CAN201: Introduction to Networking

Lecture 11 - Network Security 2

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Important Information

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- **Office Hours (Strictly via appointment)**
  - Tuesday: 14:00-15:00
  - Wednesday: 14:00-15:00

Revisit – Symmetric vs. Asymmetric Crypto

- Q1: What is the main problem of symmetric cryptography?
- Q2: How would we address this problem?
- Q3: Any issue about asymmetric cryptography?

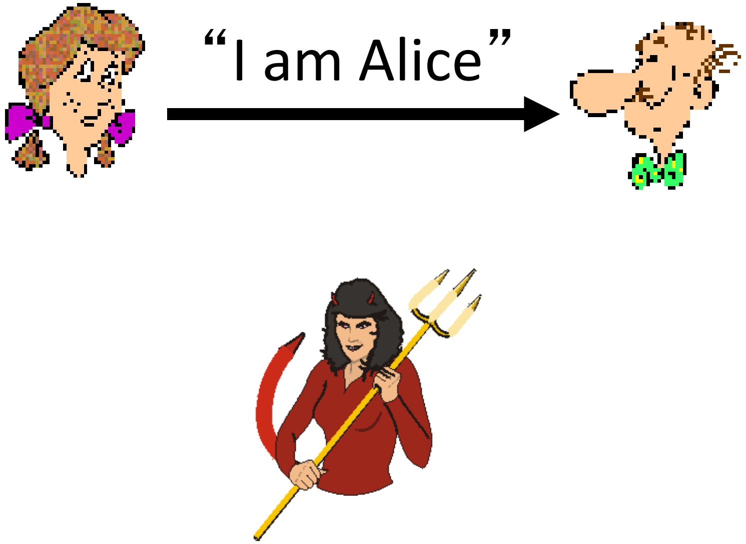
Network Security 2: roadmap

- Authentication and Message Integrity
- Securing e-mail
- Securing TCP connections: SSL

Authentication

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

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



Failure scenario??

Authentication

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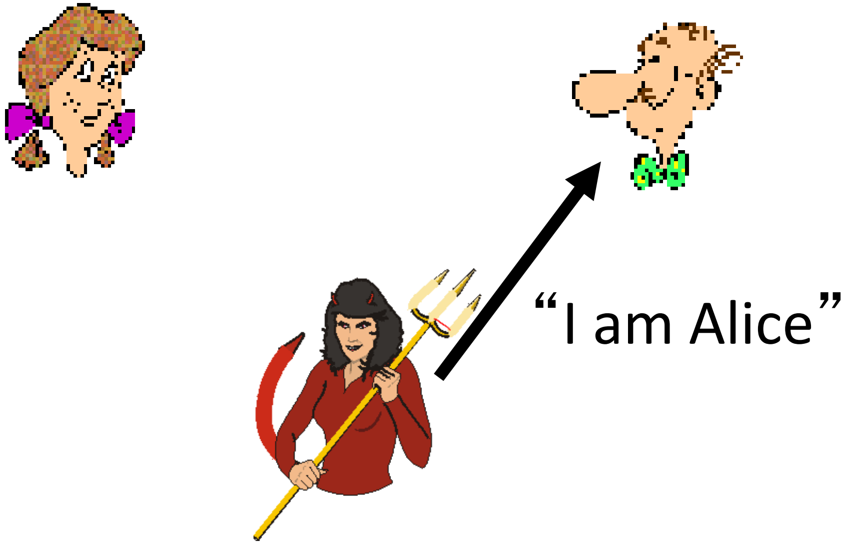
Protocol ap1.0: Alice says "I am Alice"



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

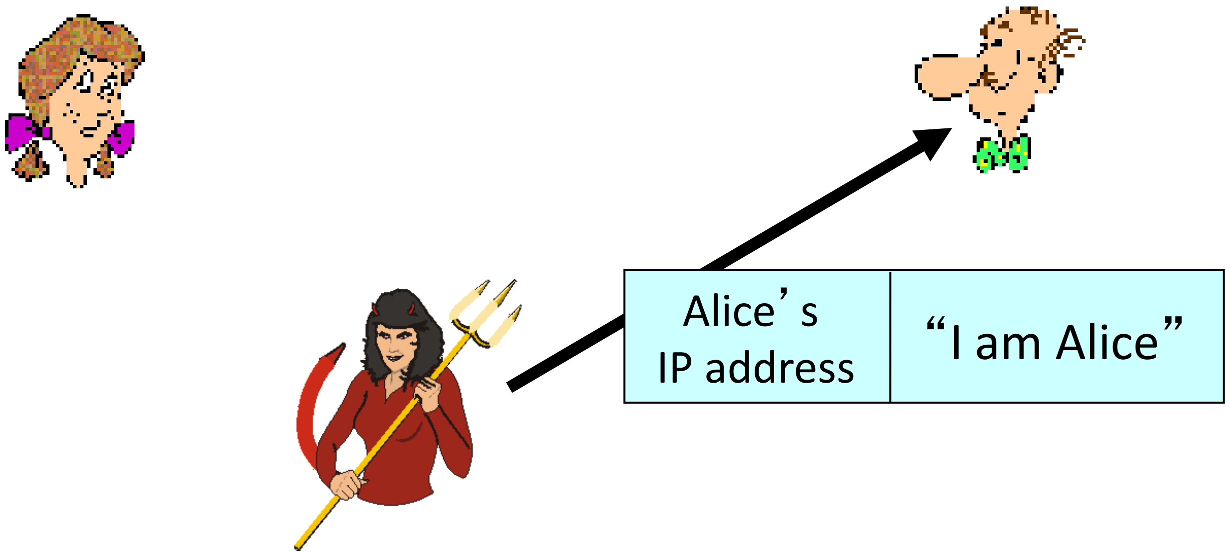
Authentication: another try

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

Failure scenario??

Authentication: another try

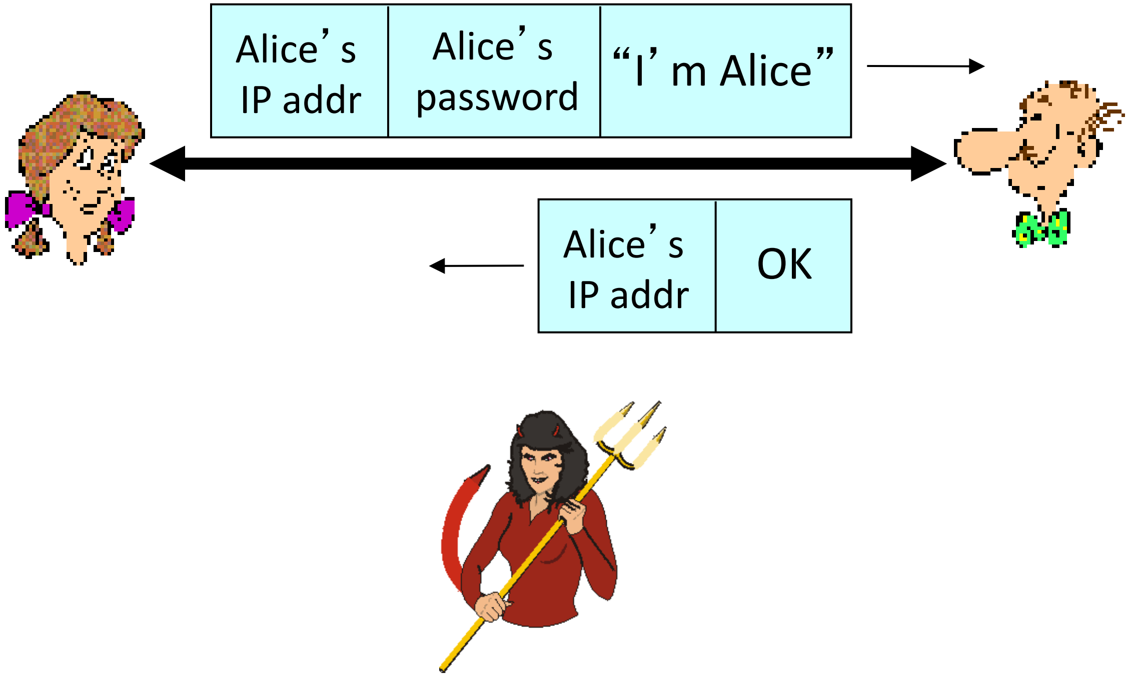
Protocol ap2.0: Alice says “I am Alice” in an IP packet containing her source IP address



Trudy can create a packet “spoofing” Alice’s address

Authentication: another try

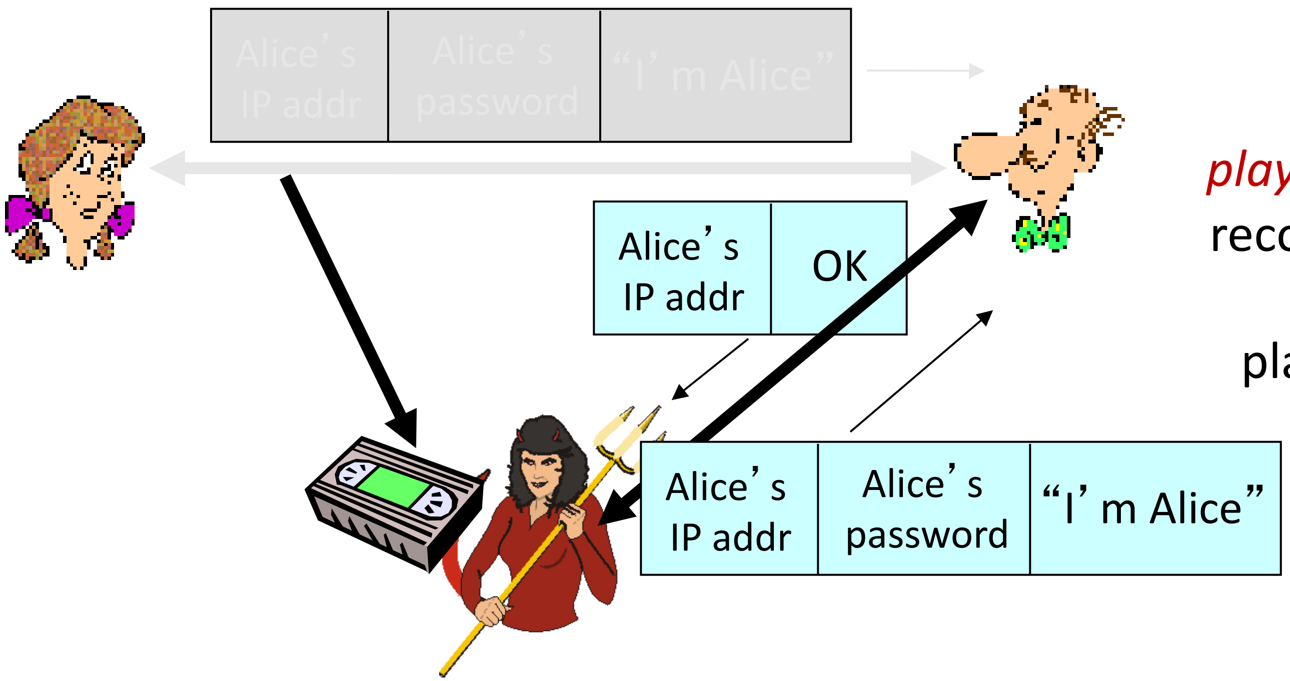
Protocol ap3.0: Alice says "I am Alice" and sends her secret password to "prove" it.



Failure scenario??

Authentication: another try

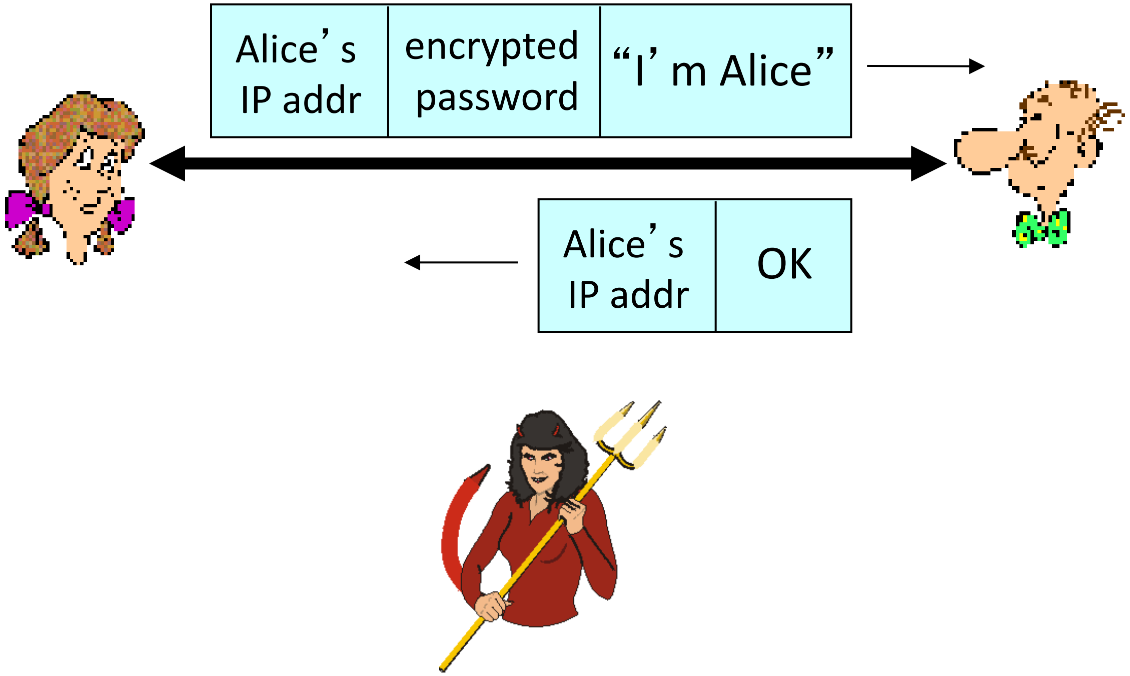
Protocol ap3.0: Alice says "I am Alice" and sends her secret password to "prove" it.



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

Authentication: yet another try

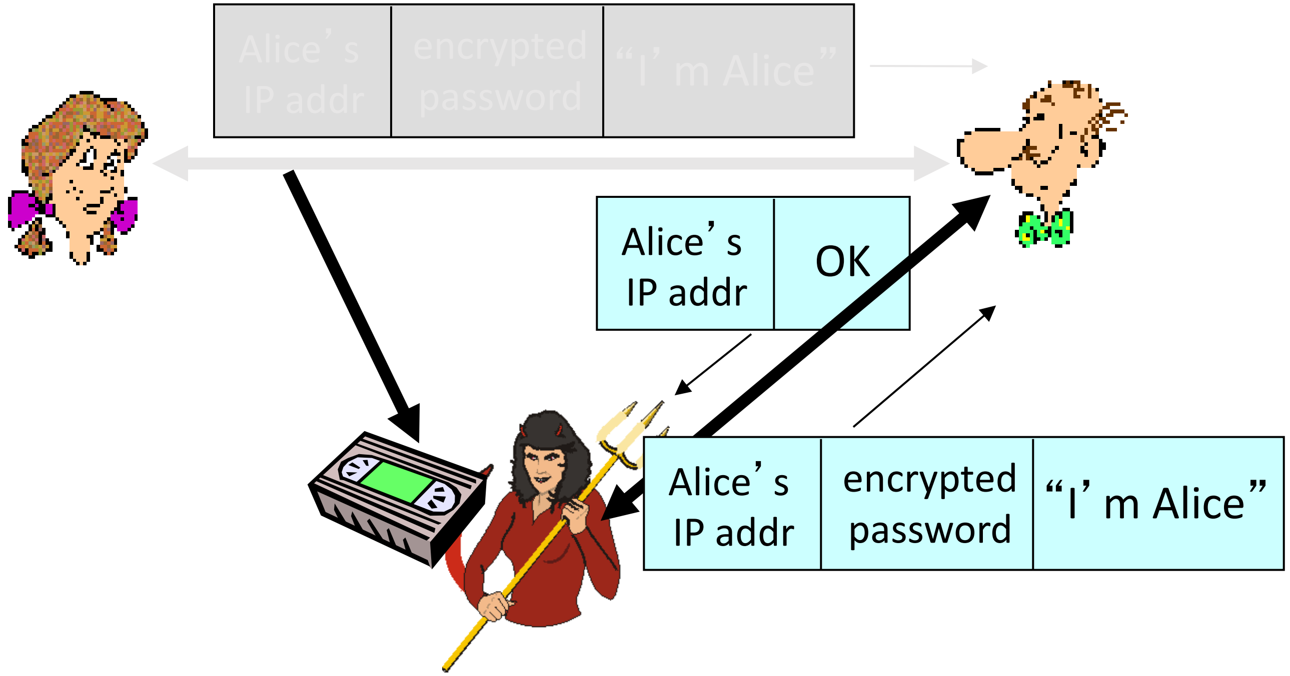
Protocol ap3.1: Alice says "I am Alice" and sends her *encrypted* secret password to "prove" it.



Failure scenario??

Authentication: yet another try

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



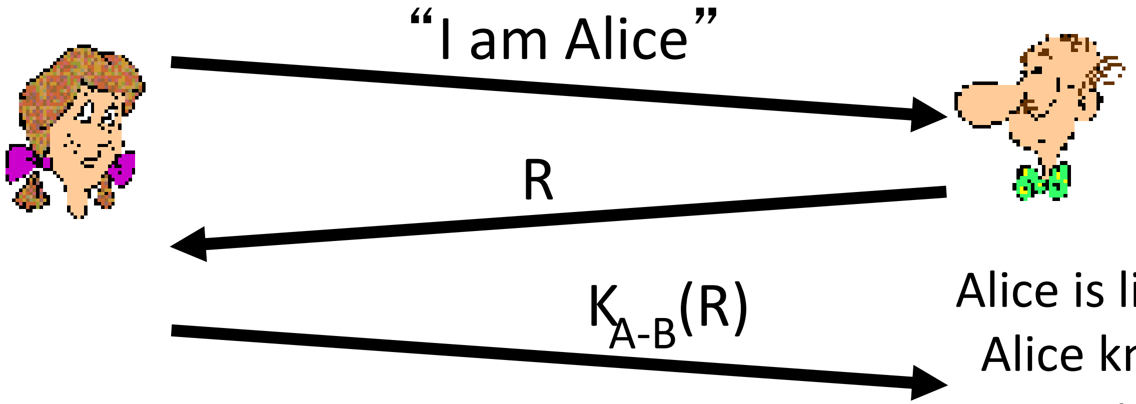
record and playback *still* works!

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



Alice is live, and only Alice knows key to encrypt nonce, so it must be Alice!

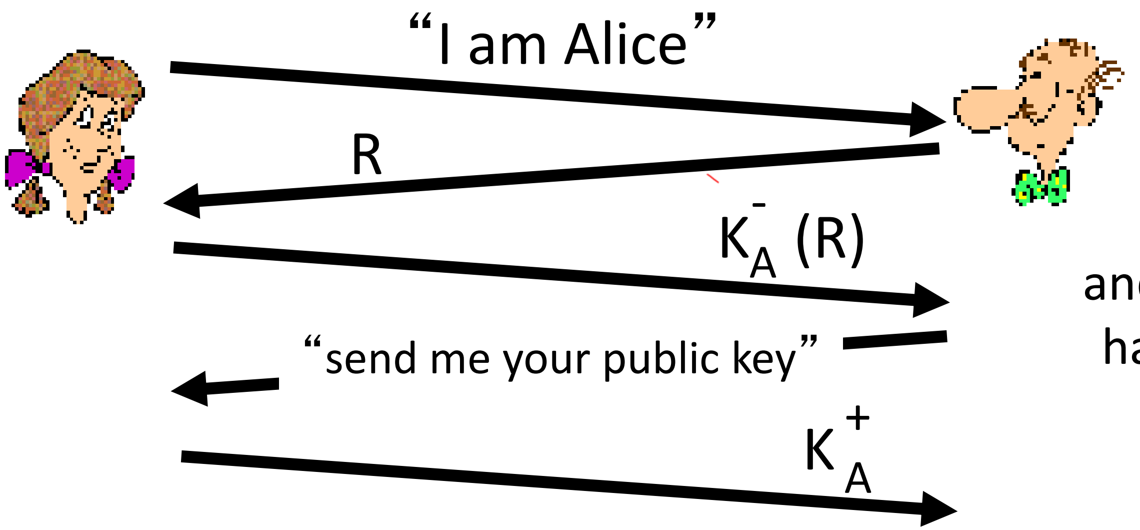
Failures, drawbacks?

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

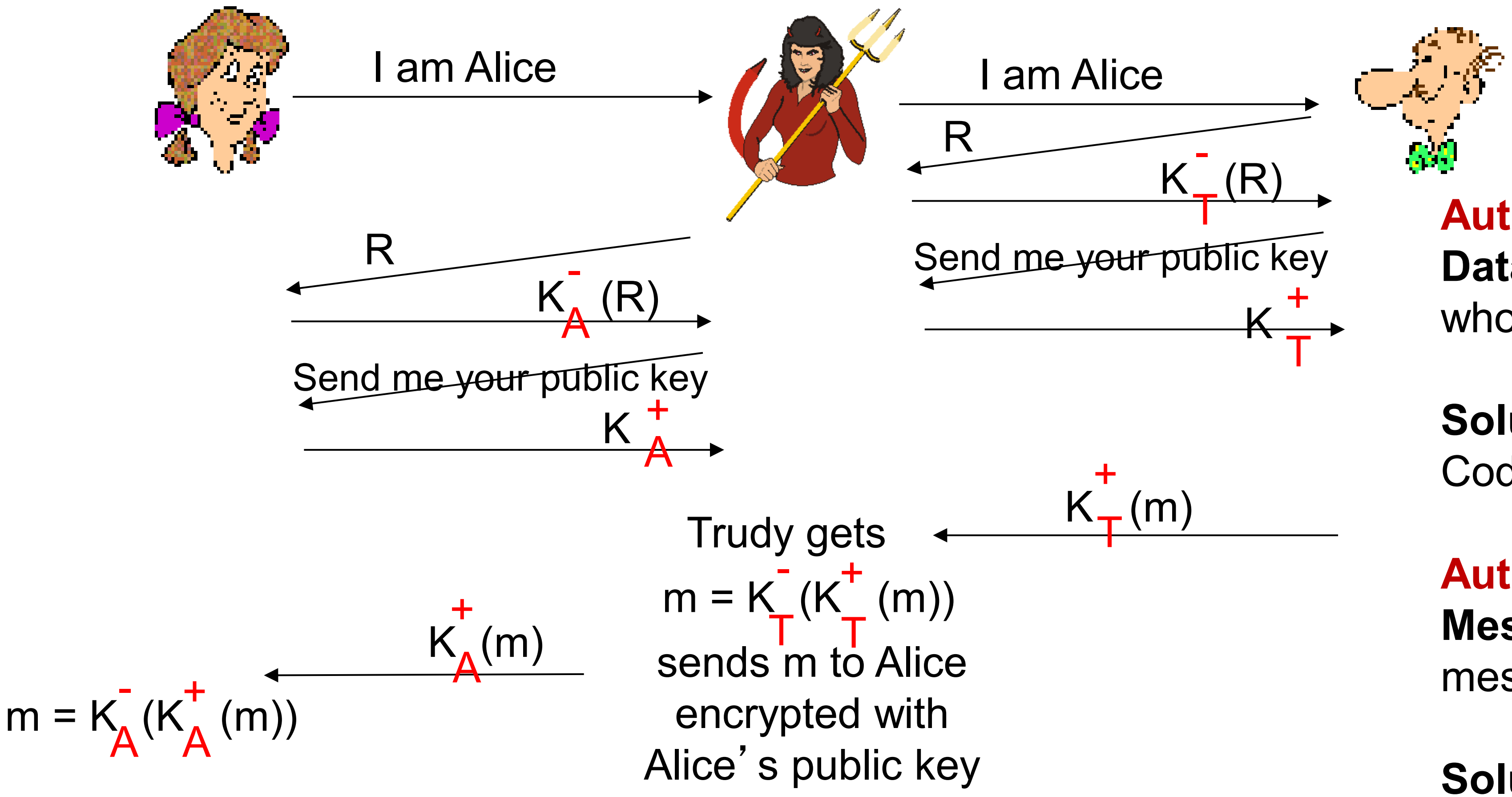
$K_A^+(K_A^-(R)) = R$

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)



Even with encryption, how do you know who really sent the message? What if Trudy intercepted and sent her own encrypted data?

Authentication Goal 1:
Data origin authentication: confirm who created/sent the message

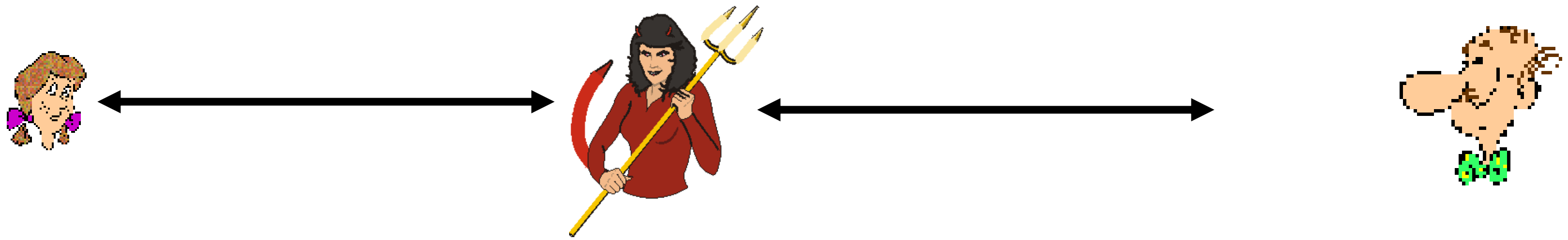
Solution: Message Authentication Code (MAC)

Authentication Goal 2:
Message integrity: ensure the message was not modified in transit

Solution: Digital Signatures

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!

Network Security 2: roadmap

- Authentication and Message Integrity
- Securing e-mail
- Securing TCP connections: SSL

Digital signatures

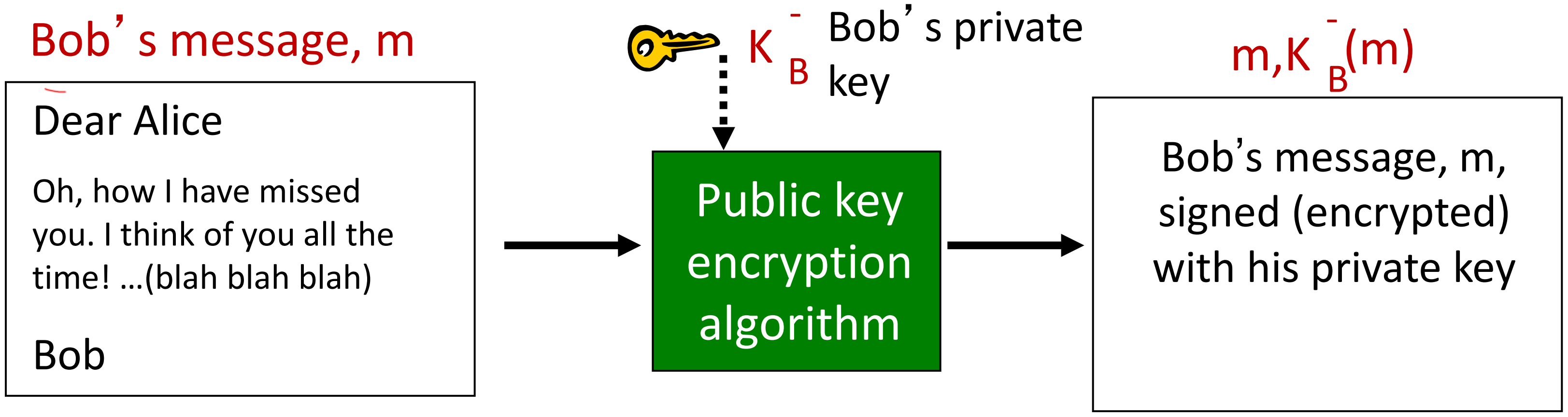
cryptographic technique analogous (likened) to hand-written signatures:

- sender (Bob) digitally signs the document, establishing he is the 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

Problem of Public Key Encryption:

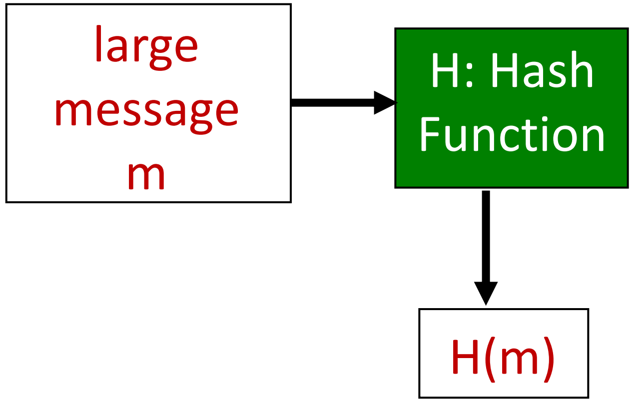
Computationally expensive to public-key-encrypt long messages

Message Digest (Solution?)

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

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

Purpose of Hashing:
Ensures integrity – any bit change creates a new digest

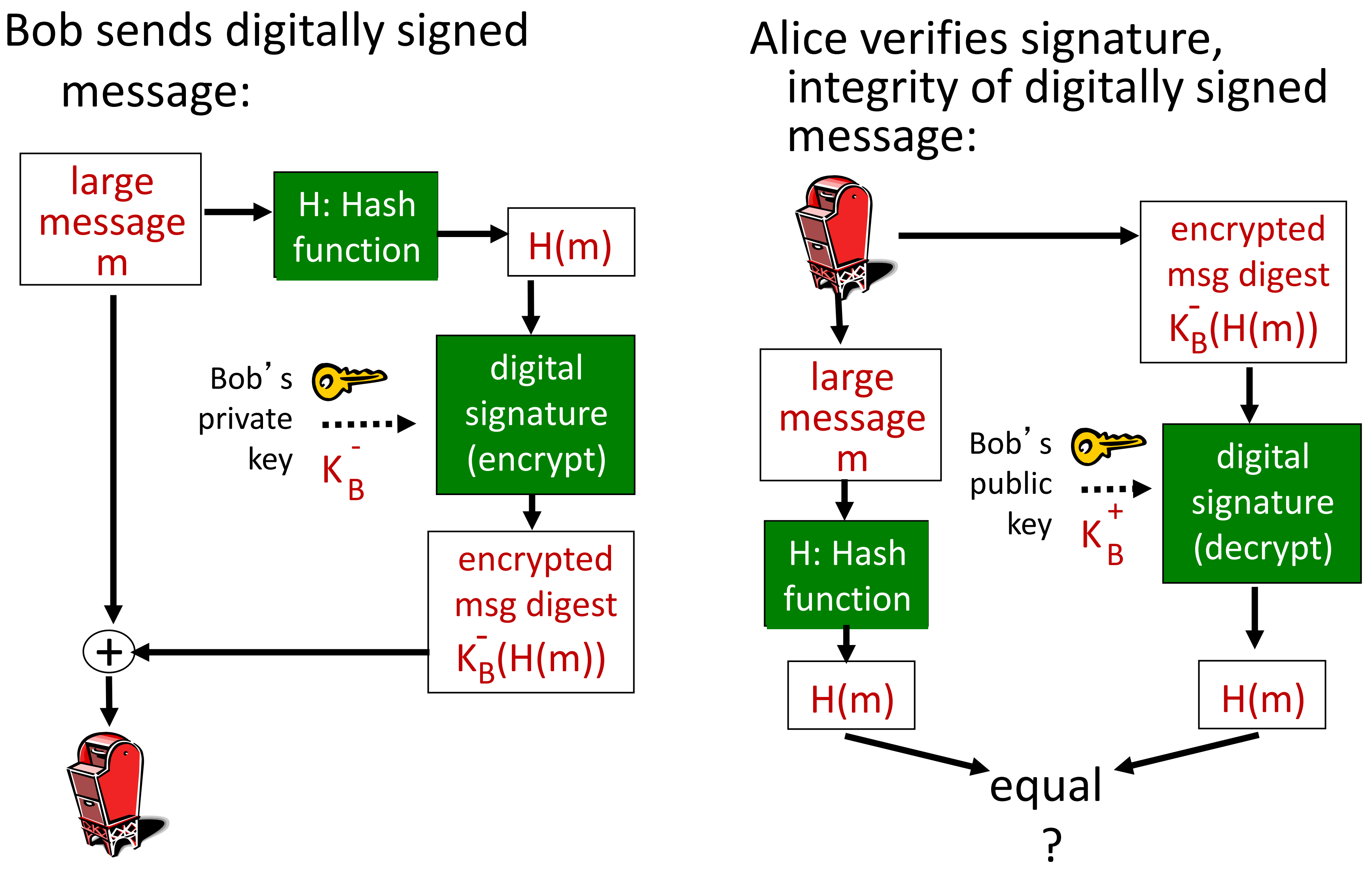


Hash function properties:

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

Digital signature = signed message digest

Hash + Digital Signature: Instead of signing the full message (expensive), sign only its hash



Internet checksum: poor crypto hash function

Internet checksum has some properties of hash function:

- Produces a fixed-length digest (16-bit sum) of message
- 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 D2 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

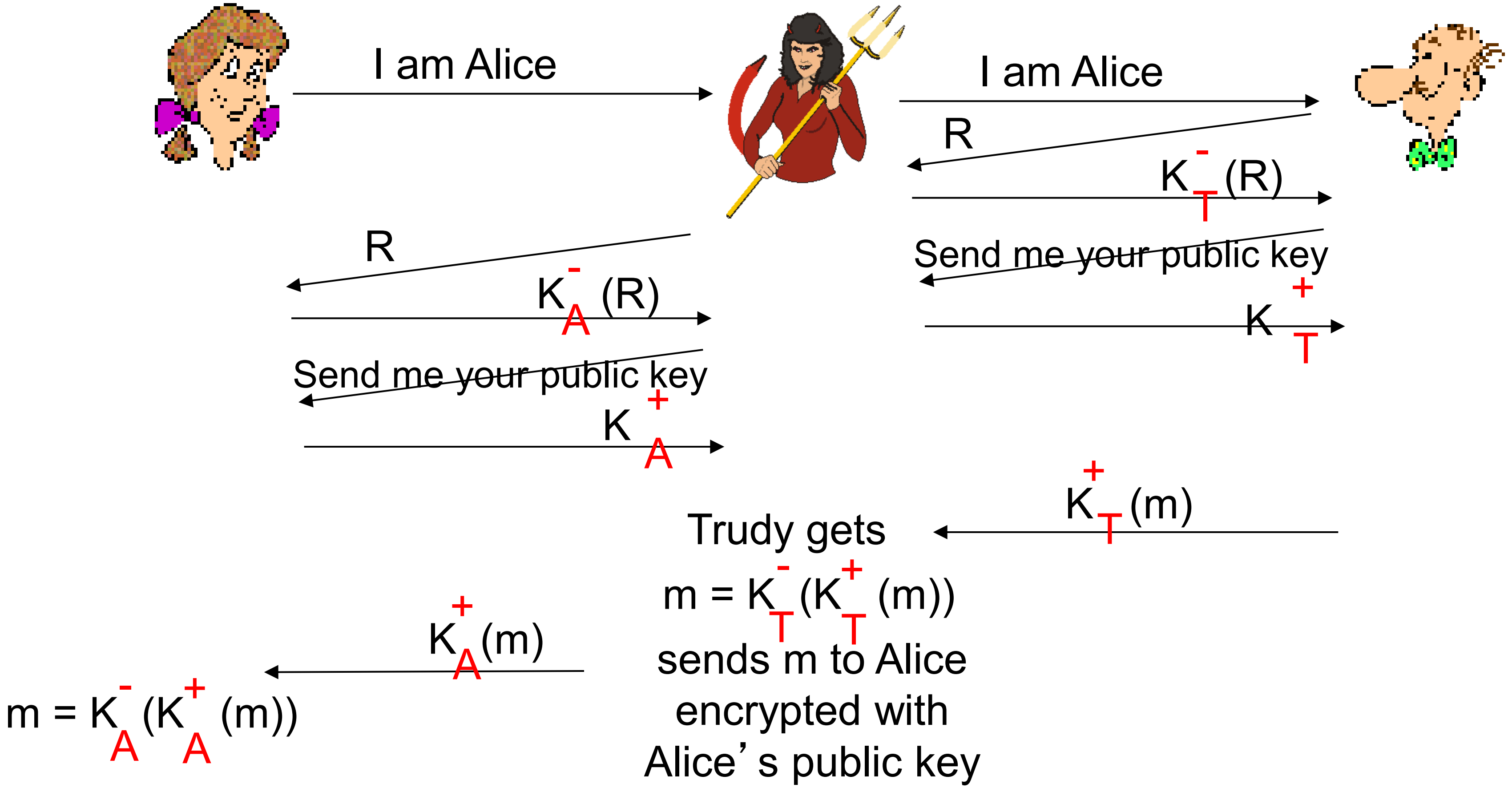
different messages but identical checksums!

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 message m whose MD5 hash is equal to x
- SHA-1 is also used
  - US standard [NIST, FIPS PUB 180-1]
  - 160-bit message digest
- SHA-256

Recall: ap5.0 security hole

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

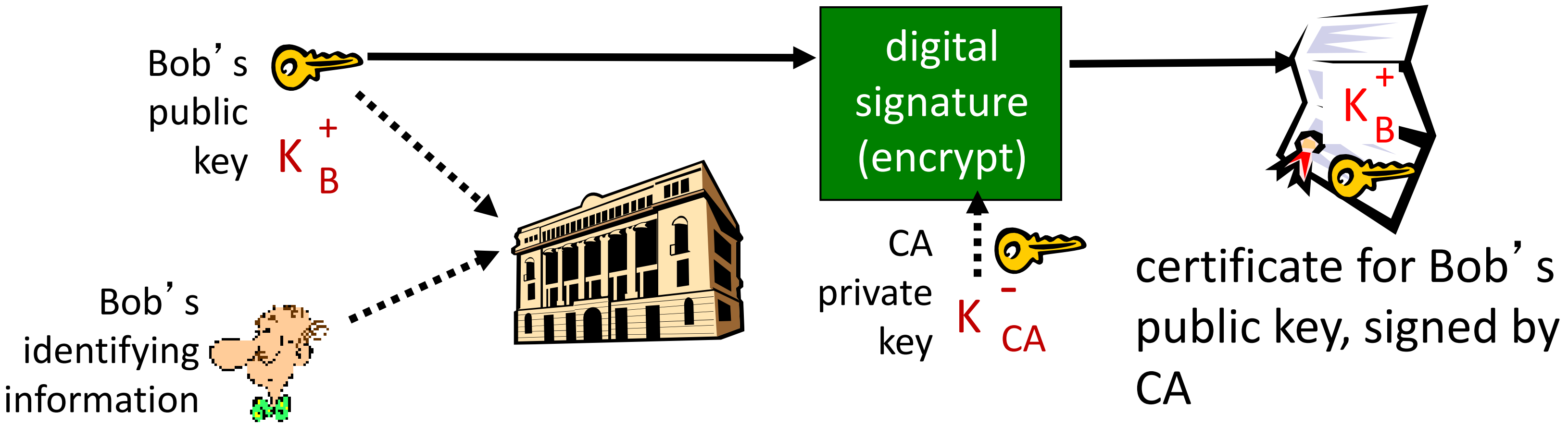


Public-key certification

- **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

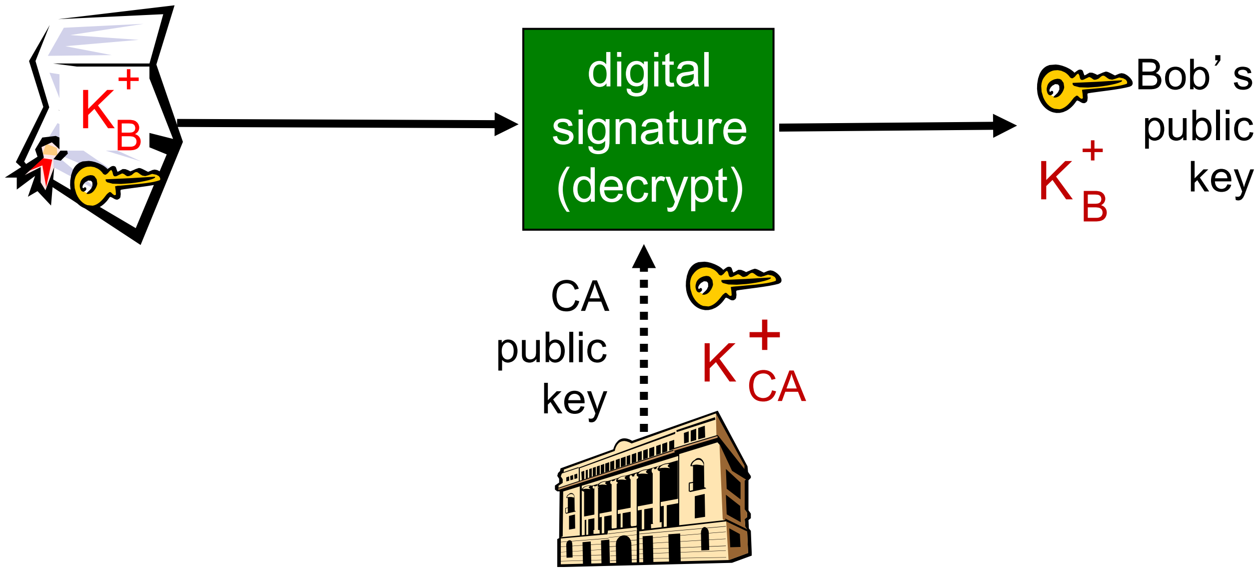
Certification authorities

- *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

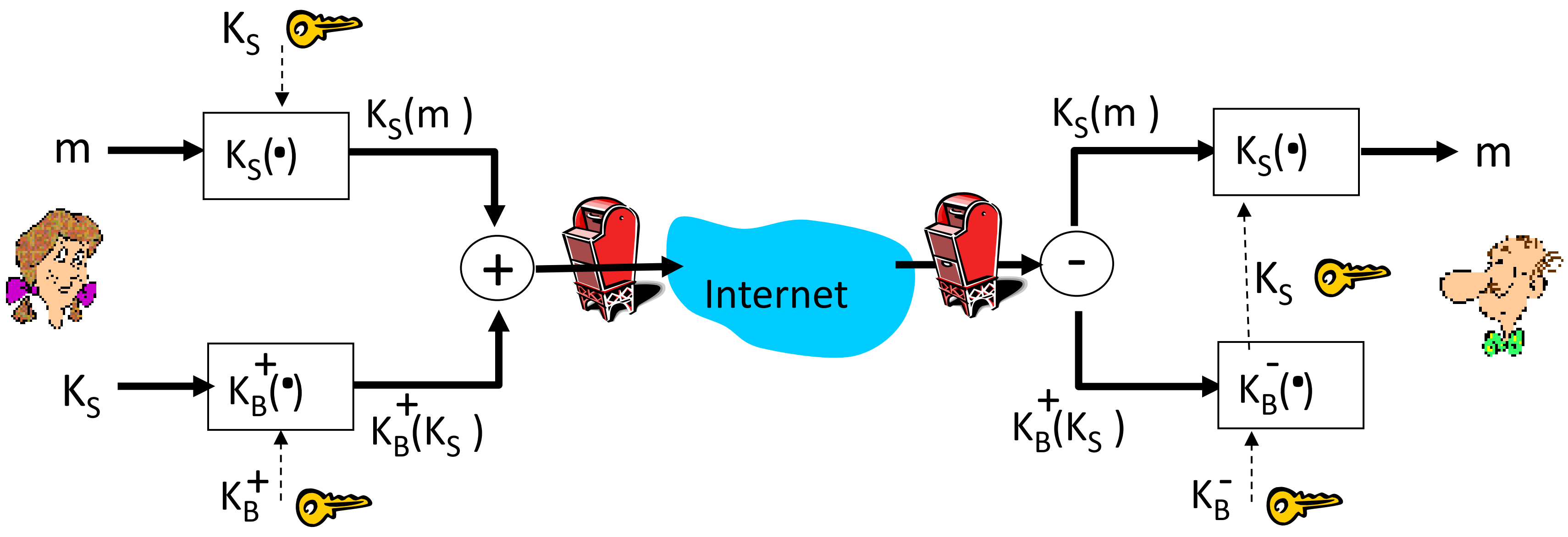


Network Security 2: roadmap

- Authentication and Message Integrity
- Securing e-mail
- Securing TCP connections: SSL

Secure e-mail

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

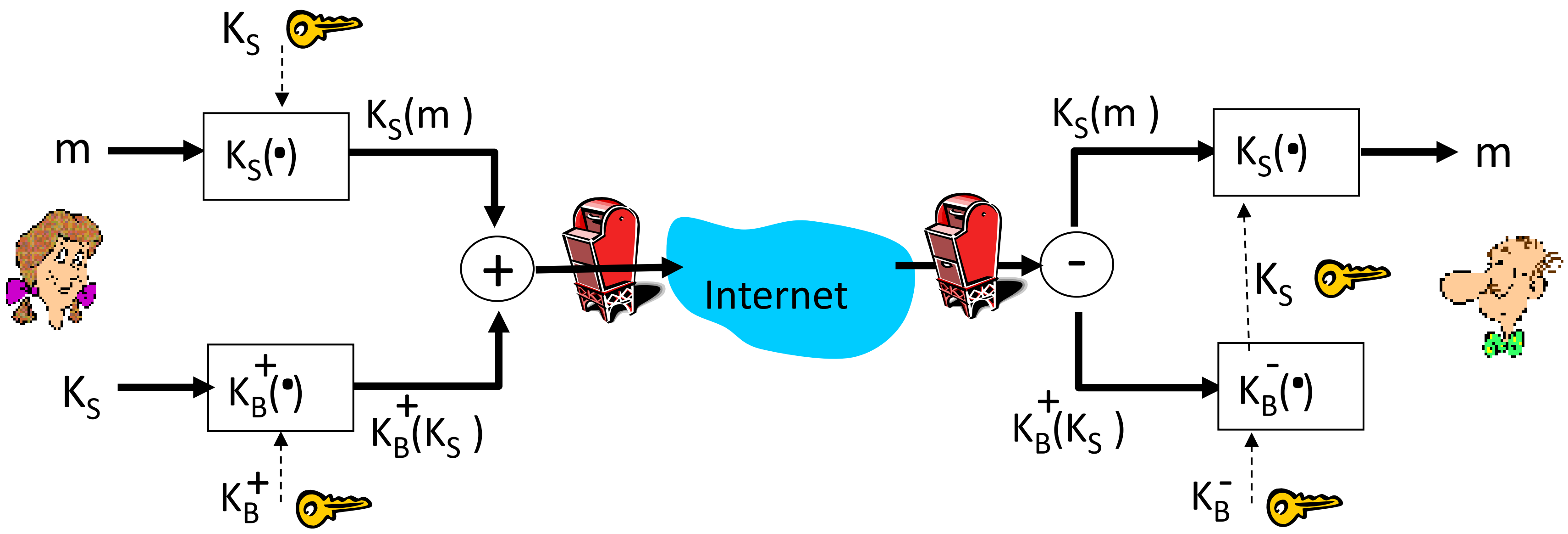


Alice:

- 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 (continued)

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

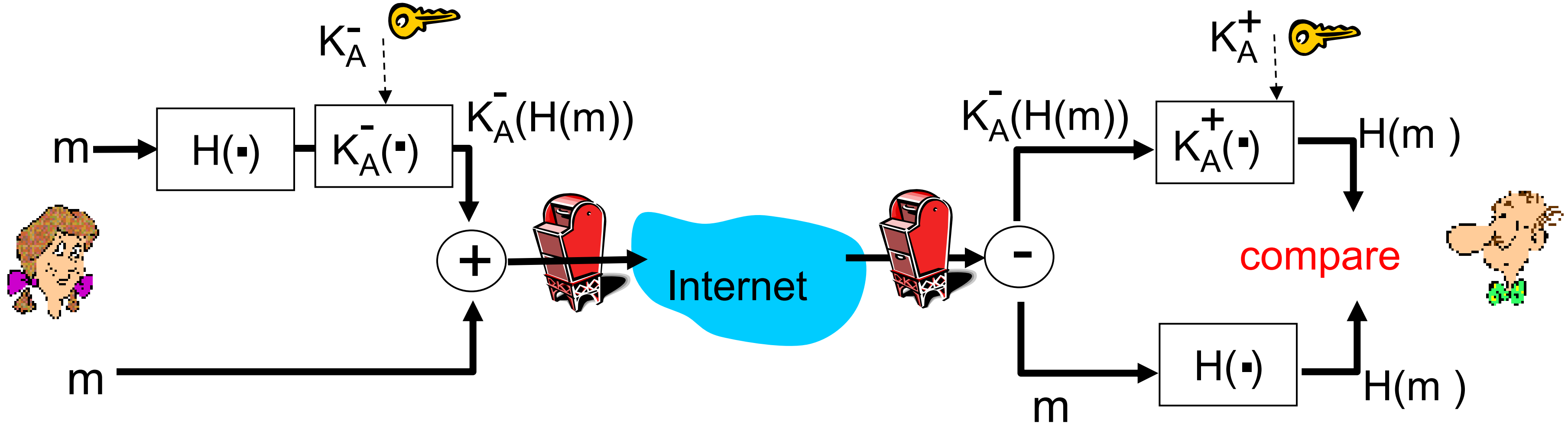


Bob:

- 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)

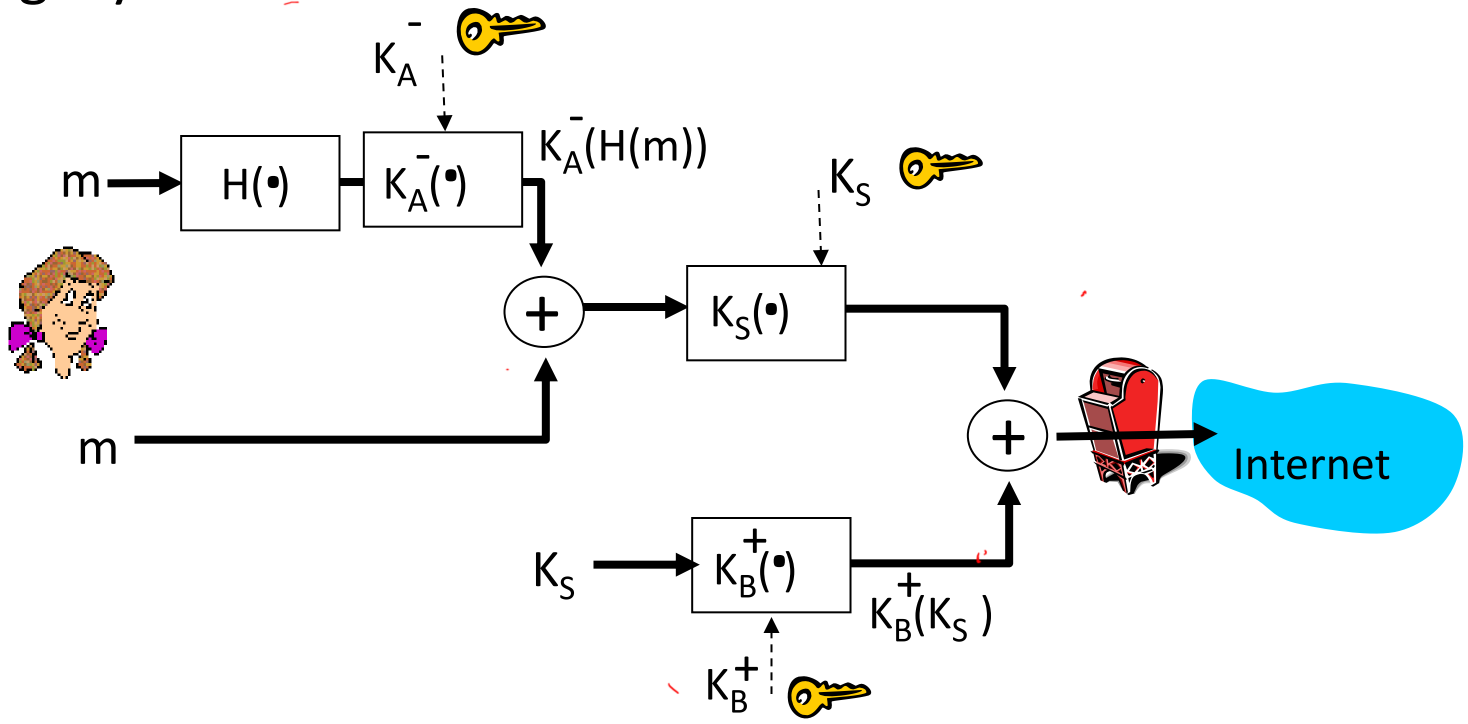
Alice wants to provide sender authentication message integrity



- 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

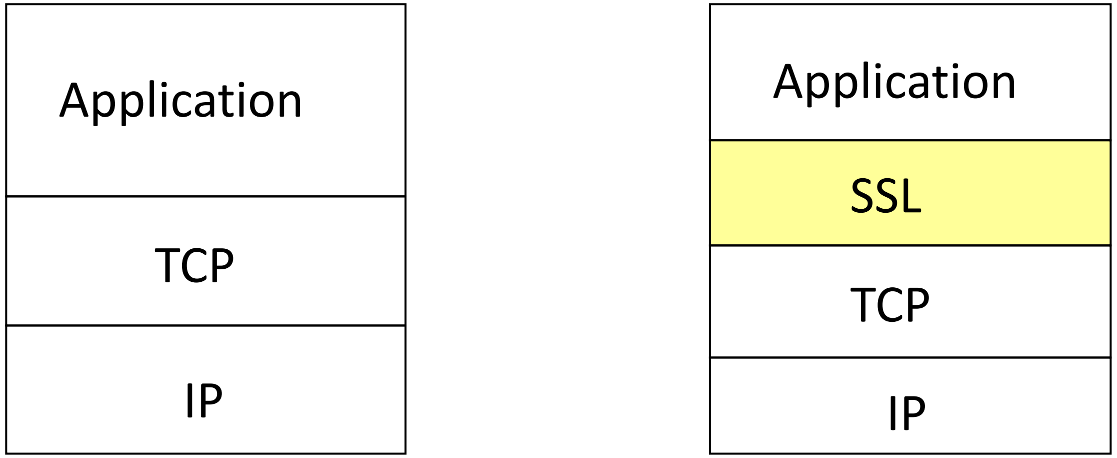
Network Security 2: roadmap

- Authentication and Message Integrity
- Securing e-mail
- Securing TCP connections: SSL

SSL: Secure Sockets Layer

- widely deployed security protocol
  - supported by almost all browsers, web servers
  - https
  - billions $/year over SSL
- 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

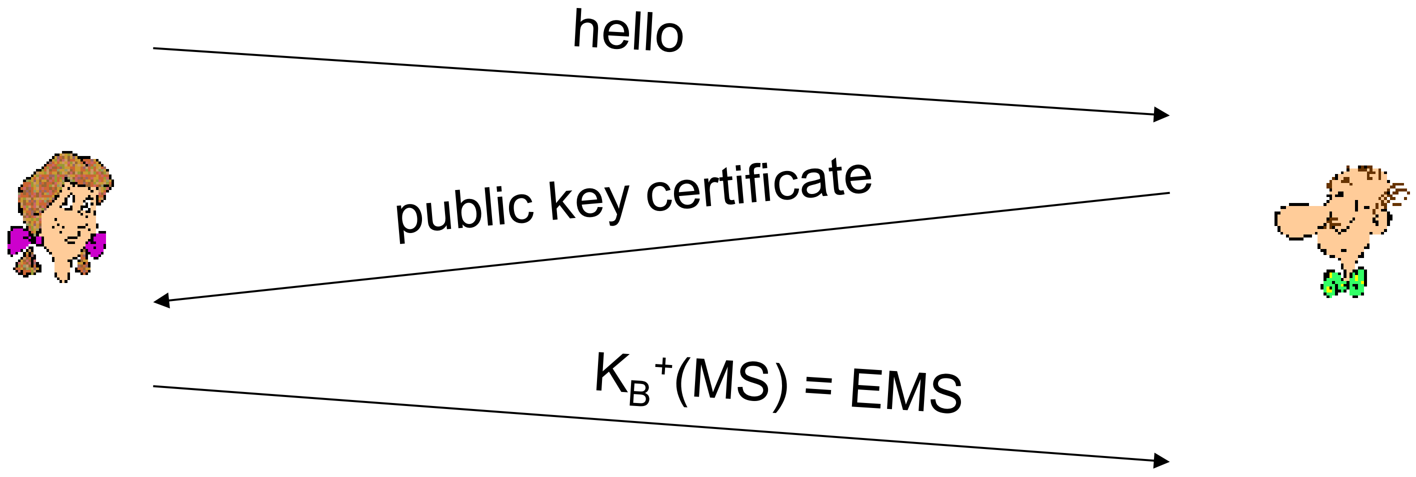
Toy SSL: a simple secure channel

Four phases:

- *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: handshake

Alice needs to
(a) establish a TCP connection with Bob,
(b) verify that Bob is *really* Bob,
(c) send Bob a master secret key



MS: **master secret**

EMS: **encrypted master secret**

Toy: key derivation

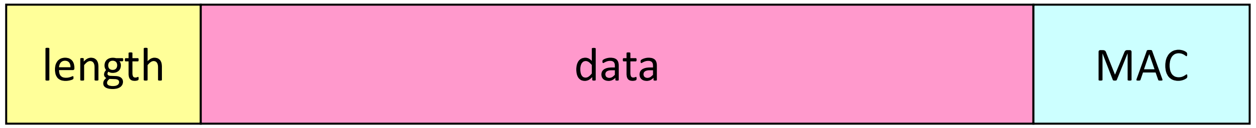
NB: the MAC here (standing for "message authentication code") is not the same MAC used in link-layer protocols (standing for "medium access control")!

- **considered bad to use same key (the master secret Key) for more than one cryptographic operation**
  - use different keys for message authentication code (MAC) and encryption
  - MAC = H(m+s), m:= message; s:= MAC key
- **four keys generated from the MS:**
  - K_c = encryption key for data sent from client to server
  - M_c = MAC key for data sent from client to server
  - K_s = encryption key for data sent from server to client
  - M_s = MAC key for data sent from server to client
- **keys derived from key derivation function (KDF)**
  - takes master secret (MS) and (possibly) some additional random data and creates the keys

Question: What is the difference between error detection (CRC) and message integrity (MAC)

Toy: data transfer – in records

- **why not encrypt data in constant stream as we write it to TCP?**
  - where would we put the MAC? If at end, no message integrity until all data processed.
  - e.g., with instant messaging, how can we do integrity check over all bytes sent before displaying?
- **instead, break stream in series of records**
  - each record carries a MAC
  - receiver can act on each record as it arrives
- **issue: in record, receiver needs to distinguish MAC from data**
  - want to use variable-length records



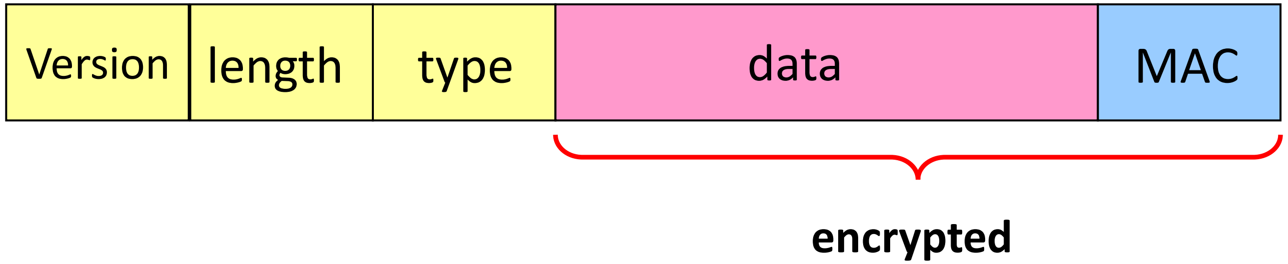
Toy: data transfer - sequence numbers

- ***problem:*** **attacker can capture and replay record or re-order records**
- ***solution:*** **put sequence number into MAC:**
  - MAC = H(M_x , sequence ||data)
  - note: no sequence number field (in the record)

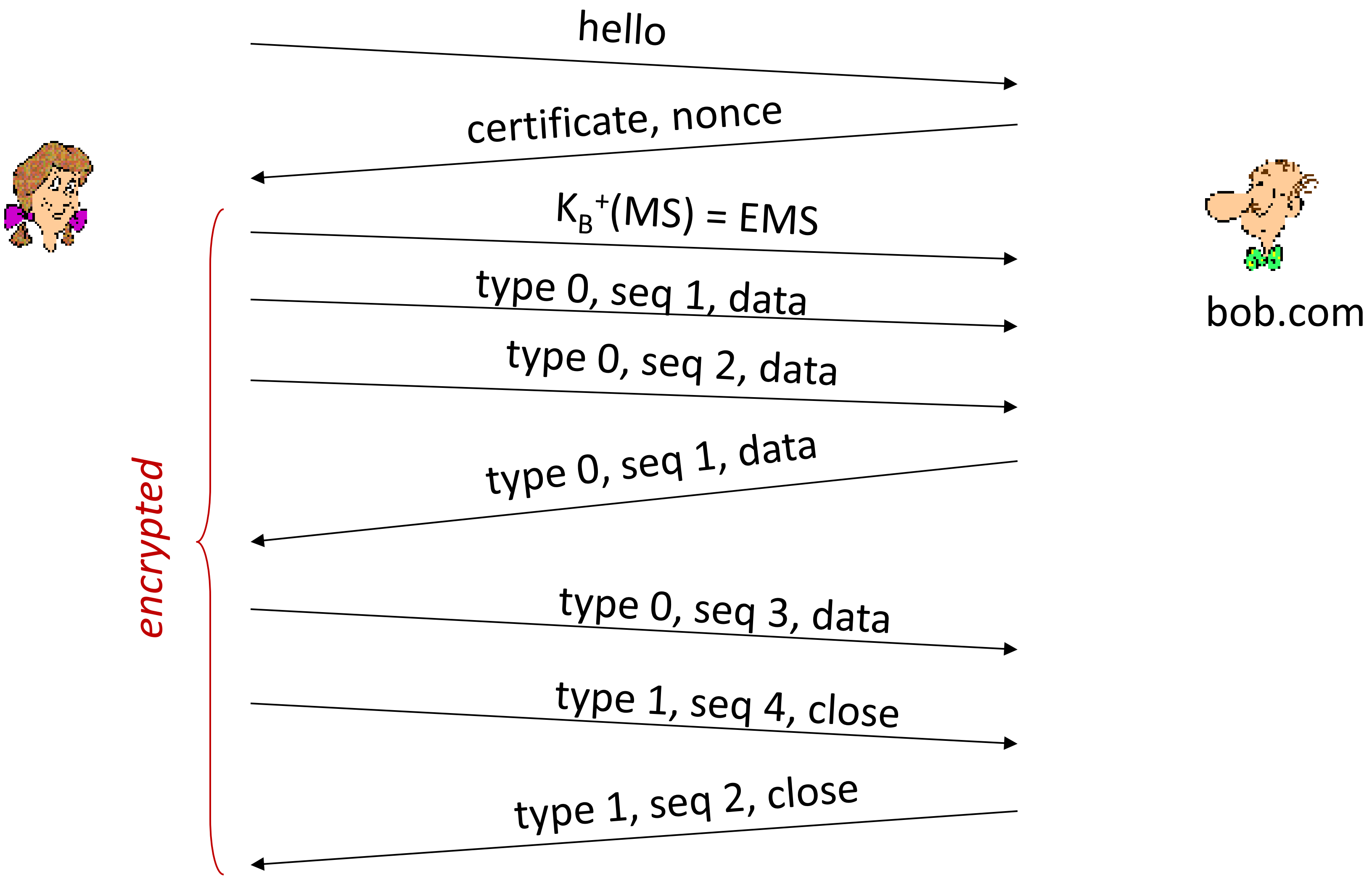
- ***problem:*** **attacker could replay all records**
- ***solution:*** **use nonce**

Toy: connection closure

- ***problem:*** **truncation attack (by MITM attacker):**
  - attacker forges TCP connection close segment (FIN)
  - one or both sides thinks there is less data than there actually is.
- ***solution:*** **different record types, with one type for closure**
  - type 0 for data; type 1 for closure
- **MAC = H(M_x, sequence||type||data)**



Toy SSL: summary



Toy SSL isn't complete

- **How long are the fields?**
- **Which encryption protocols?**
- **client and server want negotiation?**
  - allow client and server to support different encryption algorithms
  - allow client and server to choose together specific algorithm before data transfer

SSL cipher suite

- **cipher suite**
  - public-key algorithm
  - symmetric encryption algorithm
  - MAC algorithm
- **SSL supports several cipher suites**
- **negotiation: client, server agree on cipher suite**
  - client offers choice
  - server picks one

common SSL symmetric ciphers

- DES – Data Encryption Standard: block
- 3DES – Triple strength: block
- RC2 – Rivest Cipher 2: block
- RC4 – Rivest Cipher 4: stream

SSL Public key encryption

- RSA

Real SSL: handshake (1)

Purpose

1. server authentication
2. negotiation: agree on crypto algorithms
3. establish keys
4. client authentication (optional)

Real SSL: handshake (2)

1. client sends list of algorithms it supports, along with client nonce
2. server chooses algorithms from list; sends back: choice + certificate + server nonce
3. client verifies certificate, extracts server's public key, generates pre_master_secret, encrypts with server's public key, sends to server
4. client and server independently compute encryption and MAC keys from pre_master_secret and nonces
5. client sends a MAC of all the handshake messages
6. server sends a MAC of all the handshake messages

Real SSL: handshake (3)

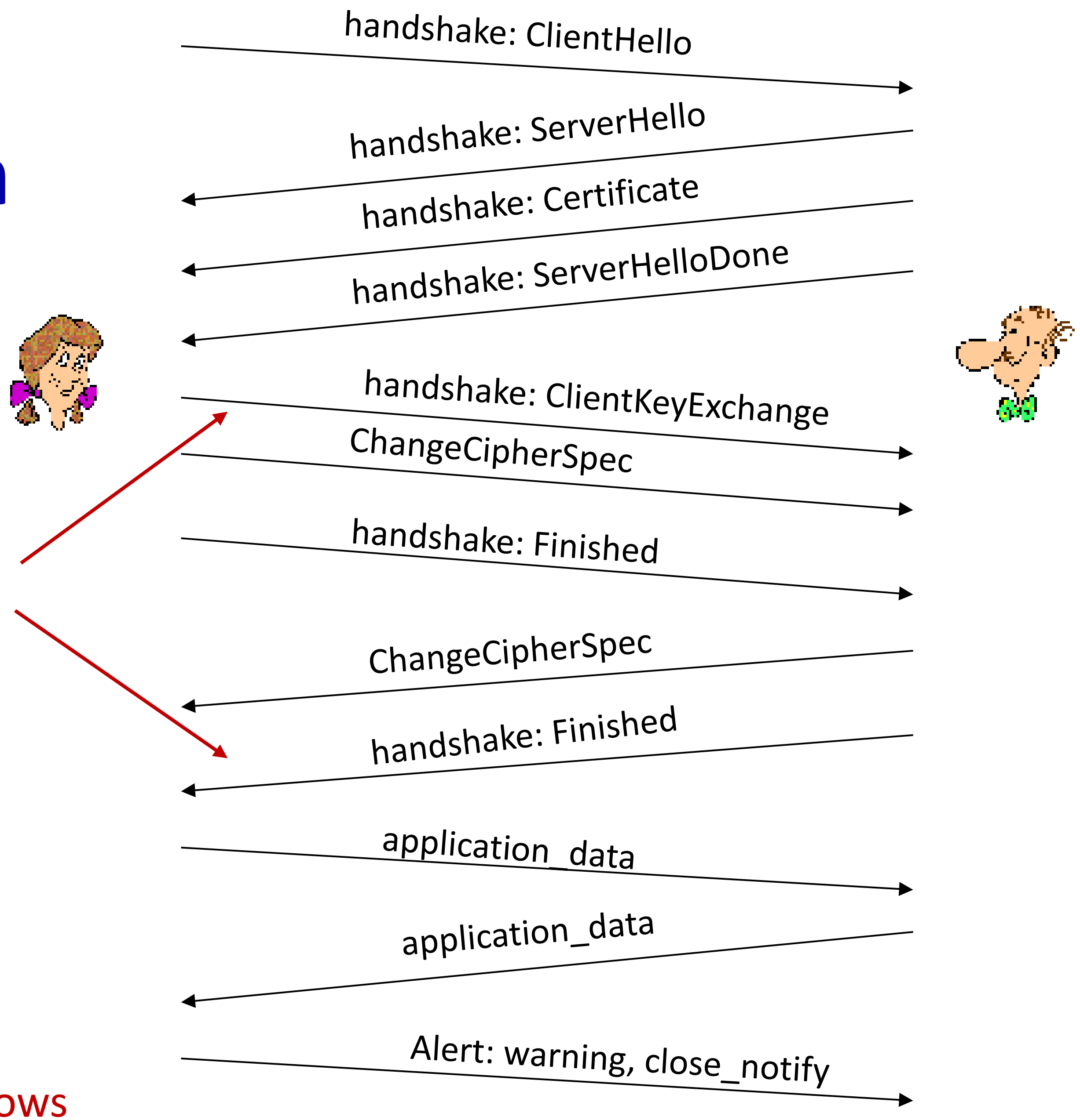
last 2 steps protect handshake from tampering

- In step 1, client typically offers range of algorithms, in plain-text, some strong, some weak
- man-in-the middle could delete stronger algorithms from list
- last 2 steps (step 5 and 6) prevent this
  - last two messages are encrypted

Real SSL: handshake (4)

- why two random nonces, in step 1 and 2 respectively?
- suppose Trudy sniffs all messages between Alice & Bob
- next day, Trudy sets up TCP connection with Bob, sends exact same sequence of records
  - Bob (Amazon) thinks Alice made two separate orders for the same thing
  - **solution**: Bob sends different random nonce for each connection. This causes encryption keys to be different on the two days
  - Trudy's messages will fail Bob's integrity check

Real SSL connection



everything henceforth is encrypted

TCP FIN follows