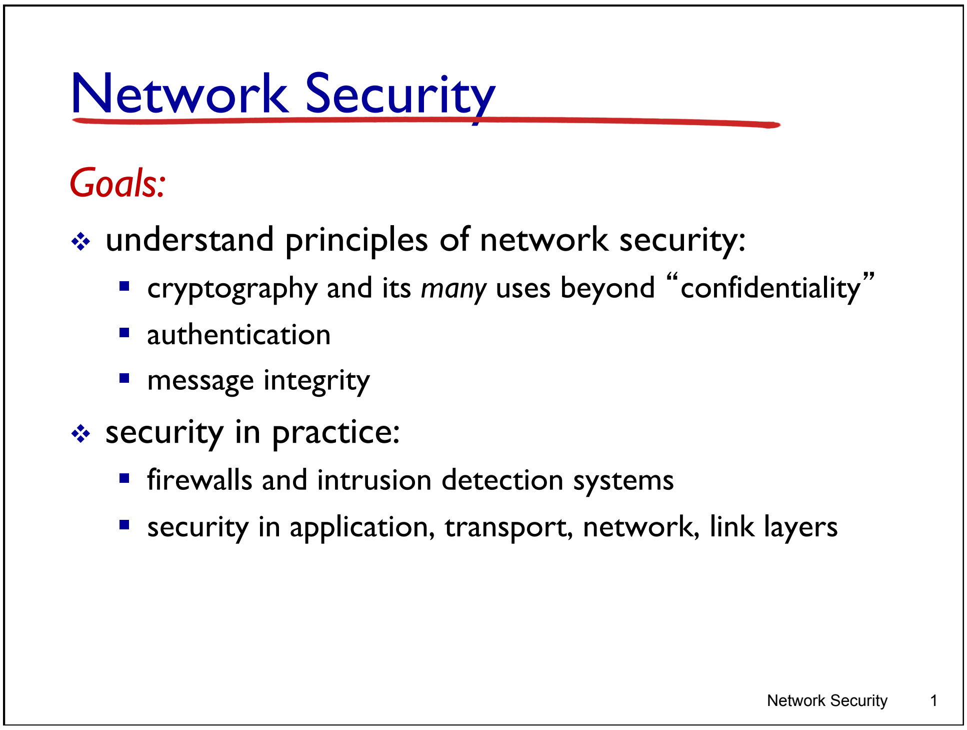
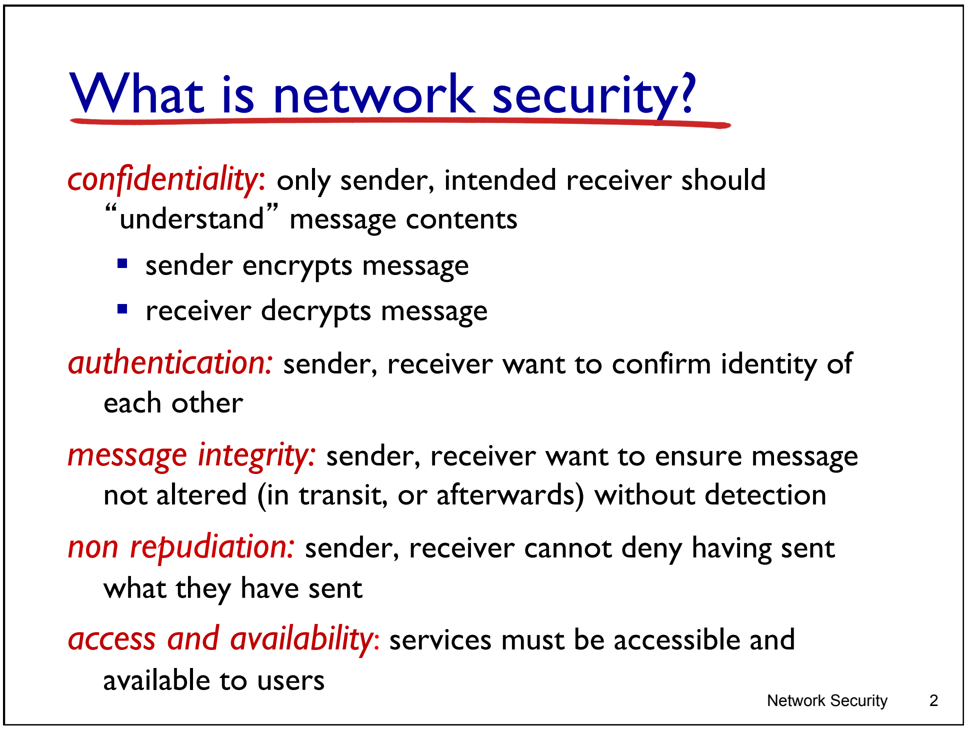


Network Security

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



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

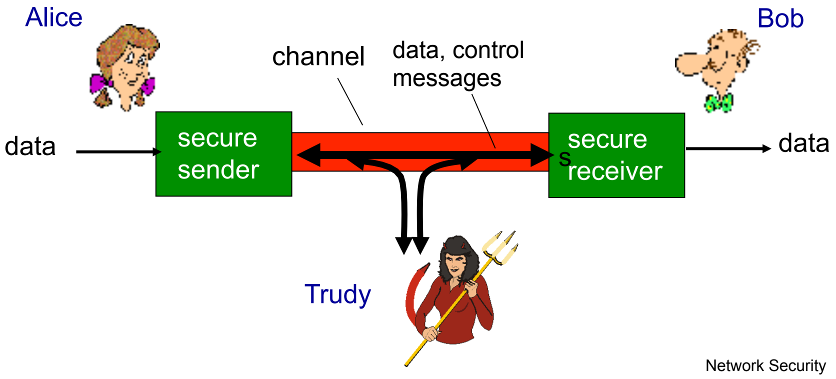
message integrity: sender, receiver want to ensure message not altered (in transit, or afterwards) without detection

non repudiation: sender, receiver cannot deny having sent what they have sent

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 (friends) want to communicate "securely"
- Trudy (intruder) may intercept, delete, add messages



Who might Bob, Alice be?

- … well, *real-life* Bobs and Alices!
- Web browser/server for electronic transactions (e.g., on-line purchases)
- on-line banking client/server
- DNS servers
- routers exchanging routing table updates
- other examples?

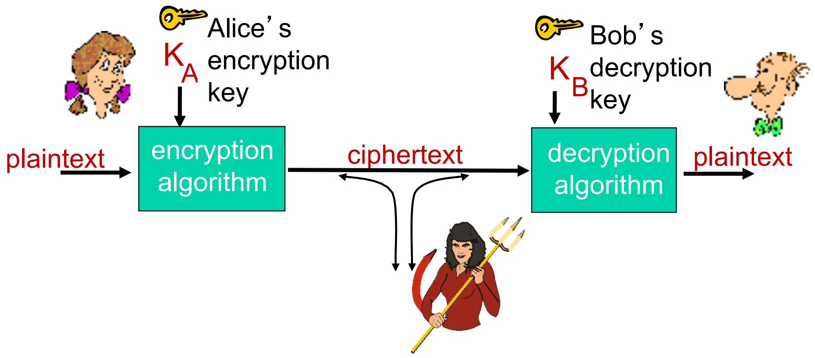
There are bad guys (and girls) out there!

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)

The language of cryptography



Alice' s encryption key K_A

Bob' s decryption key K_B

plaintext

encryption algorithm

ciphertext

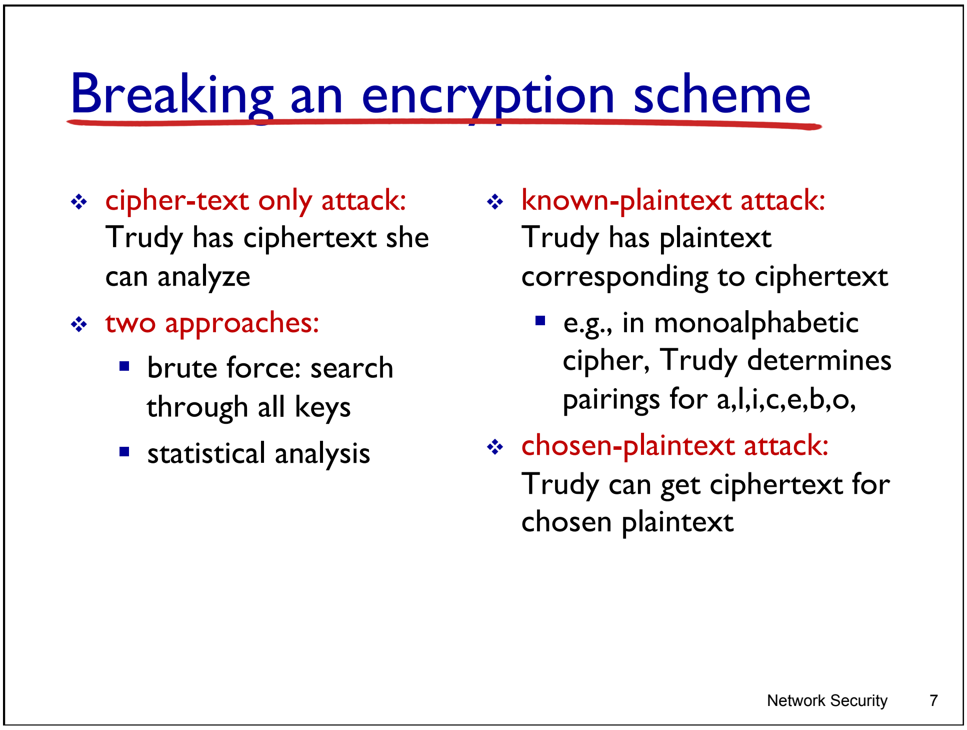
decryption algorithm

plaintext

m plaintext message

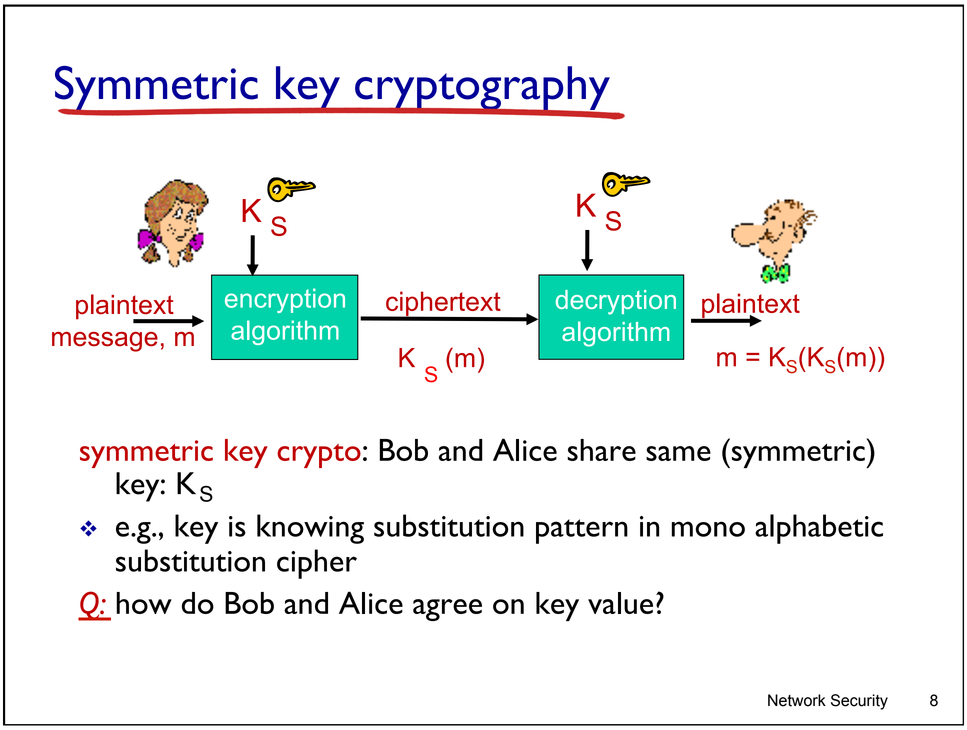
$K_A(m)$ ciphertext, encrypted with key K_A

$m = K_B(K_A(m))$



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

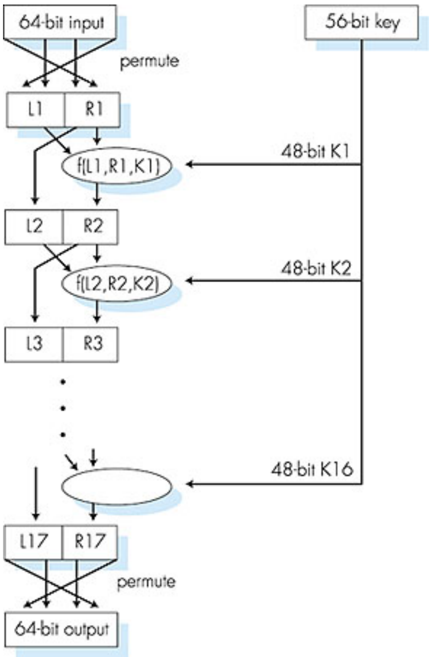
Symmetric key crypto: DES

DES operation

initial permutation

16 identical "rounds" of function application, each using different 48 bits of key

final permutation



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

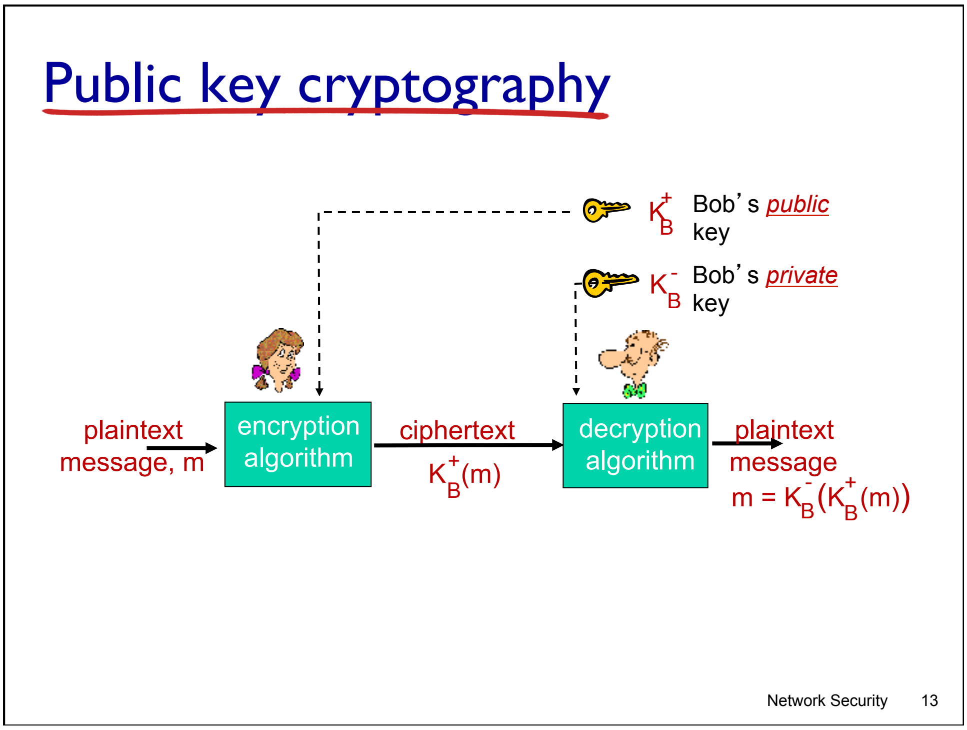
Public Key Cryptography

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



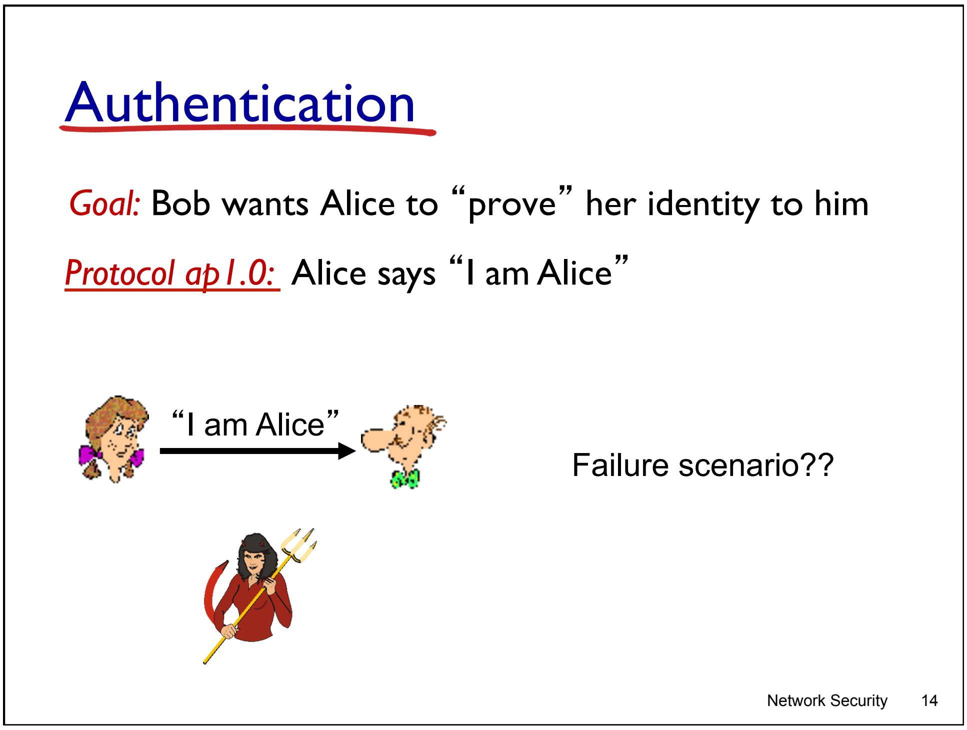
Public key cryptography

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

Network Security 13



Authentication

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

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

"I am Alice"

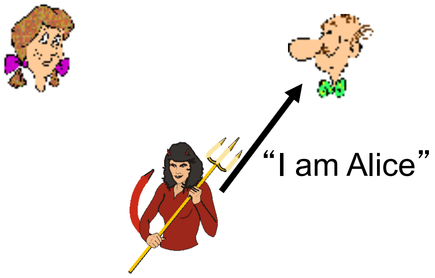
Failure scenario??

Network Security 14

Authentication

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

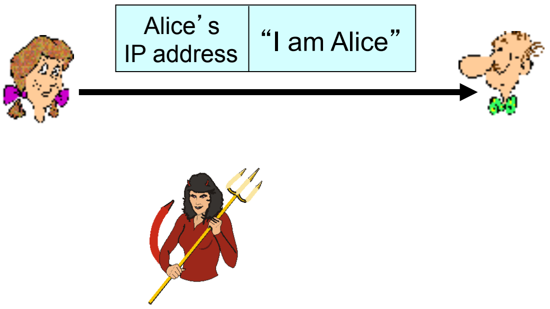
Protocol ap1.0: Alice says "I am Alice"



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

Authentication: another try

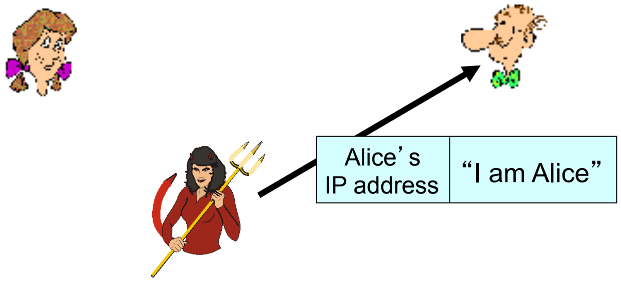
Protocol ap2.0: Alice says "I am Alice" in an IP packet containing her source IP address



Failure scenario??

Authentication: another try

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



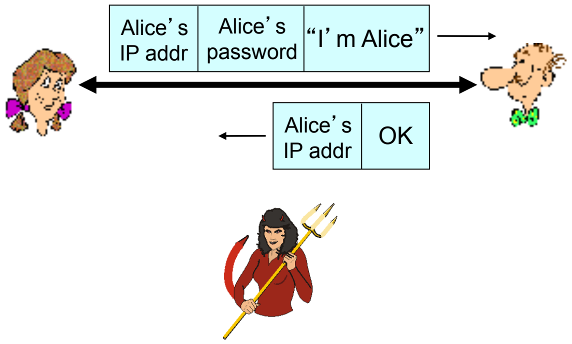
Alice’ s IP address

“I am Alice”

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.



Alice’ s IP addr

Alice’ s password

“I’ m Alice”

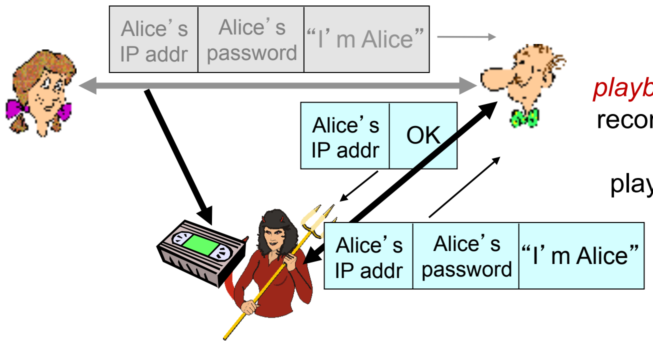
Alice’ s IP addr

OK

Failure scenario??

Authentication: another try

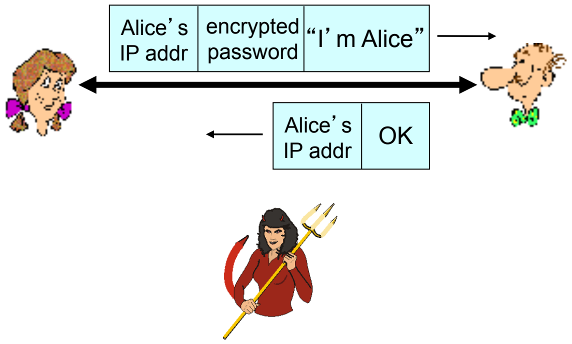
Protocol ap3.0: Alice says "I am Alice" and sends her secret password to "prove" it.



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

Authentication: yet another try

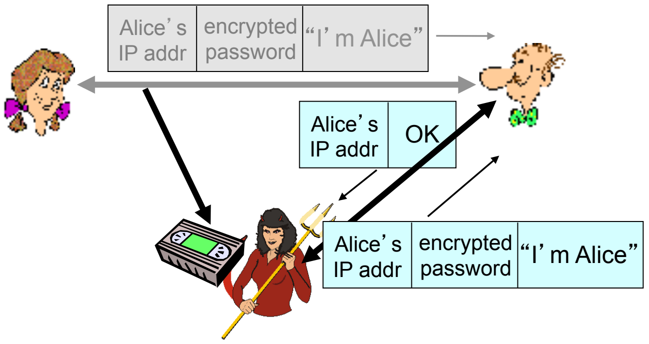
Protocol ap3.1: Alice says "I am Alice" and sends her *encrypted* secret password to "prove" it.



Failure scenario??

Authentication: yet another try

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



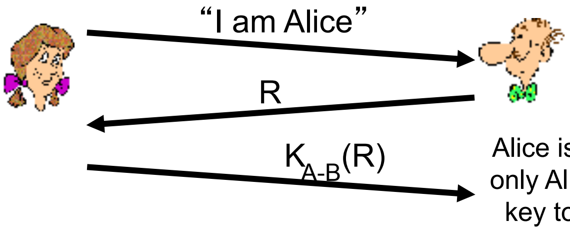
record and playback *still* works!

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!

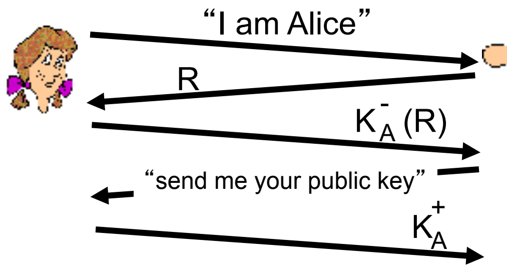
Failures, drawbacks?

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

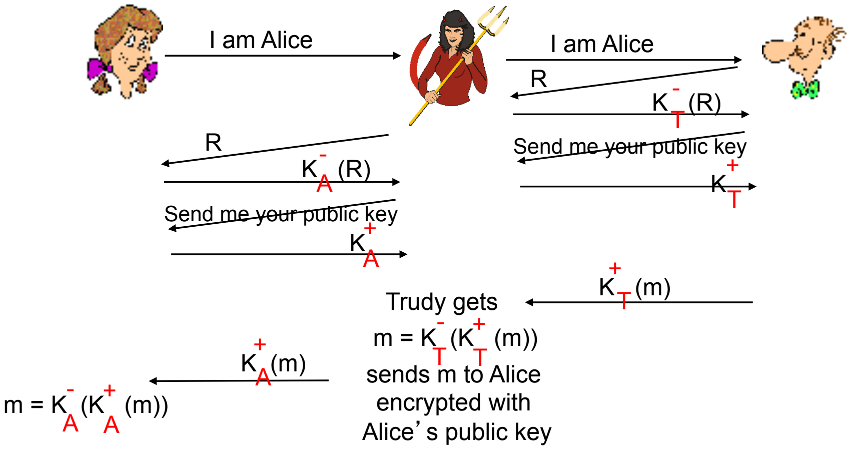
$K_A^+(K_A^-(R)) = R$

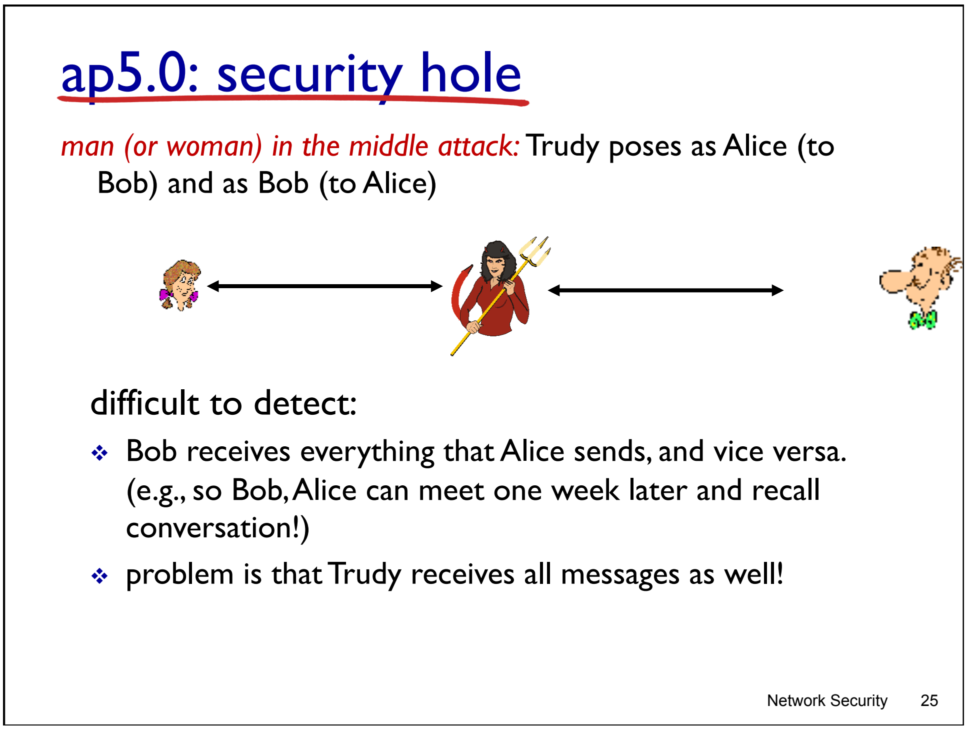
and knows only Alice could have the private key, that encrypted R such that

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

ap5.0: security hole

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



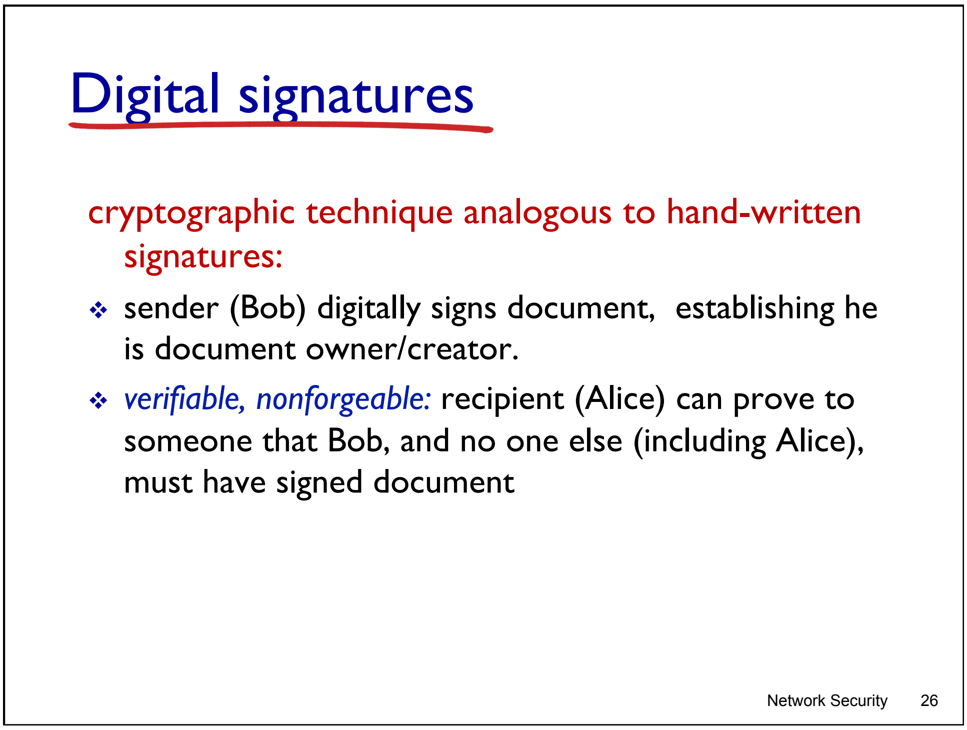


ap5.0: security hole

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

difficult to detect:

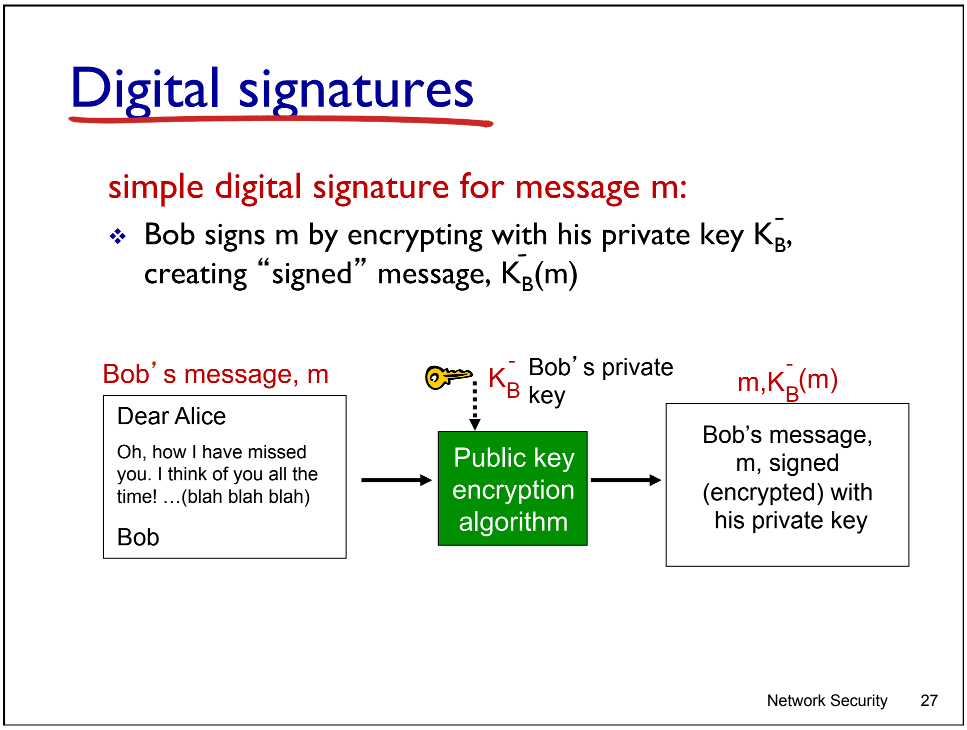
- Bob receives everything that Alice sends, and vice versa. (e.g., so Bob, Alice can meet one week later and recall conversation!)
- problem is that Trudy receives all messages as well!



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, $K_B^-(m)$

Bob's message, m

Dear Alice

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

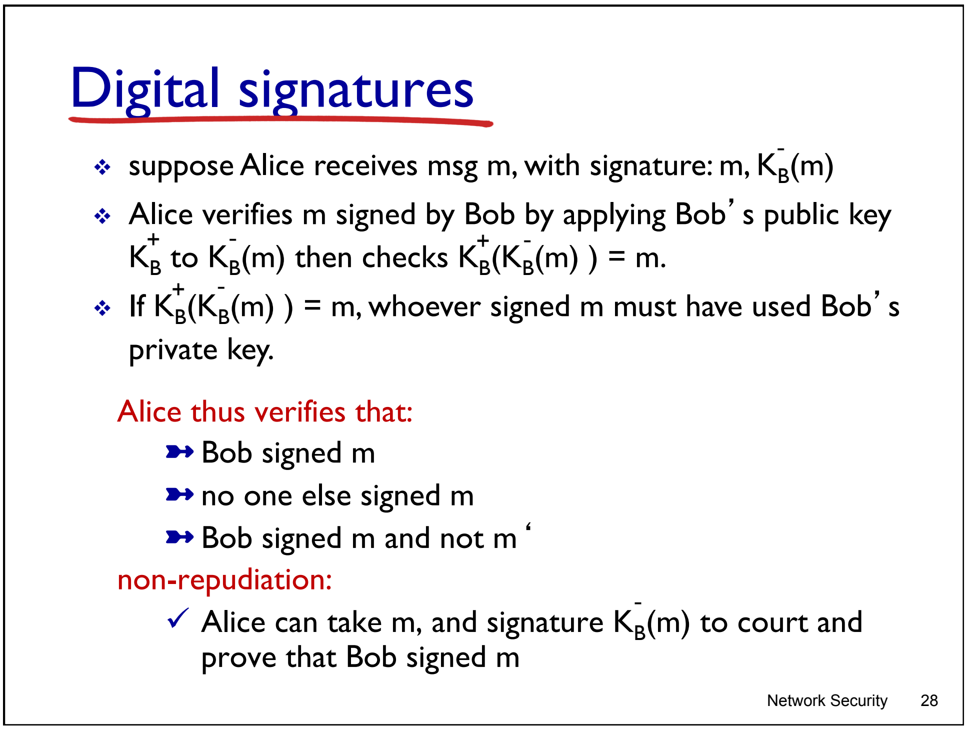
Bob

K_B^- Bob's private key

Public key encryption algorithm

$m, K_B^-(m)$

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



Digital signatures

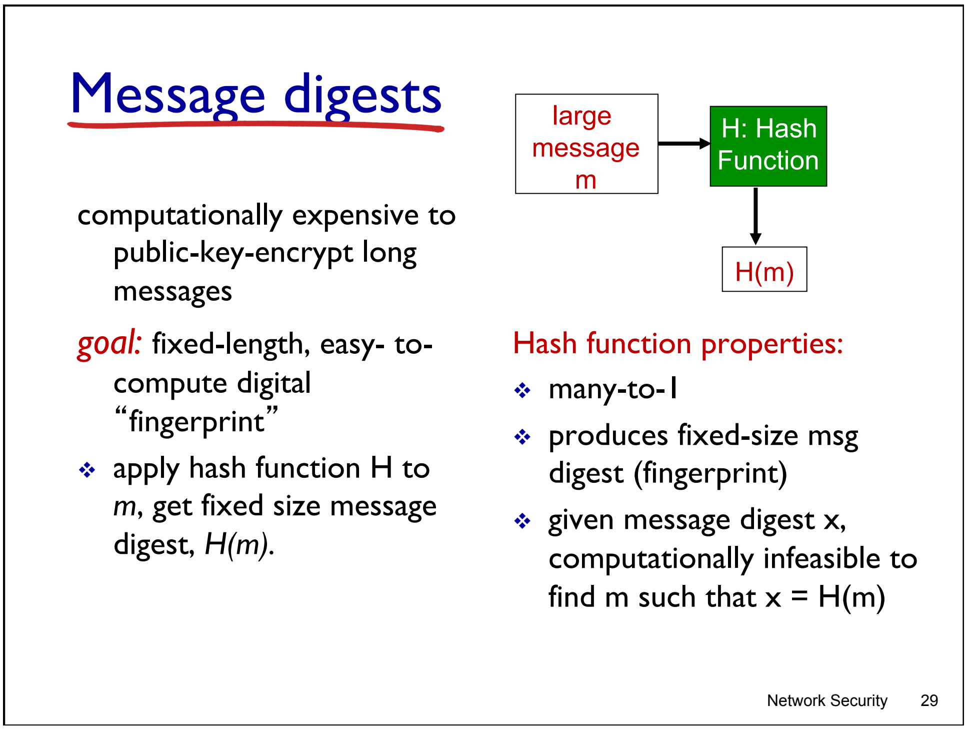
- suppose Alice receives msg m, with signature: m, $K_B^-(m)$
- Alice verifies m signed by Bob by applying Bob's public key K_B^+ to $K_B^-(m)$ then checks $K_B^+(K_B^-(m)) = m$.
- If $K_B^+(K_B^-(m)) = m$, whoever signed m must have used Bob's private key.

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

large message m
H: Hash Function
H(m)

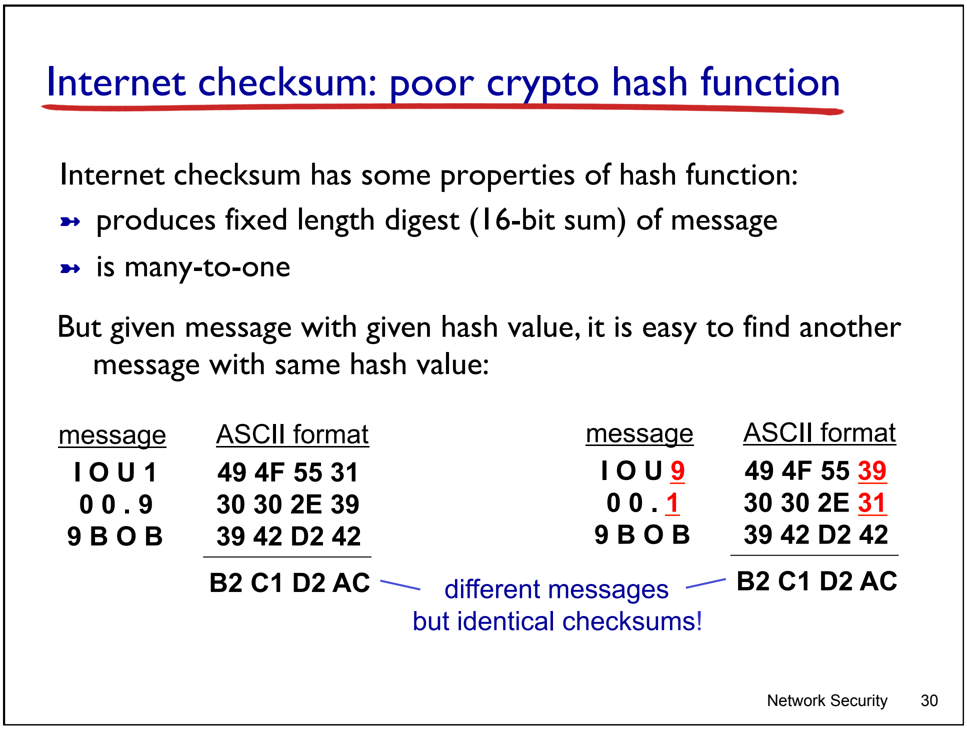
computationally expensive to public-key-encrypt long messages

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)



Internet checksum: poor crypto hash function

Internet checksum has some properties of hash function:

- produces 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:

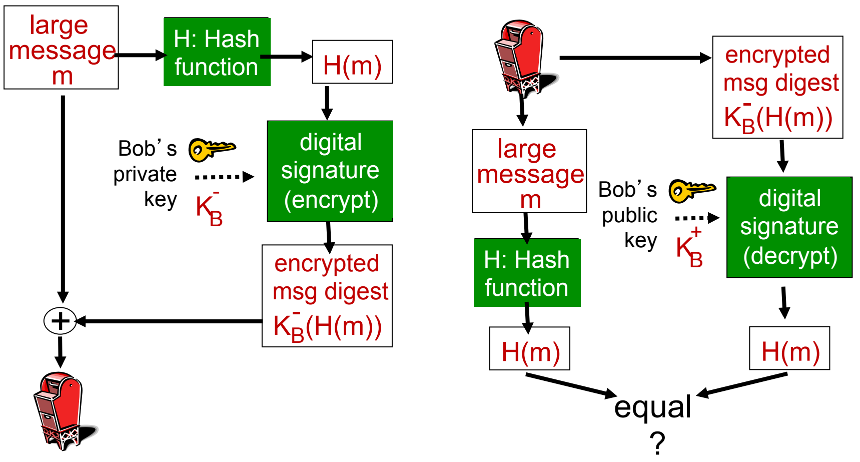
message	ASCII format	message	ASCII format
I O U 1	49 4F 55 31	I O U 9	49 4F 55 39
0 0 . 9	30 30 2E 39	0 0 . 1	30 30 2E 31
9 B O B	39 42 D2 42	9 B O B	39 42 D2 42
	B2 C1 D2 AC		B2 C1 D2 AC

different messages but identical checksums!

Digital signature = signed message digest

Bob sends digitally signed message:

Alice verifies signature, integrity of digitally signed message:



Network Security (summary)

basic techniques…...

- cryptography (symmetric and public)
- message integrity
- end-point authentication

…. used in many different security scenarios

- secure email
- secure transport (SSL)
- IP sec
- 802.11

operational security: firewalls and IDS