Lecture 12 – Part 1

Mobile IP

ELEC 3506/9506
Communication Networks

Dr Wibowo Hardjawana
School of Electrical and Information Engineering

Topics of the Day

- The need for IP mobility
- Introduction to Mobile IP
- Development considerations
- Operational principles
- Mobile IP operation
- Mobile IP inefficiency and solutions

Need for IP Mobility

- Original IP addressing assumes a host is stationary (attached to one specific network)
- IP addresses enable IP routing algorithms to get packets to the correct network
  - An IP address has two parts: network part (prefix) and host part (suffix)
  - This implies that the address is valid only when the host is attached to the network
- What happens if we move a host between networks?
- What if a user wants to roam between networks?
  - Mobile users don't want to know that they are moving between networks
  - Why can't mobile users change IP when running an application?

Changing Address for Mobile Host?

- One simple solution is to change the mobile host’s address as it goes to the new network
- However, it has several drawbacks:
  - Need to change configuration files
  - Computer needs to be rebooted every time it moves from one network to another
  - The DNS tables need to be revised
  - Data exchange will be interrupted

Introduction to Mobile IP

- Mobile IP (MIP): the extension of IP protocol that
  - Allow mobile users to move from one network to another
  - While maintaining a permanent IP address
- Location-independent routing of datagrams on the Internet
- Mobile nodes is identified by their home address (HoA)
  - Regardless of current location
- While away from home network, mobile node have a care-of address (CoA)
  - Identifies their current location
- Nodes may change their topological point-of-attachment (CoA) to without changing the address they use to communicate (HoA)
  - Allows to maintain transport and higher-layer connections while roaming

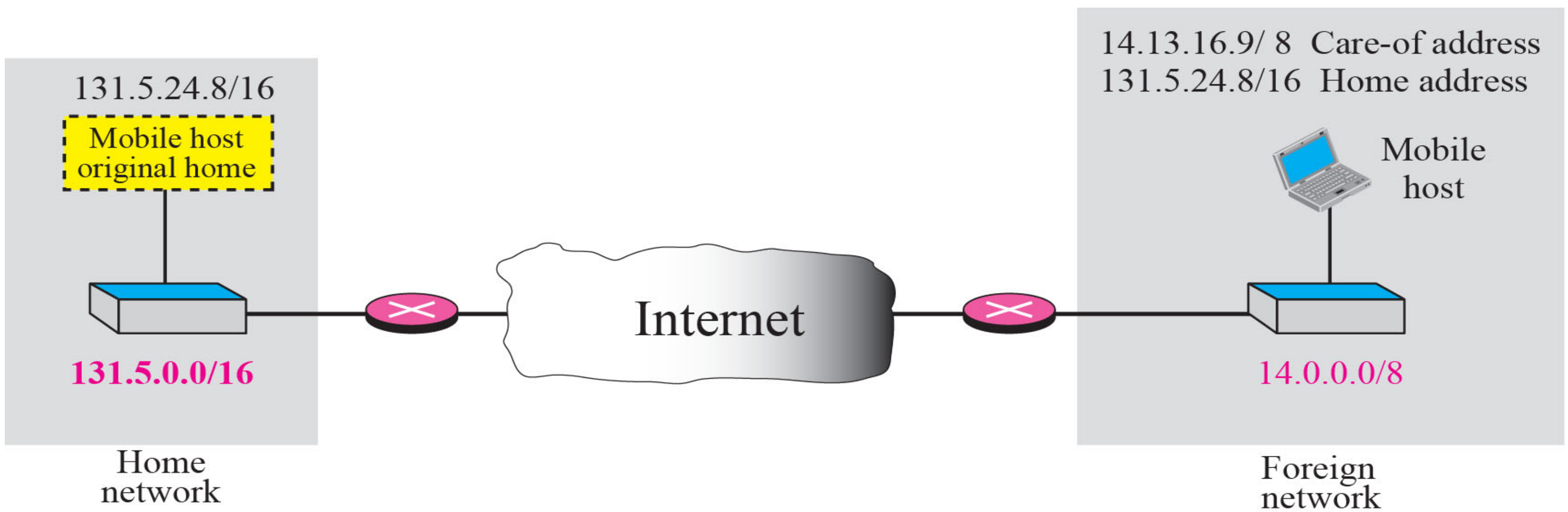
THE UNIVERSITY OF SYDNEY

Development Considerations

- Mobile IP was developed as a means for transparently dealing with problems of mobile users
  - Enables hosts to stay connected to the Internet regardless of their location
  - Enables hosts to be tracked without needing to change their IP address
  - Requires no changes to software of non-mobile hosts/routers
  - Requires addition of some infrastructure
  - Has no geographical limitations
  - Requires no modifications to IP addresses or IP address format
  - Supports security

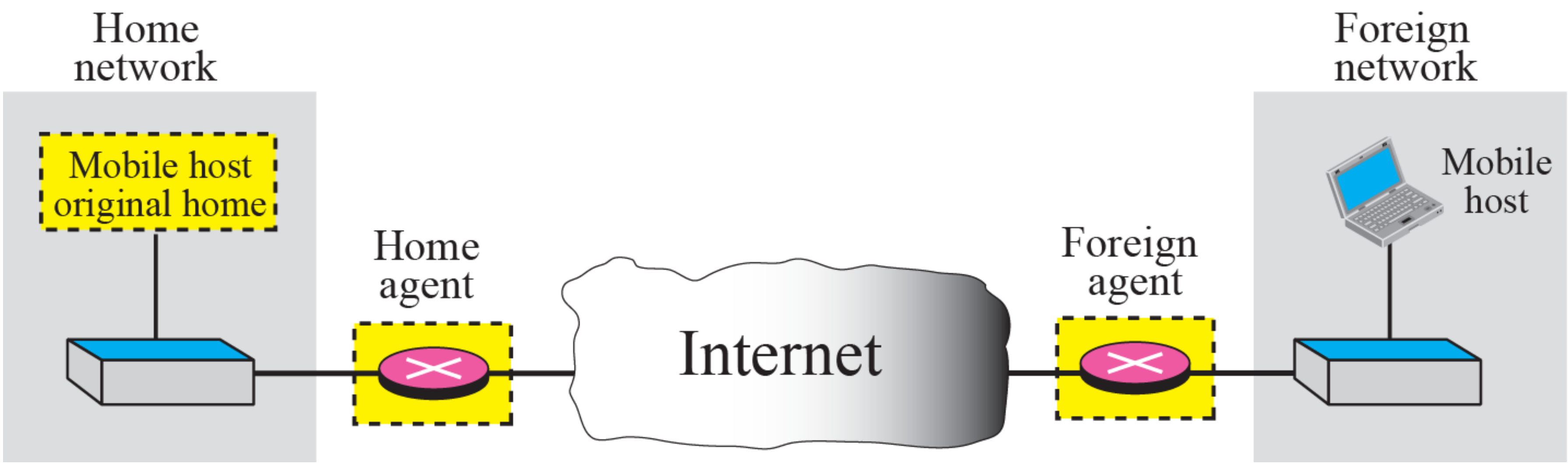
Operational Principles

- A mobile IP node has two addresses
- Home address: permanent, associates the host with its **home network**, which is the network that is the permanent home of the host
- Care-of address (CoA): temporary, associates with the **foreign network**, which is the network to the host visits. A mobile host receives its CoA during the **agent discovery** and **registration phase**.



Operational Principles

- A mobile IP implementation has two main entities:
  - Home agent: stores information about mobile nodes whose permanent home address is in the home agent's network.
  - Foreign agent: stores information about mobile nodes visiting its network. Foreign agents also advertise care-of addresses, which are used by mobile nodes.



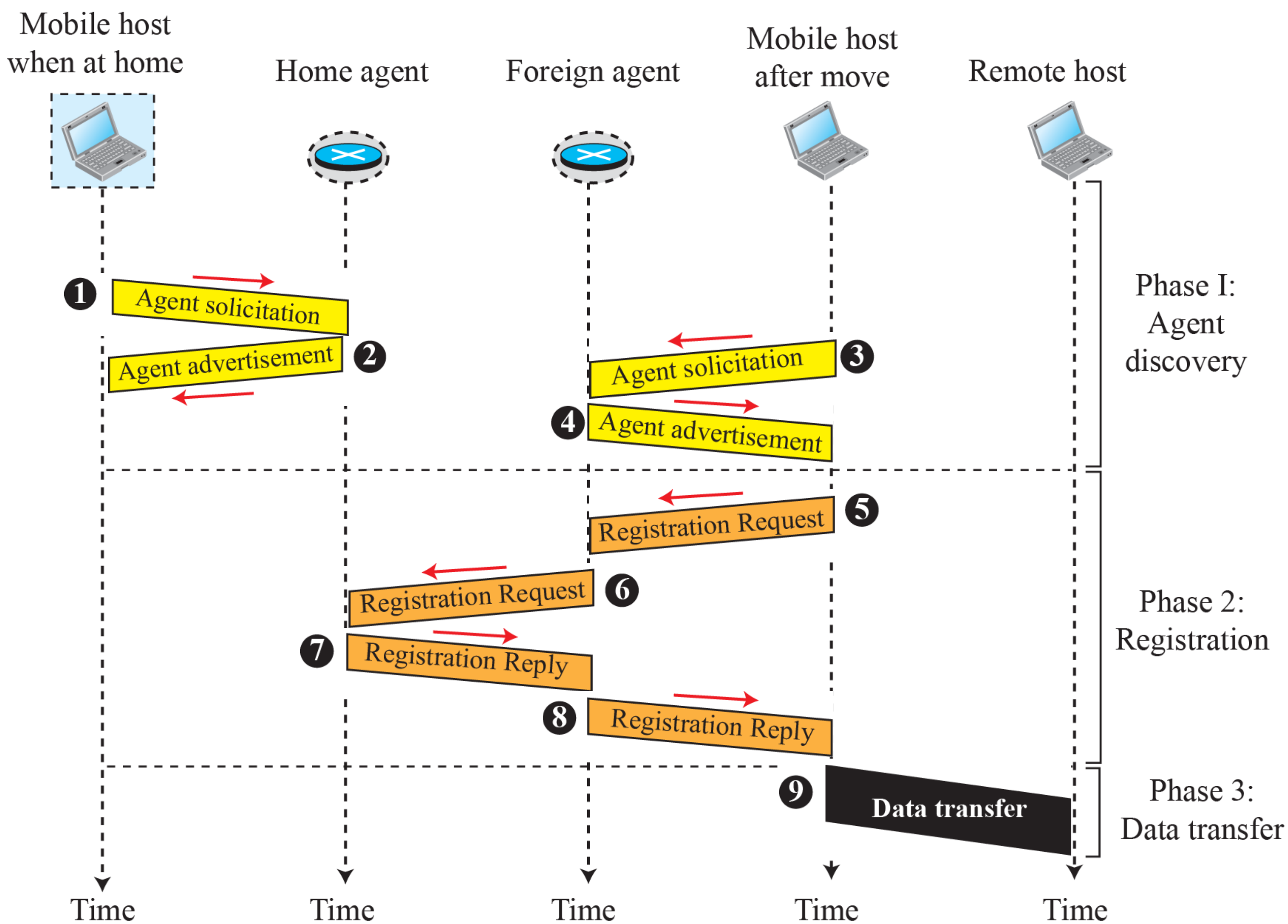
MIP Entities

- Home Agent (HA)
  - Usually a router attached to the home network of the mobile host
  - Acts on behalf of the mobile host when a remote host sends packet to the mobile host
  - Forwards packets to appropriate network when the MIP host is away
- Foreign Agent (FA)
  - Usually a router attached to the foreign network
  - If mobile node is away from home agent, it uses an FA to send/receive data to/from HA
  - Advertises itself periodically
  - Forward's MIP host's registration request
  - De-capsulates messages for delivery to MIP host

MIP Operation

- A MIP host undergoes three phases:
  - Agent discovery
  - Registration
  - Data transfer

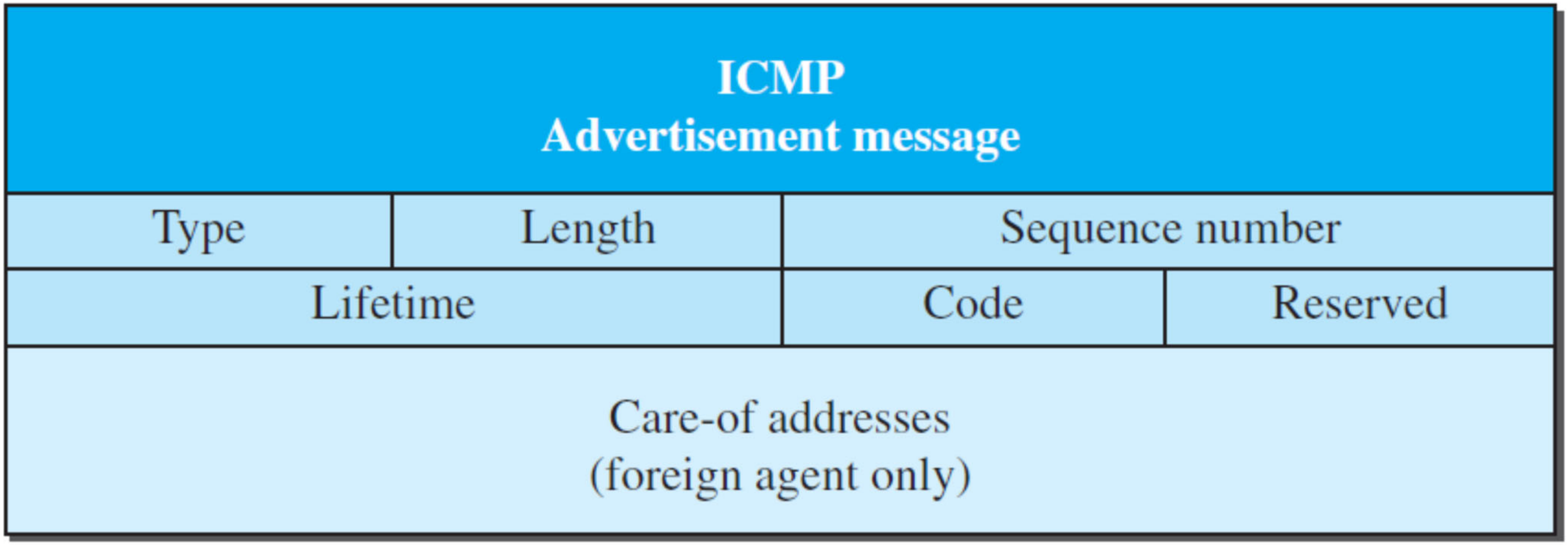
Message Flow Diagram



Agent Discovery

- First step, Agent discovery involves the mobile host, the foreign agent, and the home agent
- A mobile host must learn the address of the home agent before it leaves its home network
- Once it moves to the foreign network, it must
  - Learn the address of the foreign agent
  - Learn its new care-of address
- Two types of messages are used:
  - Agent Advertisement: If a router acts as an agent, it appends an agent advertisement message to the router advertisement packet of ICMP
  - Agent Solicitation: A mobile host uses the router solicitation packet of ICMP for agent solicitation

Agent Advertisement



- Type: 8 bit, set to 16
- Length: 8 bit, defines the total length of the extension message
- Sequence number: 16 bit
- Lifetime: the number of seconds that the agent will accept requests
- Code: 8 bit flag with various purposes, e.g., registration required, agent is busy…
- Care-of addresses: list of addresses available for use as care-of addresses

Registration

- The second phase is registration.
- After a mobile host has moved to a foreign network and discovered the foreign agent, it must register.
- There are four aspects of registration:
  - The mobile host must register with the foreign agent
  - The mobile host must register with its home agent (normally done by the foreign agent on behalf of the mobile host)
  - The mobile host must renew registration if it has expired
  - The mobile host must cancel its registration when it returns home
- Registration request or reply is encapsulated in a UDP datagram. An agent uses the well known port 434.

Registration Request Format

Type	Flag	Lifetime
Home address		
Home agent address		
Care-of address		
Identification		
Extensions ...		

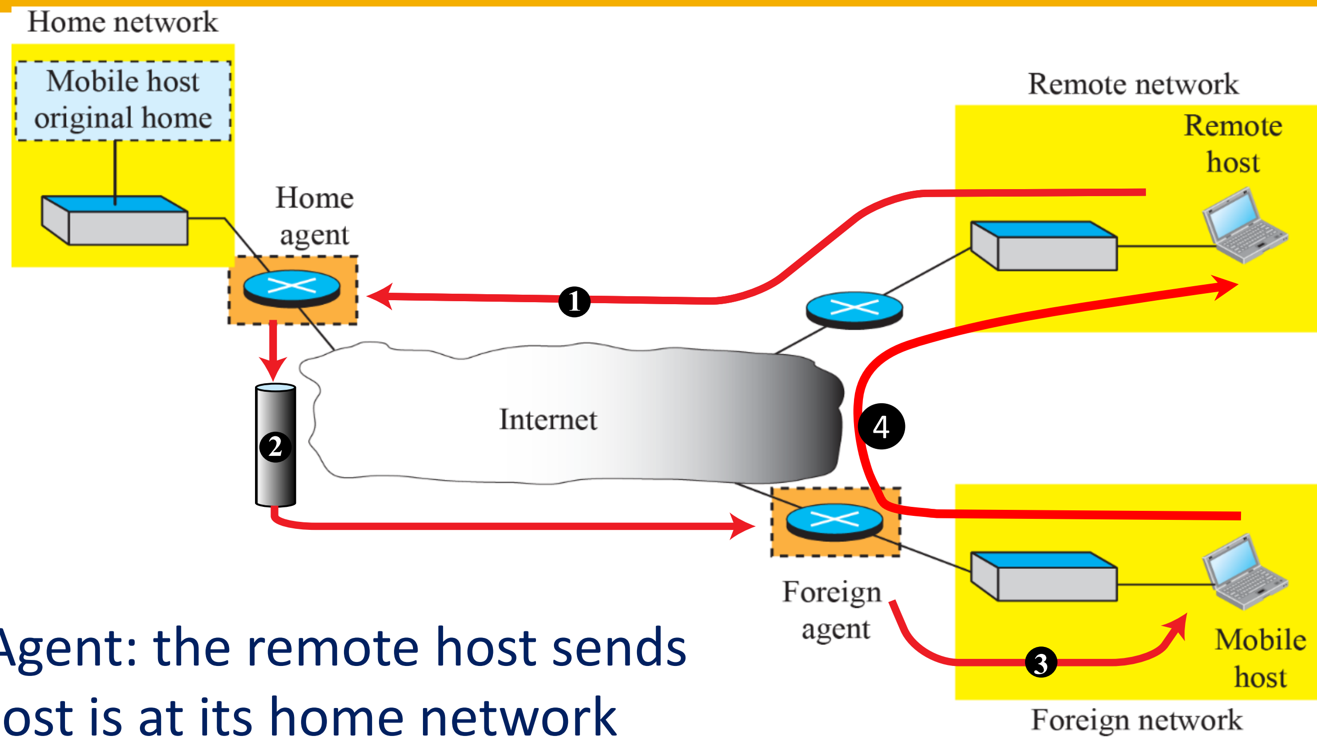
- Registration request is sent from the mobile host to foreign agent
- The foreign agent then relays the message to the home agent

Registration Reply Format

Type	Code	Lifetime
Home address		
Home agent address		
Identification		
Extensions ...		

- Registration reply is sent from home agent to foreign agent and then relayed to the mobile host
- It confirms or denies the registration request

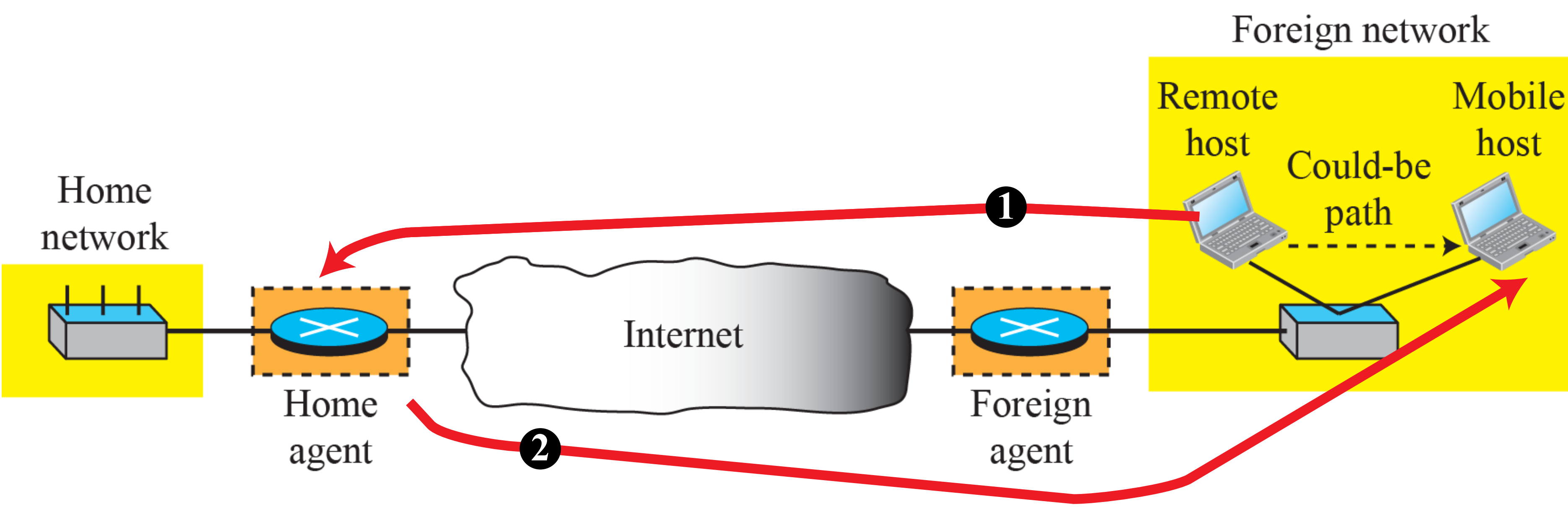
Data Transfer



- Remote Host → Home Agent: the remote host sends packet as if the mobile host is at its home network
- Home Agent → Foreign Agent: the home agent forwards packet to foreign agent
- Foreign Agent → Mobile Host: Use the care-of address
- Mobile Host → Remote Host: with its home address as the source address
- The movement of the mobile host is transparent to the rest of the Internet
- Transmission from Mobile to Remote goes directly via Foreign Agent as Mobile host knows IP address of Remote host

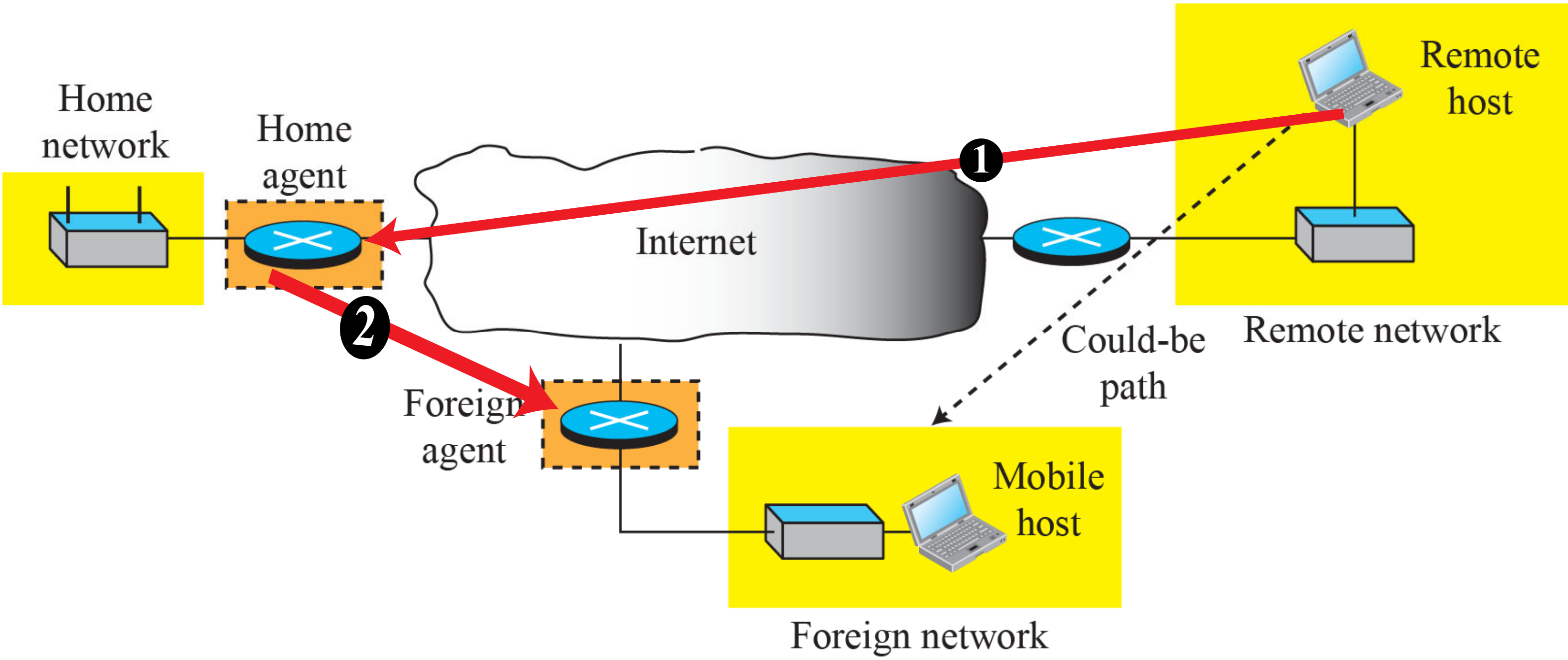
Inefficiency of Mobile IP

- Double Crossing (severe case):
- Occurs when a remote host communicates with a mobile host that has moved to the same network as the remote host
- When the remote host sends a packet to the mobile host, the packet crosses the Internet twice



Inefficiency of Mobile IP

- Triangular Routing (The less severe case)



- Transmission from Remote to Mobile host must go via Home Agent
- Solution: Binding Updates. The home agent sends an update binding packet to the remote host so that future packets to the mobile host could be sent to the care-of address. Here care-of address is kept in a cache by remote host

Recommended Reading

- J. F. Kurose and K. W. Ross, Computer Networking: A Top-Down Approach, 6th ed., 2013, Chapters 6.5 and 6.6

Lecture 12 – Part 2

Network Security

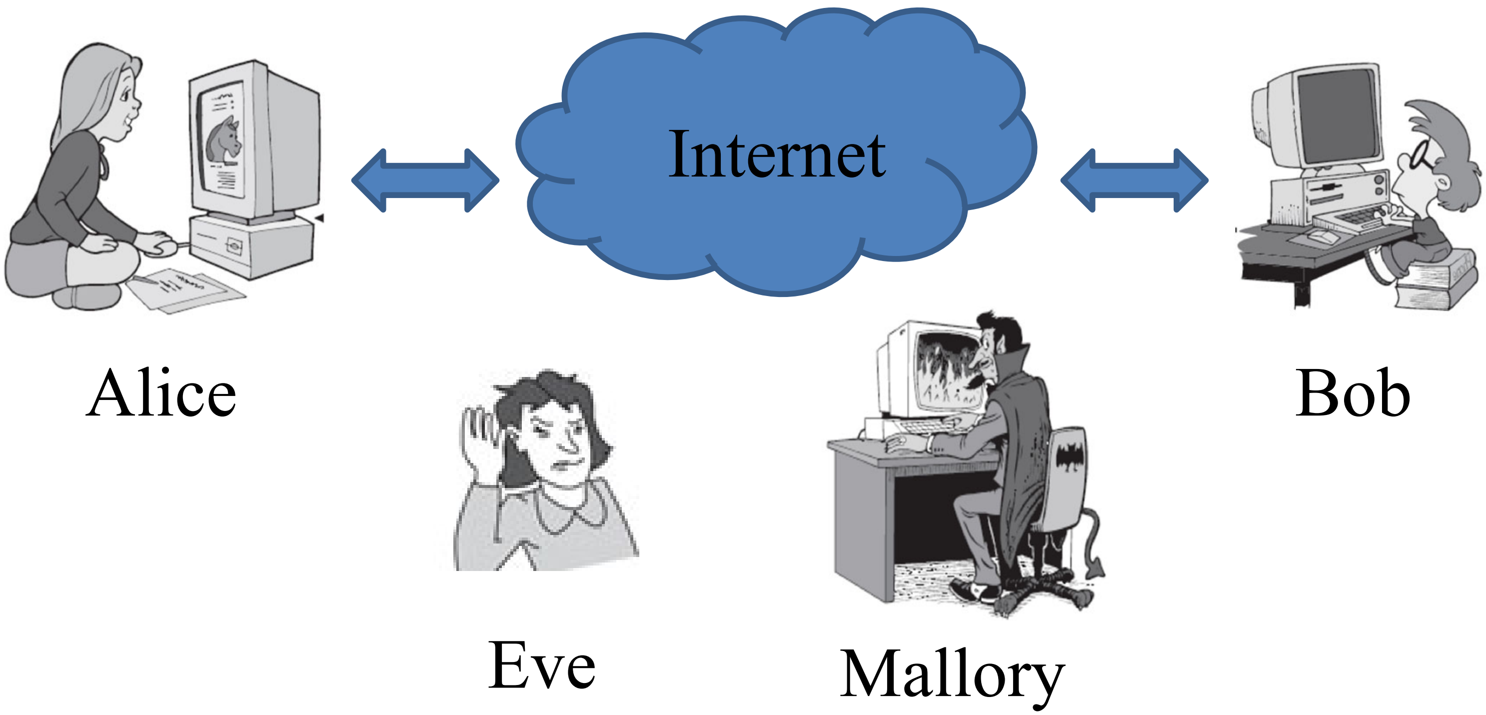
ELEC 3506/9506
Communication Networks

Dr Wibowo Hardjawana
School of Electrical and Information Engineering

Topics of the Day

- Network Security Goals
- Security Threats and Attacks
- Security Services
- Security Mechanisms
  - Confidentiality with
    - Symmetric Key
    - Asymmetric Key
  - Message Integrity
  - Message Authentication
  - Digital Signatures
  - Entity Authentication

Communication over Networks



- Alice: legitimate sender
- Bob: legitimate receiver
- Eve: eavesdropper, passive attacker.
- Mallory: malicious active attacker

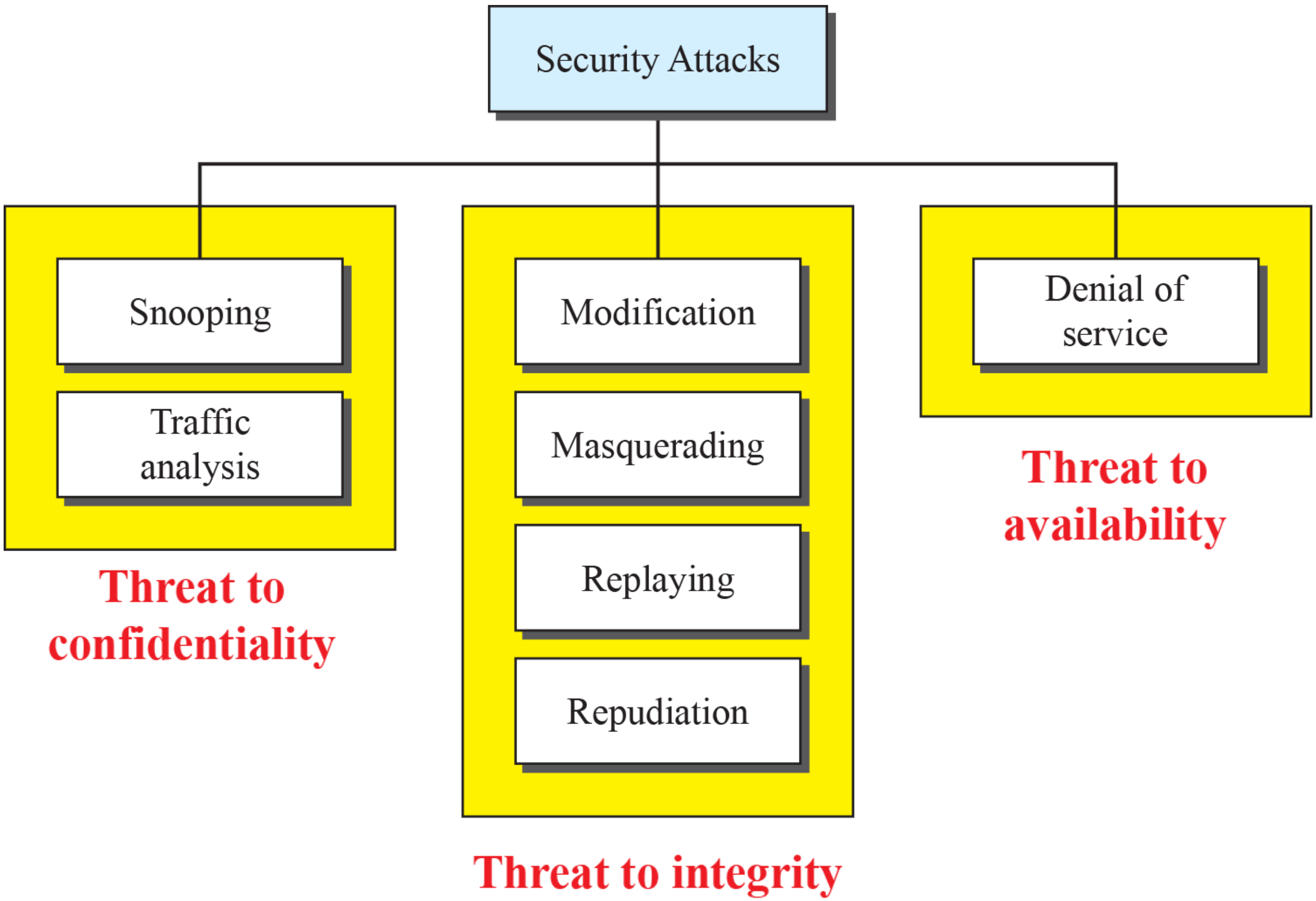
Security Goals

- Confidentiality
  - Information is hidden from unauthorized access
  - Applies to both storage and transmission of information
- Integrity
  - Information is protected from unauthorized change
  - Changes are only made by authorized entities and through authorized mechanisms
- Availability
  - Information is made available to authorized entity when it is needed
  - Information is useless if it is not available

Security Threats/Attacks

- Security attacks are of two types:
  - Passive Attack: Unauthorized party eavesdrops communication between two parties but does not tamper with the messages being communicated.
  - Active Attack: Attacker transmits tampered data to one or both of the parties or block the data stream in one or both directions.

Attacks to Security Goals



Attacks Threatening Confidentiality

- Snooping
  - Unauthorized access to or interception of data
  - To prevent snooping, the data can be made non-intelligible to the interceptor by using encipherment techniques
- Traffic analysis
  - Intercepting and examining messages in order to deduce information from patterns in communication, e.g., pattern-of-life analysis
  - Can be performed even when the messages are encrypted

Attacks Threatening Integrity

- Modification
  - The attacker modifies the information to make it beneficial to herself
- Masquerading/spoofing
  - The attacker impersonates somebody else
- Replaying
  - The attacker obtains a copy of a message sent by a user and later tries to replay it
- Repudiation of Action
  - The sender (receiver) of the message later denies that he has sent (received) the message
  - Threats against accountability

Attacks Threatening Availability

Denial of Service (DoS)

- Attacker acts to deny resources/services to entities which are authorized to use them.
- Attacker might send many bogus request to overload a server.
- Attacker might intercept and delete a server's response to a client, making the client believe that the server is not responding

Security Services

- Confidentiality Service
- Integrity Service
- Authentication Service
- Nonrepudiation Service

Security Services (cont'd)

Confidentiality Service:

- Data Confidentiality: Confidentiality of data maintained between the sender and receiver.
- Traffic Flow Confidentiality: Confidentiality of the identities of the source and destination of the data traffic.
- Mechanism implemented: Encryption

Integrity Service:

- Ensures that data modification be capable to authorized parties only.
- Data Integrity: Ensures the data received is NOT modified
- Data Sequence Integrity: Sequence of data blocks is not altered, repeated or missing.
- Mechanism implemented: Hash Functions, Cryptographic Checksums

Security Services (cont'd)

Authentication Service:

- Ensures the data is genuine, unaltered, complete and not an unlawful replay.
- Data origin Authentication: used to check the message origination from the claimed source.
- Peer-entity-authentication: Provides an entity the confidence of the authenticity of a peer entity.
- Mechanism Implemented: Private Key and Public Key based techniques, challenge response mechanisms, timestamps.

Security Services (cont'd)

Nonrepudiation service:

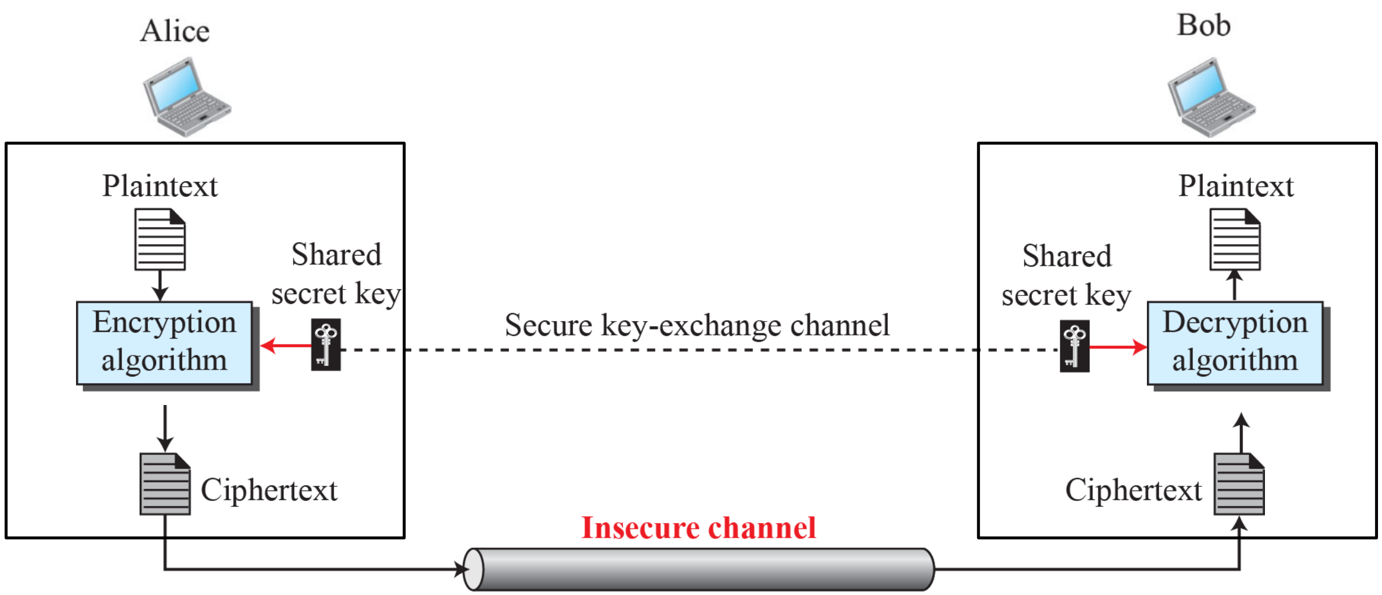
- A sender must not be able to deny sending a message that he or she, in fact, did send.
- Mechanism Implemented: Digital Signatures

Security Mechanisms

- Different mechanisms cater to different services.
- We shall only focus on the following:
  - Confidentiality
    - Symmetric/Secret Key Encryption
    - Asymmetric/Public Key Encryption
  - Integrity
    - Hash Functions and Message Digests
  - Authentication
    - Keyed Hash Functions
    - Digital Signatures

Confidentiality with Symmetric-Key Cryptography

- Both encryption and decryption is done using the same key
  - Sender and receiver share the same secret key.
  - Encryption process consists of the algorithm and the key.
  - The key is a value that is independent of the algorithm.
  - The algorithm produces a different output depending on the key being used at that time.



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

Example: Shift Ciphers

- Plaintext consists of lowercase letters and ciphertext consists of uppercase letters. Assign numerical value to each letter
- The secret key is an integer in modulo 26
- Encryption: add the key to the plain text character
- Decryption: substract the key from the ciphertext

Plaintext →	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
Ciphertext →	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Value →	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Question: Use the shift cipher with key =15 to encrypt the message “hello”

Recovery of $x \to (x+15) \bmod 26$=Ciphertext

Plaintext: h → 07	Encryption: (07 + 15) mod 26	Ciphertext: 22 → W	$x=7$
Plaintext: e → 04	Encryption: (04 + 15) mod 26	Ciphertext: 19 → T	$x=4$
Plaintext: l → 11	Encryption: (11 + 15) mod 26	Ciphertext: 00 → A	$x=11$
Plaintext: l → 11	Encryption: (11 + 15) mod 26	Ciphertext: 00 → A	$x=11$
Plaintext: o → 14	Encryption: (14 + 15) mod 26	Ciphertext: 03 → D	$x=14$

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

Examples of Symmetric Key Algorithms

- DES (Data Encryption Standard): Adopted in 1977 by National Institute of Standards Technology (NIST) as a federal information processing standard
- IDEA (International Data Encryption Algorithm: Developed in 1990 by the Swiss Federal Institute of Technology
- SKIPJACK: Designed and evaluated by the National Security Agency (NSA) in 1993
- AES: Encryption standard established by the NIST in 2001. Supersedes DES. Based on the Rijndael cipher developed by Joan Daemen and Vincent Rijmen.

Symmetric key crypto: DES

DES: Data Encryption Standard

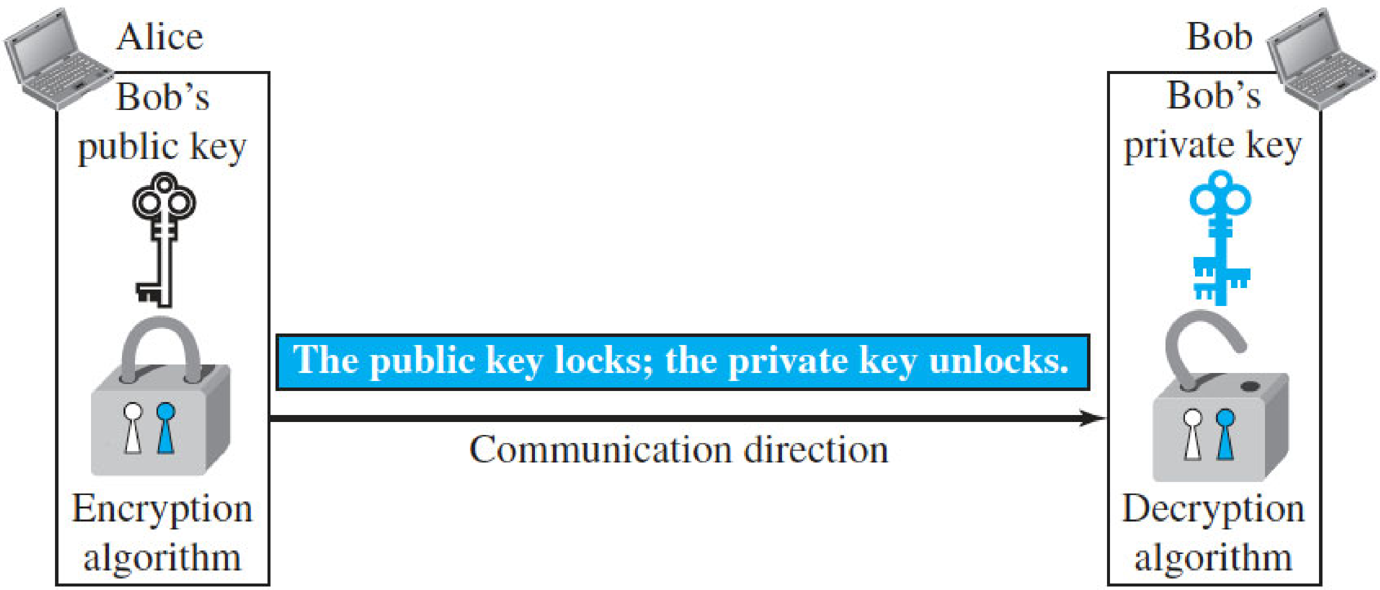
- US encryption standard [NIST 1993]
- 56-bit symmetric key, 64-bit plaintext input
- block cipher with cipher block chaining
- how secure is DES?
  - DES Challenge: 56-bit-key-encrypted phrase decrypted (brute force) in less than a day
  - no known good analytic attack
- making DES more secure:
  - 3DES: encrypt 3 times with 3 different keys

AES: Advanced Encryption Standard

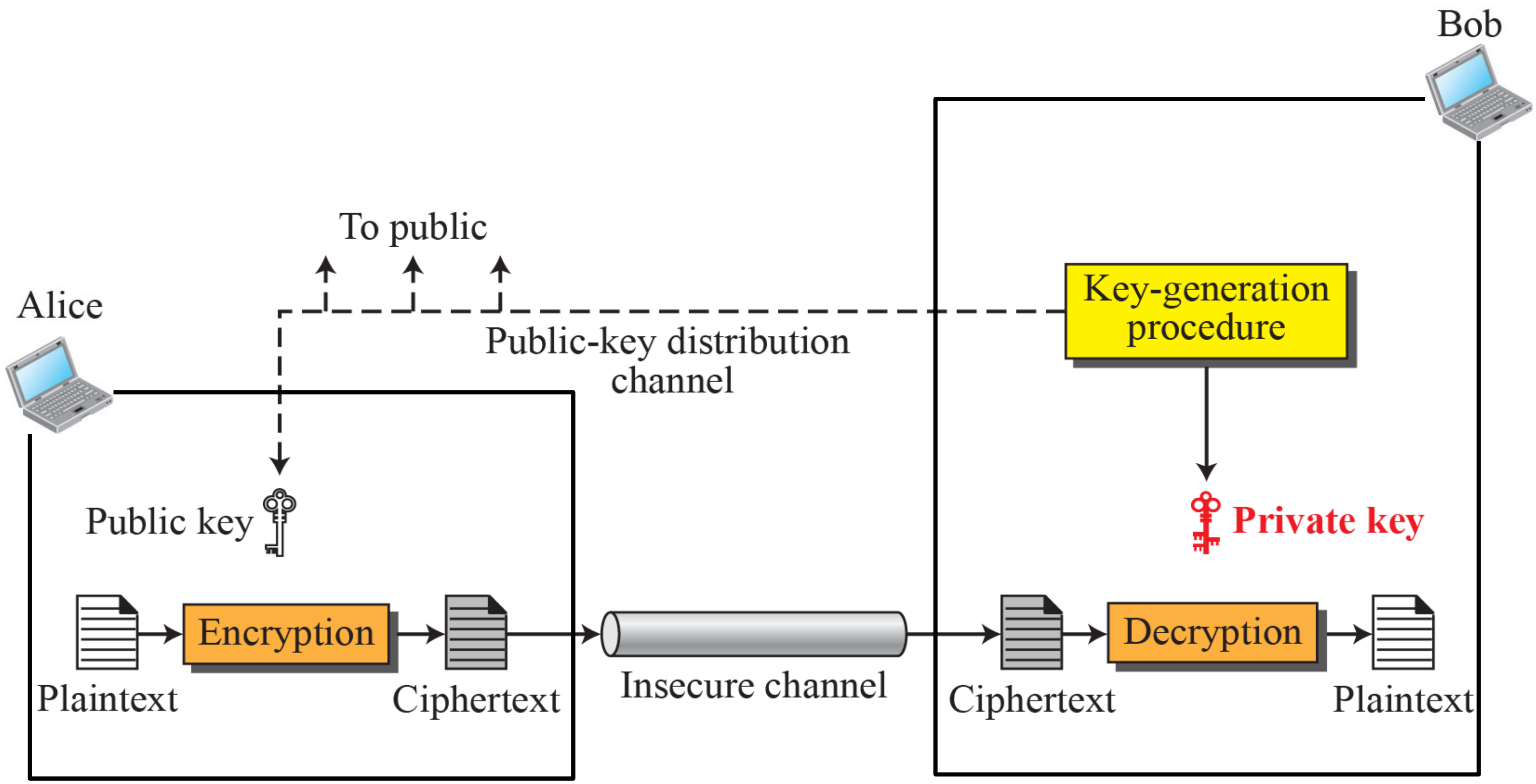
- symmetric-key NIST standard, replaced DES (Nov 2001)
- processes data in 128 bit blocks
- 128, 192, or 256 bit keys
- brute force decryption (try each key) taking 1 sec on DES, takes 149 trillion years for AES

Confidentiality with Asymmetric/Public Key Encryption

- No key sharing is needed
- Use two separate keys: one private and one public
- Public Key (exposed to the public domain) is used for encryption
- Private Key (private to the user) is used for decryption
- Public key locks the message and Private key unlocks it



Confidentiality with Asymmetric/Public Key Encryption



Confidentiality with Asymmetric/Public Key Encryption

Pros:

- No need for secret key sharing
- It is computationally infeasible to compute the Private Key given the knowledge of the cryptographic algorithm and the Public Key.
- Used for authentication, digital signatures, and secrete-key exchanges

Cons:

- Relatively long mathematical calculations using relatively long keys
- Much slower than symmetric-key encryption
- Inefficient for long messages
- Public key must be distributed via a trusted third party

THE UNIVERSITY OF SYDNEY

Public Key Encryption Algorithms

- RSA (Rivest, Shamir, Adleman) Developed in 1978 at MIT.

- De-facto standard for data transmission on the Internet and built into many software including Netscape Navigator and Internet Explorer.
- RSA uses two exponents, *e* and *d*, where *e* is public, and *d* is private.
- Suppose P is the plaintext and C is the ciphertext
  - Alice uses $C = P^e \bmod n$ to create cipher-text C from plaintext P;
  - Bob uses $P = C^d \bmod n$ to retrieve the plaintext sent by Alice.

- The modulus *n*, a very large number, is created during the key generation process.

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 $2^7+2^4+2^0= 145$.
  - to encrypt m, we encrypt the corresponding number, which gives a new number (the ciphertext).

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: $ed \bmod z = 1$).

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.

encrypt:

bit pattern	m	m^e	$c = m^e \bmod n$
00001100	12	24832	17

decrypt:

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

RSA: another important property

The following property will be *very* useful later:

$$\underbrace{K_B^-(K_B^+(m))}_{\substack{\text{use public key}\\ \text{first, followed}\\ \text{by private key}}} = m = \underbrace{K_B^+(K_B^-(m))}_{\substack{\text{use private key}\\ \text{first, followed}\\ \text{by public key}}}$$

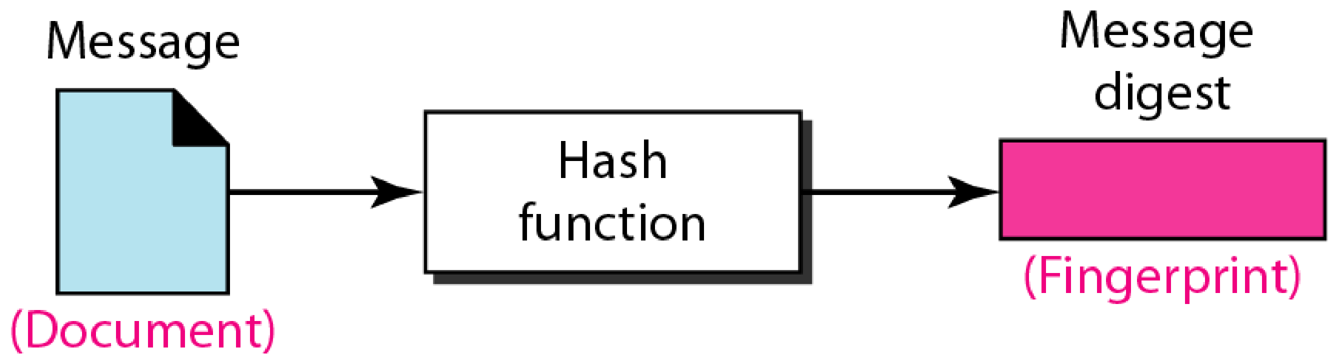
result is the same!

Why is RSA secure?

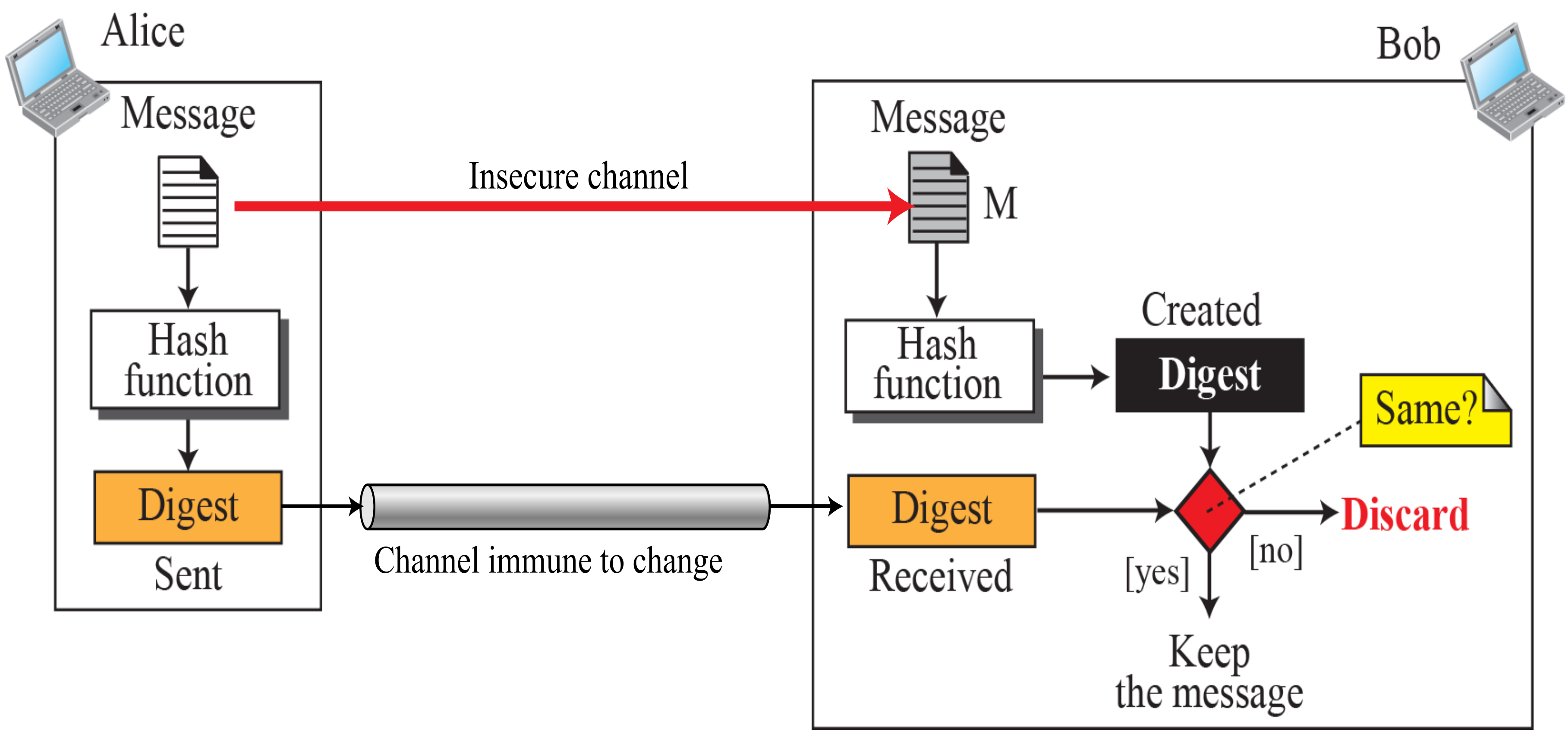
- suppose you know Bob’s public key (n,e). How hard is it to determine d?
- essentially need to find factors of n without knowing the two factors p and q
  - fact: factoring a big number is hard

Message Integrity

- Encryption/decryption provides confidentiality not integrity
- Integrity: No one temper with the message or can forge it
- One way to preserve integrity is to use a Hash function to create a Message digest (fingerprint) of a message
- Message digest: compressed image of the message that can be used like a fingerprint, also known as a Modification Detection Code (MDC)
- Message digest must be kept secret and must be encrypted when sent through a communication channel



Integrity Checking



Message unaltered

Hash Function

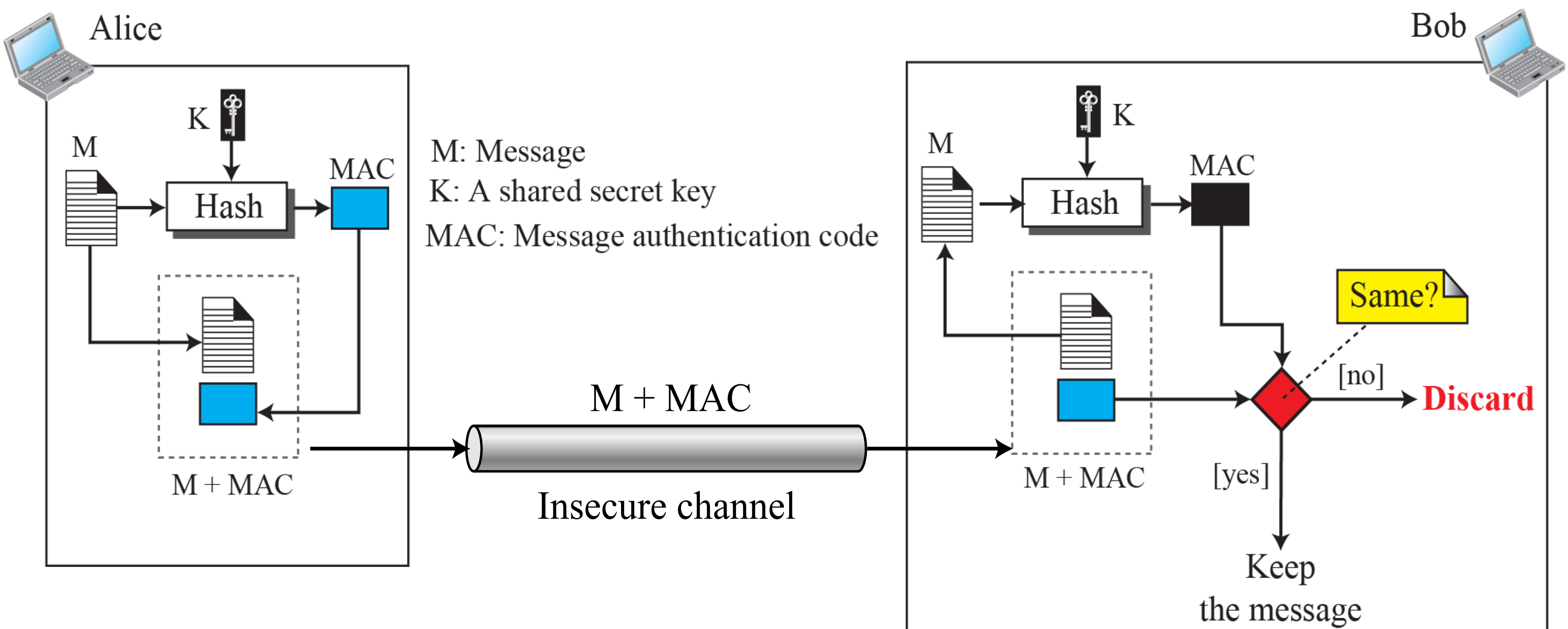
- Criteria
  - One-way: It must not be able to recreate a message using a digest
  - Weak Collision Resistance: Given a specific message and a digest, it is impossible to create another message with the same digest – This prevents from forging
  - Strong Collision Resistance: Two messages that hash to the same digest cannot be found.

- Popular Hash algorithms: MD5, Secure Hash Algorithm 1 (SHA1), SHA2

Message Authentication

- Hash function guarantees that the message has not been changed.
- However, it does not authenticate the sender of the message
- One way is to change the MDC (Message Digest) into a Message Authentication Code (MAC)
- A MAC uses a keyed Hash Function (i.e., A symmetric key is used when creating the digest)
- If the MAC is matched, then the message can be authenticated

MAC Validation

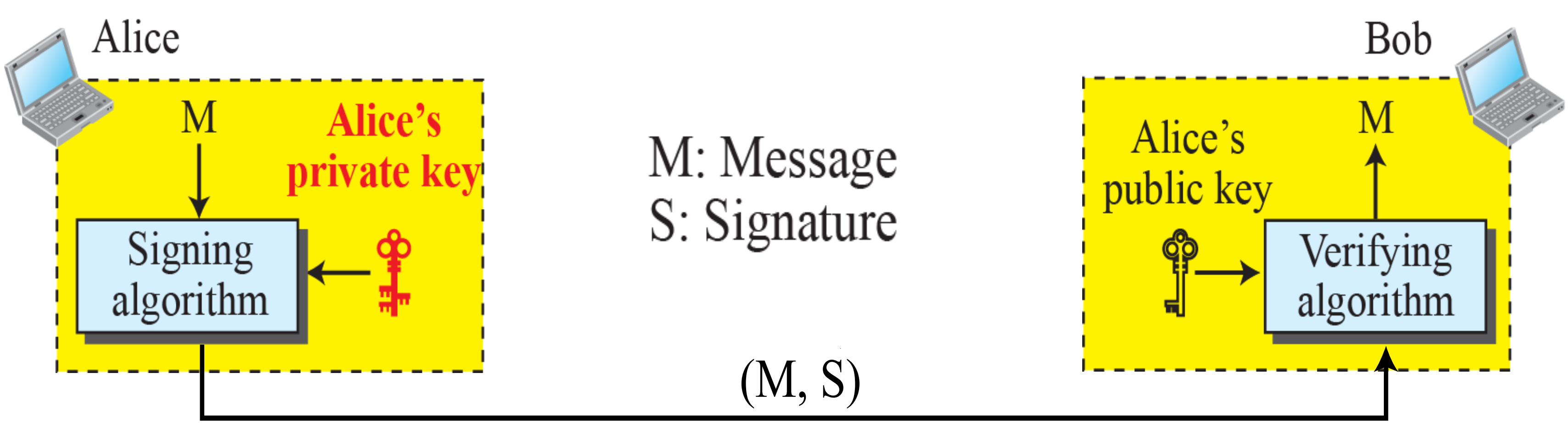


Digital Signature

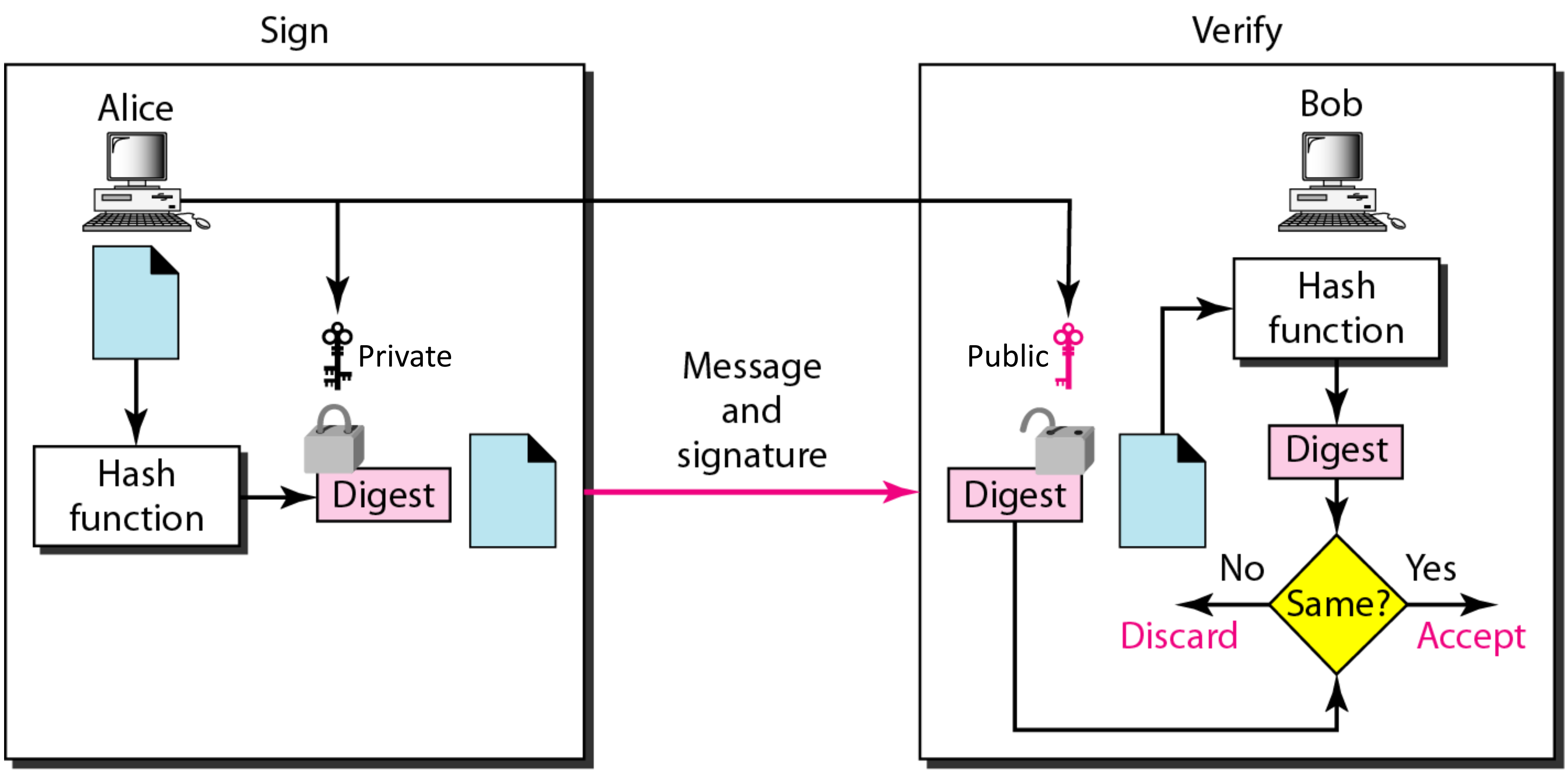
- Although a MAC provides integrity and authentication, this is done via a shared symmetric key.
- A Digital Signature uses a pair of asymmetric keys (a public one and a private one) to prove the authenticity of the message.
- This could be achieved in two ways:
  - Signing a document
  - Signing a digest of a document
- Services offered:
  - Integrity
  - Authentication
  - Message Nonrepudiation (by using a trusted third party)

Signing the Document

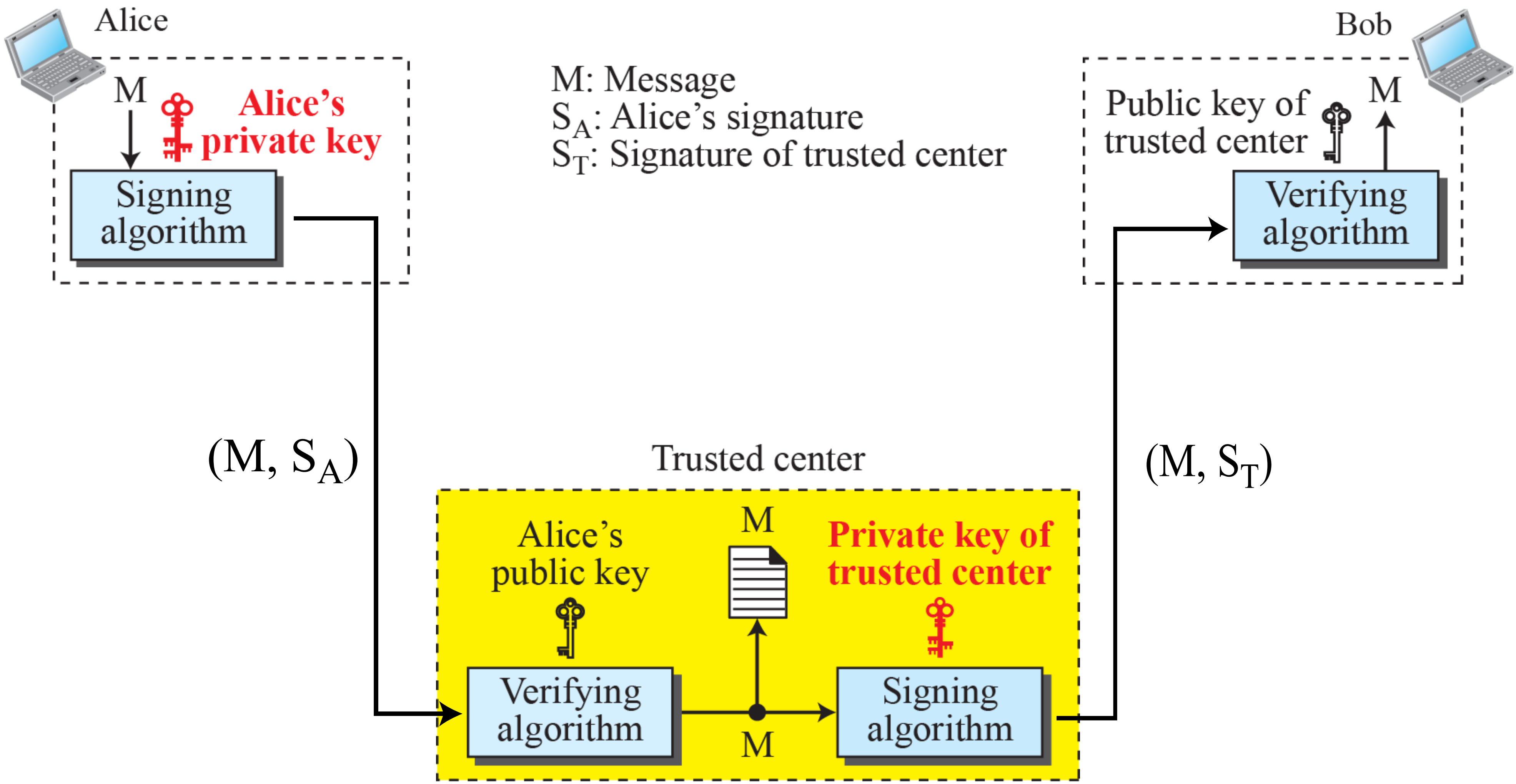
- In a cryptosystem, we use the private and public keys of the receiver
- In digital signature, we use the private and public keys of the sender



Signing the Digest



Using a trusted third party for message nonrepudiation



Trusted Center confirms Alice's identity

Entity Authentication

- Used when one party (claimant) prove the identity to another party (verifier)
- Entity can be a person, a process, a client or a server
- Differences between message and entity authentication:
  - Entity authentication is real-time
  - Entity authentication authenticates the claimant for the entire duration of the session (not message by message)
- Identification of claimant done with three kinds of witnesses:
  - Something Known: password, PIN number, secret key or private key
  - Something Possessed: passport, driver's license, ID card, credit card, smart card
  - Something Inherent: handwriting, conventional signature, biometrics

Transport-layer security (TLS)

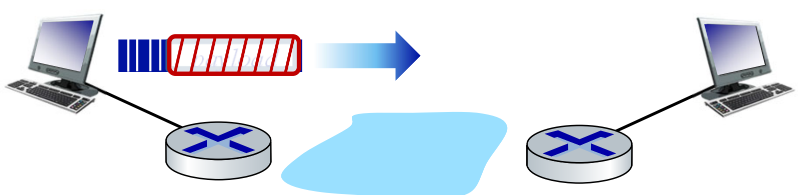
- widely deployed security protocol above the transport layer
  - supported by almost all browsers, web servers: https (port 443)
- provides:
  - confidentiality: via *symmetric encryption*
  - integrity: via *cryptographic hashing*
  - authentication: via *public key cryptography*

all techniques we have studied!

- history:
  - early research, implementation: secure network programming, secure sockets
  - secure socket layer (SSL) deprecated [2015]
  - TLS 1.3: RFC 8846 [2018]

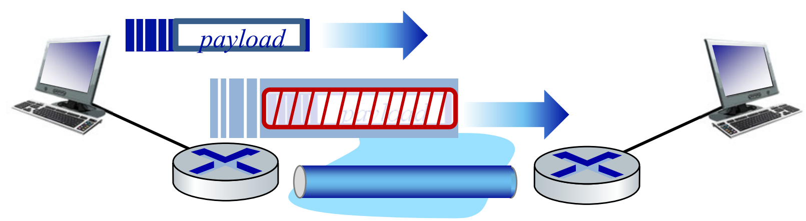
Network Layer Security

- provides datagram-level encryption, authentication, integrity
  - for both user traffic and control traffic (e.g., BGP, DNS messages)
- two “modes”:



transport mode:

- *only* datagram *payload* is encrypted, authenticated



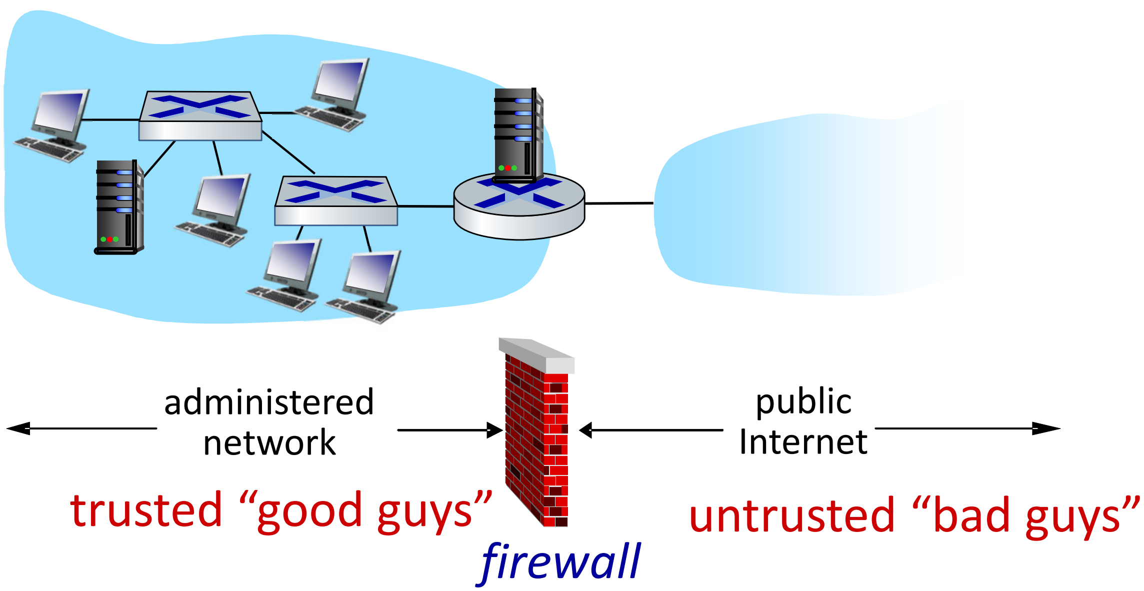
tunnel mode:

- entire datagram is encrypted, authenticated
- encrypted datagram encapsulated in new datagram with new IP header, tunneled to destination

Firewalls

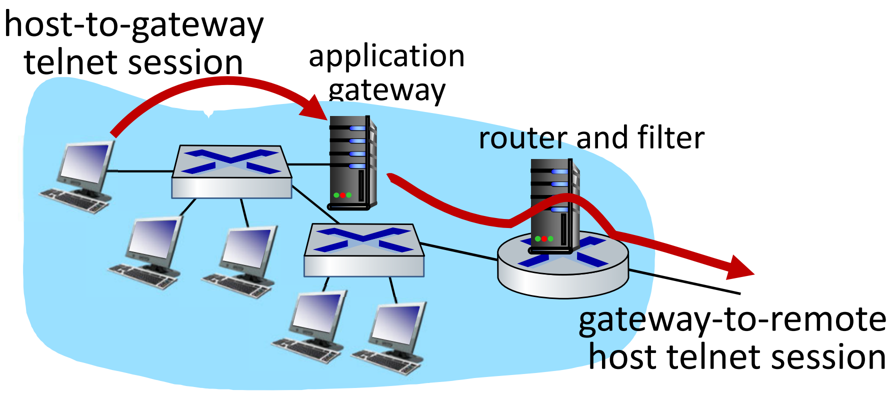
firewall

isolates organization's internal network from larger Internet, allowing some packets to pass, blocking others



Application gateways

- filter packets on application data as well as on IP/TCP/UDP fields.
- *example:* allow select internal users to telnet outside



1. require all telnet users to telnet through gateway.
2. for authorized users, gateway sets up telnet connection to dest host
   - gateway relays data between 2 connections
3. router filter blocks all telnet connections not originating from gateway

Limitations of firewalls, gateways

- IP spoofing: router can't know if data "really" comes from claimed source
- if multiple apps need special treatment, each has own app. gateway
- client software must know how to contact gateway
  - e.g., must set IP address of proxy in Web browser
- filters often use all or nothing policy for UDP
- *tradeoff:* degree of communication with outside world, level of security
- many highly protected sites still suffer from attacks

Recommended Reading

- J. F. Kurose and K. W. Ross, Computer Networking: A Top-Down Approach, 8th ed., 2022, Chapter 8