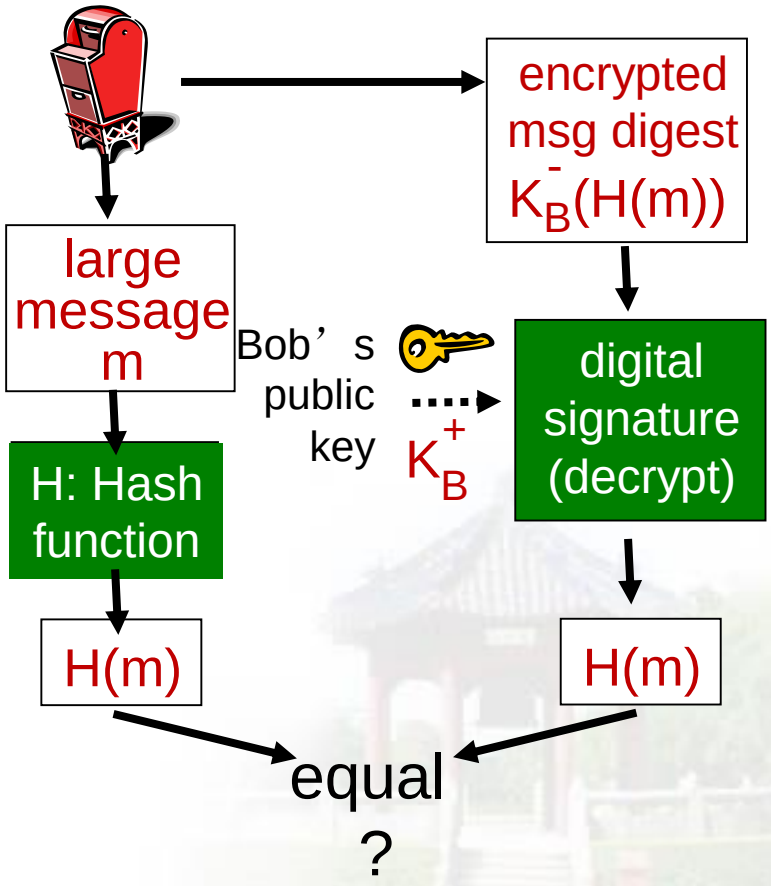
- many-to-1
- produces fixed-size msg digest (fingerprint)
- given message digest x, computationally infeasible to find m such that x = H(m)

Digital signature = signed message digest

Bob sends digitally signed message:



Alice verifies signature, integrity of digitally signed message:

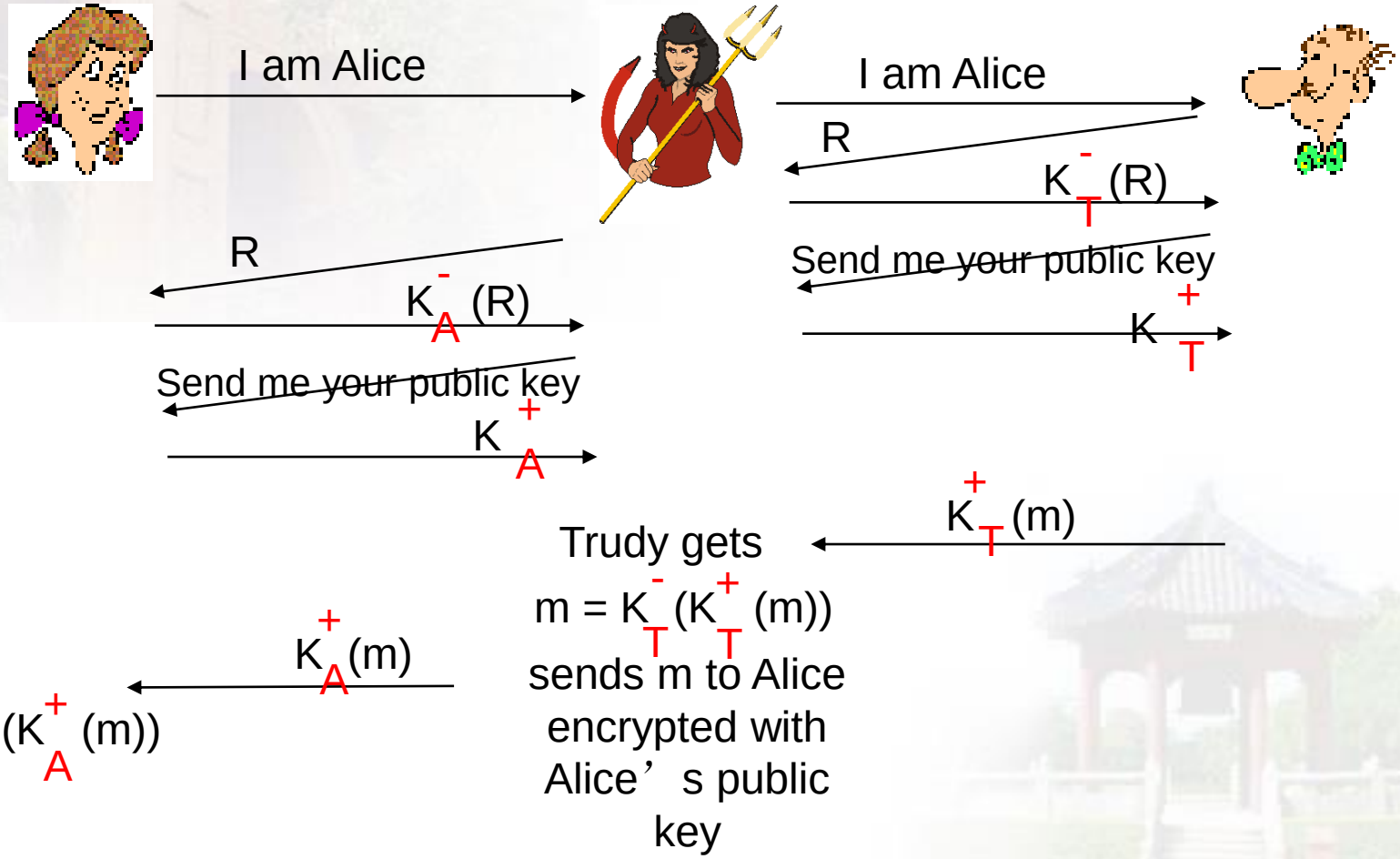


Hash function algorithms

- **MD5 hash function widely used (RFC 1321)**
  - computes 128-bit message digest in 4-step process.
  - arbitrary 128-bit string x, appears difficult to construct msg m whose MD5 hash is equal to x
- **SHA-1 is also used**
  - US standard [NIST, FIPS PUB 180-1]
  - 160-bit message digest

Recall: ap5.0 security hole

man (or woman) in the middle attack: **Trudy poses as Alice (to Bob) and as Bob (to Alice)**

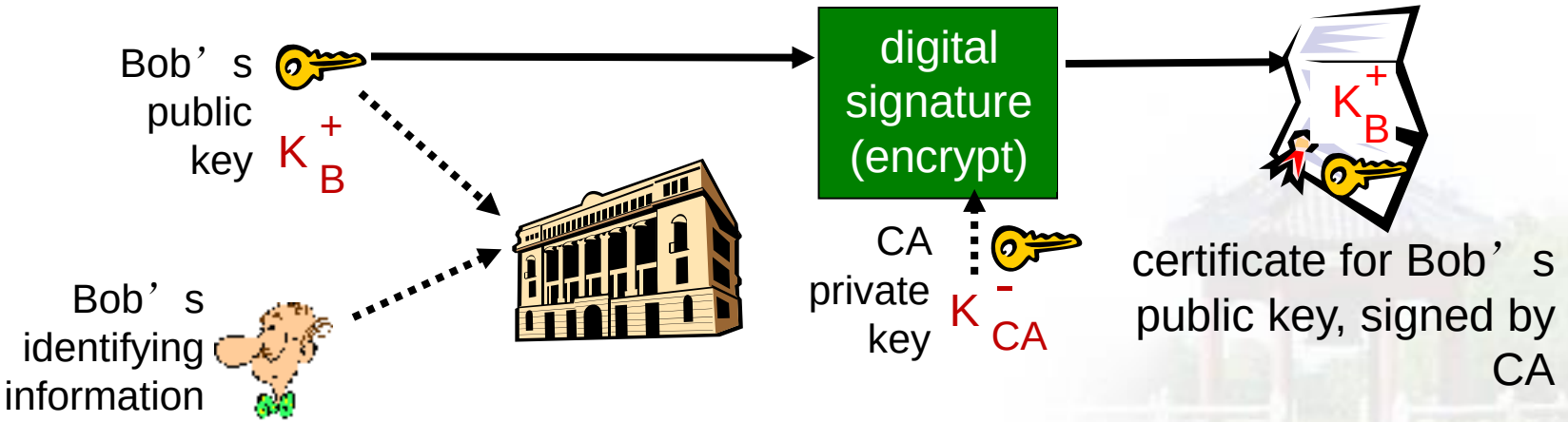


Public-key certification

- motivation: Trudy plays pizza prank on Bob
  - Trudy creates e-mail order:
    Dear Pizza Store, Please deliver to me four pepperoni pizzas. Thank you, Bob
  - Trudy signs order with her private key
  - Trudy sends order to Pizza Store
  - Trudy sends to Pizza Store her public key, but says it's Bob's public key
  - Pizza Store verifies signature; then delivers four pepperoni pizzas to Bob
  - Bob doesn't even like pepperoni

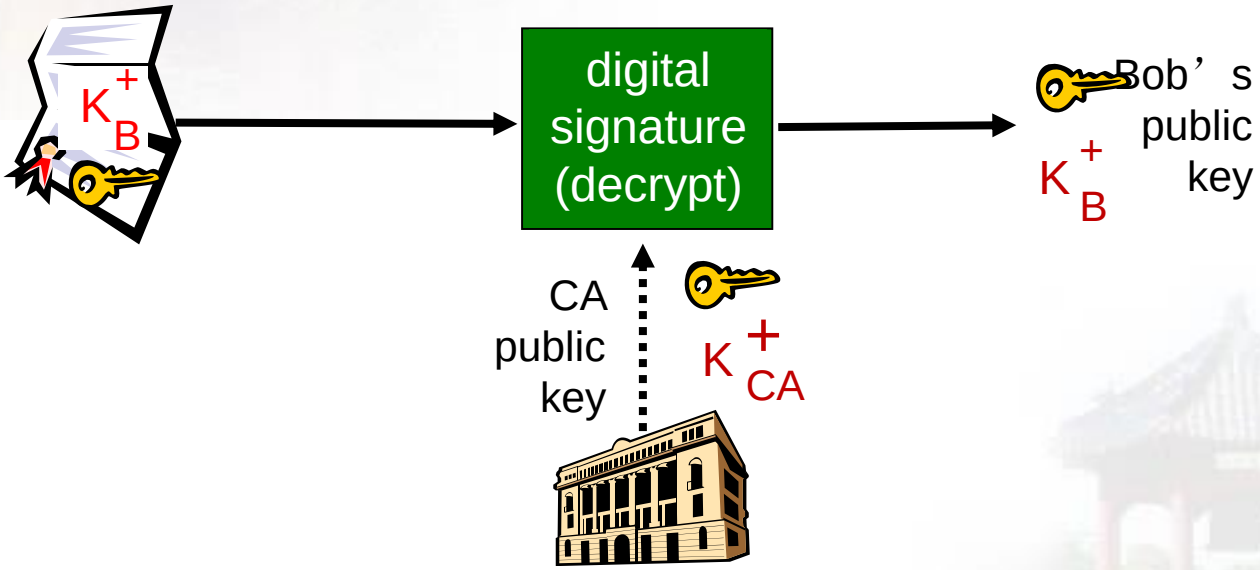
Certification authorities

- ***certification authority (CA):*** **binds public key to particular entity, E.**
- **E (person, router) 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"**



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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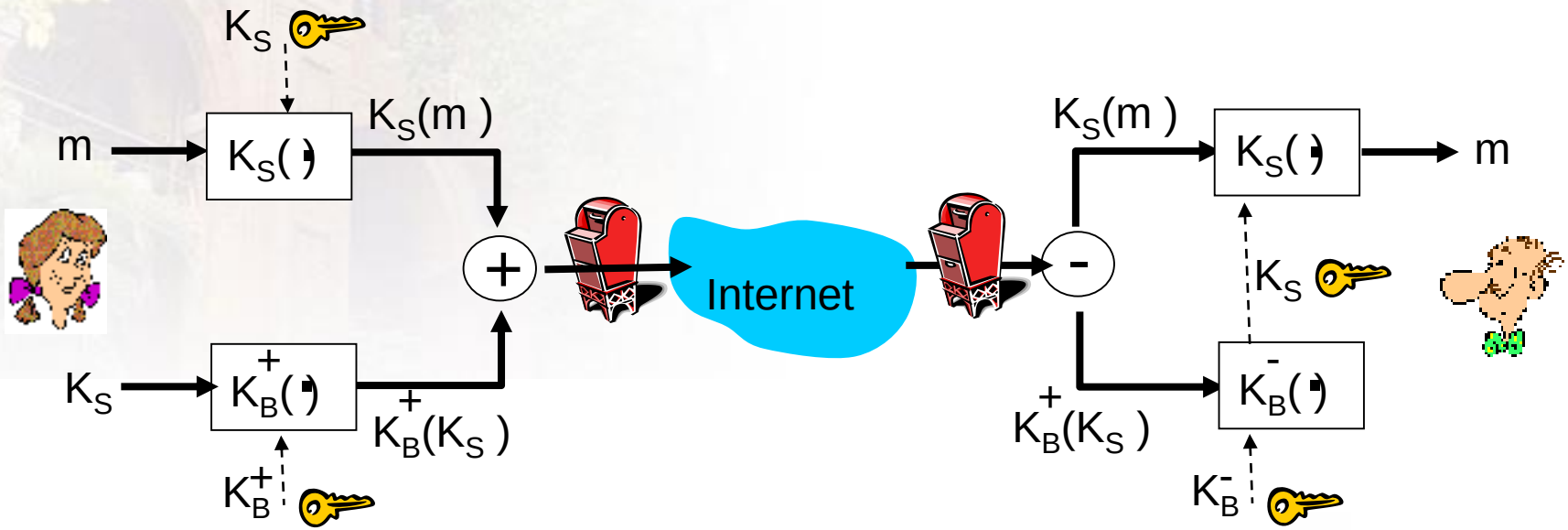
Secure e-mail

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

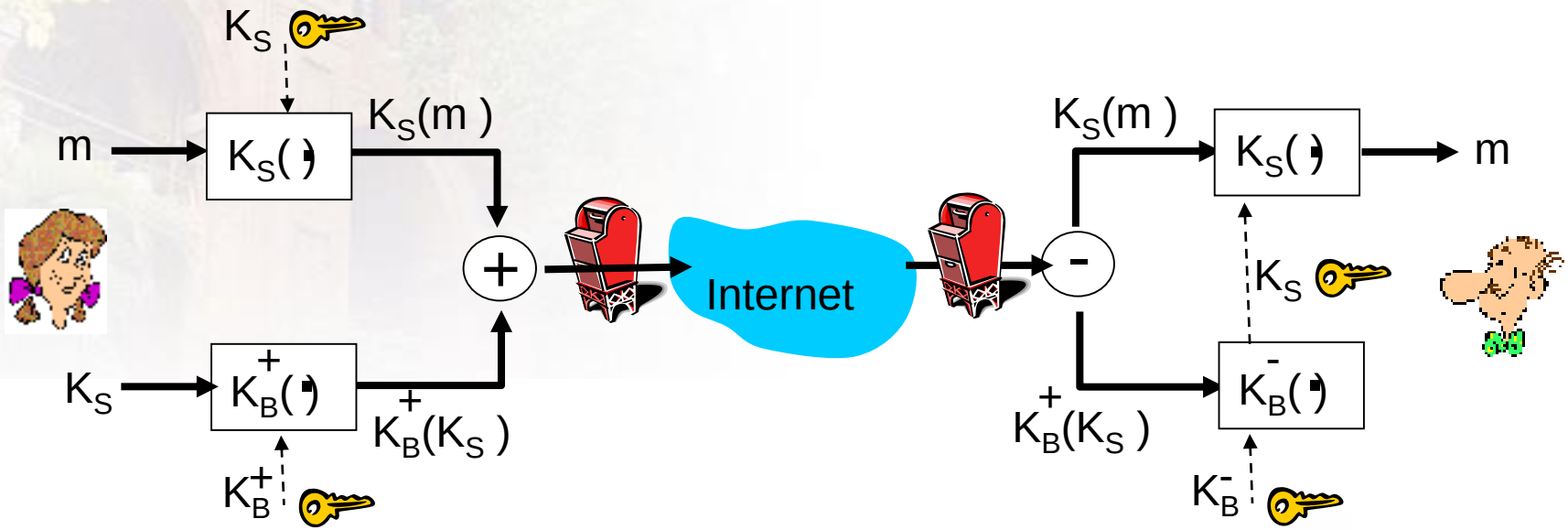


Alice:

- 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.

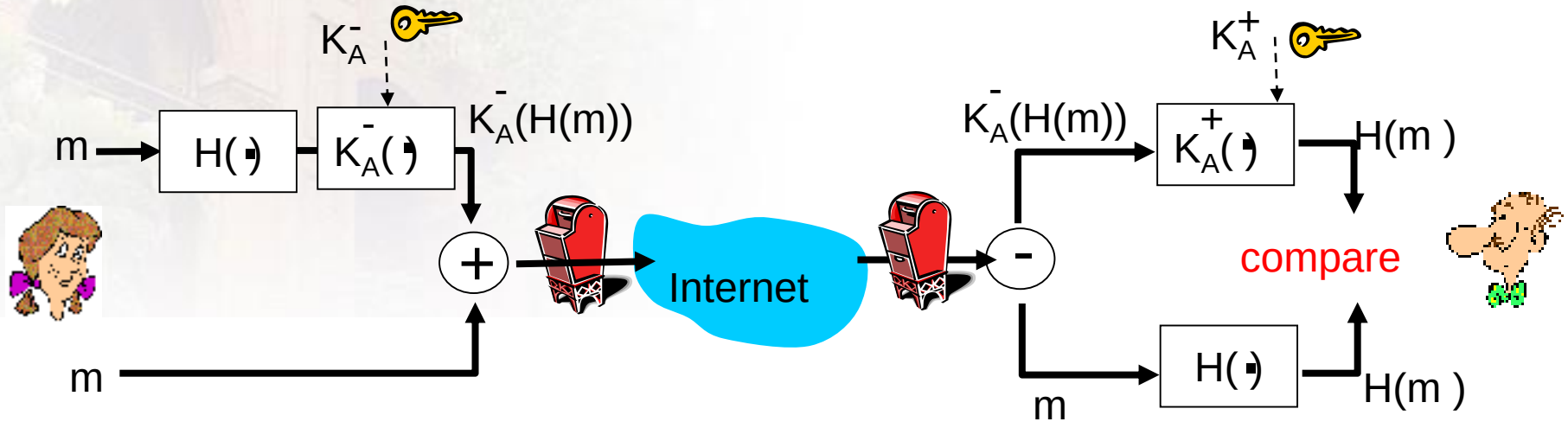


Bob:

- 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)

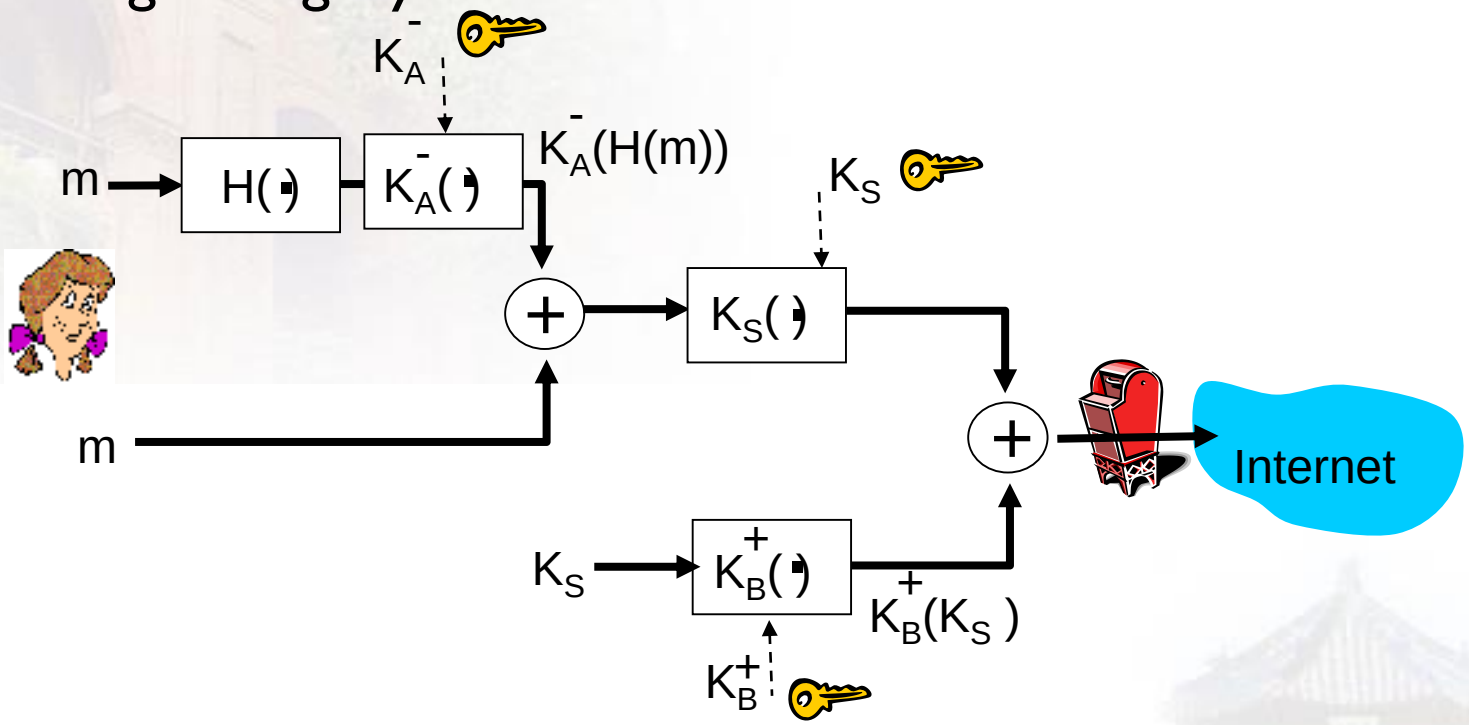
- Alice wants to provide sender authentication message integrity



- 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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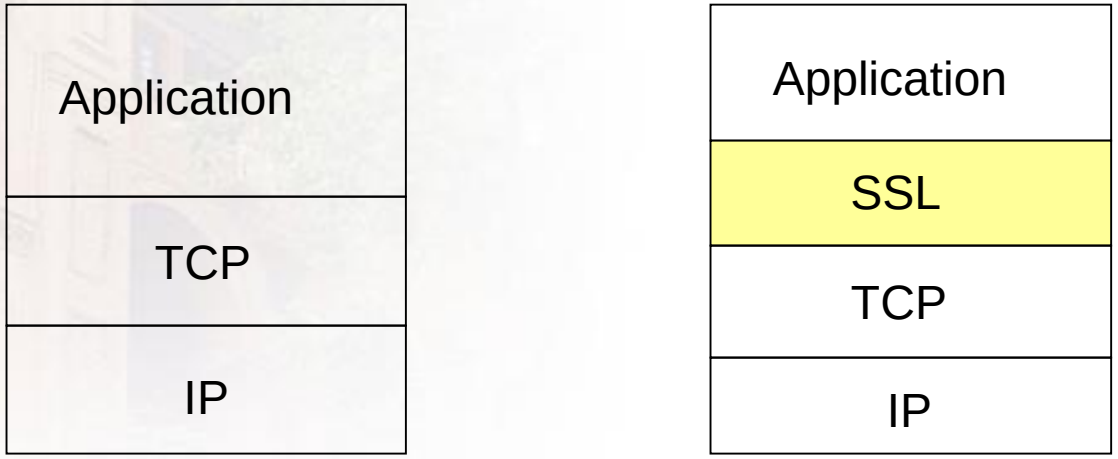
SSL: Secure Sockets Layer

- widely deployed security protocol
  - supported by almost all browsers, web servers
  - https
  - billions $/year over SSL
- mechanisms: [Woo 1994], implementation: Netscape
- variation -TLS: transport layer security, RFC 2246
- provides
  - *confidentiality*
  - *integrity*
  - *authentication*
- original goals:
  - Web e-commerce transactions
  - encryption (especially credit-card numbers)
  - Web-server authentication
  - optional client authentication
  - minimum hassle in doing business with new merchant
- available to all TCP applications
  - secure socket interface

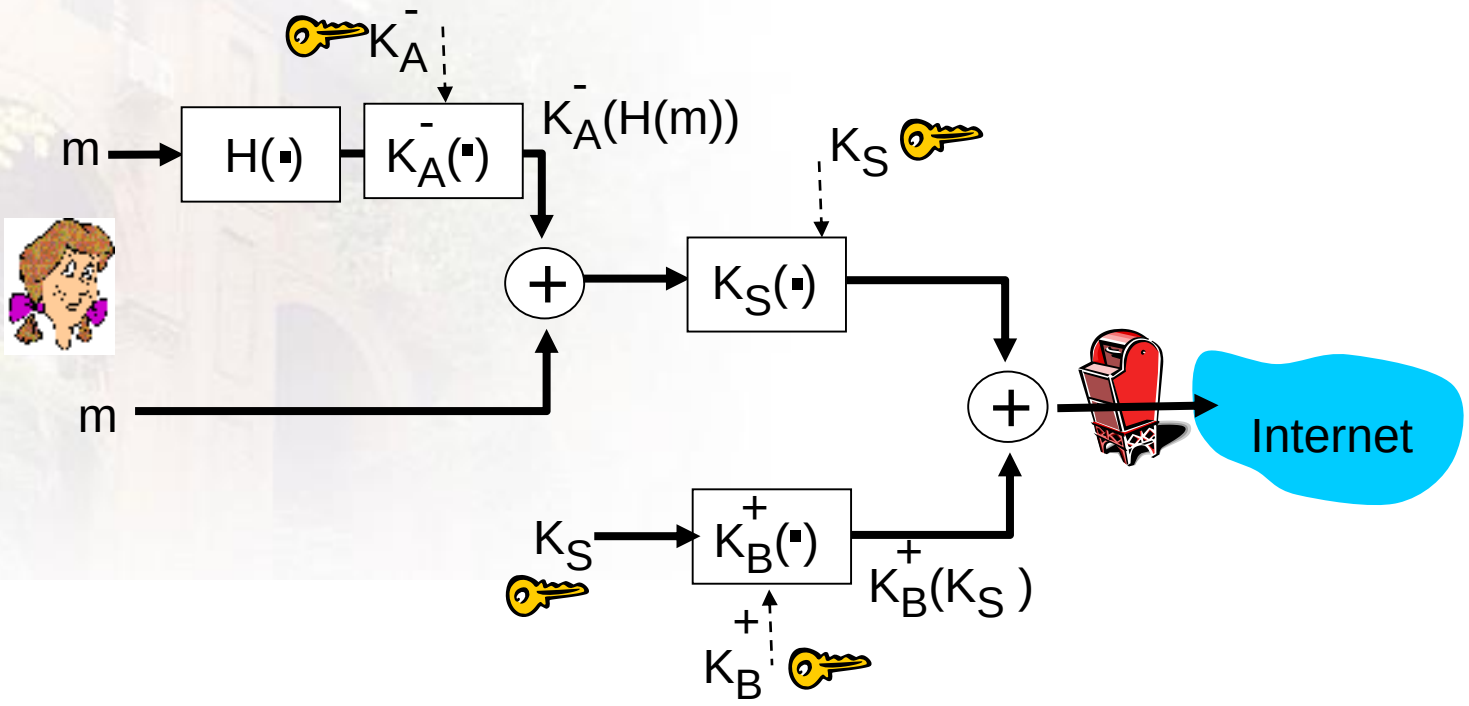
SSL and TCP/IP



normal application *application with SSL*

- SSL provides application programming interface (API) to applications
- C and Java SSL libraries/classes readily available

Could do something like PGP:

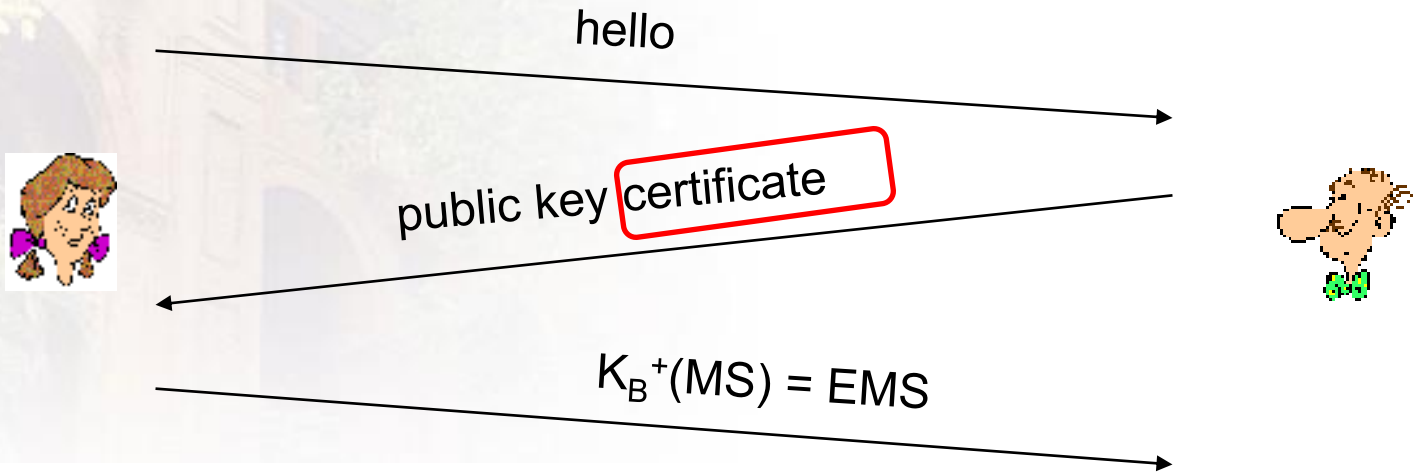


- but want to send byte streams & interactive data
- want set of secret keys for entire connection
- want certificate exchange as part of protocol: handshake phase

Toy SSL: a simple secure channel

- *handshake:* Alice and Bob use their certificates, private keys to authenticate each other and exchange shared secret
- *key derivation:* Alice and Bob use shared secret to derive set of keys
- *data transfer:* data to be transferred is broken up into series of records
- *connection closure:* special messages to securely close connection

Toy: a simple handshake



MS: **master secret**

EMS: **encrypted master secret**

Toy SSL: summary

hello

certificate, nonce

$K_B^+(MS) = EMS$

type 0, seq 1, data

type 0, seq 2, data

type 0, seq 1, data

type 0, seq 3, data

type 1, seq 4, close

type 1, seq 2, close

encrypted

bob.com

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 Securing TCP connections: SSL

8.6 Network layer security: IPsec

8.7 Securing wireless LANs

8.8 Operational security: firewalls and IDS

What is network-layer confidentiality ?

between two network entities:

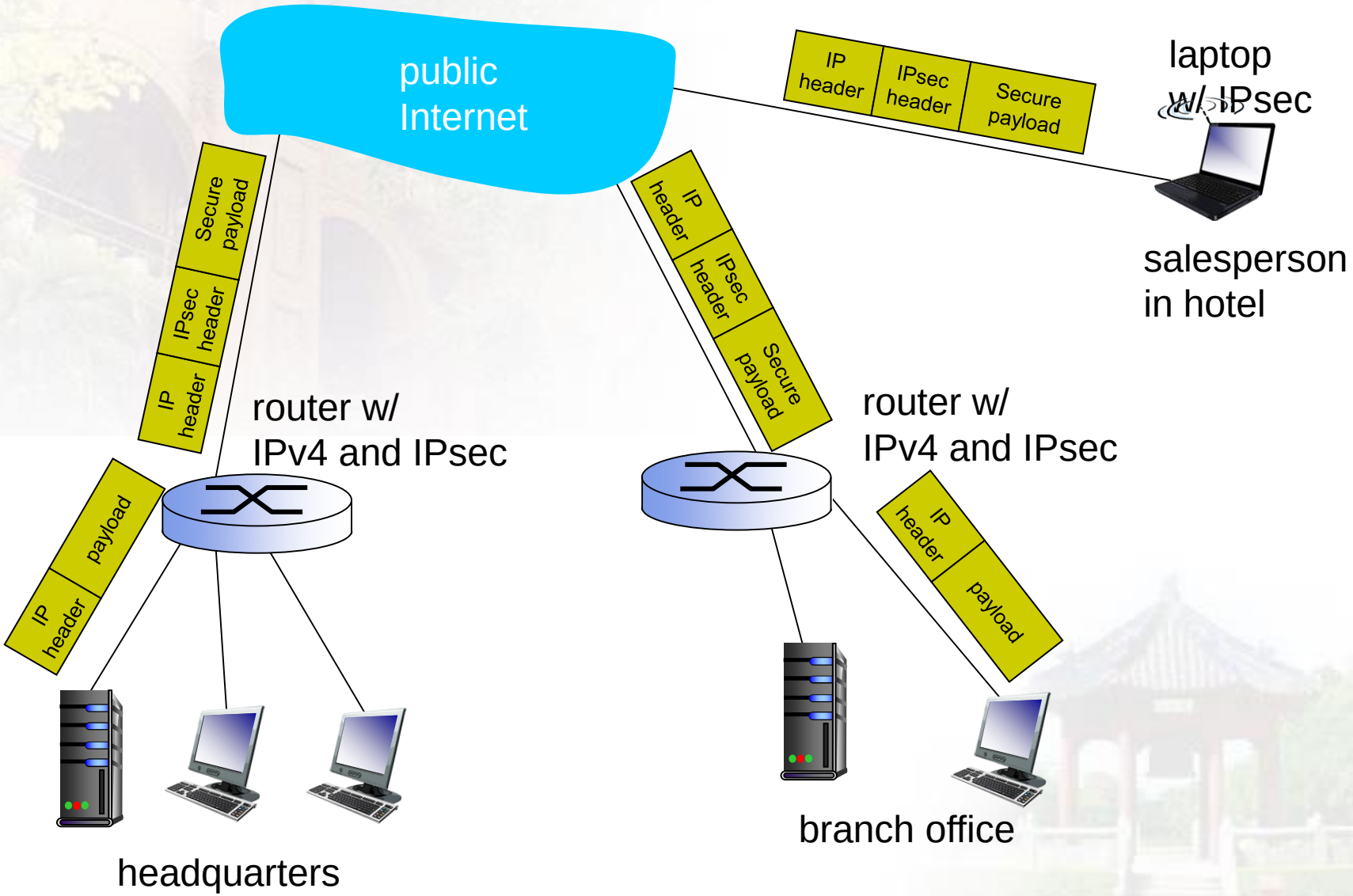
- sending entity encrypts datagram payload, payload could be:
  - TCP or UDP segment, ICMP message, OSPF message ….
- all data sent from one entity to other would be hidden:
  - web pages, e-mail, P2P file transfers, TCP SYN packets …
- "blanket coverage"

Virtual Private Networks (VPNs)

motivation:

- institutions often want private networks for security.
  - costly: separate routers, links, DNS infrastructure.
- VPN: institution's inter-office traffic is sent over public Internet instead
  - encrypted before entering public Internet
  - logically separate from other traffic

Virtual Private Networks (VPNs)

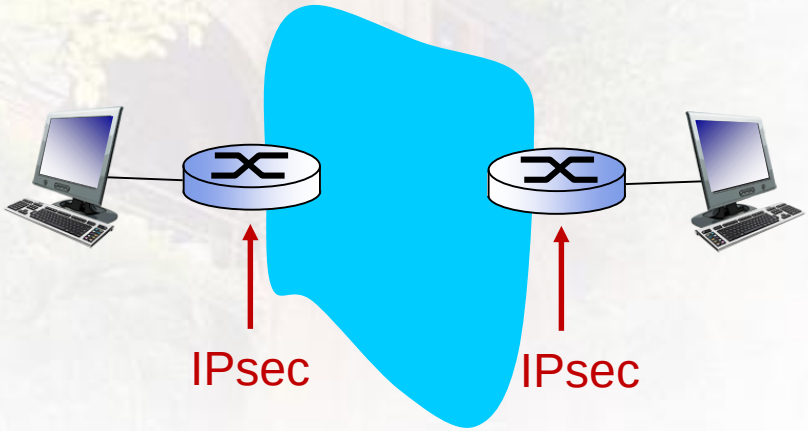


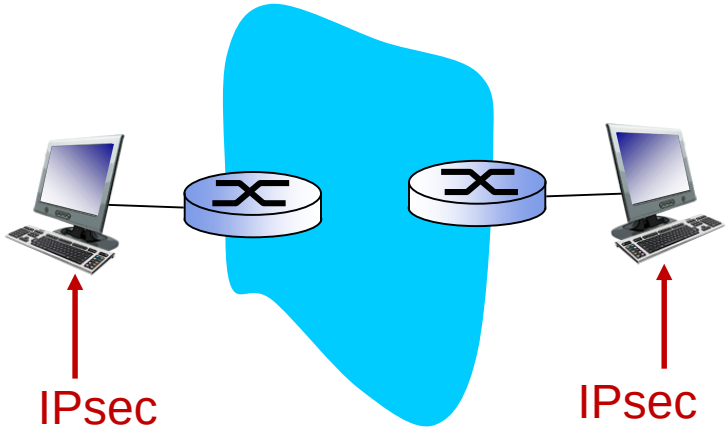
IPsec services

- data integrity
- origin authentication
- replay attack prevention
- confidentiality

- two protocols providing different service models:
  - AH
  - ESP

IPsec – tunneling mode



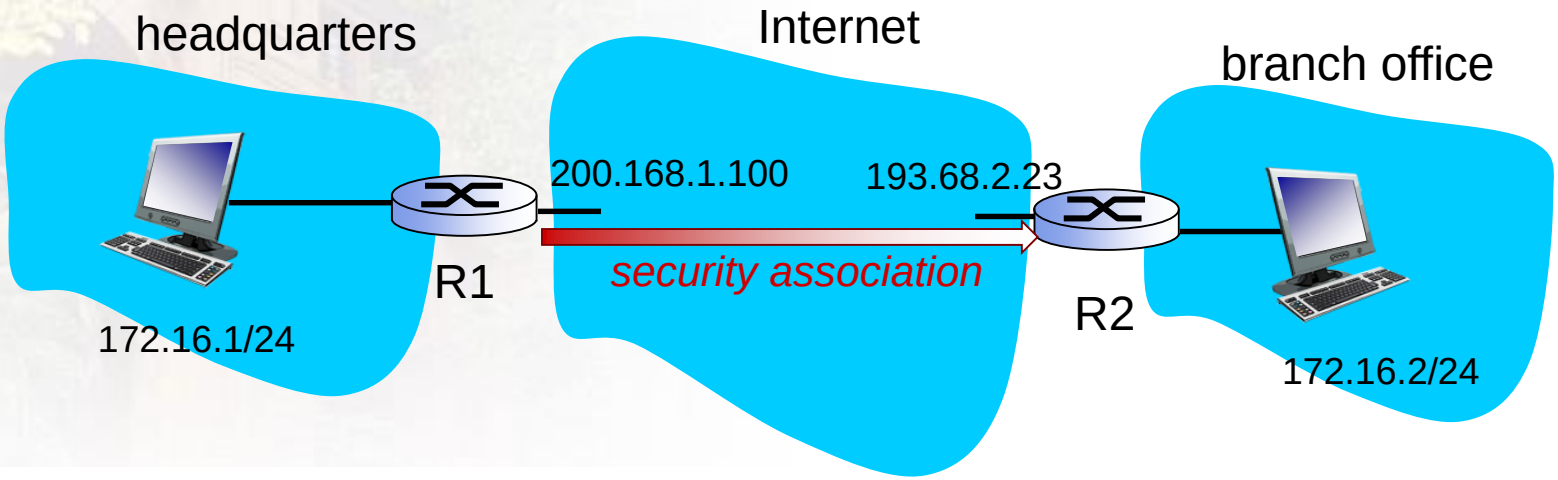


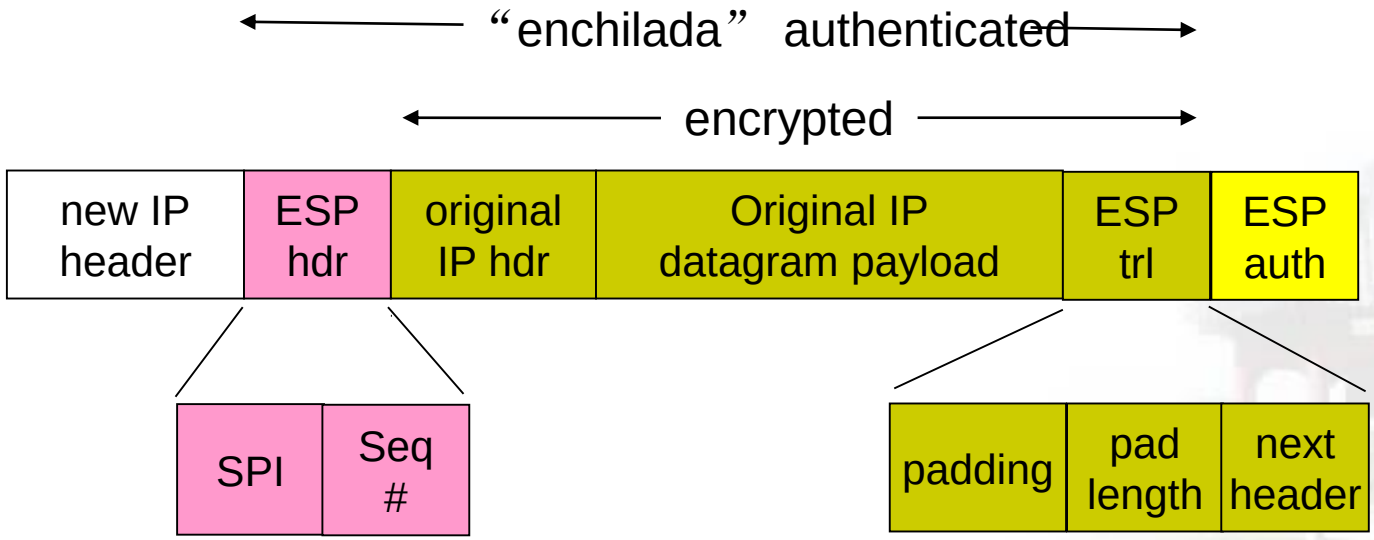
- **edge routers IPsec-aware**
  - hosts IPsec-aware

Two IPsec protocols

- **Authentication Header (AH) protocol**
  - **provides source authentication & data integrity but *not* confidentiality**
- **Encapsulation Security Protocol (ESP)**
  - **provides source authentication, data integrity, *and confidentiality***
  - **more widely used than AH**

IPsec datagram~~What happens?





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WEP design goals

- symmetric key crypto
  - confidentiality
  - end host authorization
  - data integrity
- self-synchronizing: each packet separately encrypted
  - given encrypted packet and key, can decrypt; can continue to decrypt packets when preceding packet was lost (unlike Cipher Block Chaining (CBC) in block ciphers)
- Efficient
  - implementable in hardware or software

WEP authentication

authentication request

nonce (128 bytes)

nonce encrypted shared key

success if decrypted value equals nonce

Notes:

- not all APs do it, even if WEP is being used
- AP indicates if authentication is necessary in beacon frame
- done before association

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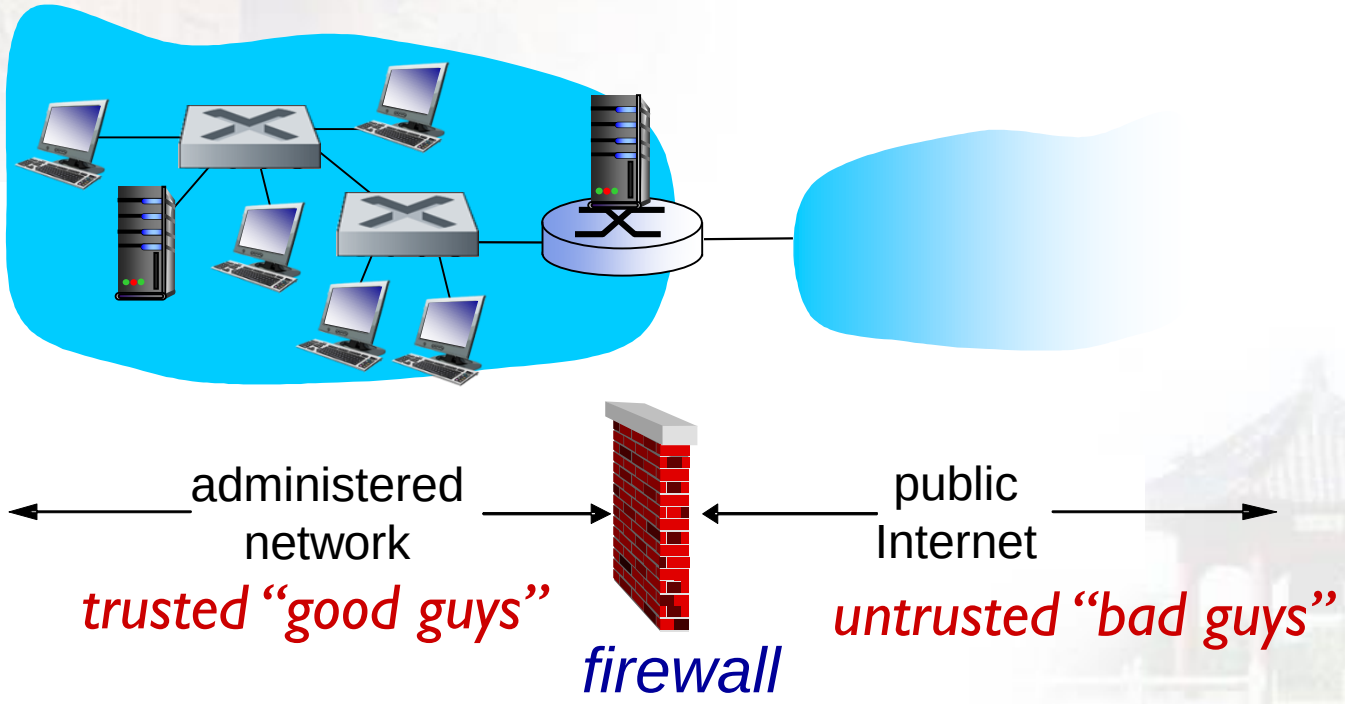
Firewalls

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

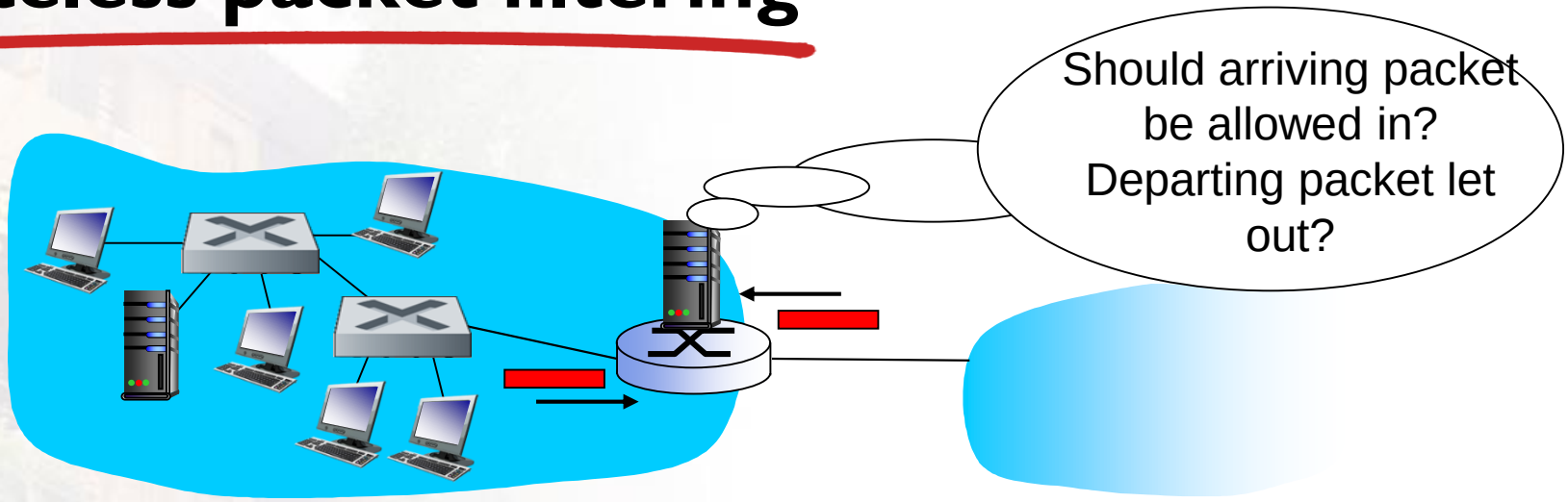
allow only authorized access to inside network

- set of authenticated users/hosts

three types of firewalls:

- stateless packet filters
- stateful packet filters
- application gateways

Stateless packet filtering



- 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

Stateful packet filtering

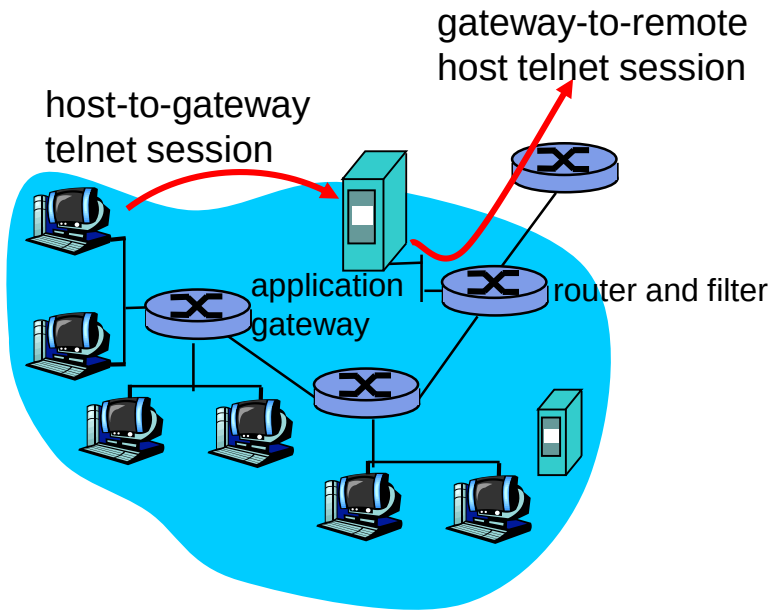
- ***stateless packet filter:*** **heavy handed tool**
  - **admits packets that "make no sense," e.g., dest port = 80, ACK bit set, even though no TCP connection established:**

action	source address	dest address	protocol	source port	dest port	flag bit
allow	outside of 222.22/16	222.22/16	TCP	80	> 1023	ACK

- *stateful packet filter:* track status of every TCP connection
  - track connection setup (SYN), teardown (FIN): determine whether incoming, outgoing packets "makes sense"
  - timeout inactive connections at firewall: no longer admit packets

Application gateways

- **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.

Limitations of firewalls, gateways

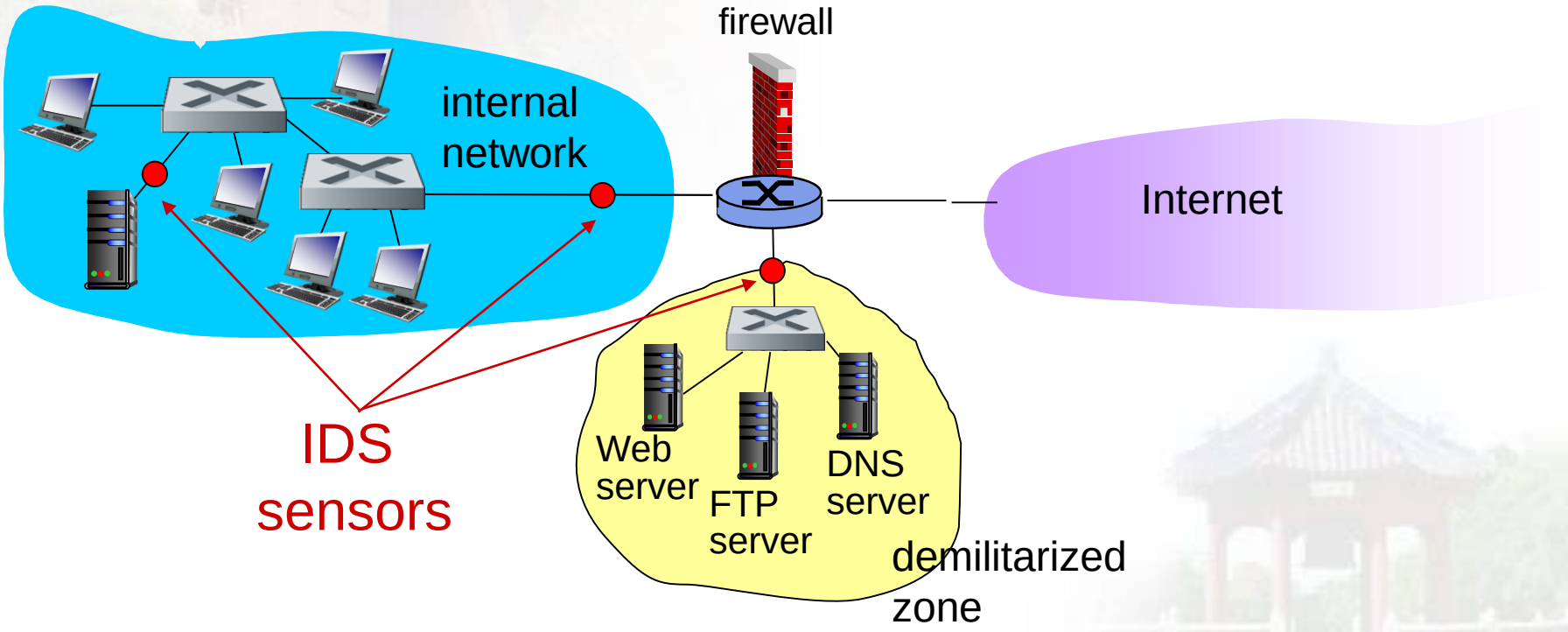
- *IP spoofing:* router can't know if data "really" comes from claimed source
- if multiple app's. need special treatment, each has own app. gateway
- client software must know how to contact gateway.
  - e.g., must set IP address of proxy in Web browser
- filters often use all or nothing policy for UDP
- *tradeoff:* degree of communication with outside world, level of security
- many highly protected sites still suffer from attacks

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**



The End of Chapter 8
The End of this Course

Appreciated for your tolerant and support

Gook Luck!

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