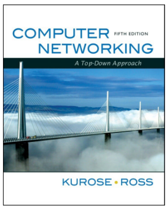
Chapter 8
Network Security



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Thanks and enjoy! JFK/KWR

Computer Networking: A Top Down Approach ,
5th edition.
Jim Kurose, Keith Ross
Addison-Wesley, April 2009.

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

  - We stopped at slide 86. Elad Michael Schiller

Encryption

http://techchannel.att.com/play-video.cfm/2009/10/12/From-the-Labs:-Encryption1

http://techchannel.att.com/play-video.cfm/2009/9/15/From-The-Labs:-Encryption

Network-Security

http://techchannel.att.com/play-video.cfm/2009/12/7/From-The-Labs:-Network-Security11

http://techchannel.att.com/play-video.cfm/2009/12/10/From-the-Labs:-Network-Security111

http://techchannel.att.com/play-video.cfm/2009/9/21/From-The-Labs:-Network-Security1

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Chapter 8 roadmap

What is network security?

Confidentiality: only sender, intended receiver should "understand" message contents
- sender encrypts message
- receiver decrypts message

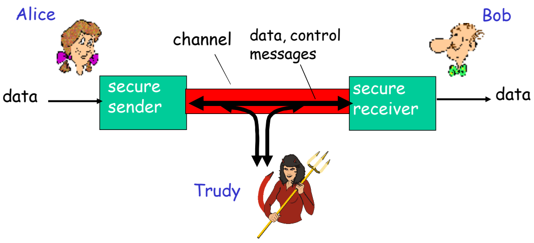
Authentication: sender, receiver want to confirm identity of each other

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



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?

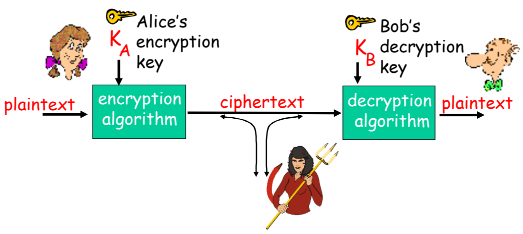
A: A lot! See section 1.6

- *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)

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

The language of cryptography



m plaintext message

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

$m = K_B(K_A(m))$

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Simple encryption scheme

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
```

Key: the mapping from the set of 26 letters to the set of 26 letters

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Polyalphabetic encryption

- n monoalphabetic cyphers, $M_1,M_2,\ldots,M_n$
- Cycling pattern:
  - e.g., n=4, M_1,M_3,M_4,M_3,M_2; M_1,M_3,M_4,M_3,M_2;
- For each new plaintext symbol, use subsequent monoalphabetic pattern in cyclic pattern
  - dog: d from M_1, o from M_3, g from M_4
- Key: the n ciphers and the cyclic pattern

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Breaking an encryption scheme

- Cipher-text only attack: Trudy has ciphertext that she can analyze
- Two approaches:
  - Search through all keys: must be able to differentiate resulting plaintext from gibberish
  - Statistical analysis
- Known-plaintext attack: trudy has some plaintext corresponding to some ciphertext
  - eg, in monoalphabetic cipher, trudy determines pairings for a,l,i,c,e,b,o,
- Chosen-plaintext attack: trudy can get the cyphertext for some chosen plaintext

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Types of Cryptography

- Crypto often uses keys:
  - Algorithm is known to everyone
  - Only "keys" are secret
- Public key cryptography
  - Involves the use of two keys: 1 private + 1 public
- Symmetric key cryptography
  - Involves the use one key
- Hash functions
  - Involves the use of no keys
  - Nothing secret: How can this be useful?

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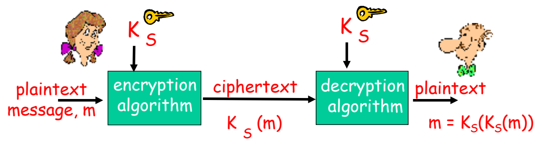
Symmetric key cryptography



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?

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Two types of symmetric ciphers

- Stream ciphers
  - encrypt one bit at time
- Block ciphers
  - Break plaintext message in equal-size blocks
  - Encrypt each block as a unit

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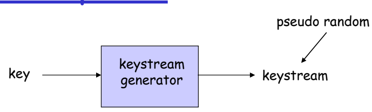
Stream Ciphers



- Combine each bit of keystream with bit of plaintext to get bit of ciphertext
- m(i) = i-th bit of message
- ks(i) = i-th bit of keystream
- c(i) = i-th bit of ciphertext
- $c(i) = ks(i) \oplus m(i)$ ($\oplus$ = exclusive or)
- $m(i) = ks(i) \oplus c(i)$

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RC4 Stream Cipher

- RC4 is a popular stream cipher
  - Extensively analyzed and considered good
  - Key can be from 1 to 256 bytes
  - Used in WEP for 802.11
  - Can be used in SSL

Block ciphers

- Message to be encrypted is processed in blocks of k bits (e.g., 64-bit blocks).
- 1-to-1 mapping is used to map k-bit block of plaintext to k-bit block of ciphertext

Example with k=3:

input	output
000	110
001	111
010	101
011	100

input	output
100	011
101	010
110	000
111	001

What is the ciphertext for 010110001111 ?

Block ciphers

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What is the ciphertext for 010110001111 ?

101

Block ciphers

- Message to be encrypted is processed in blocks of k bits (e.g., 64-bit blocks).
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Example with k=3:

input	output
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001	111
010	101
011	100

input	output
100	011
101	010
110	000
111	001

What is the ciphertext for 010110001111 ?

101000

Block ciphers

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010	101
011	100

input	output
100	011
101	010
110	000
111	001

What is the ciphertext for 010110001111 ?

101000111

Block ciphers

- Message to be encrypted is processed in blocks of k bits (e.g., 64-bit blocks).
- 1-to-1 mapping is used to map k-bit block of plaintext to k-bit block of ciphertext

Example with k=3:

input	output
000	110
001	111
010	101
011	100

input	output
100	011
101	010
110	000
111	001

What is the ciphertext for 010110001111 ?

101000111001

Block ciphers

- How many possible mappings are there for k=3?
  - How many 3-bit inputs?
  - How many permutations of the 3-bit inputs?
  - Answer: 40,320 ; not very many!
- In general, $2^k!$ mappings; huge for k=64
- Problem:
  - Table approach requires table with 2^{64} entries, each entry with 64 bits
- Table too big: instead use function that simulates a randomly permuted table

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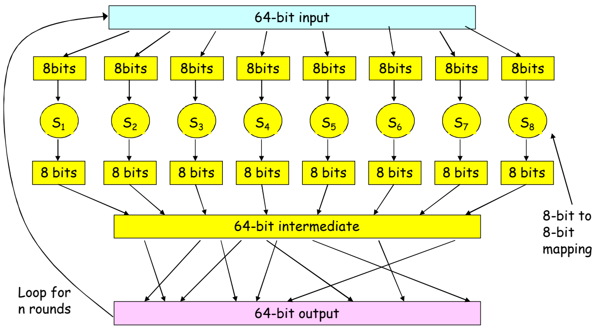
Prototype function

From Kaufman et al



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Why rounds in prototpe?

- If only a single round, then one bit of input affects at most 8 bits of output.
- In 2^{nd} round, the 8 affected bits get scattered and inputted into multiple substitution boxes.
- How many rounds?
  - How many times do you need to shuffle cards
  - Becomes less efficient as n increases

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Encrypting a large message

- Why not just break message in 64-bit blocks, encrypt each block separately?
  - If same block of plaintext appears twice, will give same cyphertext.
- How about:
  - Generate random 64-bit number r(i) for each plaintext block m(i)
  - Calculate c(i) = K_S(m(i) ⊕ r(i))
  - Transmit c(i), r(i), i=1,2,…
  - At receiver: m(i) = K_S(c(i)) ⊕ r(i)
  - Problem: inefficient, need to send c(i) and r(i)

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Cipher Block Chaining (CBC)

- CBC generates its own random numbers
  - Have encryption of current block depend on result of previous block
  - c(i) = K_S(m(i) ⊕ c(i-1))
  - m(i) = K_S(c(i)) ⊕ c(i-1)
- How do we encrypt first block?
  - Initialization vector (IV): random block = c(0)
  - IV does not have to be secret
- Change IV for each message (or session)
  - Guarantees that even if the same message is sent repeatedly, the ciphertext will be completely different each time

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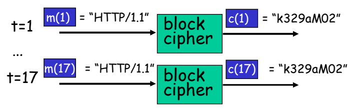
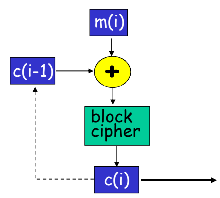
Cipher Block Chaining

- cipher block: if input block repeated, will produce same cipher text:



- *cipher block chaining:* XOR ith input block, m(i), with previous block of cipher text, c(i-1)
  - c(0) transmitted to receiver in clear
  - what happens in "HTTP/1.1" scenario from above?



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 (actually encrypt, decrypt, encrypt)

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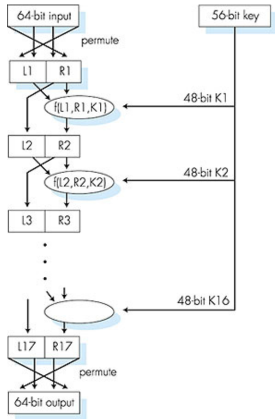
Symmetric key crypto: DES

DES operation

initial permutation

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

final permutation



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AES: Advanced Encryption Standard

- new (Nov. 2001) symmetric-key NIST standard, replacing DES
- 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

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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

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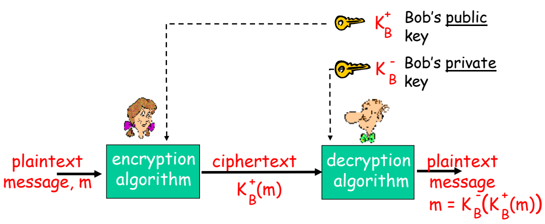
Public key cryptography



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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: Ronald Rivest, Adi Shamir, Leonard Adelson

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Prerequisite: modular arithmetic

- x mod n = remainder of x when divide by n
- Facts:
  [(a mod n) + (b mod n)] mod n = (a+b) mod n
  [(a mod n) - (b mod n)] mod n = (a-b) mod n
  [(a mod n) * (b mod n)] mod n = (a*b) mod n
- Thus
  $(a \bmod n)^d \bmod n = a^d \bmod n$
- Example: x=14, n=10, d=2:
  $(x \bmod n)^d \bmod n = 4^2 \bmod 10 = 6$
  $x^d = 14^2 = 196 \quad x^d \bmod 10 = 6$

RSA: getting ready

- A message is a bit pattern.
- A bit pattern can be uniquely represented by an integer number.
- Thus encrypting a message is equivalent to encrypting a number.

Example

- m= 10010001 . This message is uniquely represented by the decimal number 145.
- To encrypt m, we encrypt the corresponding number, which gives a new number (the cyphertext).

RSA: Creating public/private key pair

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* mod *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 message *m* (<*n*), compute
   $c = m^e \bmod n$
2. To decrypt received bit pattern, *c*, compute
   $m = c^d \bmod n$

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).

Encrypting 8-bit messages.

	bit pattern	m	m^e	$c = m^e \bmod n$
encrypt:	00001000	12	24832	17

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

Why does RSA work?

- Must show that $c^d \bmod n = m$ where $c = m^e \bmod n$
- Fact: for any x and y: $x^y \bmod n = x^{(y \bmod z)} \bmod n$
  - where n= pq and z = (p-1)(q-1)
- Thus,
  $c^d \bmod n = (m^e \bmod n)^d \bmod n$
  $= m^{ed} \bmod n$
  $= m^{(ed \bmod z)} \bmod n$
  $= m^1 \bmod n$
  $= m$

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

Follows directly from modular arithmetic:

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

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Why is RSA Secure?

- Suppose you know Bob's public key (n,e). How hard is it to determine d?
- Essentially need to find factors of n without knowing the two factors p and q.
- Fact: factoring a big number is hard.

Generating RSA keys

- Have to find big primes p and q
- Approach: make good guess then apply testing rules (see Kaufman)

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Session keys

- Exponentiation is computationally intensive
- DES is at least 100 times faster than RSA

Session key, K_S

- Bob and Alice use RSA to exchange a symmetric key K_S
- Once both have K_S, they use symmetric key cryptography

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8.8 Operational security: firewalls and IDS

Message Integrity

- Allows communicating parties to verify that received messages are authentic.
  - Content of message has not been altered
  - Source of message is who/what you think it is
  - Message has not been replayed
  - Sequence of messages is maintained
- Let's first talk about message digests

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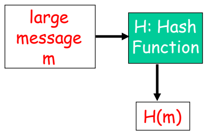
Message Digests



- Function H( ) that takes as input an arbitrary length message and outputs a fixed-length string: "message signature"
- Note that H( ) is a many-to-1 function
- H( ) is often called a "hash function"

- Desirable properties:
  - Easy to calculate
  - Irreversibility: Can't determine m from H(m)
  - Collision resistance: Computationally difficult to produce m and m' such that H(m) = H(m')
  - Seemingly random output

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Internet checksum: poor message digest

Internet checksum has some properties of hash function:
- produces fixed length digest (16-bit sum) of input
- is many-to-one

- But given message with given hash value, it is easy to find another message with same hash value.
- Example: Simplified checksum: add 4-byte chunks at a time:

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	49 4F 55
0 0 .	30 30 2E
9 B O B	39 42 D2 42
	B2 C1 D2 AC

different messages but identical checksums!

0

Hash Function Algorithms

- MD5 hash function widely used (RFC 1321)
  - computes 128-bit message digest in 4-step process.
- SHA-1 is also used.
  - US standard [NIST, FIPS PUB 180-1]
  - 160-bit message digest

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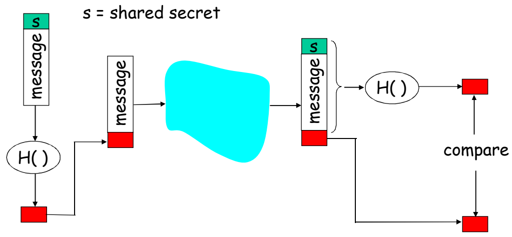
Message Authentication Code (MAC)



- ***Authenticates sender***
- ***Verifies message integrity***
- No encryption !
- Also called "keyed hash"
- Notation: $MD_m = H(s||m)$; send $m||MD_m$

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Hash-based Message Authentication Code (HMAC)

- Popular MAC standard
- Addresses some subtle security flaws

1. Concatenates secret to front of message.
2. Hashes concatenated message
3. Concatenates the secret to front of digest
4. Hashes the combination again.

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Hash-based Message Authentication Code (HMAC)

- Could we have the same security that HMAC provides by using MAC = H(s||m)
  - A serious flaw: with most hash functions, it is easy to append data to the message without knowing the key and obtain another valid MAC.
  - The alternative, appending the key using MAC = H(m||s) , suffers from the problem that an attacker who can find a collision in the (unkeyed) hash function has a collision in the MAC.
  - Using MAC = MAC = H(s||m||s) is better, however there are vulnerabilities with this approach, even when two different keys are used.

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Hash-based Message Authentication Code (HMAC)

- No known extensions attacks have been found against the current HMAC specification which is defined as H(s||H(s||m)) because the outer application of the hash function masks the intermediate result of the internal hash.
  - The values of ipad and opad are not critical to the security of the algorithm, but were defined in such a way to have a large Hamming distance from each other and so the inner and outer keys will have fewer bits in common.

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Example: OSPF

- Recall that OSPF is an intra-AS routing protocol
- Each router creates map of entire AS (or area) and runs shortest path algorithm over map
- Router receives link-state advertisements (LSAs) from all other routers in AS

Attacks:
- Message insertion
- Message deletion
- Message modification

- How do we know if an OSPF message is authentic?

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OSPF Authentication

- Within an Autonomous System, routers send OSPF messages to each other.
- OSPF provides authentication choices
  - No authentication
  - Shared password: inserted in clear in 64-bit authentication field in OSPF packet
  - Cryptographic hash
- Cryptographic hash with MD5
  - 64-bit authentication field includes 32-bit sequence number
  - MD5 is run over a concatenation of the OSPF packet and shared secret key
  - MD5 hash then appended to OSPF packet; encapsulated in IP datagram

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End-point authentication

- Want to be sure of the originator of the message – *end-point authentication*.
- Assuming Alice and Bob have a shared secret, will MAC provide end-point authentication.
  - We do know that Alice created the message.
  - But did she send it?

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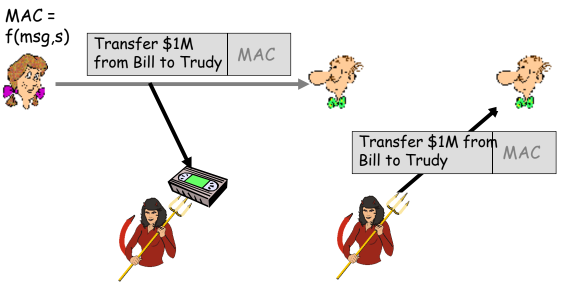
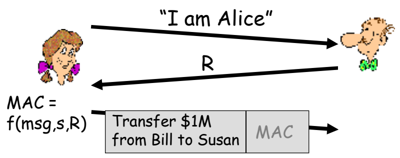
Playback attack



Defending against playback attack: nonce



Digital Signatures

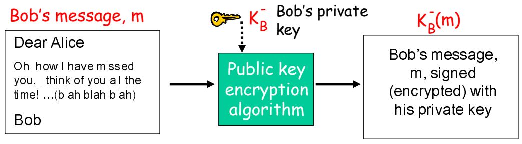
Cryptographic technique analogous to hand-written signatures.

- sender (Bob) digitally signs document, establishing he is document owner/creator.
- Goal is similar to that of a MAC, except now use public-key cryptography
- verifiable, nonforgeable: recipient (Alice) can prove to someone that Bob, and no one else (including Alice), must have signed document

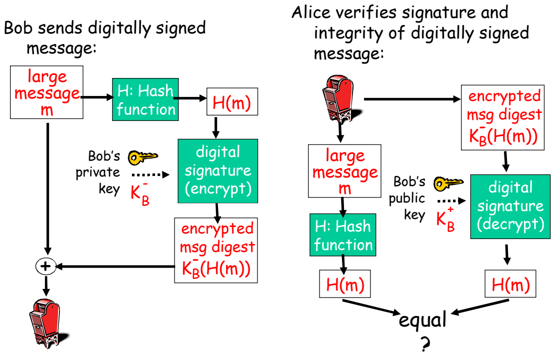
Digital Signatures

Simple digital signature for message m:

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



Digital signature = signed message digest



Digital Signatures (more)

- Suppose Alice receives msg m, digital signature $K_B^-(m)$
- 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'.

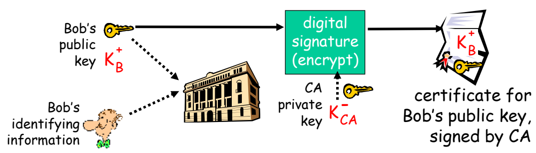
Non-repudiation:
- ✓ Alice can take m, and signature $K_B^-(m)$ to court and prove that Bob signed m.

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 pizzas to Bob.
  - Bob doesn't even like Pepperoni

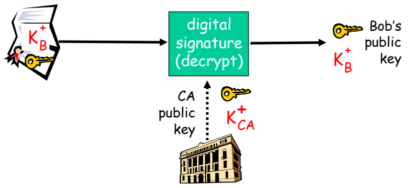
Certification Authorities

- 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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Certificates: summary

- Primary standard X.509 (RFC 2459)
- Certificate contains:
  - Issuer name
  - Entity name, address, domain name, etc.
  - Entity's public key
  - Digital signature (signed with issuer's private key)
- Public-Key Infrastructure (PKI)
  - Certificates and certification authorities
  - Often considered "heavy"

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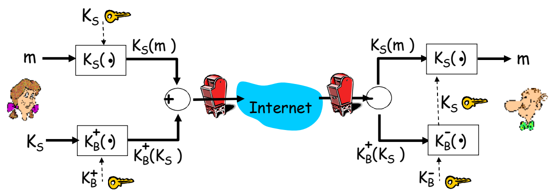
Chapter 8 roadmap

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

Secure e-mail

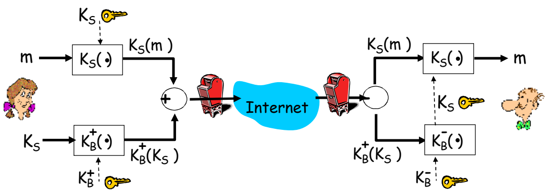
- Alice wants to send confidential e-mail, m, to Bob.



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

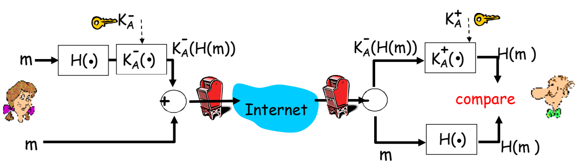
- Alice wants to send confidential e-mail, m, to Bob.



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)

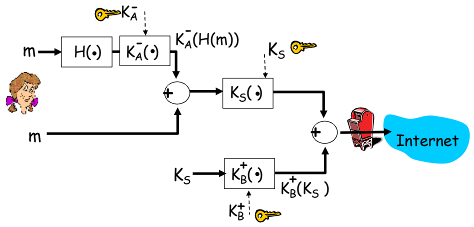
- Alice wants to provide sender authentication message integrity.



- 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

Chapter 8 roadmap

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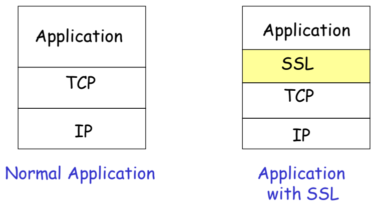
SSL: Secure Sockets Layer

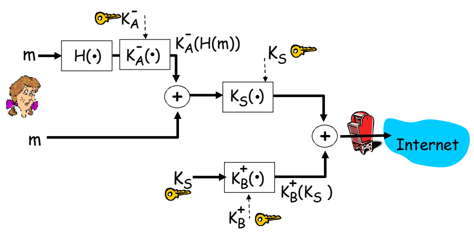
- Widely deployed security protocol
  - Supported by almost all browsers and web servers
  - https
  - Tens of billions $ spent per year over SSL
- Originally designed by Netscape in 1993
- Number of variations:
  - TLS: transport layer security, RFC 2246
- Provides
  - Confidentiality
  - Integrity
  - Authentication
- Original goals:
  - Had Web e-commerce transactions in mind
  - 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



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

Could do something like PGP:

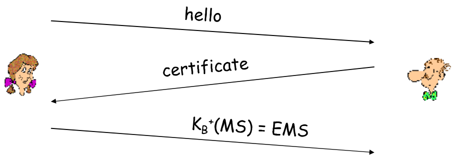


- But want to send byte streams & interactive data
- Want a set of secret keys for the entire connection
- Want certificate exchange part of protocol: handshake phase

Toy SSL: a simple secure channel

- Handshake: Alice and Bob use their certificates and 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 a series of records
- Connection Closure: Special messages to securely close connection

Toy: A simple handshake



- MS = master secret
- EMS = encrypted master secret

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Toy: Key derivation

- Considered bad to use same key for more than one cryptographic operation
  - Use different keys for message authentication code (MAC) and encryption
- Four keys:
  - 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 and (possibly) some additional random data and creates the keys

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Toy: Data 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.
  - For example, 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

length	data	MAC

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Toy: Sequence Numbers

- Attacker can capture and replay record or re-order records
- Solution: put sequence number into MAC:
  - MAC = MAC(M_x, sequence||data)
  - Note: no sequence number field
- Attacker could still replay all of the records
  - Use random nonce

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Toy: Control information

- Truncation attack:
  - attacker forges TCP connection close segment
  - One or both sides thinks there is less data than there actually is.
- Solution: record types, with one type for closure
  - type 0 for data; type 1 for closure
- MAC = MAC(M_x, sequence||type||data)

length	type	data	MAC

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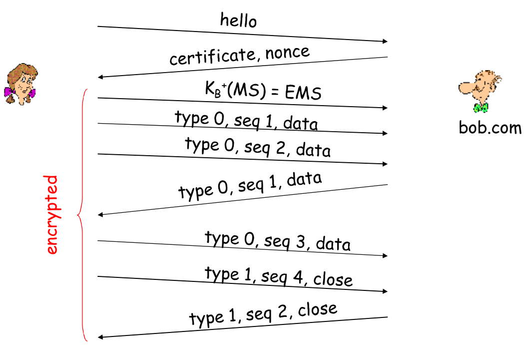
Toy SSL: summary



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Toy SSL isn't complete

- How long are the fields?
- What encryption protocols?
- No negotiation
  - Allow client and server to support different encryption algorithms
  - Allow client and server to choose together specific algorithm before data transfer

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Most common symmetric ciphers in SSL

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

Public key encryption
- RSA

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