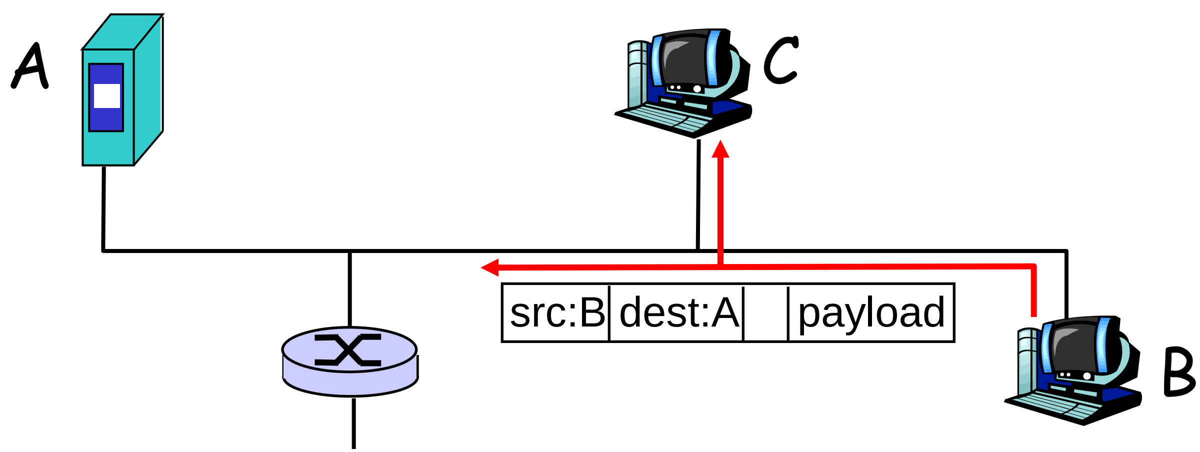
Chapter 8
Network Security

Internet security threats

Packet sniffing:

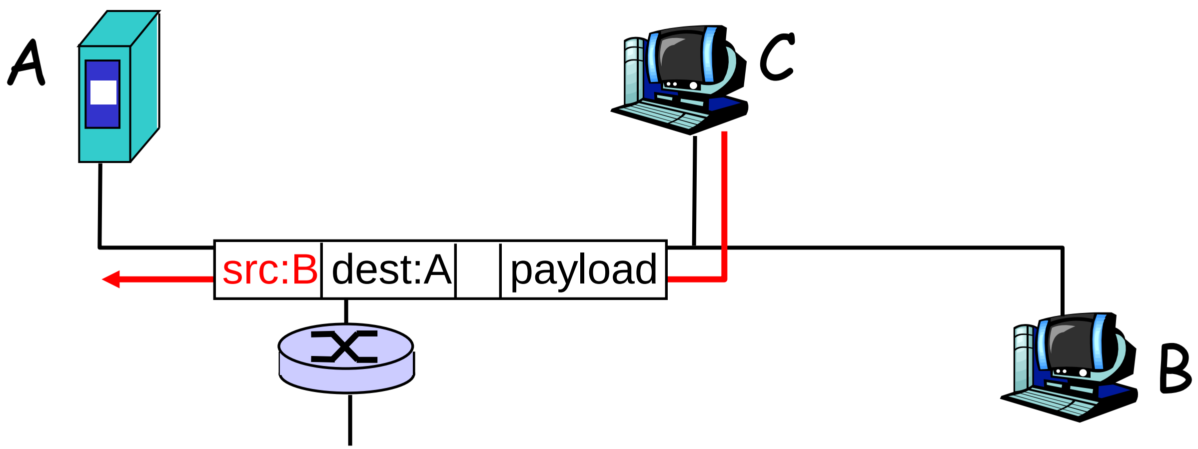
- broadcast media
- promiscuous NIC reads all packets passing by
- can read all unencrypted data (e.g. passwords)
- e.g.: C sniffs B's packets



Internet security threats

IP Spoofing:

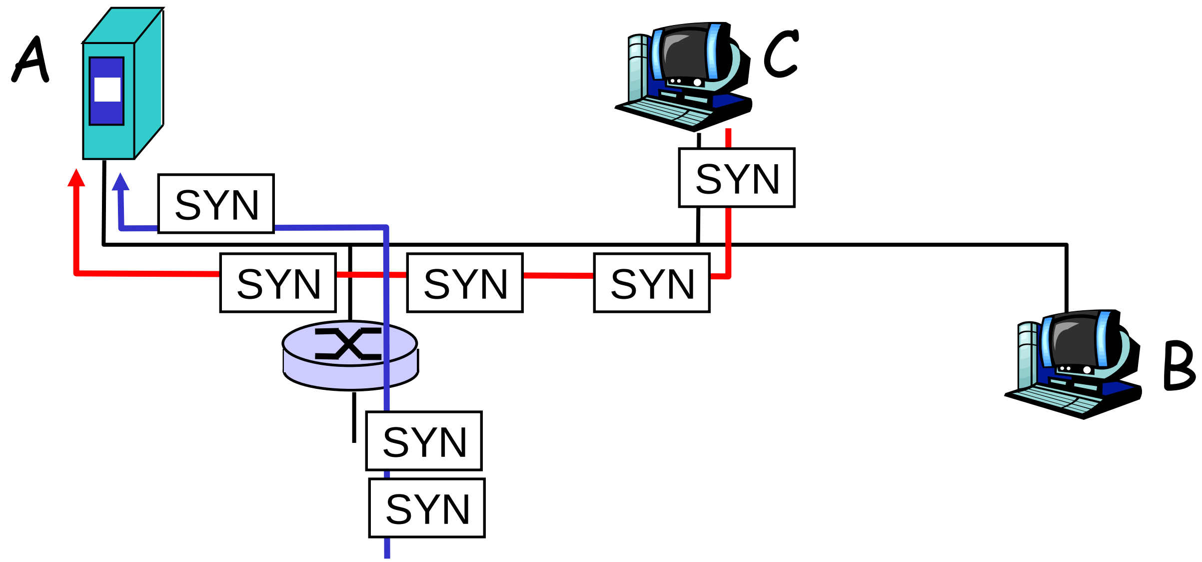
- can generate "raw" IP packets directly from application, putting any value into IP source address field
- receiver can't tell if source is spoofed
- e.g.: C pretends to be B



Internet security threats

Denial of service (DOS):

- flood of maliciously generated packets "swamp" receiver
- Distributed DOS (DDOS): multiple coordinated sources swamp receiver
- e.g., C and remote host SYN-attack A



What is network security?

Confidentiality (Secrecy, Privacy) : only sender, intended receiver should "understand" msg contents

- sender encrypts msg
- receiver decrypts msg

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

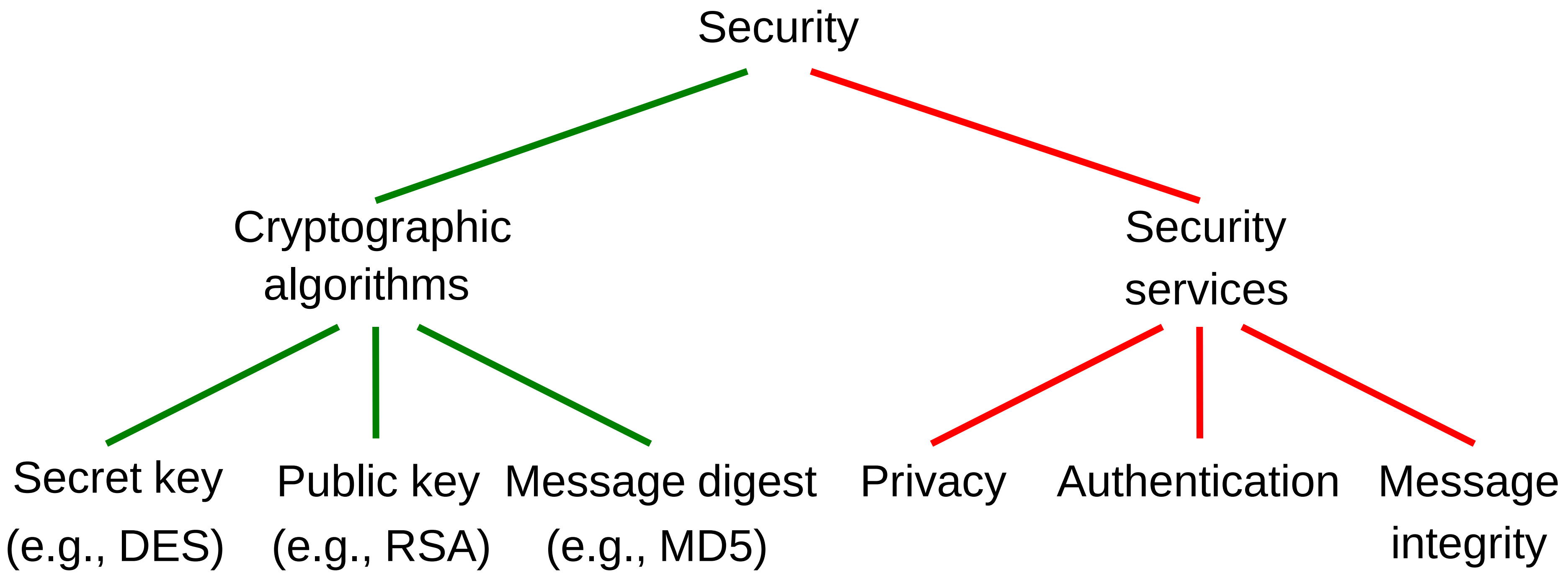
Message Integrity: sender, receiver want to ensure message not altered (in transit, or afterwards) without detection

Network Security

- Sometimes the data transmitted between application processes is **confidential**, such as **credit card numbers**
- The idea of **encryption** is that
  - The sender applies an encryption function to the original **plaintext message**
  - The resulting **ciphertext message** is sent over the network
  - The receiver applies a reverse function (**decryption**) to recover the original plaintext
- The **encryption/decryption process** generally depends on a **secret key** shared between the sender and the receiver
- It can also be used to support **authentication** (verifying the identity of the remote participant) and **integrity** (making sure that the message has not been altered)

Security Issues

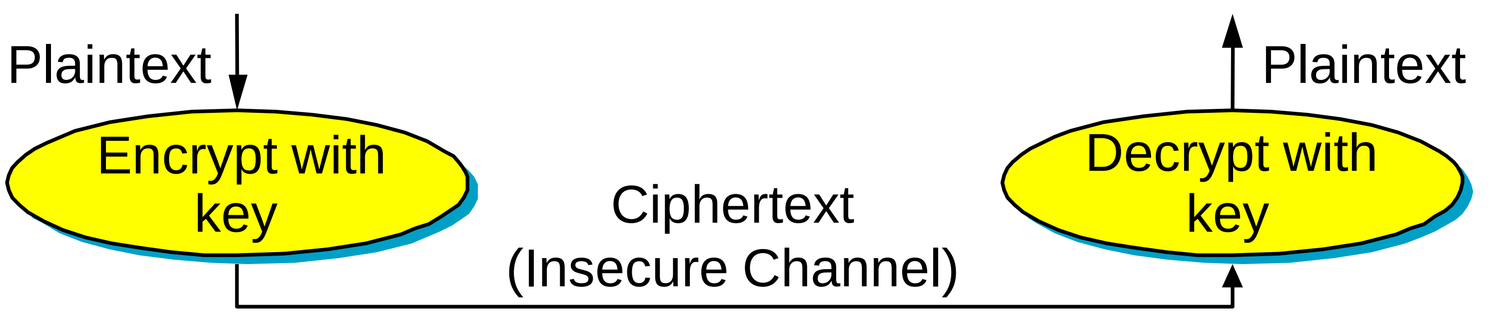
- The security issue can be divided into two parts
  - **Cryptographic algorithms**
  - **Security services**



Cryptographic Tools

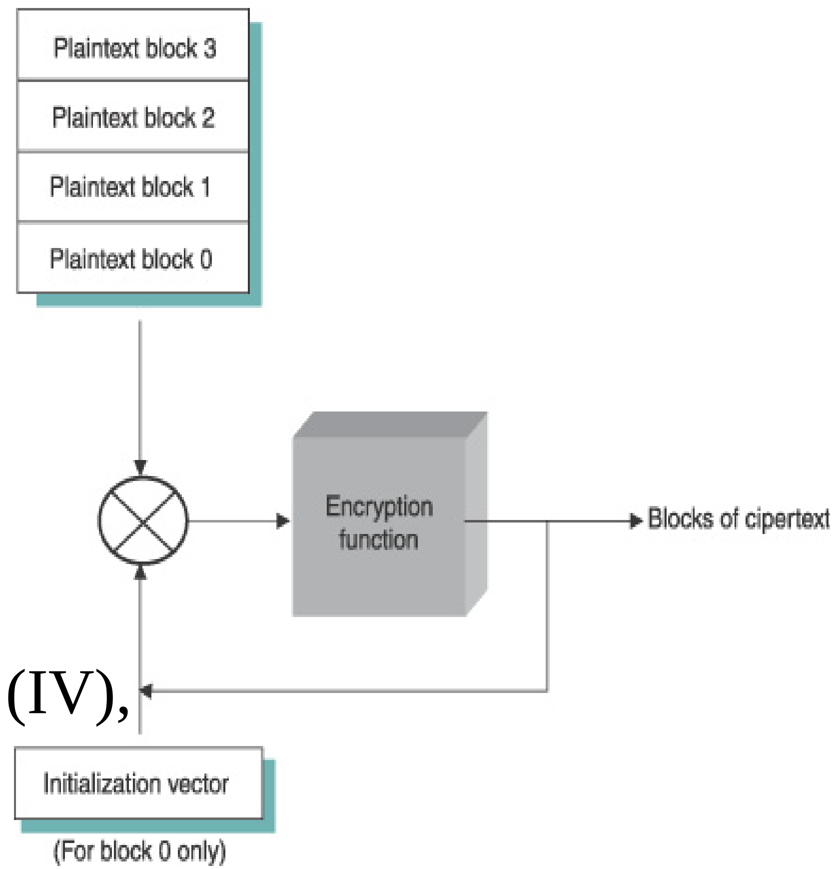
Principles of Ciphers

- The **sender** applies an **encryption function** to the original **plaintext** message, resulting in a **ciphertext** message that is sent over the network
- The receiver applies a **decryption function** – the **inverse** of the encryption function – to recover the original plaintext
- Cryptographers have been led to the principle that encryption and decryption functions should be parameterized by a **key**
  - The functions should be considered **public knowledge**
  - Only the key need be **secret**



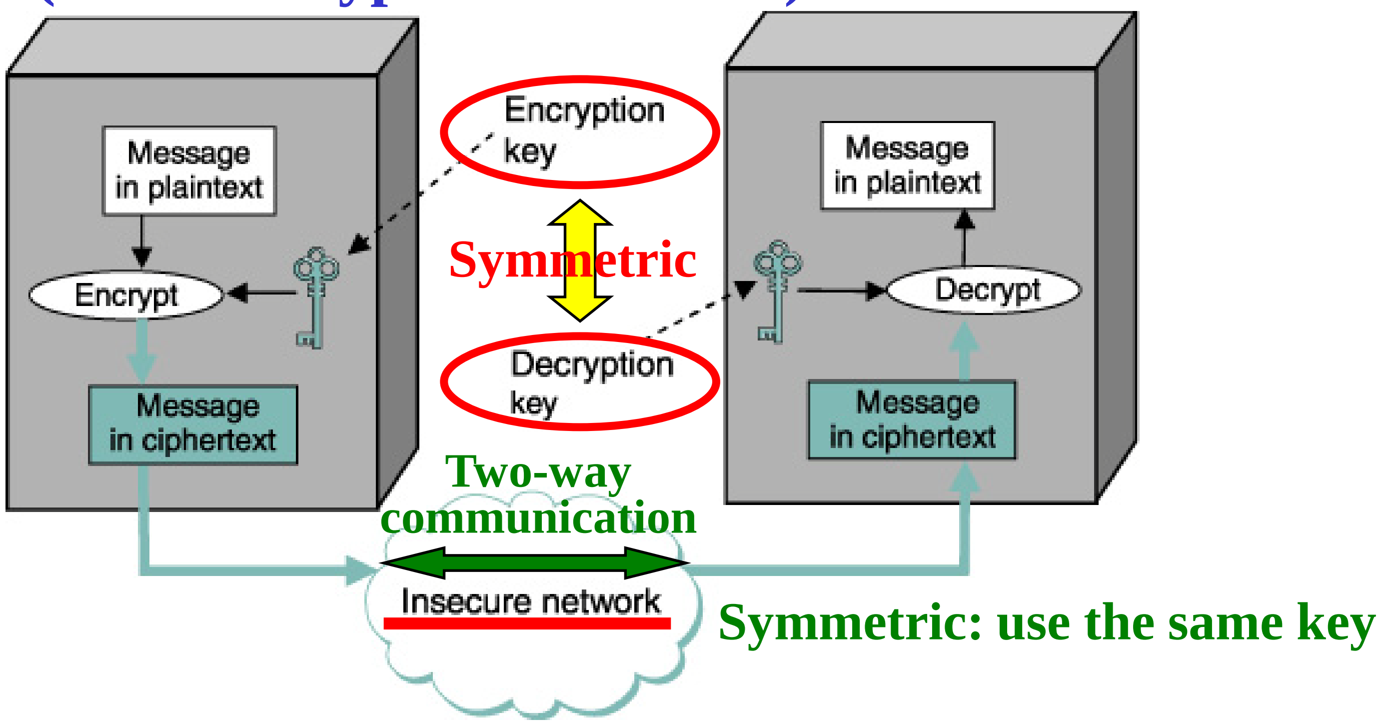
Principles of Ciphers

- Most ciphers are **block ciphers**
  - Take a plaintext block of a **fixed size**
  - The same plaintext block will always result in the same ciphtext block
- To prevent this problem
  - Each plaintext blocks is **XORed** with the previous block's ciphertext before being encrypted
  - Use an **initialization vector** (IV), which is a random number

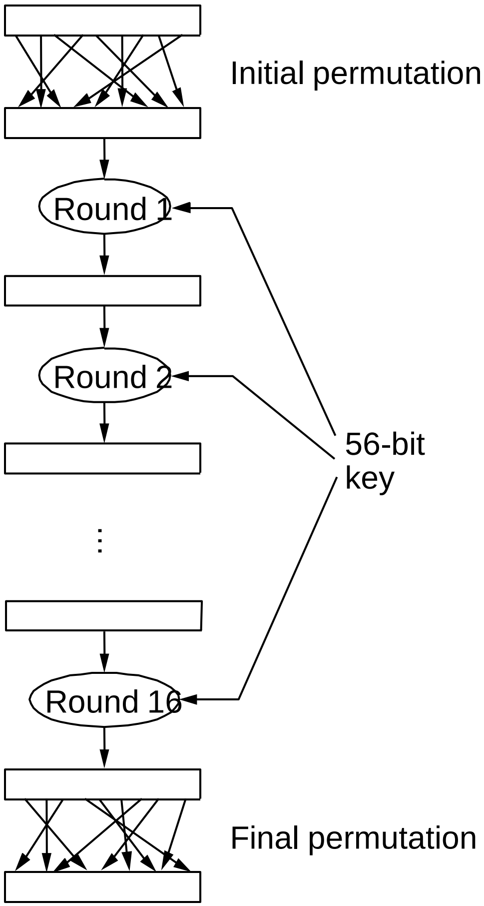


Symmetric-key Ciphers

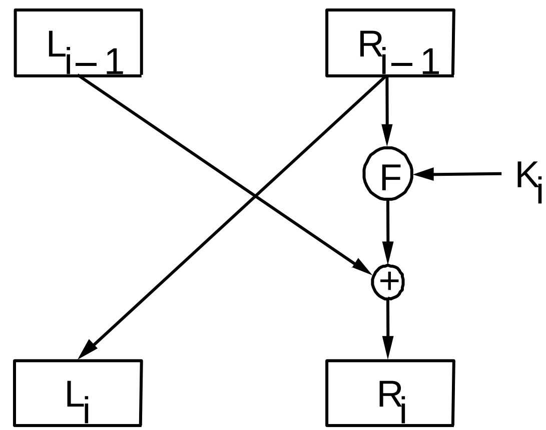
- In a symmetric-key cipher, both participants share **the same key**
- Symmetric-key ciphers are also known as secret-key ciphers
  - The shared key must be known only to the participants
  - **DES (Data Encryption Standard)**



- 64-bit key (56-bits + 8-bit parity)
- 16 rounds



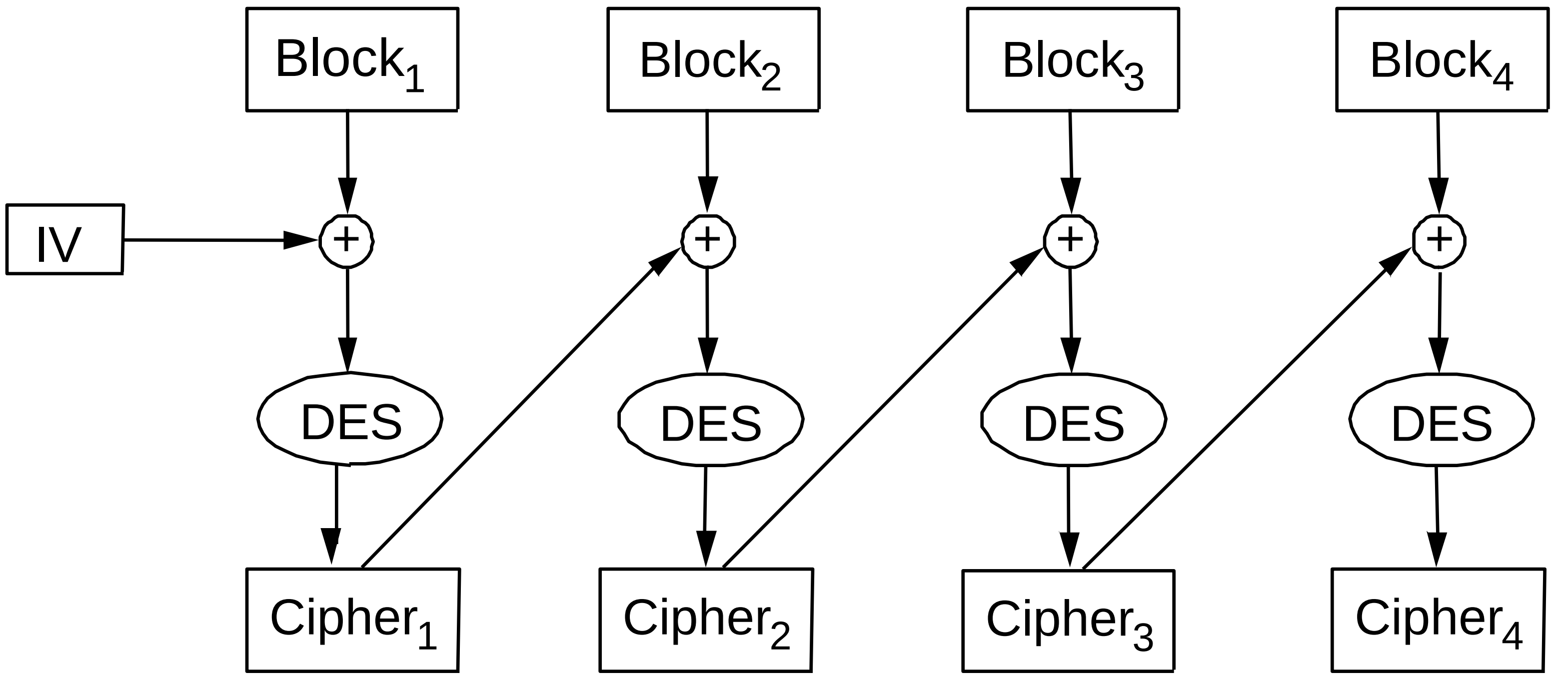
- Each Round



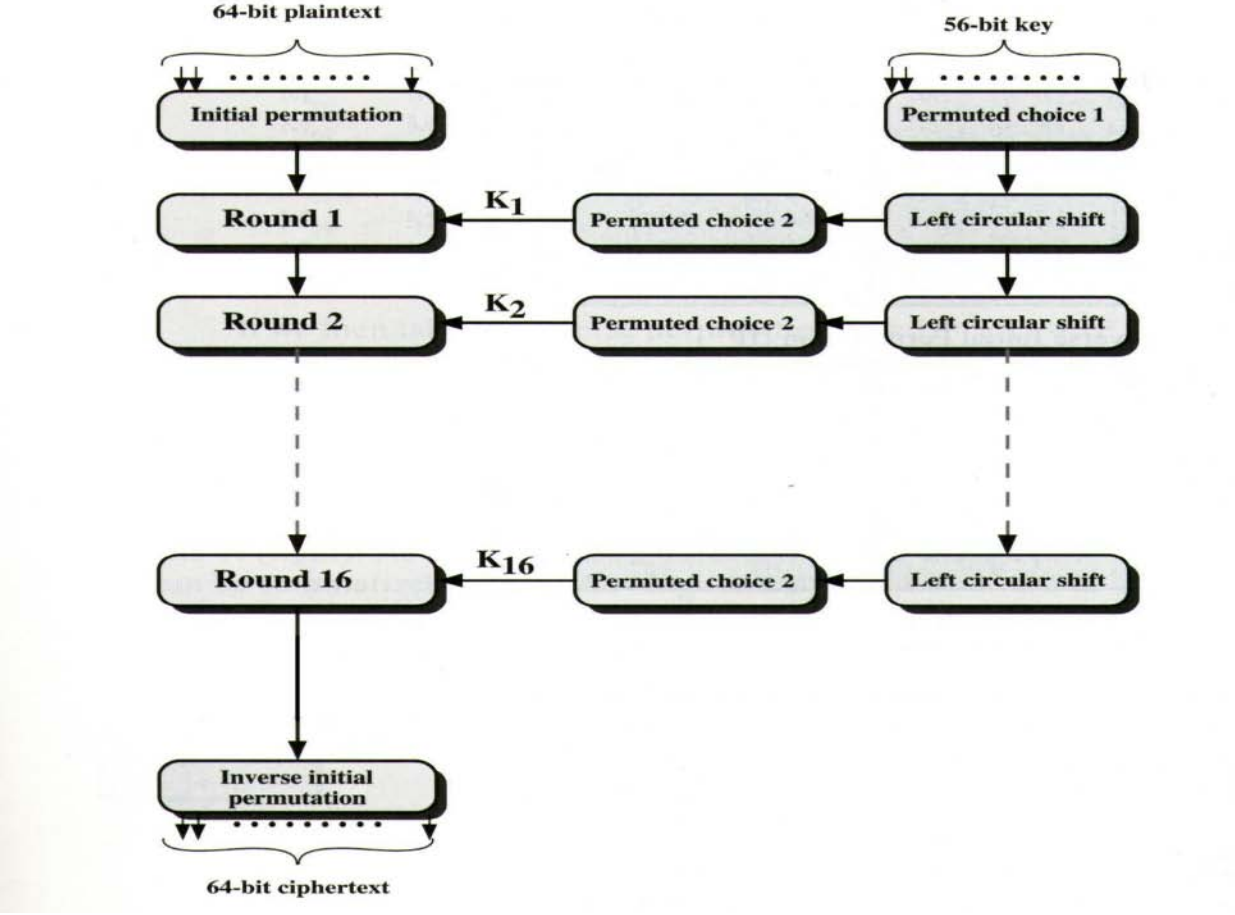
$$L_i = R_{i-1}$$

$$R_i = L_{i-1} \oplus F\left(R_{i-1}, K_i\right)$$

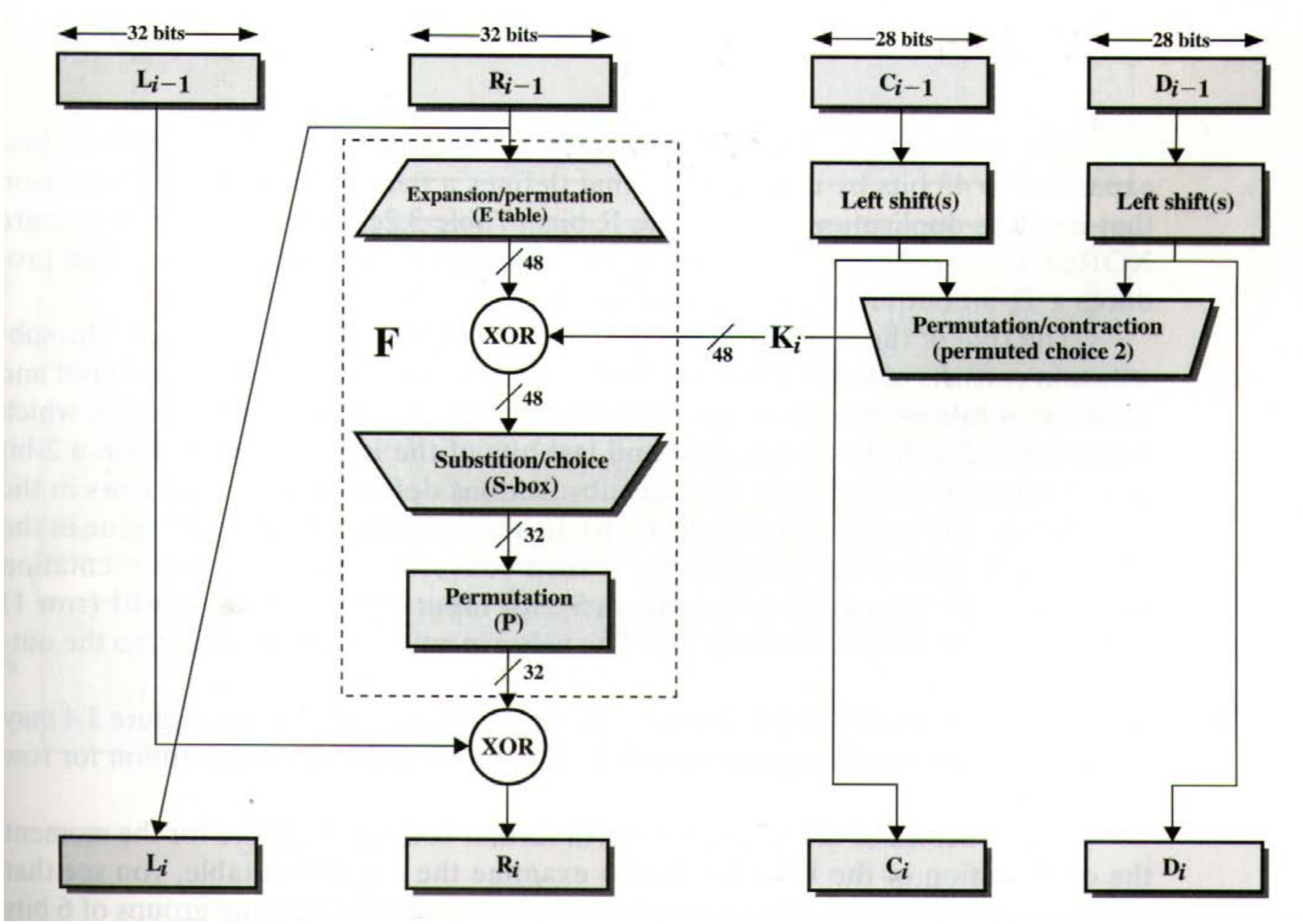
- Repeat for larger messages



General Depiction of DES Encryption Algorithm



Detail of Single Round



Detail of Single Round (cont.)

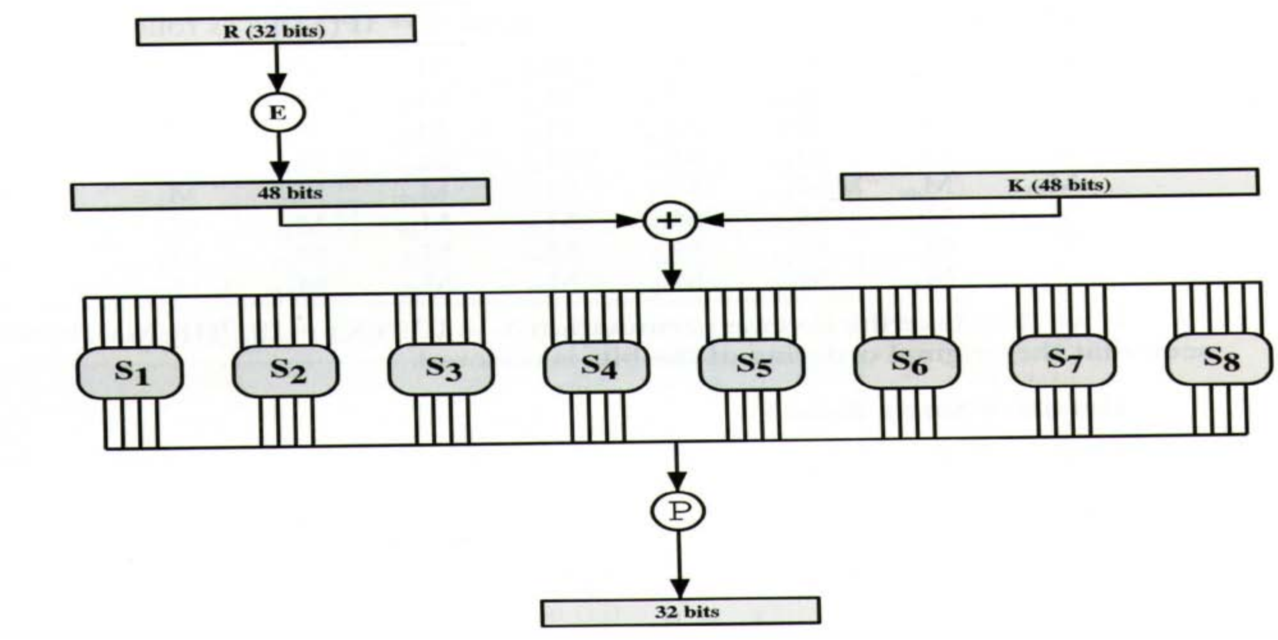
- L_i is the left half of the output text at round i.
- R_i is the right half of the output text at round i.
- C_i is the left half of the key at round i.
- D_i is the right half of the key at round i.

Expansion/Permutation (E table)

- We must expands R from 32 bits into 48 bits, so that it can be combined with the 48 bits K.
- Break R into eight 4-bits chunks and expand each chunk into 6 bits by stealing the rightmost and leftmost bit from the left and right adjacent 4-bits chunks (consult E table).

S-box

- You can think of S-box as just performing a many-to-one mapping from 6-bits numbers to 4-bits numbers.



S-box (cont.)

Middle 4 bits of input

Outer bits

S_1	14	4	13	1	2	15	11	8	3	10	6	12	5	9	0	7
	0	15	7	4	14	2	13	1	10	6	12	11	9	5	3	8
	4	1	14	8	13	6	2	11	15	12	9	7	3	10	5	0
	15	12	8	2	4	9	1	7	5	11	3	14	10	0	6	13
S_2	15	1	8	14	6	11	3	4	9	7	2	13	12	0	5	10
	3	13	4	7	15	2	8	14	12	0	1	10	6	9	11	5
	0	14	7	11	10	4	13	1	5	8	12	6	9	3	2	15
	13	8	10	1	3	15	4	2	11	6	7	12	0	5	14	9
S_3	10	0	9	14	6	3	15	5	1	13	12	7	11	4	2	8
	13	7	0	9	3	4	6	10	2	8	5	14	12	11	15	1
	13	6	4	9	8	15	3	0	11	1	2	12	5	10	14	7
	1	10	13	0	6	9	8	7	4	15	14	3	11	5	2	12
S_4	7	13	14	3	0	6	9	10	1	2	8	5	11	12	4	15
	13	8	11	5	6	15	0	3	4	7	2	12	1	10	14	9
	10	6	9	0	12	11	7	13	15	1	3	14	5	2	8	4
	3	15	0	6	10	1	13	8	9	4	5	11	12	7	2	14
S_5	2	12	4	1	7	10	11	6	8	5	3	15	13	0	14	9
	14	11	2	12	4	7	13	1	5	0	15	10	3	9	8	6
	4	2	1	11	10	13	7	8	15	9	12	5	6	3	0	14
	11	8	12	7	1	14	2	13	6	15	0	9	10	4	5	3
S_6	12	1	10	15	9	2	6	8	0	13	3	4	14	7	5	11
	10	15	4	2	7	12	9	5	6	1	13	14	0	11	3	8
	9	14	15	5	2	8	12	3	7	0	4	10	1	13	11	6
	4	3	2	12	9	5	15	10	11	14	1	7	6	0	8	13
S_7	4	11	2	14	15	0	8	13	3	12	9	7	5	10	6	1
	13	0	11	7	4	9	1	10	14	3	5	12	2	15	8	6
	1	4	11	13	12	3	7	14	10	15	6	8	0	5	9	2
	6	11	13	8	1	4	10	7	9	5	0	15	14	2	3	12
S_8	13	2	8	4	6	15	11	1	10	9	3	14	5	0	12	7
	1	15	13	8	10	3	7	4	12	5	6	11	0	14	9	2
	7	11	4	1	9	12	14	2	0	6	10	13	15	3	5	8
	2	1	14	7	4	10	8	13	15	12	9	0	3	5	6	11

Permutation Tables for DES

(a) Initial Permutation (IP)

58	50	42	34	26	18	10	2
60	52	44	36	28	20	12	4
62	54	46	38	30	22	14	6
64	56	48	40	32	24	16	8
57	49	41	33	25	17	9	1
59	51	43	35	27	19	11	3
61	53	45	37	29	21	13	5
63	55	47	39	31	23	15	7

(b) Inverse Initial Permutation (IP^{-1})

40	8	48	16	56	24	64	32
39	7	47	15	55	23	63	31
38	6	46	14	54	22	62	30
37	5	45	13	53	21	61	29
36	4	44	12	52	20	60	28
35	3	43	11	51	19	59	27
34	2	42	10	50	18	58	26
33	1	41	9	49	17	57	25

(c) Expansion Permutation (E)

32bit-48bit expansion

32	1	2	3	4	5
4	5	6	7	8	9
8	9	10	11	12	13
12	13	14	15	16	17
16	17	18	19	20	21
20	21	22	23	24	25
24	25	26	27	28	29
28	29	30	31	32	1

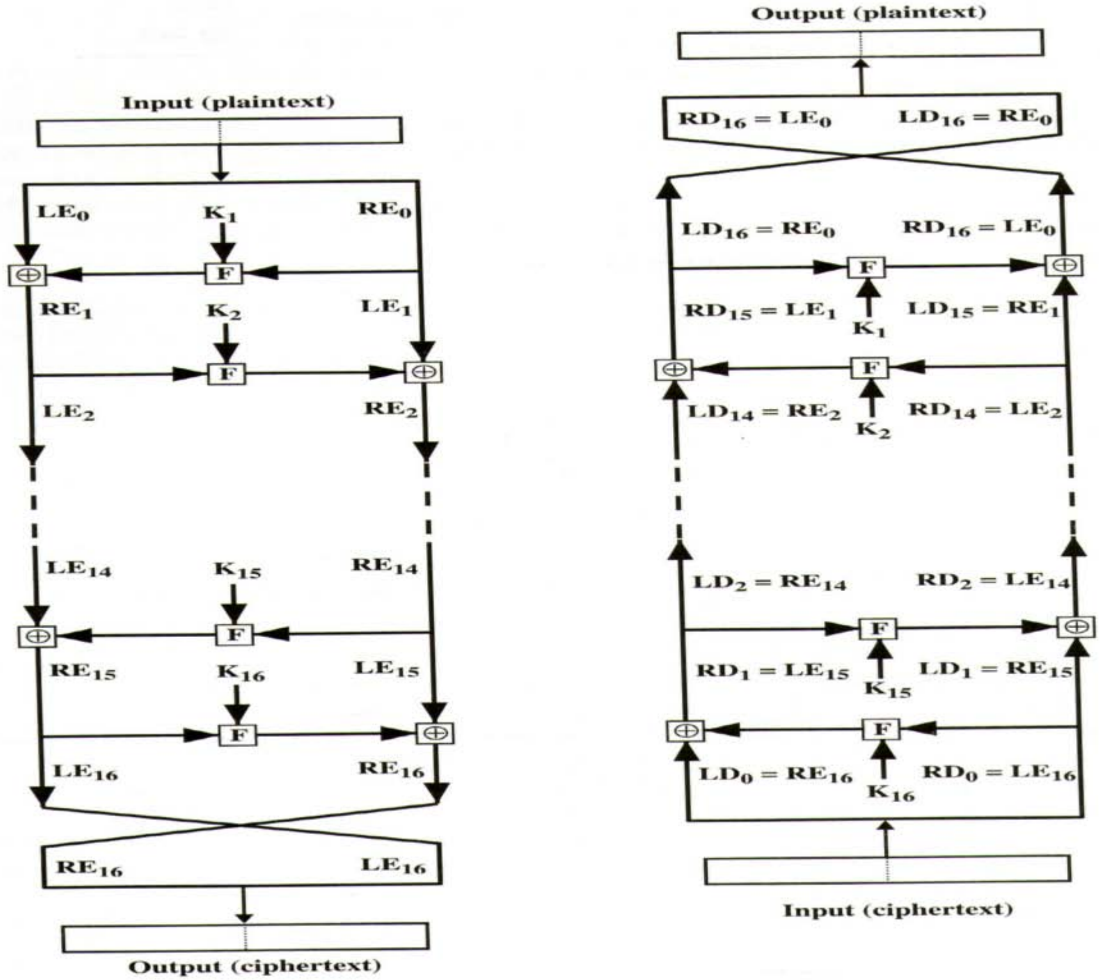
(d) Permutation Function (P)

16	7	20	21	29	12	28	17
1	15	23	26	5	18	31	10
2	8	24	14	32	27	3	9
19	13	30	6	22	11	4	25

How to Decrypt?

- One nice feature of DES is that decryption uses the same algorithm as encryption, except that the application of the subkeys (K_i) is reversed.
- Why?
- Next, we consider a general combiner function F.

How to Decrypt? (cont.)



How to Decrypt? (cont.)

- First, consider the encryption process :

$$LE_{16} = RE_{15}$$
$$RE_{16} = LE_{15} \oplus F\left(RE_{15}, K_{16}\right)$$

- On the decryption side :

$$LD_1 = RD_0 = LE_{16} = RE_{15}$$
$$LD_0 = RE_{16}$$
$$\begin{aligned} RD_1 &= LD_0 \oplus F\left(RD_0, K_{16}\right) \\ &= RE_{16} \oplus F\left(RE_{15}, K_{16}\right) \\ &= \left[LE_{15} \oplus F\left(RE_{15}, K_{16}\right)\right] \oplus F\left(RE_{15}, K_{16}\right) \end{aligned}$$

How to Decrypt? (cont.)

- The XOR has the following properties :

$$[A \oplus B] \oplus C = A \oplus [B \oplus C]$$

$$D \oplus D = 0$$

$$E \oplus 0 = E$$

- Thus, we have :

$$LD_1 = RE_{15}$$

$$RD_1 = LE_{15}$$

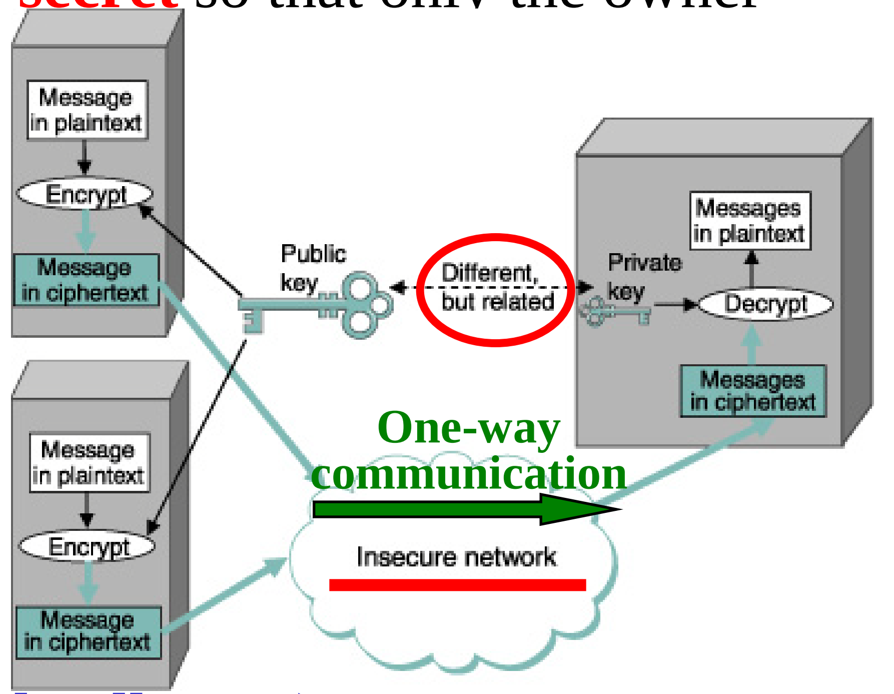
- In general case :

$$LD_i = RE_{16-i}$$

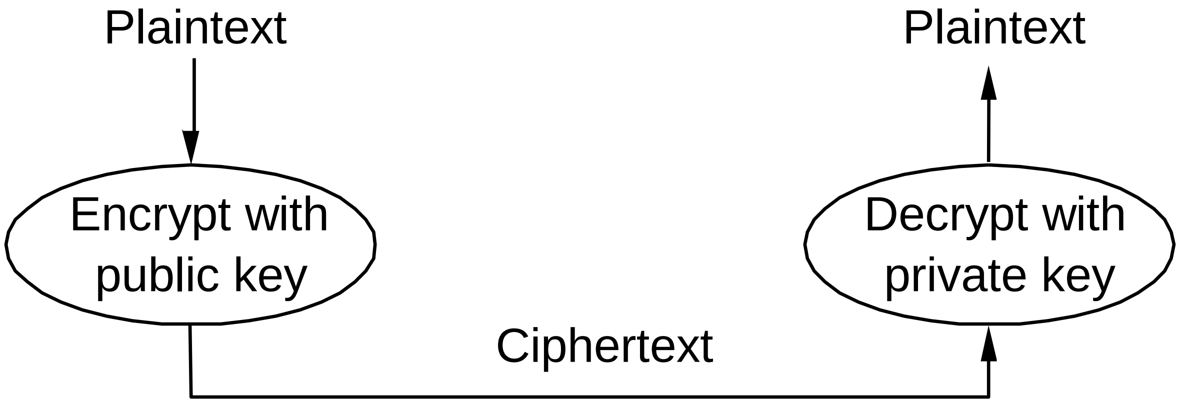
$$RD_i = LE_{16-i}$$

Public-key Ciphers

- A public-key cipher uses a pair of related keys, one for encryption and a different one for decryption
- The pair of keys is "owned" by just one participant
  - Keeps the **decryption key** **secret** so that only the owner can decrypt messages; this key is called the **private key**
  - Make the **encryption key** **public** so that anyone can encrypt messages for the owner; this key is called the **public key**
  - **RSA (Rivest, Shamir, and Adleman)**



Public Key (RSA)



- Encryption & Decryption

$$c = m^e \bmod n$$
$$m = c^d \bmod n$$

RSA (cont.)

- Choose two large prime numbers p and q (each 256 bits)
- Multiply p and q together to get n
- Choose the encryption key e, such that e and $(p - 1) \times (q - 1)$ are relatively prime.
- Two numbers are relatively prime if they have no common factor greater than one
- Compute decryption key d such that

$$d = e^{-1} mod\ ((p - 1) \times (q - 1))$$

- Construct public key as (e, n)
- Construct private key as (d, n)
- Discard (do not disclose) original primes p and q

The Mathematic Theory for RSA

- Theorem:

If $C = M^e \bmod n$

then $M = C^d \bmod n$ (The parameters are defined above.)

Properties of Modular Arithmetic

Lemma 1 :

If a is relatively prime to n and $(a \times b) \bmod n = (a \times c) \bmod n$

then $b \bmod n = c \bmod n$.

pf :

$b \bmod n = c \bmod n$ (同餘), iff $\exists\ p \in Z \ni (b-c) = pn.$

Let $(a \times b) \bmod n = (a \times c) \bmod n = r$

Then $\exists\ p_1, p_2 \in Z \ni \begin{cases} a \times b = p_1 \times n + r \ldots (1) \\ a \times c = p_2 \times n + r \ldots (2) \end{cases}$

Properties of Modular Arithmetic (cont.)

(1)-(2) :

$$(b\text{-}c)a = (p_1\text{-}p_2)n$$

Since *a* is relatively prime to *n*, (*b*-*c*) is an integer Multiple of *n*, *i.e.*,

$$(b\text{-}c) = kn \ \textit{ for some n.}$$

Thus, $b \bmod n = c \bmod n.$

■

Properties of Modular Arithmetic (cont.)

Lemma 2 :

$ab \bmod n = (a \bmod n)(b \bmod n) \bmod n$

pf :

Let $a \bmod n = r_1 \Rightarrow a = np_1 + r_1$

$b \bmod n = r_2 \Rightarrow b = np_2 + r_2$ where p_1, p_2

then $ab = (np_1+r_1)(np_2+r_2) = n(np_1p_2+p_2r_1+p_1r_2)+r_1r_2$

$\Rightarrow ab \bmod n = [n(np_1p_2+p_2r_1+p_1r_2)+r_1r_2] \bmod n$

$= r_1r_2 \bmod n = (a \bmod n)(b \bmod n) \bmod n$

■

Fermat's Theorem

- Let Z_n is the set of nonnegative integers less then n, $i.e.$, $Z_n = \{0,1,\ldots,(n-1)\}$

Fermat's Theorem (cont.)

Lemma 3 :

Let $Z_p^a = \{0, (a \bmod p), (2a \bmod p), \ldots, ((p-1)a \bmod p)\}$.

If p is prime and a is a positive integer not divisible by p, then

$$Z_p^a = Z_p.$$

Fermat’s Theorem (cont.)

Theorem (*Fermat’s Theorem*) :

If p is prime and a is a positive integer not divisible by p, then

$$a^{p-1} \bmod p = 1 \bmod p$$

pf :

Since $Z_p^a = Z_p$, the products of all the elements in Z_p^a and Z_p are the same.

Fermat's Theorem (cont.)

Thus,

$$\left(a \times 2a \times \ldots \times (p-1)a\right) \bmod p$$
$$= \left[(a \bmod p) \times (2a \bmod p) \times \ldots \times \left((p-1)a \bmod p\right)\right] \bmod p$$
$$= (p-1)\,!\; \bmod p$$

Note that

$$a \times 2a \times \ldots \times \left((p-1)a\right) = a^{p-1} \times (p-1)!$$

Therefore,

$$\left[a^{p-1} \times (p-1)!\right] \bmod p = (p-1)! \bmod p$$

Since (p-1)! is relatively prime to p,

$$a^{p-1} \bmod p = 1 \bmod p \quad \text{(Lemma 1)}$$

Euler's Theorem

Define (*Euler's totient funtion*) :

Euler's totient function $\phi(n)$ is defined to be the number of positive integers that are less than *n* and relatively prime to *n*.

- It is clear that for a prime number *p* ,

$$\phi(p) = p - 1.$$

- Then, for *n* = *pq* (*p* and *q* are two prime numbers)

$$\begin{aligned}\phi(n) = \phi(pq) &= pq - [(q-1) + (p-1) + 1] \\ &= pq - (p+q) + 1 = (p-1)\times(q-1) \\ &= \phi(p)\times\phi(q)\end{aligned}$$

Euler's Theorem (cont.)

Theorem (*Euler's Theorem*) :

For every *a* and *n* that are relatively prime, then

$$a^{\phi(n)} \bmod n = 1 \bmod n.$$

pf :

Let *R* be the set of all integers that are less than *n* and relatively prime to *n*,

$$R = \{x_1, x_2, \ldots, x_{\phi(n)}\}.$$

Now multiply each element by *a*, and then modulo *n*,

$$S = \{ax_1 \bmod n, ax_2 \bmod n, \ldots, ax_{\phi(n)} \bmod n\}.$$

Euler's Theorem (cont.)

Then $R = S$.

1. Since a is relatively prime to n and x_i is relatively prime to n, ax_i must also be relatively prime to n. Th-us, all the members of S are intergers less than n and they are relatively prime to n.
2. All the elements in S are distinct. If $ax_i \bmod n = ax_j \bmod n$, then $x_i = x_j$ (contraction to that all the element in R are distinct.)

Euler's Theorem (cont.)

$$\prod_{i=1}^{\phi(n)} (ax_i \bmod n) = \prod_{i=1}^{\phi(n)} x_i$$

$$\Rightarrow \left(a^{\phi(n)} \prod_{i=1}^{\phi(n)} x_i \right) \bmod n = \left(\prod_{i=1}^{\phi(n)} x_i \right) \bmod n$$

$$\Rightarrow a^{\phi(n)} \bmod n = 1 \bmod n \quad \text{(Lemma 1)}$$

$\blacksquare$

The Mathematical Theory for RSA (cont.)

Let's recall the definitions of all parameters.

- p, q, two prime numbers.
- $n = pq$.
- e is relatively prime to $(p-1)(q-1)$, i.e. $\gcd((p-1)(q-1), e) = 1$.
- $de \bmod [(p-1)(q-1)] = 1 \bmod [(p-1)(q-1)]$

Now, we need to prove :

$$\text{if } C = M^e \bmod n$$
$$\text{then } M = C^d \bmod n \ \forall M < n$$

The Mathematical Theory for RSA (cont.)

pf :

$$de = k(p-1)(q-1)+1 = k\phi(n)+1,$$ where k is an integer.

If M is relatively prime to n, then

$$\begin{aligned}
C^d \bmod n &= \left(M^e\right)^d \bmod n \\
&= M^{ed} \bmod n \\
&= M^{k\phi(n)+1} \bmod n \\
&= \left[\left(M^{\phi(n)}\right)^k \times M\right] \bmod n \\
&= \left[\left(\left(M^{\phi(n)}\right)^k \bmod n\right) \times \left(M \bmod n\right)\right] \bmod n \quad \text{(Lemma 2)} \\
&= M \bmod n = M \qquad \forall M < n
\end{aligned}$$

The Mathematical Theory for RSA (cont.)

Suppose M is not relatively prime to n and $M < n = pq$.
W.L.G., let $M = sp$ for some integer s. From Euler's theorem,

$$M^{\phi(q)} \bmod q = 1 \bmod q$$

$$\Rightarrow M^{k\phi(q)} \bmod q = 1 \bmod q$$

$$\Rightarrow \left[M^{k\phi(q)}\right]^{\phi(p)} \bmod q = 1 \bmod q$$

$$\Rightarrow M^{k\phi(n)} \bmod q = 1 \bmod q$$

$$\Rightarrow M^{k\phi(n)} = 1 + tq \qquad \text{for some integer } t$$

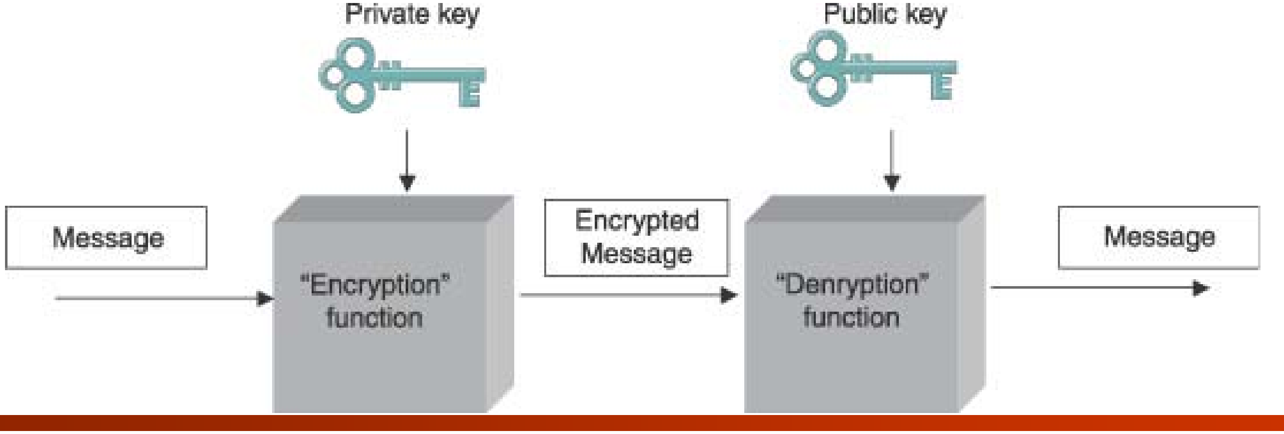
Multiplying each side by $M=sp$, then

$$M^{ed} = M^{k\phi(n)+1} = M + tspq = M + tsn$$

$$\Rightarrow M^{ed} \bmod n = M \bmod n = M \qquad \forall \mathrm{M} < n$$

Authentication

- Another application of public-key ciphers is **authentication**
- The **private key** can be used with the **encryption** function to encrypt messages so that they can only be **decrypted** using the **public key**
- **Anyone** with the public key could decrypt such a message
- It tells the receiver that such a message could only have been **created** by the **owner of the keys**
  - **Authenticate** the owner of the keys

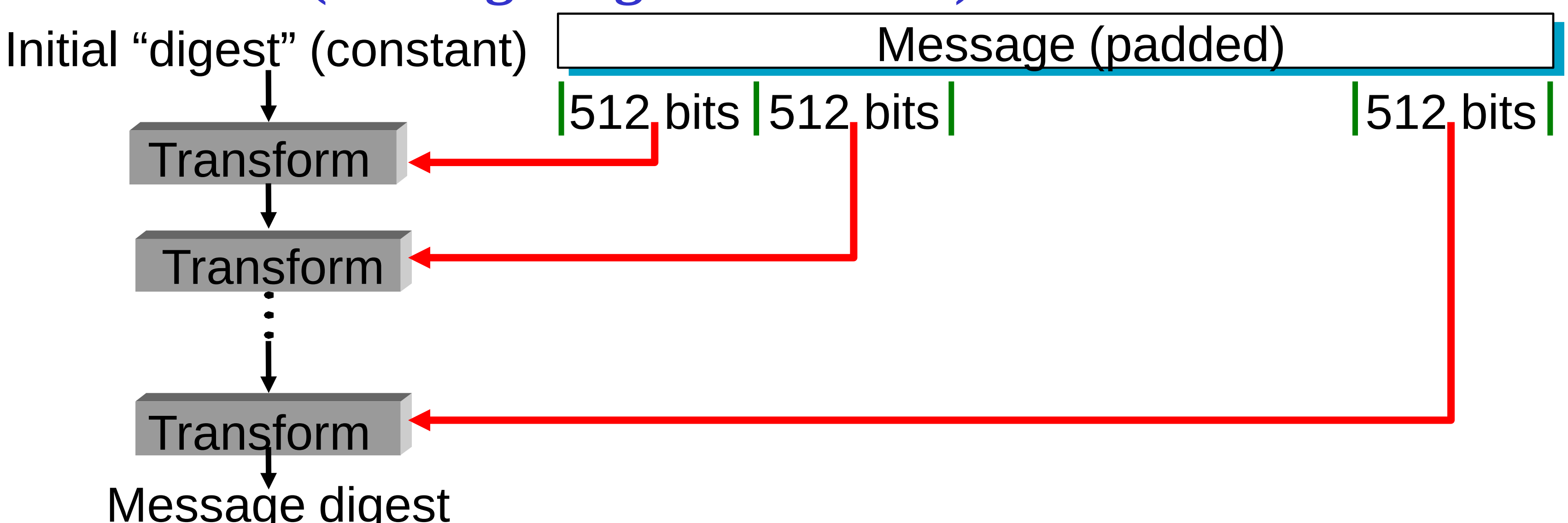


Message Integrity

- Encryption alone does not provide **data integrity**
- Sometimes two participants are worried about the possibility of an impostor sending message that claim to be from one of them
- An **authenticator** is a value, to be included in a transmitted message, that can be used to verify simultaneously the **authenticity** and the **data integrity** of a message
- An authenticator includes **redundant information** about the message contents
  - Like a checksum or cyclic redundancy check (CRC)
  - Also known as a **message integrity code (MIC)**
  - The receiver can check the MIC to verify the **validity** of the message

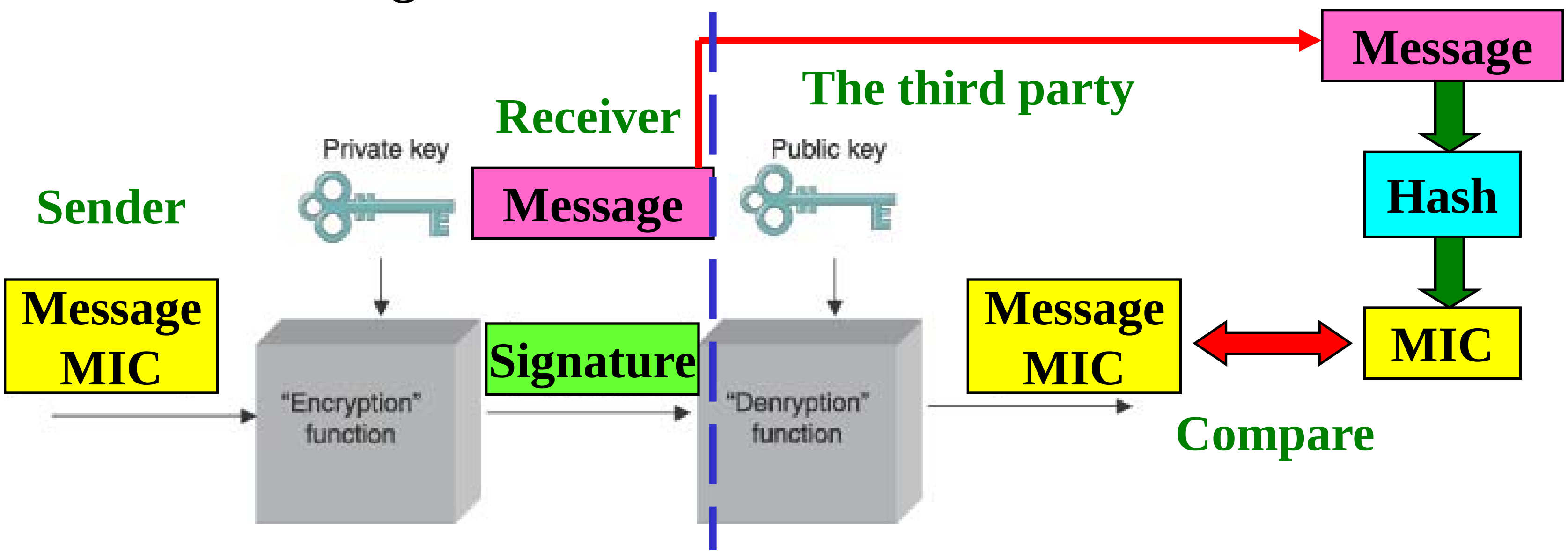
Hash Function

- One way to generate an authenticator is using a hash function
- **Hashing algorithms (message digest function):** does not involve the use of keys
  - Map a potentially **large message** into a **small fixed-length number** (cryptographic **checksum**)
  - **MD5 (Message Digest version 5)**



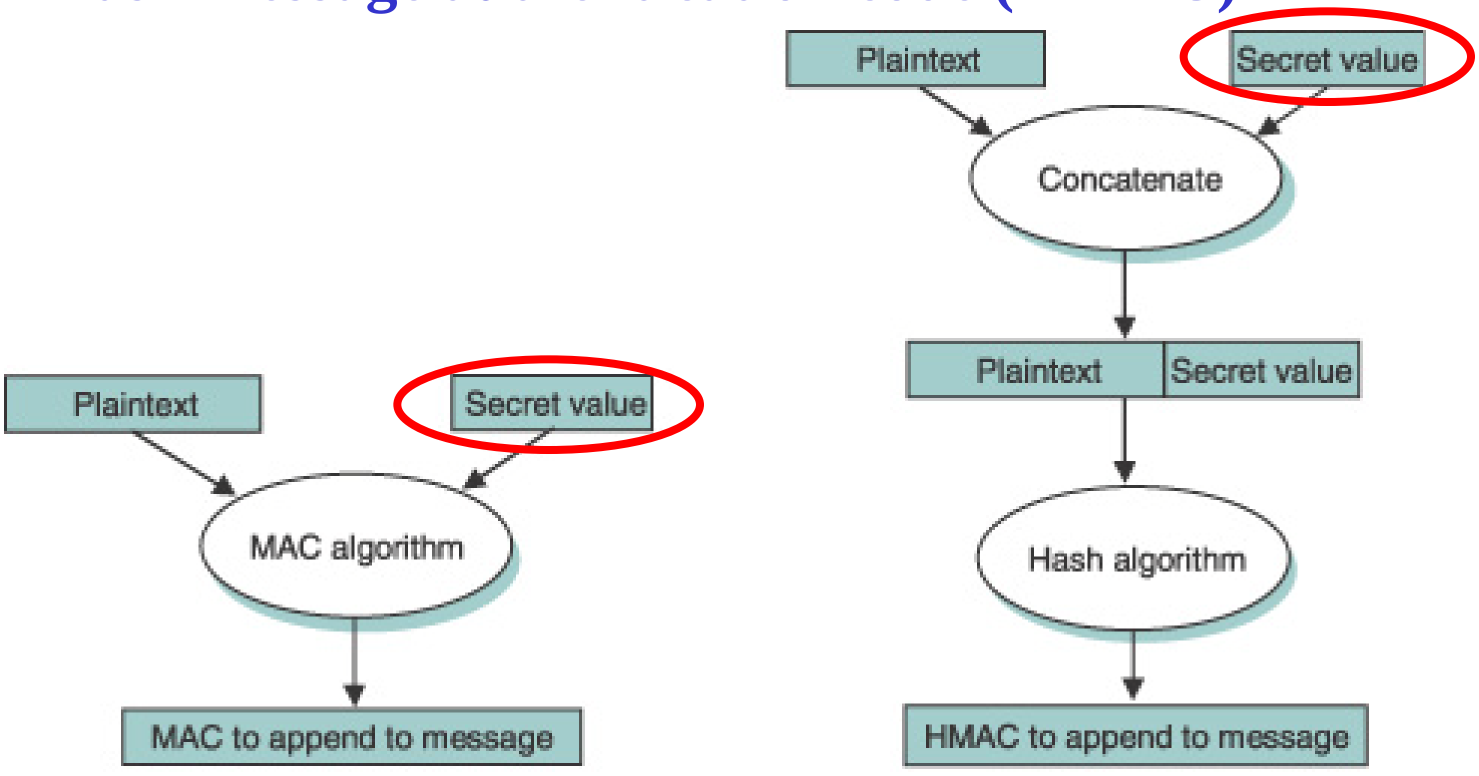
Message Integrity – Signature

- A digest encrypted with a public-key algorithm but using the **private key** is called a **digital signature**
- The receiver of a message with a digital signature can prove to any **third party** that the sender **really sent** that message
  - The third party can use the sender's **public key** to check for the message



Message Integrity – Hash with Secret Value

- Take a **secret value** known to only the sender and the receiver
  - **Message authentication code (MAC)**
  - **Hash message authentication code (HMAC)**



(a) (b)

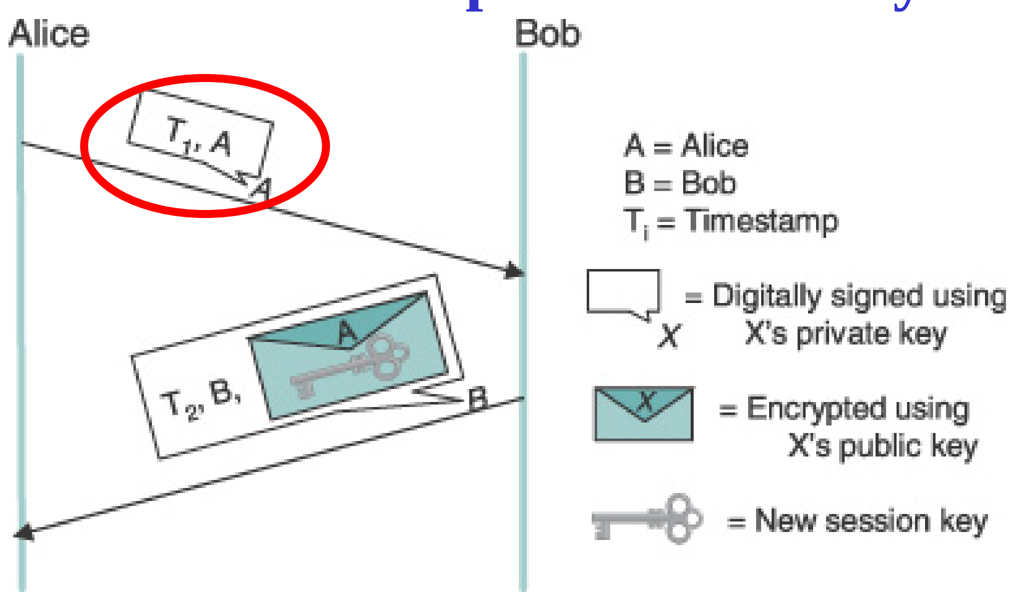
Authentication Protocols

Authentication Protocols

- Before two participants are likely to establish a secure channel between themselves
  - They wish to **verify** that the other participant is who he or she **claims to be**
- The authentication protocols may base on:
  - Using **secret key cryptography** (such as DES)
    - Need to share a secret key
  - Using **public key cryptography** (such as RSA)
    - Do not need to share a secret key

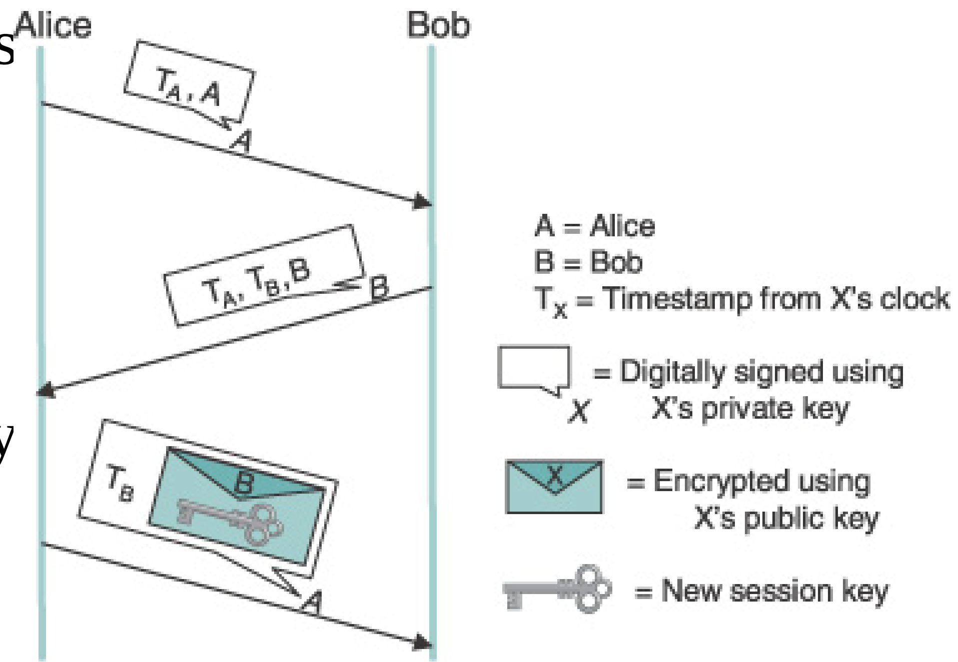
Public-key Authentication (Synchronous)

- In the first protocol, Alice and Bob's clocks are **synchronized**
- Alice sends Bob a message with a **timestamp** and her **identity** in plaintext plus her **digital signature**
- Bob uses the digital signature to authenticate the message, and the timestamp to verify its **freshness**
- Bob sends back a message with a **timestamp** and his **identity** in plaintext, and a new **session key** encrypted by Alice's **public key**, all digitally signed
- Alice can verify the authenticity and freshness of the message



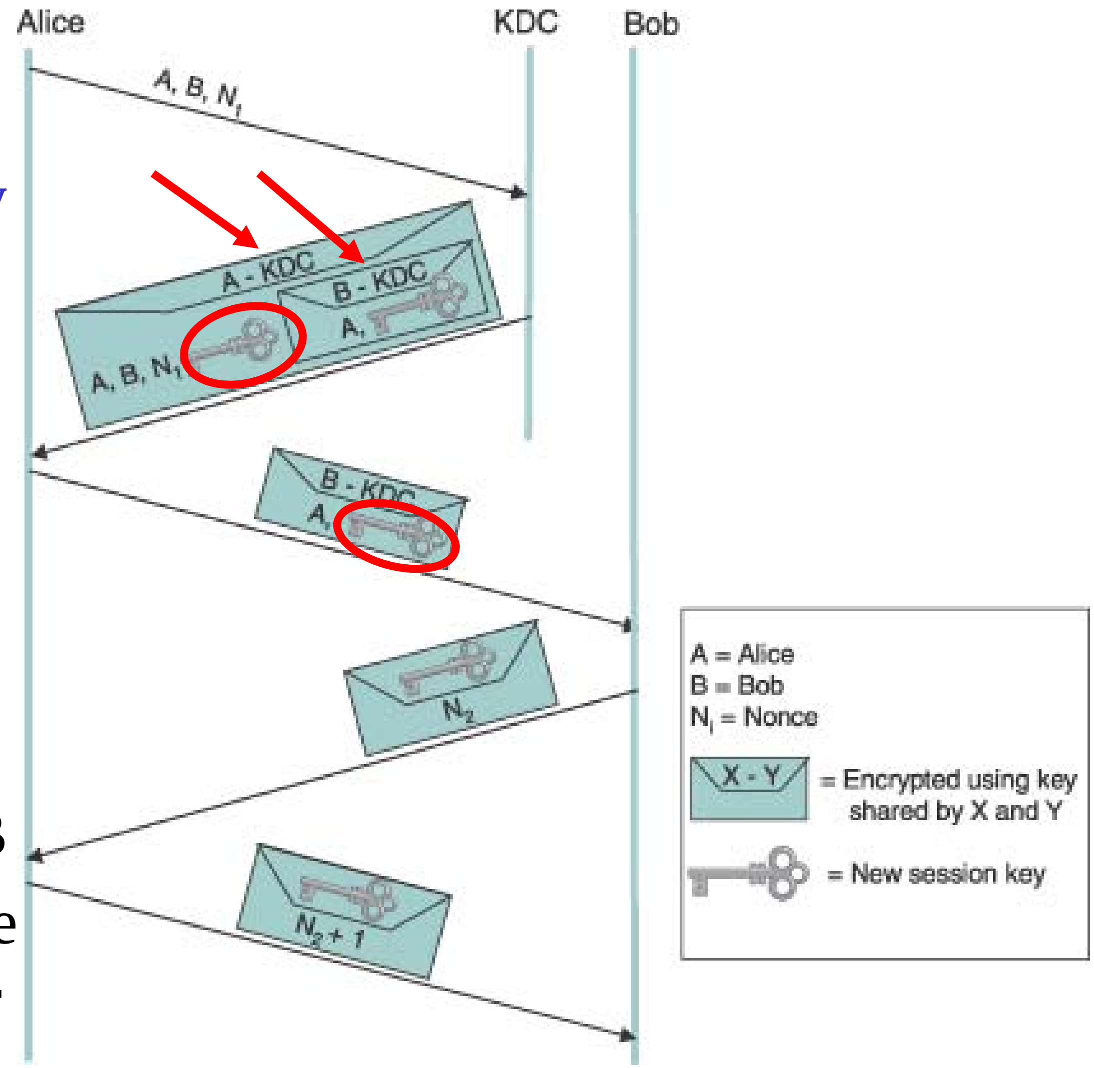
Public-key Authentication (Asynchronous)

- The second protocol **does not** rely on clock synchronization
- Alice sends Bob a digitally signed message with $\mathbf{T_A}$ and **A**
- Bob cannot be sure that the message is fresh, since their clocks are **not** synchronized
- Bob sends back a digitally signed message with $\mathbf{T_A}$, $\mathbf{T_B}$ and **B**
- Alice can verify the freshness of Bob's reply by comparing her **current time**
- Alice sends Bob back a signed message with $\mathbf{T_B}$ and an encrypted new session key
- Bob can verify the freshness of Alice's reply



Symmetric-key Authentication

- It involves three parties: Alice, Bob, and a **KDC**
  - KDC is a trusted **key distribution center** (also known as **Authentication Server, AS**)
- A (B) and KDC already share a secret key
- Finally, a **session key** is shared between A and B
- A & B can communicate **directly** with each other



Diffie-Hellman Key Agreement

- Two parameter p and g
- Parameter p is a prime number
- Parameter g is the generator of the group {1,2, …, p-1}
- For every n in {1,2, …, p-1}, there is some k such that $n=g^k \bmod p$
- Alice generates a random number a in {1,2, …, p-1}
- Bob generates a random number b in {1,2, …, p-1}
- Alice's public value is $g^a \bmod p$
- Bob's public value is $g^b \bmod p$
- Then they exchange their public values

Diffie-Hellman Key Agreement

- Alice computes $g^{ab} \bmod p = (g^b \bmod p)^a \bmod p$
- Bob computes $g^{ab} \bmod p = (g^a \bmod p)^b \bmod p$
- Alice and Bob now have $g^{ab} \bmod p$ as their shared symmetric key
- Discrete logarithm problem: knowing the public value public value is $g^a \bmod p$ is difficult to compute a for suitably large p
- Note that Diffie-Hellman does not authenticate the participants
- Suffer from the man-in-the-middle attack

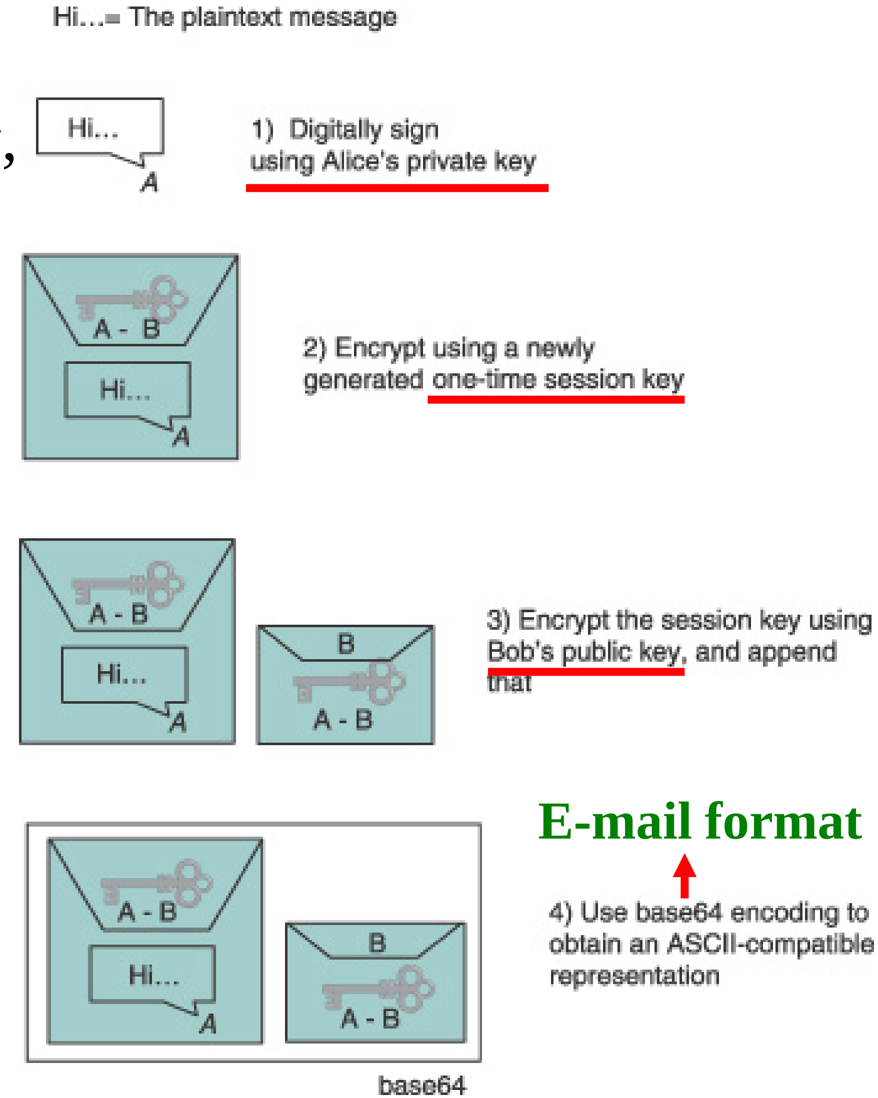
Secure Systems

Secure Systems

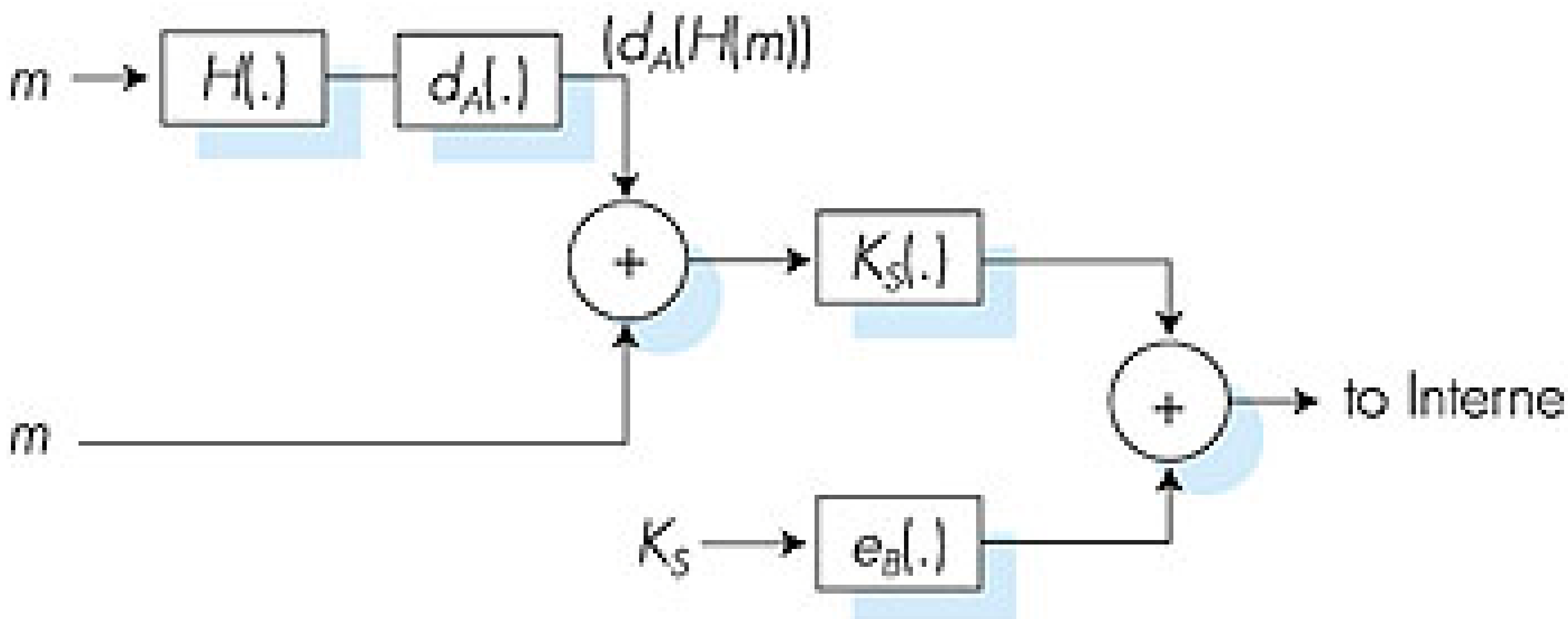
- Systems that operate at the **application** layer:
  - **Pretty Good Privacy (PGP)** provides electronic mail security
  - **Secure Shell (SSH)** provides secure remote login services
- For **transport** layer:
  - **Transport Layer Security (TLS)**
- For **network (IP)** layer:
  - **IP Security (IPsec) protocols**
- For **data link** layer:
  - **IEEE 802.11i** for WLAN

Pretty Good Privacy (PGP)

- PGP provides **authentication, confidentiality**, **data integrity**, and **non-repudiation**
- The confidentiality, and **receiver** authentication rely on the receiver having a known **public key**
- The non-repudiation, and **sender** authentication rely on the sender having a known **public key**



- Provide secrecy, sender authentication, message integrity.



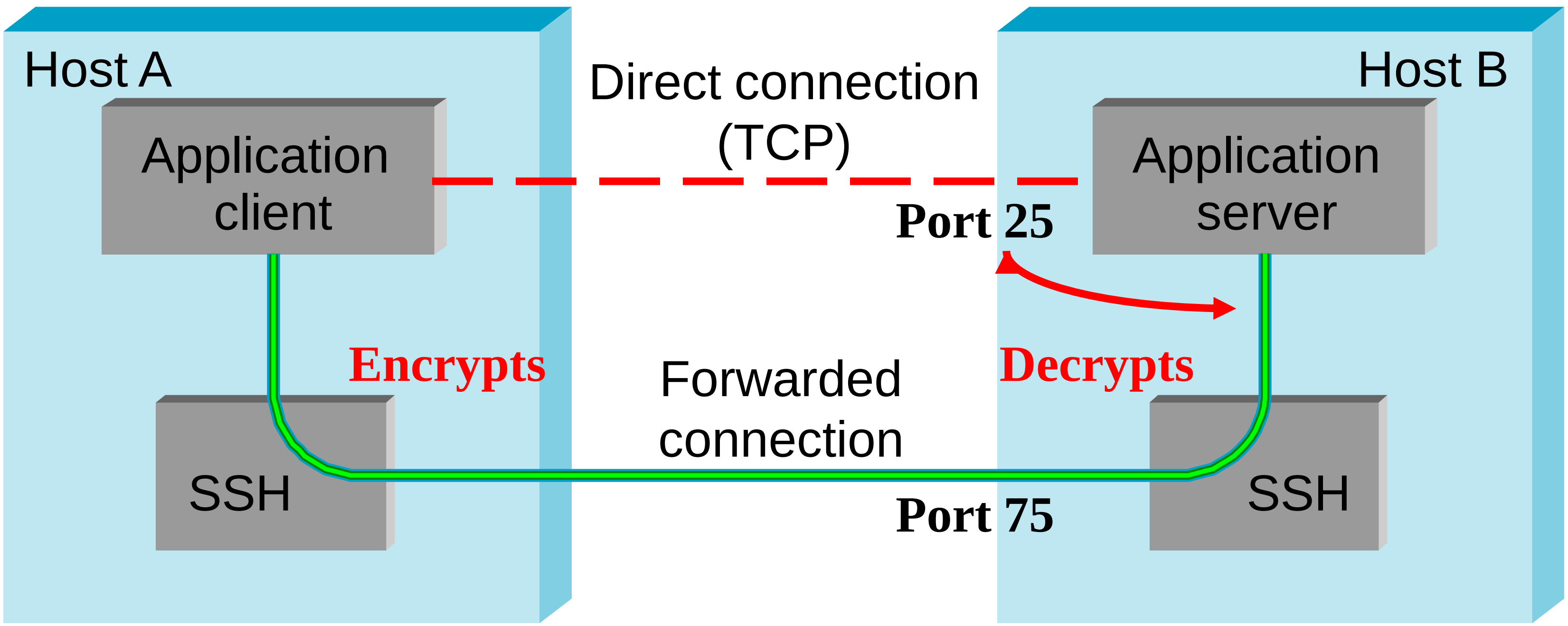
Note: Alice uses both her private key, Bob's public key.

Secure Shell (SSH)

- The SSH provides a **remote login service** and is intended to replace the less secure Telnet and rlogin programs
- SSH consists of three protocols:
  - **SSH-TRANS:** is a **transport layer** protocol
  - **SSH-AUTH:** is an **authentication** protocol
  - **SSH-CONN:** is a **connection** protocol
- SSH can also support other insecure **TCP-based** applications
  - Run the applications over a secure **"SSH tunnel"**
  - Use the SSH-CONN protocol

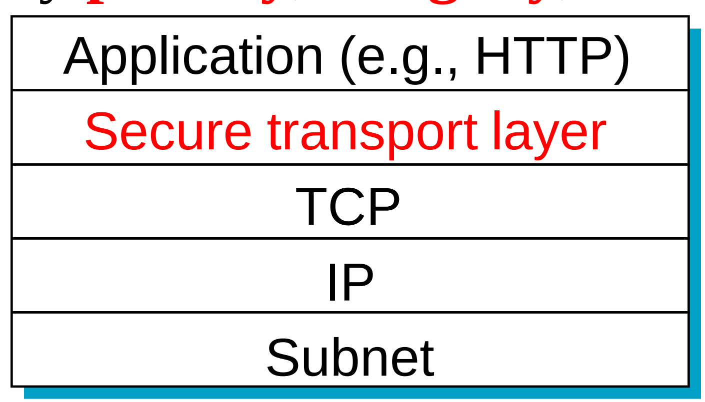
Secure Shell (SSH)

- When messages arrive at the well-known **SSH port** on the server
  - SSH **decrypts** the connects, and then
  - Forwards the data to the **actual port** at which the server is listening



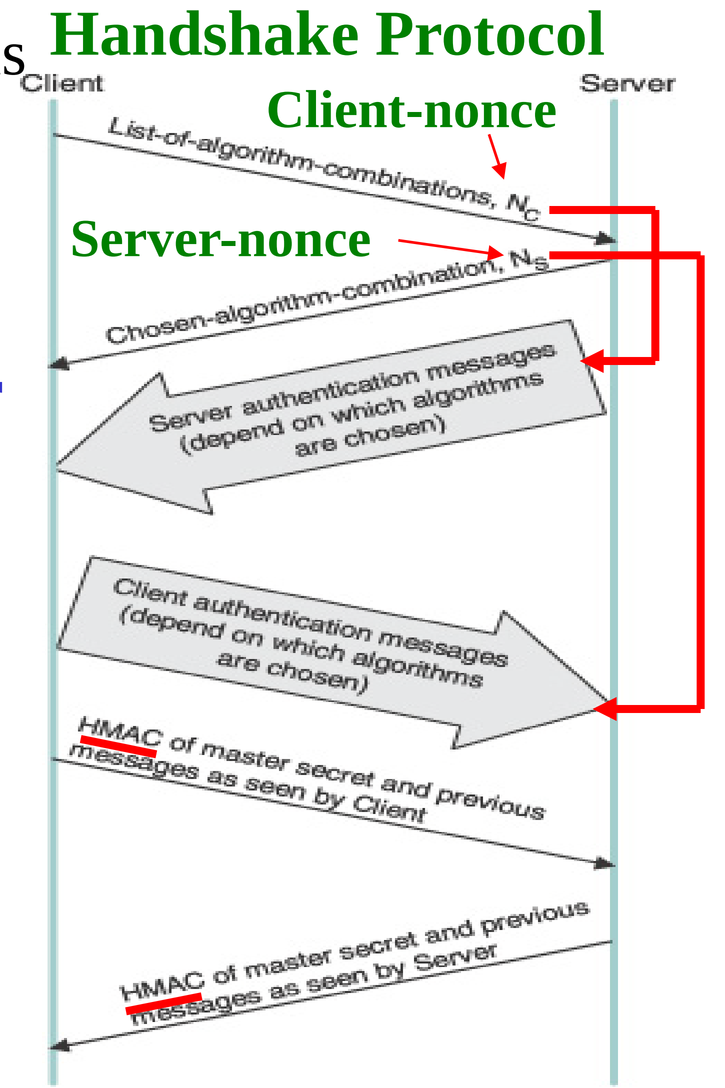
Transport Layer Security (TLS)

- Since **World Wide Web** becomes popular and has been applied for **commercial applications**
  - Such as making purchases by **credit card**
  - Some level of security would be necessary for transactions on the Web
- **TLS** looks just like a **normal transport protocol**, except for the fact that it is **secure**
  - Provides the necessary **privacy**, **integrity**, and **authentication**



Transport Layer Security (TLS)

- When HTTP is used in this way, it is known as **HTTPS (secure HTTP)**
  - HTTP is **unchanged**
  - It simply delivers data to and accepts data from the **TLS layer** rather than TCP
- TLS is broken into two parts:
  - **Handshake protocol:** is used to negotiate parameters of the communication
  - **Record protocol:** is used for actual data transfer



Secure electronic transactions (SET)

- designed for payment-card transactions over Internet.
- provides security services among 3 players:
  - customer
  - merchant
  - merchant's bank

  All must have certificates.
- SET specifies legal meanings of certificates.
  - apportionment of liabilities for
- Customer's card number passed to merchant's bank without merchant ever seeing number in plain text.
  - Prevents merchants from stealing, leaking payment card numbers.
- Three software components:
  - Browser wallet
  - Merchant server
  - Acquirer gateway
- See text for description of SET

IP Security (IPSEC)

- **IPSEC** consists of two pieces:
  - The first piece is a pair of protocols that implement the available **security services**
    - **Authentication Header (AH):** provides **access control**, connectionless message **integrity**, **authentication** and **anti-replay** protection
    - **Encapsulating Security Payload:** supports these same services, plus **confidentiality**
  - The second piece is the support for **key management**
    - **ISAKMP: Internet Security Association and Key Management Protocol**

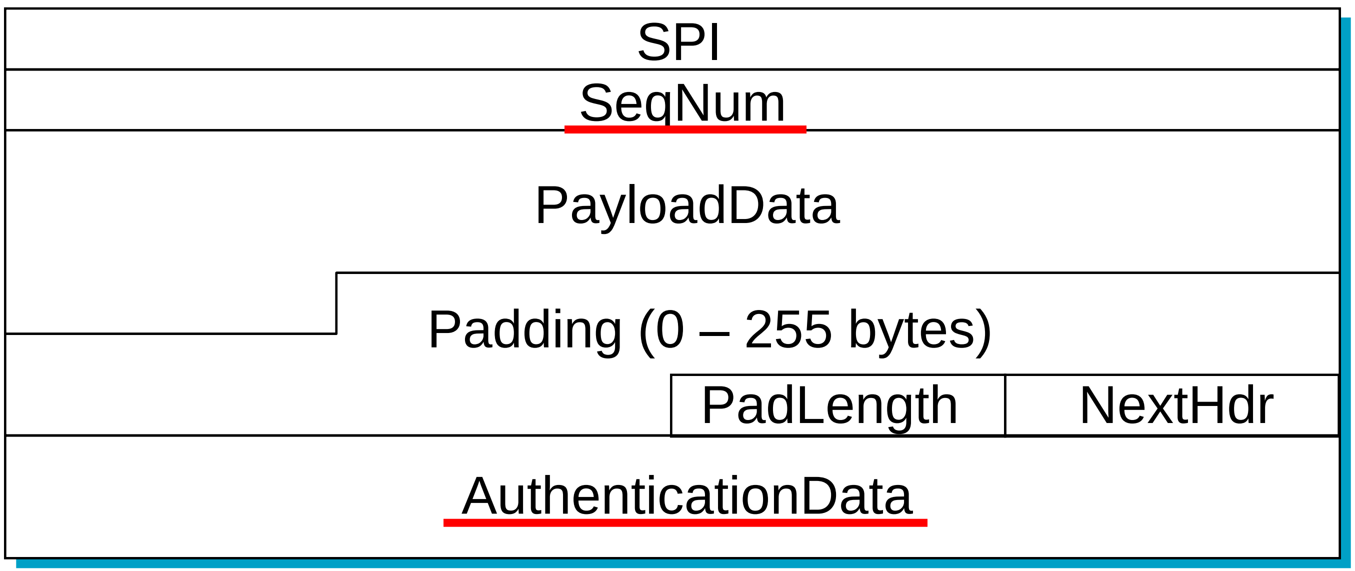
IP Security (IPSEC)

- **Authentication Header (AH):**
  - **NextHdr:** is the type of the next payload after the AH
  - **PayloadLength:** is the length of the AH
  - **Reserved:** is reserved and set to 0
  - **SPI:** identifies the security association for this datagram
  - **SeqNum:** is used to protect against **replay**
  - **AuthenticationData:** contains the **message integrity code** for this packet

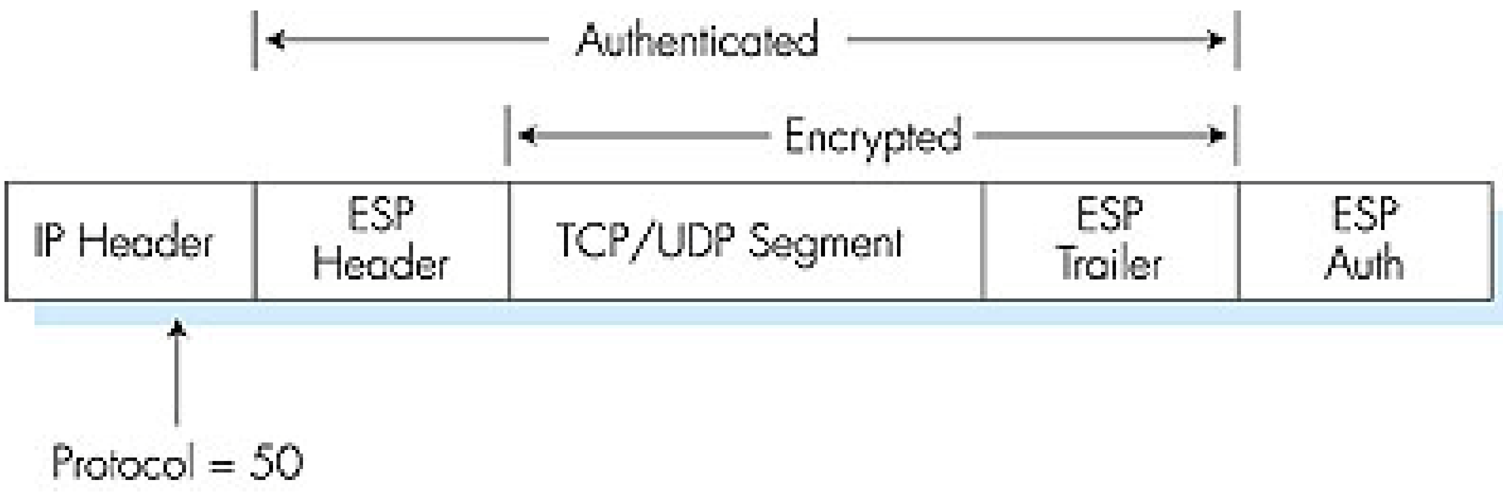
<table>
<tr><td>NextHdr</td><td>PayloadLength</td><td>Reserved</td></tr>
<tr><td colspan="3">SPI</td></tr>
<tr><td colspan="3">SeqNum</td></tr>
<tr><td colspan="3">AuthenticationData</td></tr>
</table>

IP Security (IPSEC)

- **Encapsulating Security Payload (ESP):**
  - **PayloadData:** contains the data described by the NextHdr
  - **PadLength:** is the length of the padding



ESP Tunnel Mode

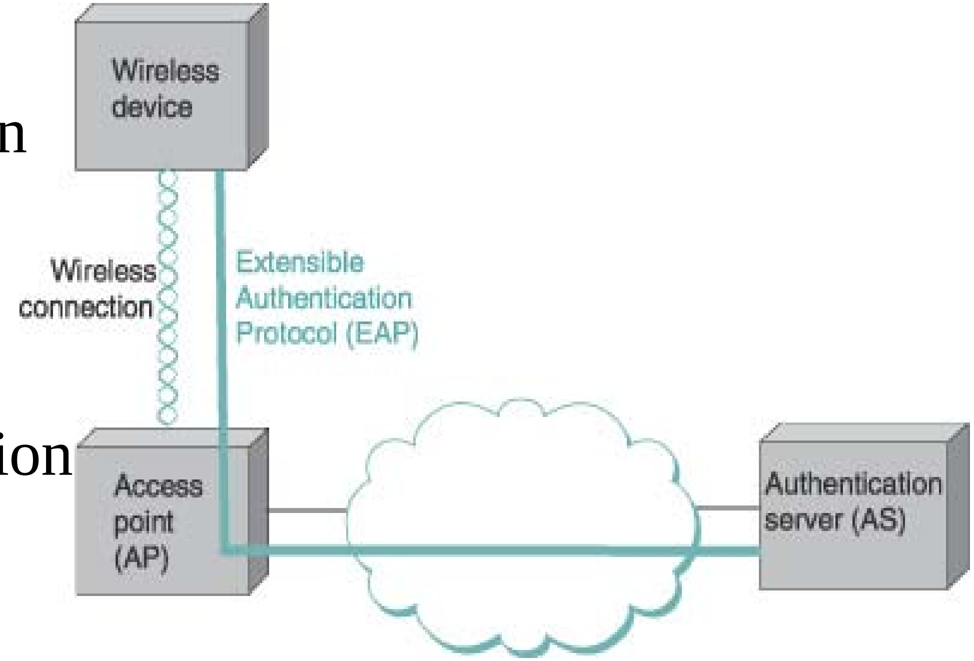


Wireless Security (IEEE 802.11i)

- **IEEE 802.11i** provides **authentication**, **message integrity**, and **confidentiality** to IEEE 802.11 at the **link layer**
- 802.11i authentication supports two modes. In either mode, the end result of successful authentication is a shared pairwise master key
  - **Personal mode:** provides weaker security but is more convenient and economical for situations like a **home** 802.11 network
    - Uses a **preconfigured password**
    - Between **wireless device** and the **AP** (access point)
  - **Stronger authentication mode:** is based on the IEEE 802.1X framework for controlling access to a LAN
    - Uses an **authentication server (AS)**

Wireless Security (IEEE 802.11i)

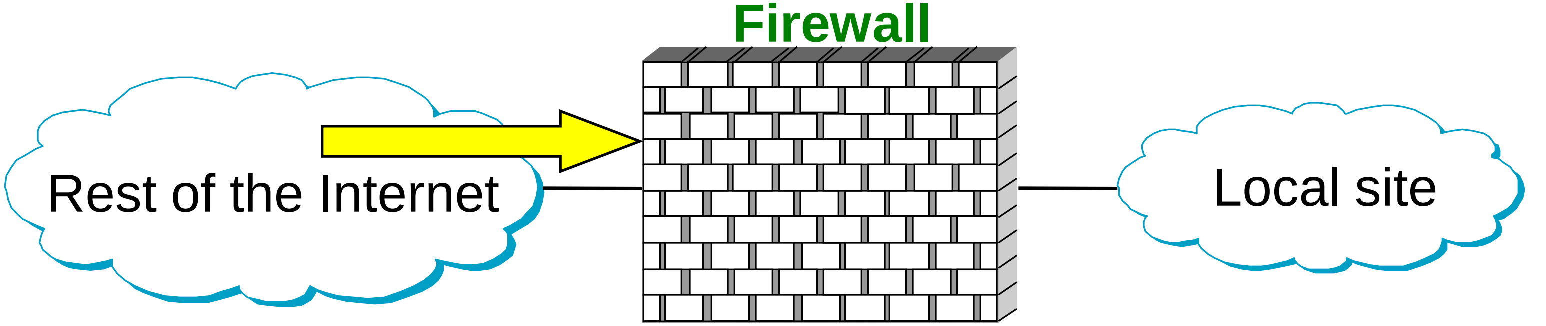
- For stronger authentication mode, the **AS** and **AP** must be connected by a **secure** channel
  - The AP forwards authentication messages between the wireless device and the AS
- The **Extensible Authentication Protocol (EAP)** is used
  - Is designed to support **multiple** authentication methods
  - smart cart, Kerberos, one-time passwords, public-key authentication



Firewalls

Firewalls

- A **firewall** is a specially programmed **router** that sits between a site and the rest of the network
  - A router connects to two or more networks and it **forwards or filters** the packets that flow through it
- The firewall might filter packets **based on the destination IP or source IP**
  - Prevent external users to **access** a particular host
  - Prevent an unwanted **flood** of packets from an external host
- Such a flood of packets is called a **denial-of-service attack**

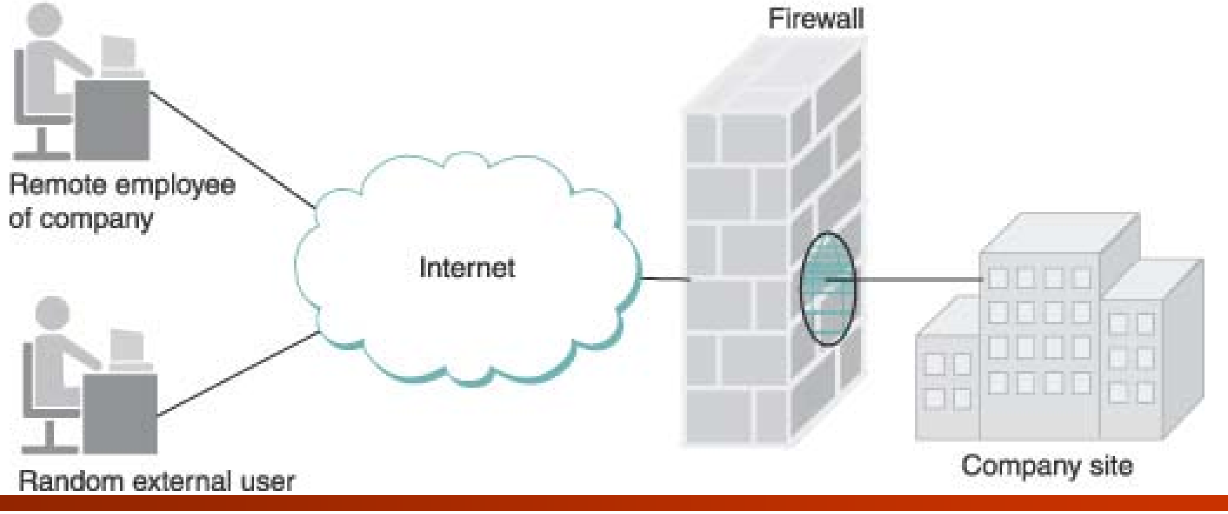


Filter-Based Firewalls

- **Filter-based firewalls** are the simplest and most widely deployed type of firewalls
  - Configured with **a table of addresses** that characterize the packets they **will**, and **will not**, be forwarded
- Generally, each entry in the table is a 4-tuple:
  - It gives the **IP address and TCP port number for both the source and destination**
- For example: to filter **<192.12.13.14, 1234, 128.7.6.5, 80>**
  - Filter all packets from port 1234 on host 192.12.13.14 addressed to port 80 on host 128.7.6.5
- For example: to filter **<*, *, 128.7.6.5, 80>**
  - Filter **all packets** addressed to port 80 on host 128.7.6.5

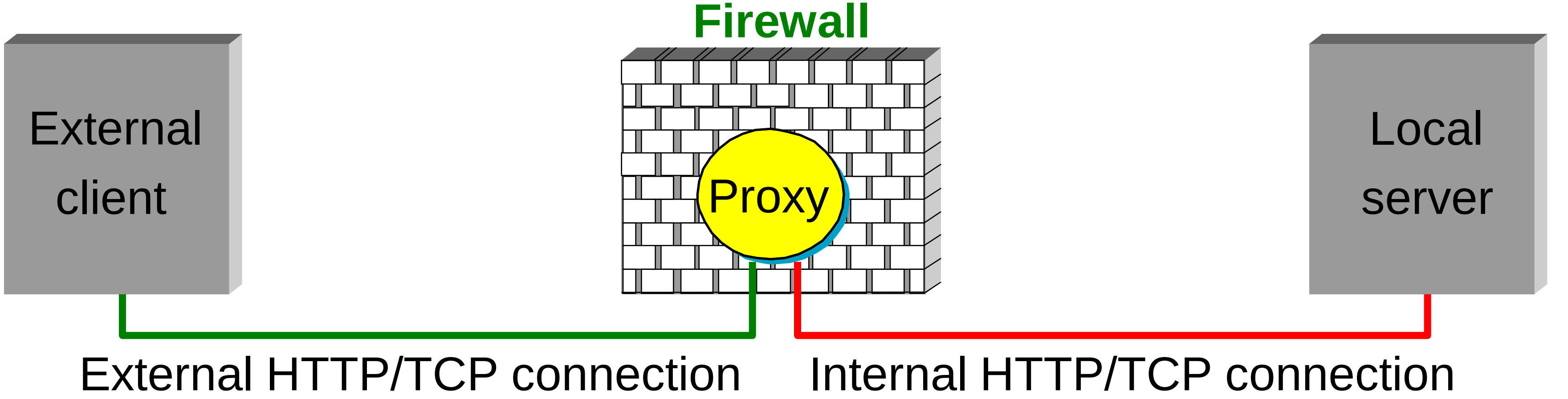
Proxy-Based Firewalls

- A **proxy** is a process that sits between a **client process** and a **server process**
  - To the client, the proxy appears to be the **server**
  - To the server, the proxy appears to be the **client**
- Considering a corporate Web server, some of the server's pages are accessible to **all external users**, and some pages are restricted to **corporate users** at one or more remote sites



Proxy-Based Firewalls

- The solution is to **put an HTTP proxy on the firewall**
- Remote users establish an **HTTP/TCP** connection to the proxy
- The proxy looks at the **URL** contained in the request message
  - If the requested page is **allowed** for the source host
    - The proxy establishes **a second HTTP/TCP connection** to the server and forwards the request to the server
    - The proxy forwards the response to the remote user



Proxy-Based Firewalls

  - If the requested page is **not allowed**
    - The proxy does not create this second connection
    - **Returns an error to the source**
- The proxy has to **understand** the HTTP protocol in order to response to the client
- Once an HTTP proxy is in place for security reasons
  - It might be extended to decide which of **many local Web servers** to forward a given request to **(i.e. load balance)**
  - It might also **cache hot Web pages**
    - Access the server only once for multiple requests
- Proxies can be defined for applications other than HTTP
  - For example, FTP and Telnet proxies