# ECE 356/COMPSI 356
# Computer Network Architecture

## Network Security

Monday December 2nd, 2019

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## Previous Lecture Recap

- Application layer protocols
  - Web and HTTP
  - Electronic mail
- Readings for this lecture: **PD Ch. 8**

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# Lecture Outline

- **What is network security?**
- Principles of cryptography
- Authentication
- Message integrity
- Securing e-mail
- Securing TCP connections: SSL
- Operational security: firewalls and IDS

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# The Internet is Insecure

- A network is a shared resource
- Attackers may eavesdrop, modify, or drop your packets!
- Can mount attacks on massive scales

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# Network Security Concepts (1/2)

- **Confidentiality**
  - Do you want to send your credit card #, login password over the Internet in plaintext?
  - *Traffic* confidentiality: knowing that communication has taken place might give away information as well
- **Integrity**
  - Data integrity: Imagine an Amazon transaction. Do you want your payment to be modified from $10.0 to $100?
  - Replay attack: You do not want the same transaction confirmation to be sent multiple times!
    - **Encryption does not prevent replay attacks**
  - Timeliness: delay a stock purchase

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# Network Security Concepts (2/2)

- **Authenticity**
  - Entity authentication: who are you talking to? Phishing attack
  - Message authentication: who sent this message?
- **Availability**
  - Denial of service attacks
- **Non-repudiation**
  - You've clicked the confirmation button!

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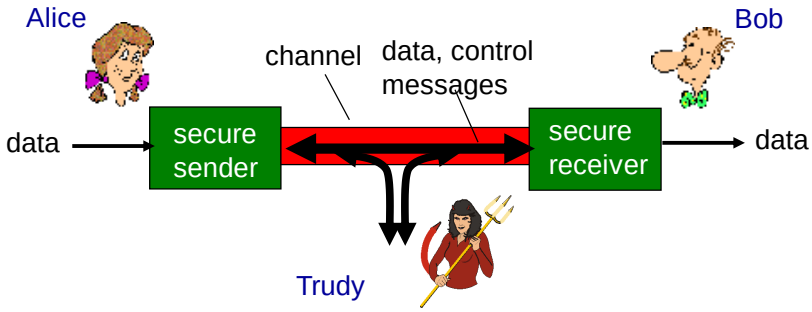
# Friends and Enemies: Alice, Bob, Trudy, Eve

- Well-known in network security world
- Bob, Alice want to communicate "securely"
- Trudy (intruder) may intercept, delete, add messages
- Eve (eavesdropper) listens in on traffic

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# 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
- …

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# Who are Trudy and Eve?

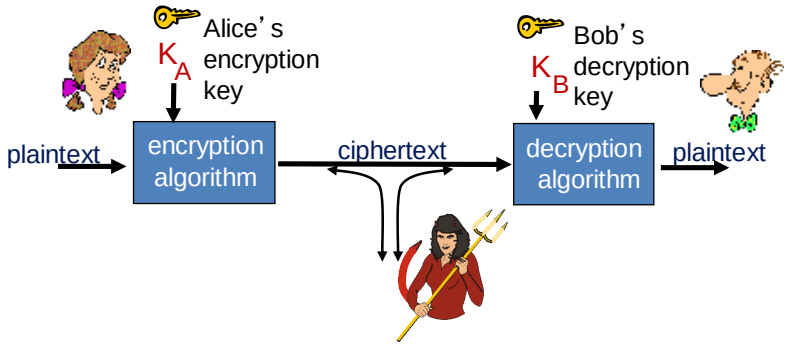
- Who mounts network attacks and why?



# Lecture Outline

- What is network security?
- **Principles of cryptography**
  - Symmetric keys
  - Public/private keys
- Authentication
- Message integrity
- Securing e-mail
- Securing TCP connections: SSL
- 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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# 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

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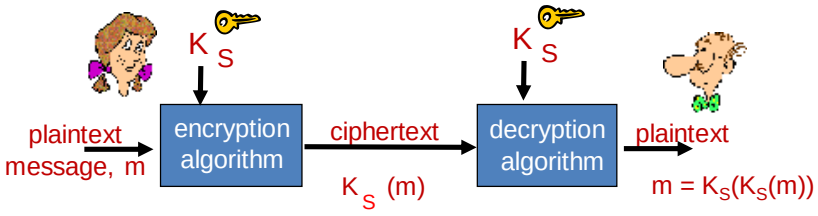
# Symmetric Key Cryptography




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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# 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 pay you. alice`
`ciphertext: nkn. s lmw wky. mgsbc`

*Encryption key:* mapping from set of 26 letters to set of 26 letters

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# A More Sophisticated Encryption Approach

- n substitution ciphers, $M_1, M_2, \ldots, M_n$
- 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 substitution pattern in cyclic pattern
  - dog: d from $M_1$, o from $M_3$, g from $M_4$

*Encryption key:* n substitution ciphers, and cyclic pattern

- Key need not be just n-bit pattern

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# Block Ciphers (1/2)

- **Block ciphers**: cleartext processed in blocks
- k-bit block of cleartext mapped directly to k-bit block of ciphertext
- E.g., for k = 3:
  - Input {0,0,0} mapped to output {1,1,0}
  - 2^3 = 8 possible inputs, permuted in 8! = 40,320 different ways
- Typically k is large, e.g.,64
  - 2^k! possible mappings
  - For k = 64, **18,446,744,073,709,551,616!** possible mappings
- In practice, cannot maintain and regenerate direct mappings of this scale

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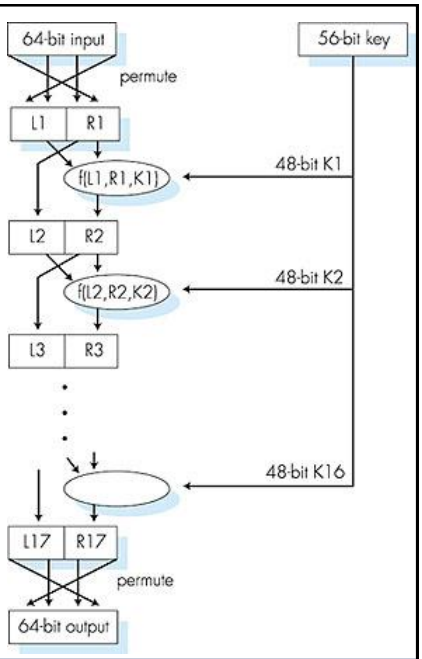
# Block Ciphers (2/2)

- In practice:
  - Use functions that simulate randomly permuted tables
  - Use keys to customize the transformations
- E.g., DES:
  - Multiple rounds of expansion permutation (duplicating some of the bits), key mixing, substitution, permutation
- **Brute-force attacks**: cycle through all keys
  - Key of length n: 2^n possible keys






# Symmetric Key Crypto: DES

## DES: Data Encryption Standard

- US encryption standard, first published in 1977
- 56-bit symmetric key, 64-bit plaintext input
- Weakness: small key size
  - Concerns about the key size were raised early on
- Making DES more secure:
  - 3DES: encrypt 3 times with 3 different keys

# AES: Advanced Encryption Standard

- Symmetric-key NIST standard, replaced DES (Nov 2001)
- Processes data in 128 bit blocks
- 128, 192, or 256 bit keys
- A machine that could crack DES in 1 second would **take 149 trillion years for AES**

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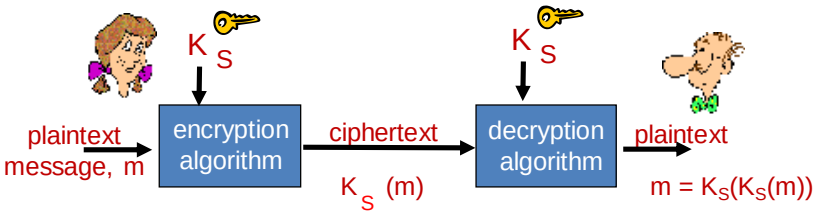
# Symmetric Keys: Key Points to Remember




- Symmetric key cryptography: Bob and Alice share the same **secret key**
- Ciphertext usually generated from plaintext and key by using functions that simulate randomly permuted tables
  - Standards: DES, AES

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# Public Key Cryptography

## *Symmetric key crypto*

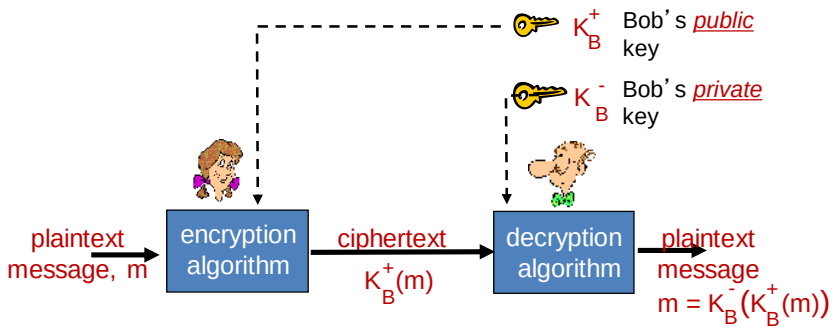
- Requires sender, receiver know shared secret key
- Q: how to agree on key in first place (particularly if never "met")?

## *Public key 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 to have:

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

2. Given public key $K_B^+$, it should be impossible to compute private key $K_B^-$

***RSA:*** Rivest, Shamir, Adelson algorithm

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# Prerequisite: Modular Arithmetic

- x mod n = remainder of x when divided by n
  - E.g., 19 mod 5 = 4
- Facts:

(1) $[(a \bmod n) + (b \bmod n)] \bmod n = (a+b) \bmod n$

(2) $[(a \bmod n) - (b \bmod n)] \bmod n = (a-b) \bmod n$

(3) $[(a \bmod n) * (b \bmod n)] \bmod n = (a*b) \bmod n$

- Thus, from (3):

$$(a \bmod n)^d \bmod n = a^d \bmod n$$

- Example: x=14, n=10, d=2:
  $(x \bmod n)^d \bmod n = 4^2 \bmod 10 = 6$
  $x^d = 14^2 = 196 \quad x^d \bmod 10 = 6$

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# RSA: Getting Ready

- Message: just a bit pattern
- 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 ciphertext)

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# RSA: Creating Public/Private Key Pair (1/2)

- Choose two large **prime numbers** *p, q*
  - These need to be kept secret
  - e.g., 1024 bits each
- From them, calculate **n**, **e** that will be public, and **d** that will be private
  - We share (n,e), calculated from p,q, but not p,q themselves

*public* key is $(n,e)$. $K_B^+$ *private* key is $(n,d)$. $K_B^-$

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# RSA: Creating Public/Private Key Pair

- Compute $n = pq$
  - Counting on the difficulty of factorization of the product of large prime numbers
- Compute $z = (p-1)(q-1)$
- Choose $e$ (with $e<n$) that has no common factors with z
  - $e$, $z$ are "relatively prime"
- Choose $d$ such that $ed-1$ is exactly divisible by $z$
  - In other words: $ed$ mod $z = 1$

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

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# RSA: Encryption, Decryption

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

1. to encrypt message $m$, compute
   $c = m^e \bmod n$

2. to decrypt received bit pattern $c$, compute
   $m = c^d \bmod n$

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

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# 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

encrypt: $m$ → $m^e$ → $c = m^e \bmod n$

12 → 24832 → 17

decrypt: $c$ → $c^d$ → $m = c^d \bmod n$

17 → 48196857210675091509141182522307169 7 → 12

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# Why Does RSA Work?

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

$$c^d \bmod n = (m^e \bmod n)^d \bmod n$$
$$= m^{ed} \bmod n$$
$$= m^{(ed \bmod z)} \bmod n$$
$$= m^1 \bmod n$$
$$= m$$

Selected *ed* mod *z* = *1*

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# 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

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# RSA in Practice: Session Keys

- Exponentiation in RSA is computationally intensive
- DES is at least 100 times faster than RSA
- Use public key crypto to establish secure connection, then establish second key – symmetric session key – for encrypting data

*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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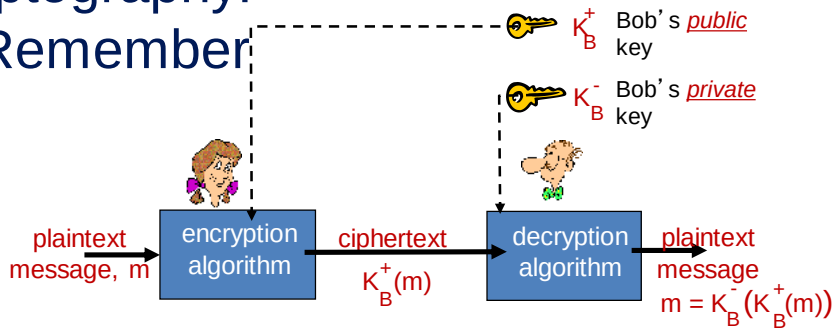
# Public Key Cryptography: Key Points to Remember




- Public key known to **everyone**
- Private key is known only to Bob
- Cryptographic algorithms ensure that private key cannot be calculated from the public one
- RSA is a widely used for secure data transmission

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# Lecture Outline

- What is network security?
- Principles of cryptography
- **Authentication**
- Message integrity
- Securing e-mail
- Securing TCP connections: SSL
- Operational security: firewalls and IDS

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# Authentication Protocols

- Authentication protocols: identify communicating parties
  - In real life, identify each other by face, voice, posture, …
  - Customs official authenticates us based on a picture in our passport
- Typically run before communication protocols



# 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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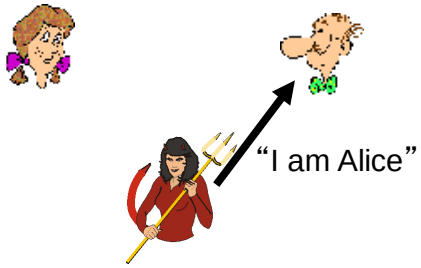


In a network,
Bob cannot "see" Alice,
so Trudy simply
declares
herself to be Alice

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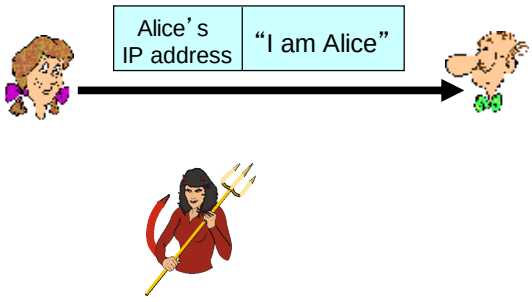
# Authentication: Another Try

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




Failure scenario?

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# Authentication: Another Try

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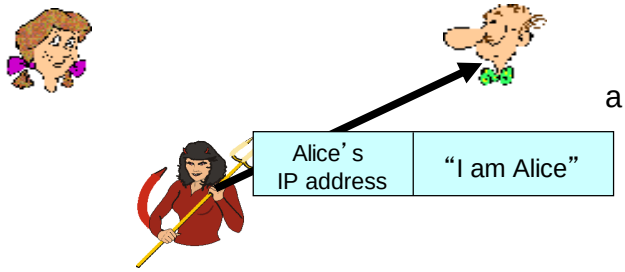


Trudy can create a packet "spoofing" Alice's address

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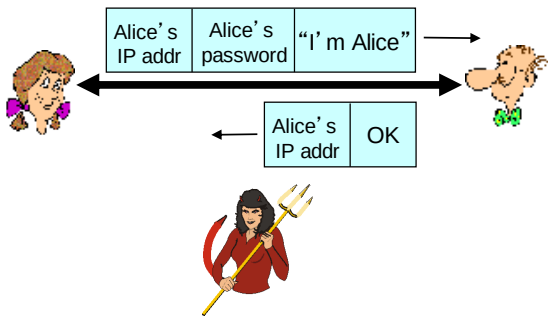
# Authentication: Another Try

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




Failure scenario?

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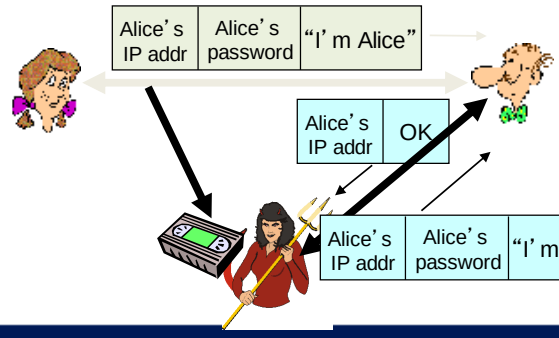
# Authentication: Another Try

*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

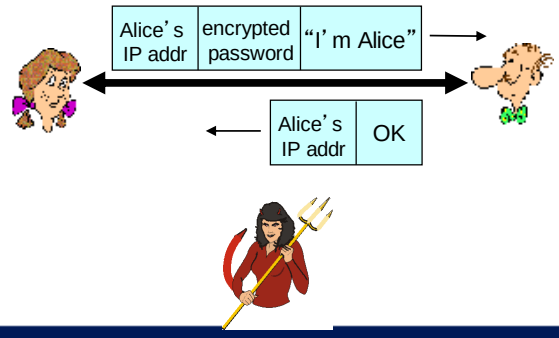






# Authentication: Yet Another Try

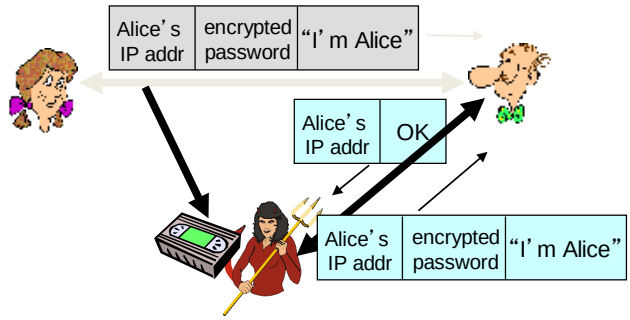
*Protocol ap3.1:* Alice says "I am Alice" and sends her *encrypted* secret password to "prove" it.




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!

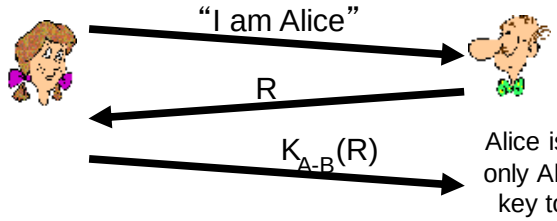






# Authentication: Yet Another Try

- *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!

# Authentication Protocols: Key Points to Remember

- Verify that you are talking to the person you believe
- Typically run before communication protocols
- Approach: shared secret key + a nonce
  - Use of a nonce prevents a replay attack



# Final Policy

- Date, location: on Duke Hub
  - December 15th, 7 – 10 PM, HH 125
- Covers all lectures, with an emphasis on post-midterm material
  - Includes the invited lecture
- Closed book/notes
- No Internet
- Allowed:
  - One two-sided hand-written page, written by you (letter-size)
  - A calculator

# You Need to Know The Material Covered in Class

- Will not ask questions on material covered in the book but not in class
- Will ask questions on lecture materials not covered in the book

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# Additional Study Materials

- HW1, HW2, HW3 solutions
- Lab2, Lab3 concepts and materials
  - If you are working in a group, please make sure to understand the parts done by your lab partner
- In-class quiz answers
  - Make sure you understand everything you did not get right
- Midterm and makeup midterm solutions
  - Make sure you understand everything you did not get right
  - Note that final emphasizes post-midterm materials

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# Lecture Outline

- What is network security?
- Principles of cryptography
- Authentication
- **Message integrity**
- Securing e-mail
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# Message Integrity

- Need to know that the message was not modified in transit
- Possible approach:
  - Sender calculates a checksum and appends it to the message
  - Receiver verifies that the received checksum is correct
- Seen a similar approach for error checking before
- Need to keep *malicious modifications* in mind in integrity verification

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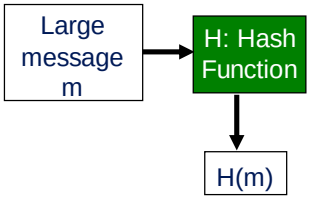
# Cryptographic Hash Functions




Hash function properties:

- Many-to-1
- Produces fixed-size message "fingerprint" that can be used to verify that the message has not been tampered with

- **Cryptographic hash function** has to have an additional property
  - ➢ It should be computationally infeasible to find any two different messages x and y such that H(x) = H(y)

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# Widely Used 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 Codes

- Rely on a shared secret s + hash calculation
  - Alice creates message m, concatenates s to create m+s, and calculates **message authentication code** H(m+s)
  - Alice appends the MAC to the message
    - Sends (m, H(m+s))
  - Bob, knowing s, calculates H(m+s), verifies the correctness of the message
- Note that MAC calculations do not require encryption
  - E.g., router communications need to be authenticated but may not need to be encrypted

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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
  - Cannot use message authentication codes since they rely on a shared secret

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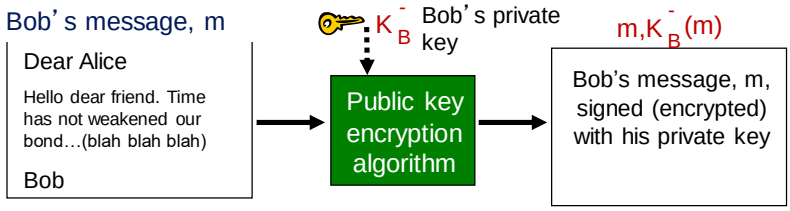
# Digital Signatures

## Simple digital signature for message m:

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

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# 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

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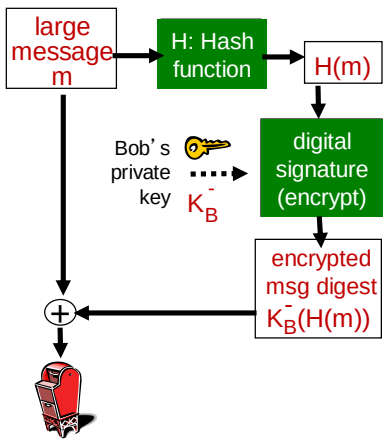
# Message Digests

- 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)*

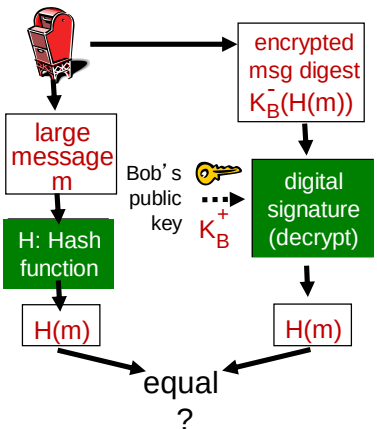


# Digital Signature = Signed Message Digest

Bob sends digitally signed message:




Alice verifies signature, integrity of digitally signed message:



# Message Authentication Codes and Digital Signatures: Key Points to Remember

- Create "checksums" of documents using **cryptographic hash functions**
  - Internet checksum and the CRC are not suitable for these calculations
  - It needs to be difficult to find any two different messages x,y such that H(x) = H(y)
- MAC calculations rely on a shared secret
- Digital signatures use public-private keys

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# 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

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# Certification Authorities (1/2)

- *Certification authority (CA):* binds public key to particular entity, E
- So-called trusted 3rd party
- Commercial entities
  - Symantec, Comodo, GoDaddy, GlobalSign, DigitCert, …

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# 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 a **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*"

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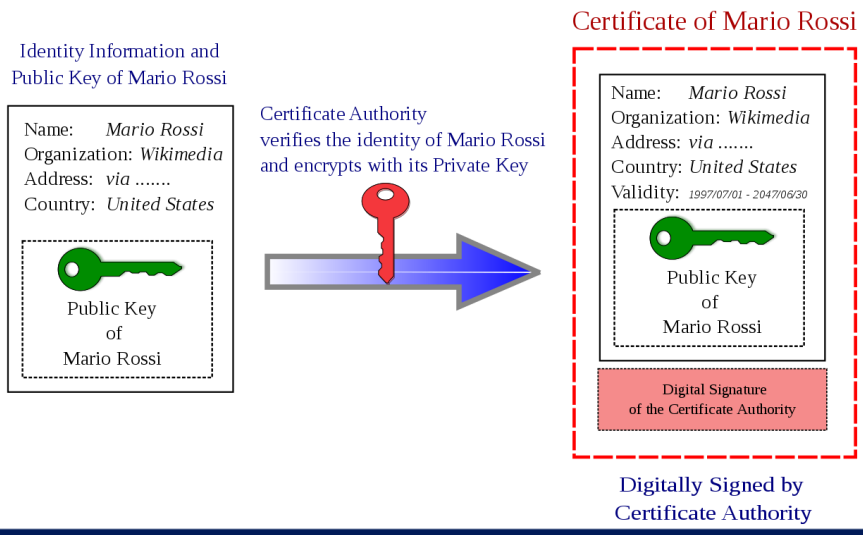
# Obtaining a Public Key Certificate



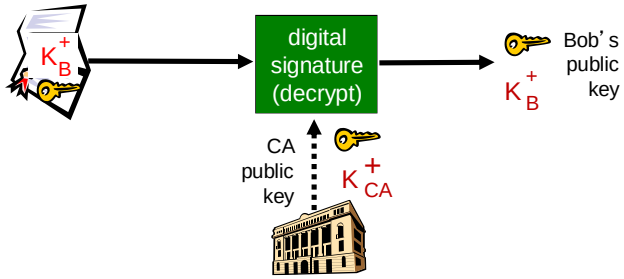







# Verifying Identity via Certificates

- When Alice wants Bob's public key:
  - Gets Bob's certificate
  - Apply CA's public key to Bob's certificate, get Bob's public key



# Lecture Outline

- What is network security?
- Principles of cryptography
- Authentication
- Message integrity
- **Securing e-mail**
- Securing TCP connections: SSL
- Operational security: firewalls and IDS

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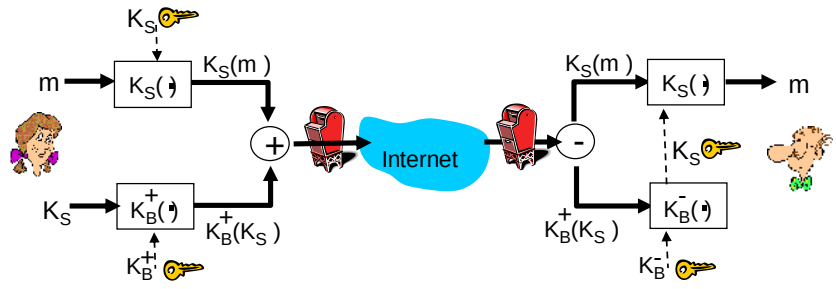
# Secure E-mail: Confidentiality (1/2)

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




**Session key approach**

*Alice:*

1. Generates random symmetric session key, $K_S$
2. Encrypts message with $K_S$
3. Encrypts $K_S$ with Bob's public key
4. Sends both $K_S(m)$ and $K_B(K_S)$ to Bob

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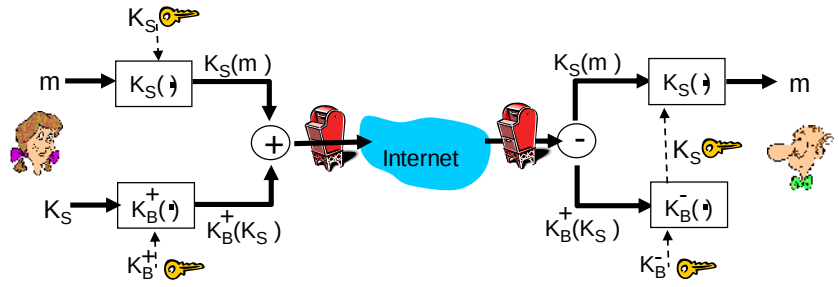
# Secure E-mail: Confidentiality (2/2)

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




**Session key approach**

*Bob:*

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

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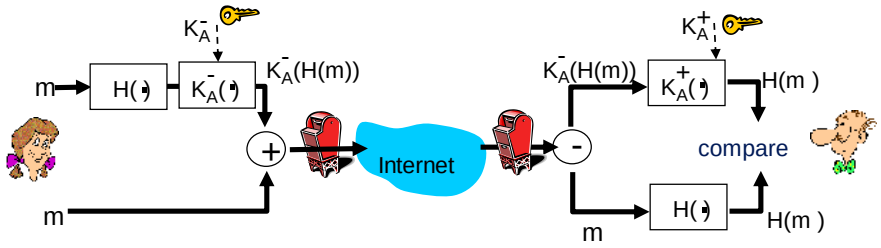
# Secure E-mail: Sender Authentication And Message Integrity

Alice wants to provide sender authentication and message integrity




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

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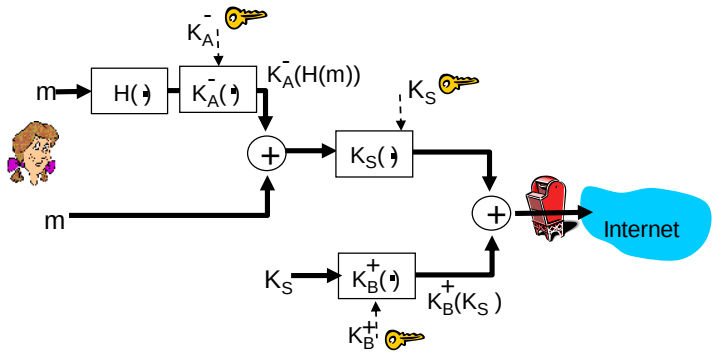
# Secure E-mail: Secrecy and Integrity

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




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

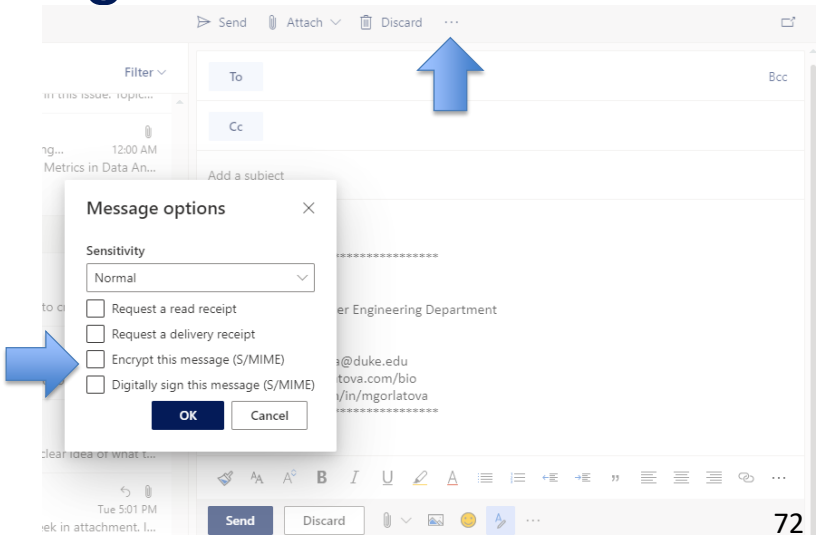






# Securing Duke E-mails

- May require installing an extension



# Lecture Outline

- What is network security?
- Principles of cryptography
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- Securing e-mail
- **Securing TCP connections: SSL**
- Operational security: firewalls and IDS

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# Secure Sockets Layer (SSL)

- Originally designed by Netscape
- Widely deployed security protocol
  - Supported by almost all browsers, web servers
  - **Https**
  - Billions $/year over SSL
- 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

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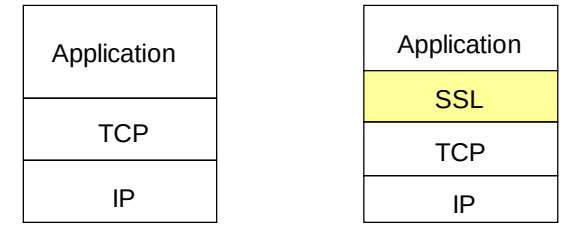
# SSL and TCP/IP




*Normal application* *Application with SSL*

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

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# 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

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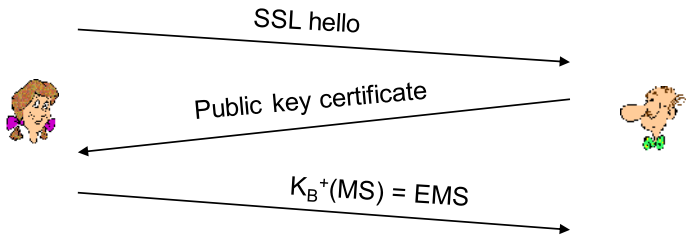
# Toy: A Simple Handshake

- First, a TCP handshake. Then:




*MS:* master secret generated by Alice

*EMS:* encrypted master secret

- Bob decrypts it with his private key to get MS

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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
- Alice and Bob use the MS to generate **four keys**:
  - $K_c$ = encryption key for data sent from client to server
  - $M_c$ = *integrity verification* MAC key for data sent from client to server
  - $K_s$ = encryption key for data sent from server to client
  - $M_s$ = *integrity verification* 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 (1/2)

- 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?

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# Toy: Data Records (2/2)

- 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


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# Toy: Sequence Numbers

- *Problem:* attacker can capture and replay record or re-order records
  - TCP sequence numbers are not encrypted
- *Solution:* put sequence number in the MAC calculations
  - MAC = MAC($M_x$, sequence number)
  - Note: no sequence number field



# SSL: Cipher Suites

- 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

# Real SSL: Handshake (1/4)

*Purpose*

1. Server authentication
2. Negotiation: agree on crypto algorithms
3. Establish keys
4. Client authentication (optional)



# Real SSL: Handshake (2/4)

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: Handshaking (3/4)

Last 2 steps protect handshake from tampering

- Client typically offers range of algorithms, some strong, some weak
- Man-in-the middle could delete stronger algorithms from list
- Last 2 steps prevent this
  - Last two messages are encrypted

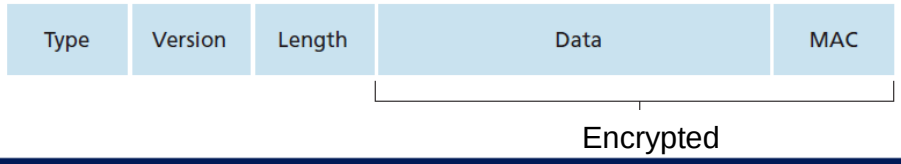


# Real SSL: Handshaking (4/4)

- Why two random nonces?
- 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

# Closing an SSL Connection

- Problem: **truncation attack**
  - Attacker forges TCP connection close segment
  - One or both sides thinks there is less data than there actually is
- Solution:
  - Indicate closure in an SSL fragment
  - Use type field: Type 0 for data; type 1 for closure






# Secure Sockets Layer: Key Points to Remember

- Widely deployed protocol
  - Anything done over HTTPS is done over SSL
- Encrypted data transmitted in segments, which include a MAC


- Uses handshaking to agree on a cipher suite and to establish encryption and MAC keys

# Lecture Outline

- What is network security?
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- Securing e-mail
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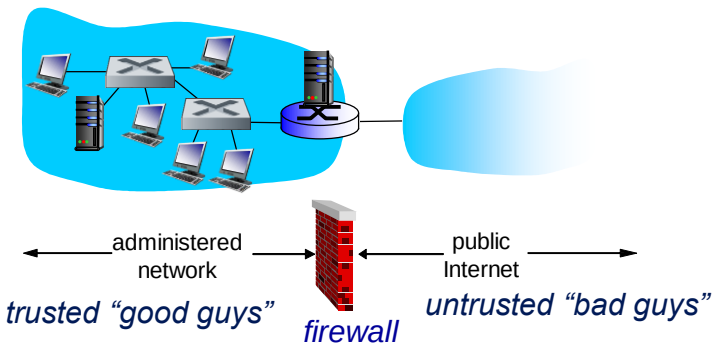
- **Operational security: firewalls and IDS**



# Firewalls

*Firewall*

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



# Firewall Goals

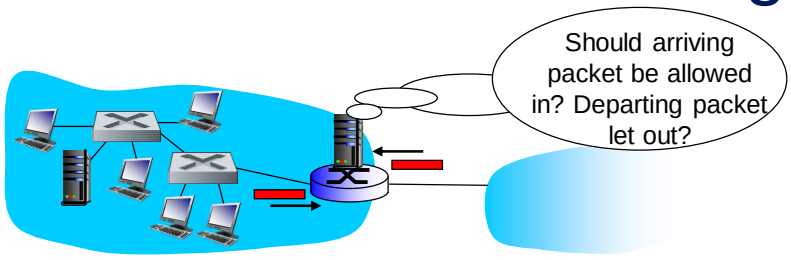
- All traffic from outside to inside, and vise versa, passes through the firewall
- Only authorized traffic, as defined by the local access policy, will be allowed to pass
- The firewall itself is immune from penetration

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

# Stateless Packet Filtering: Example

- *Example 1:* block incoming and outgoing datagrams with IP protocol field = 17 and with either source or dest port = 23
  - *Result:* all incoming, outgoing UDP flows and telnet connections are blocked
- *Example 2:* block inbound TCP segments with ACK=0.
  - *Result:* prevents external clients from making TCP connections with internal clients, but allows internal clients to connect to outside



# Stateless Packet Filtering: More Examples

| *Policy* | *Firewall Setting* |
|---|---|
| No outside Web access. | Drop all outgoing packets to any IP address, port 80 |
| No incoming TCP connections, except those for institution's public Web server only. | Drop all incoming TCP SYN packets to any IP except 130.207.244.203, port 80 |
| Prevent Web-radios from eating up the available bandwidth. | Drop all incoming UDP packets - except DNS and router broadcasts. |
| Prevent your network from being used for a smurf DoS attack. | Drop all ICMP packets going to a "broadcast" address (e.g. 130.207.255.255). |
| Prevent your network from being tracerouted | Drop all outgoing ICMP TTL expired traffic |

# Access Control Lists

*ACL:* table of rules, applied top to bottom to incoming packets: (action, condition) pairs

| action | source address | dest address | protocol | source port | dest port | flag bit |
|---|---|---|---|---|---|---|
| allow | 222.22/16 | outside of 222.22/16 | TCP | > 1023 | 80 | any |
| allow | outside of 222.22/16 | 222.22/16 | TCP | 80 | > 1023 | ACK |
| allow | 222.22/16 | outside of 222.22/16 | UDP | > 1023 | 53 | --- |
| allow | outside of 222.22/16 | 222.22/16 | UDP | 53 | > 1023 | ---- |
| deny | all | all | all | all | all | all |



# Stateful Packet Filtering (1/2)

- *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

# Stateful Packet Filtering (2/2)

ACL augmented to indicate need to check connection state table before admitting packet

| action | source address | dest address | proto | source port | dest port | flag bit | check conxion |
|---|---|---|---|---|---|---|---|
| allow | 222.22/16 | outside of 222.22/16 | TCP | > 1023 | 80 | any | |
| allow | outside of 222.22/16 | 222.22/16 | TCP | 80 | > 1023 | ACK | X |
| allow | 222.22/16 | outside of 222.22/16 | UDP | > 1023 | 53 | --- | |
| allow | outside of 222.22/16 | 222.22/16 | UDP | 53 | > 1023 | ---- | X |
| deny | all | all | all | all | all | all | |



# Limitations of Firewalls

- *Tradeoff:* degree of communication with outside world, level of security
- Offer only perimeter defense
- *IP spoofing:* router cannot know if data "really" comes from claimed source
- Many highly protected sites still suffer from attacks

# Intrusion Detection Systems (1/3)

- 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

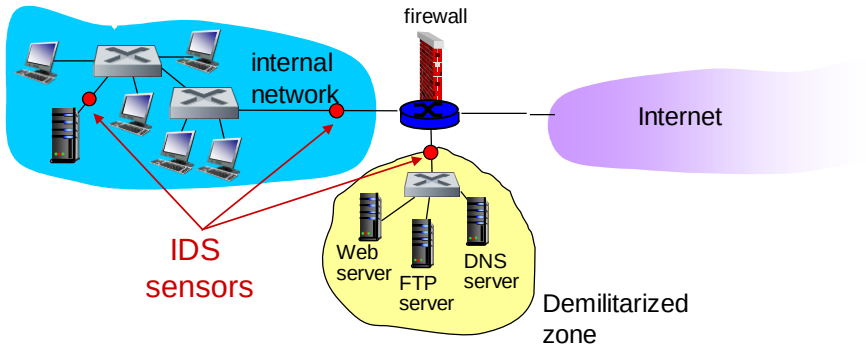


# Intrusion Detection Systems (2/3)

- Signature-based systems
  - Compare traffic against a set of attack signatures
  - Con: cannot detect attacks that have not been seen before
- Anomaly-based systems
  - Compare traffic to traffic under “normal operation”
  - Subject of much machine learning research

# Intrusion Detection Systems (3/3)

Multiple IDSs: different types of checking at different locations






# Lecture Summary

- What is network security?
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- Message integrity
- Securing e-mail
- Securing TCP connections: SSL
- Operational security: firewalls and IDS

# Next Lecture

- Final review



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