MF20006: Introduction to Computer Science

Lecture 3: Computer Networks

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Outline

1. Internet: IP and Routing

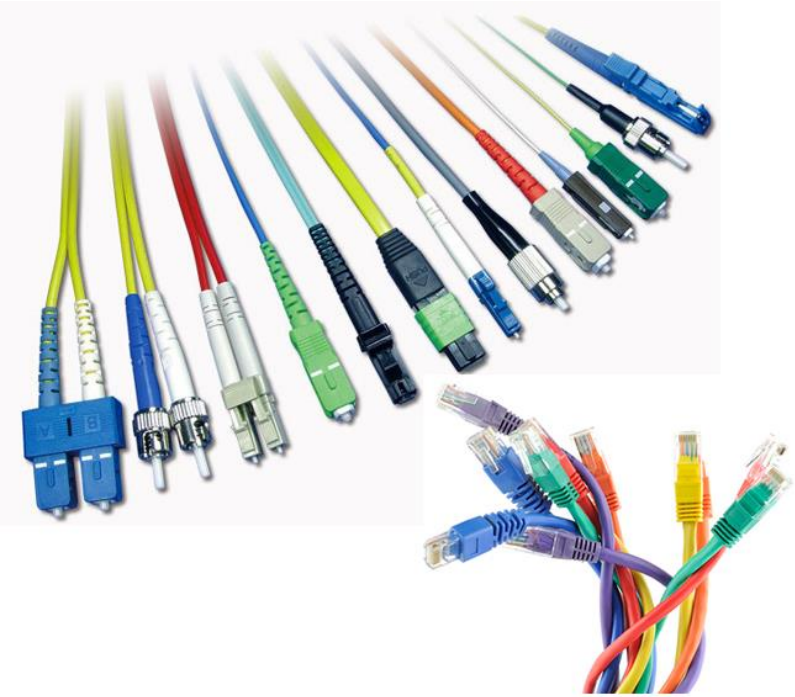
2. Messaging

3. Practice: Packet Analysis

1. Internet: IP and Routing

Pre Knowledge: Wired Communication

- **Use physical media such as copper cables or optical fibers.**
- **Send data (bits) as electrical or light signals over the wire.**
  - Electrical signals: the bits are turned into tiny changes in voltage or current.
  - Light signals: In a fiber-optic cable, the bits are turned into pulses of light.



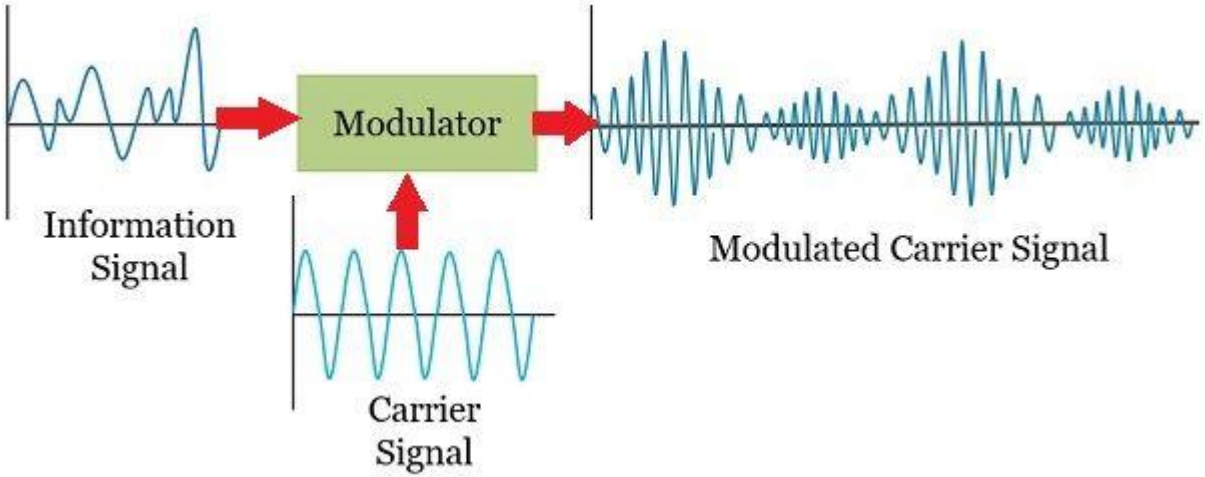
Pre Knowledge: Wireless Communication

❑Send information using electromagnetic waves.

- ➢Examples: Wi-Fi, Bluetooth, Cellular (4G/5G), Satellite.

❑Digital data is modulated onto a carrier wave.

- ➢Transmitted through the air.
- ➢Receiver demodulates the signal to recover the original data.



The Problem We Studied in this Lecture

- **How do two computers exchange information over the Internet?**
  - This may not be hard to understand with 1-on-1 wired/wireless communication.
  - Based on some pre-agreed protocols.
- **Problem: Billions of devices accessing Internet simultaneously.**
  - How can messages be delivered reliably to their destinations?
  - The process is similar to the way a traditional postal system works.

Internet: Network of Networks

❑Originally named ARPANET.

- ➢Built in the late 1960s by the U.S. Department of Defense's ARPA (Advanced Research Projects Agency).

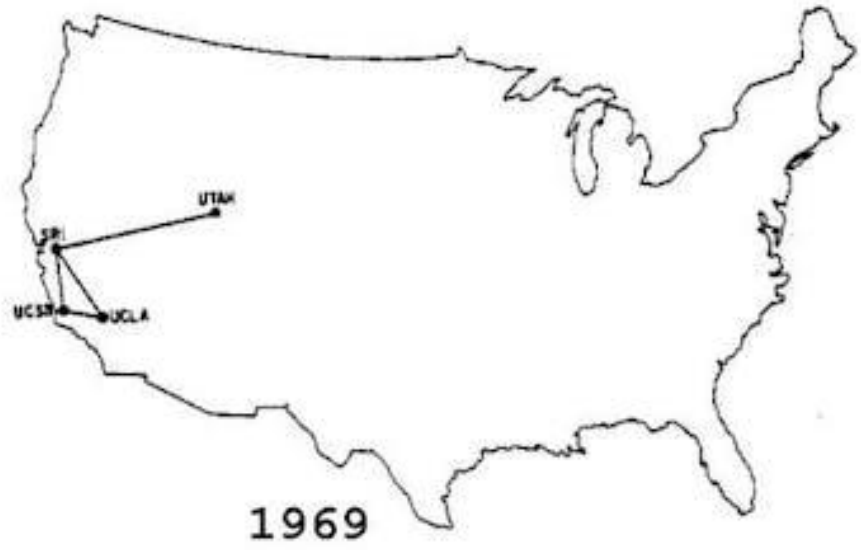
❑Goal: To connect research computers at universities and labs.

- ➢First message sent October 29, 1969 (between UCLA & Stanford).

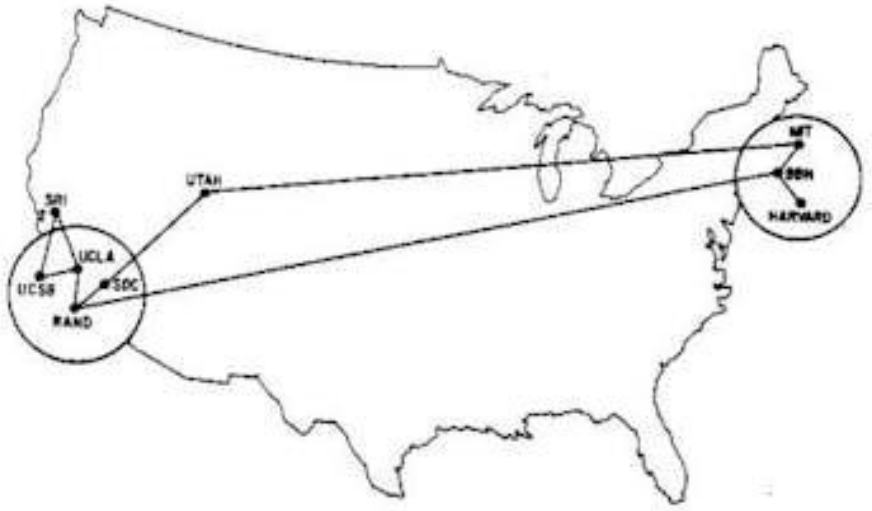
❑ARPANET proved packet-switched networking works.

- ➢Circuit switching: Dedicated path is established between sender and receiver.
- ➢Packet switching: Multiple conversations can share the same path

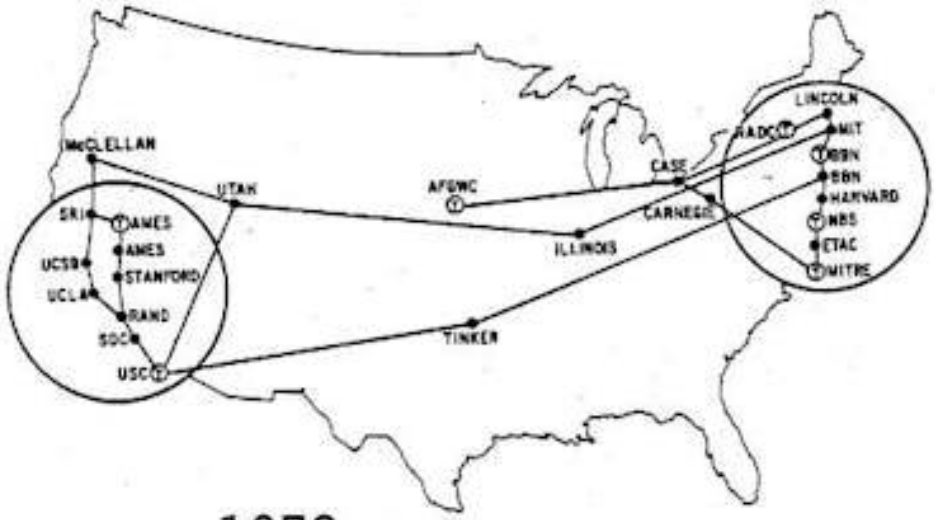
ARPANET



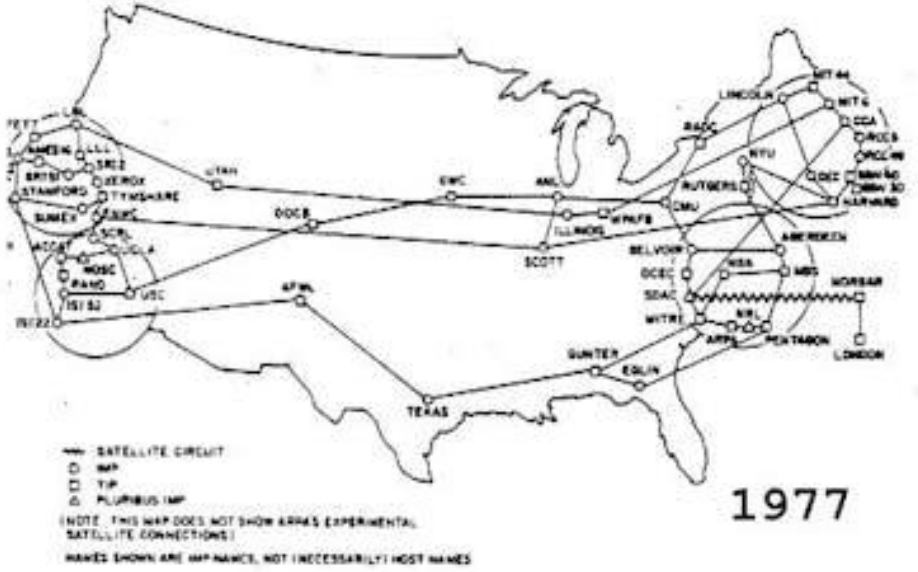
1969



1970

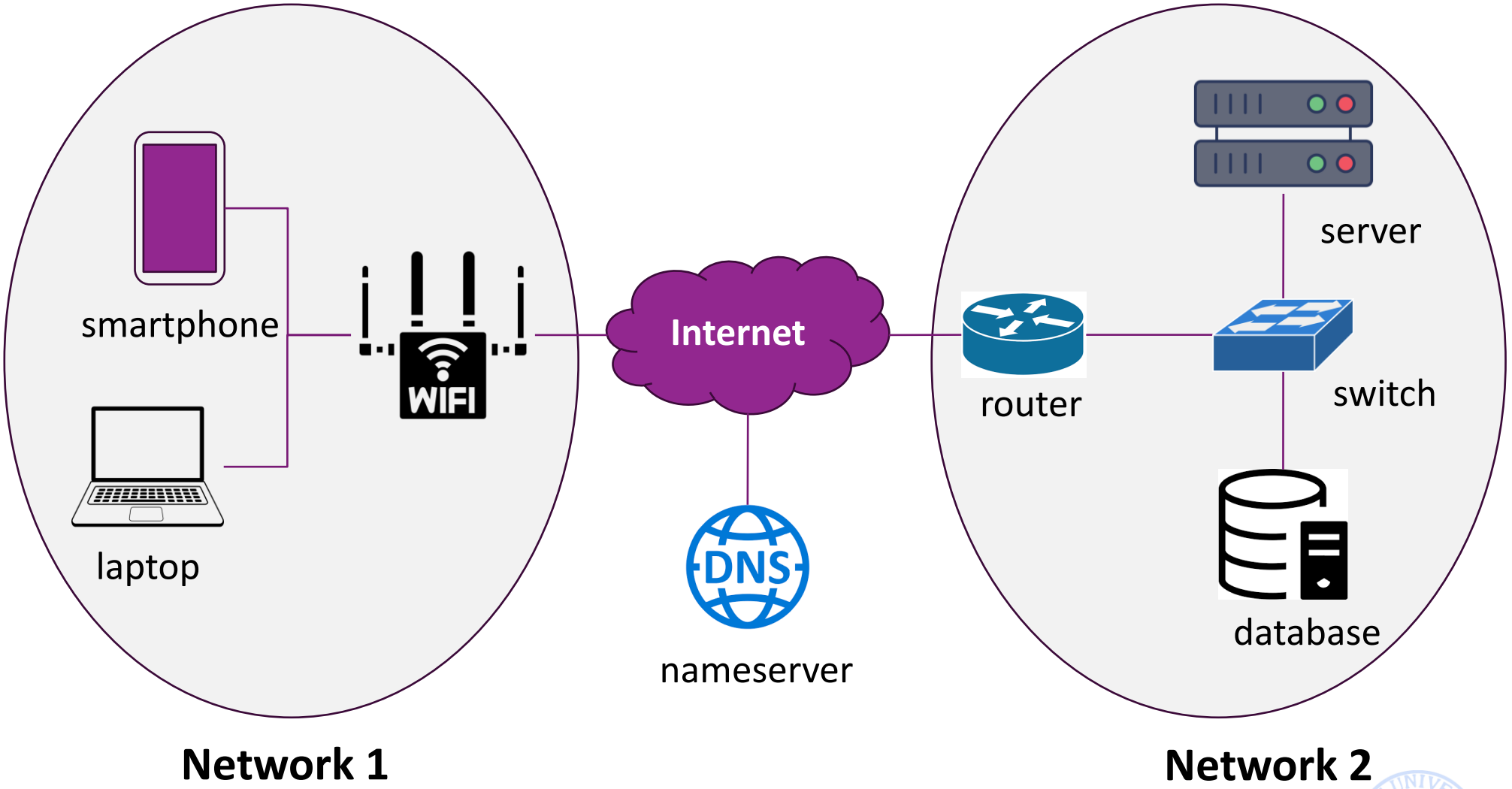


1972



1977

Problem Scenario



Detailed Questions and Techniques

❑How does a client get registered in a network?

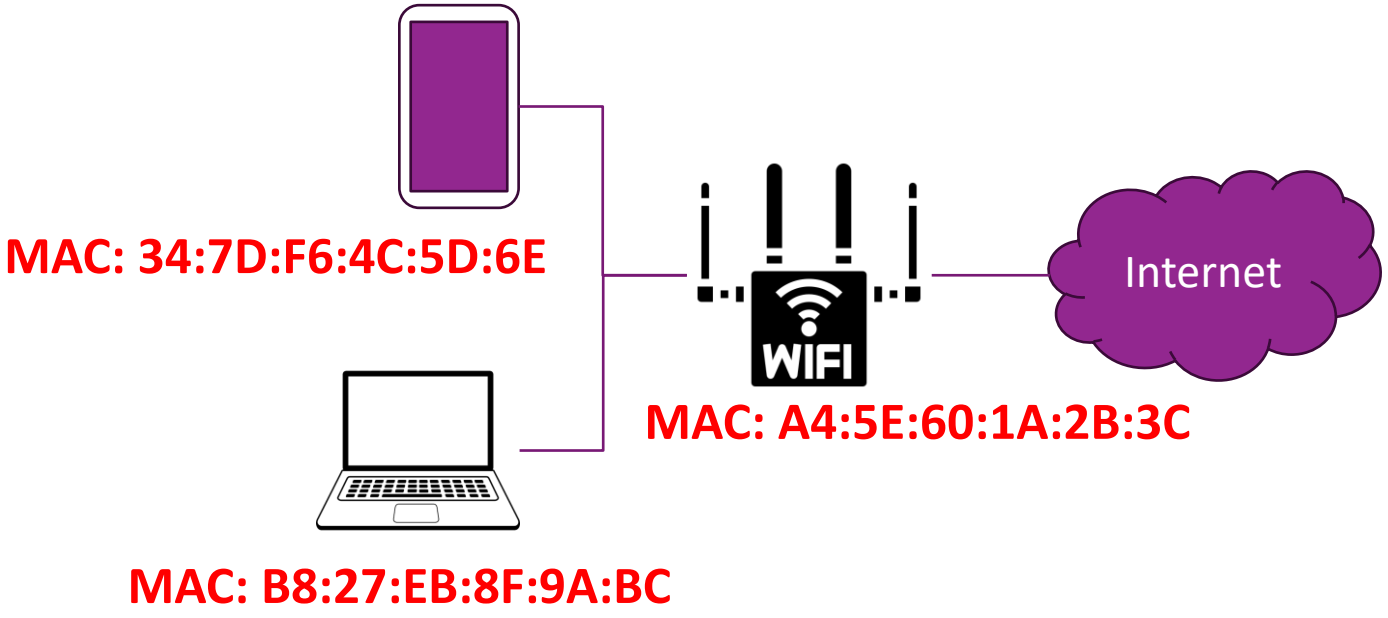
- ➢MAC address: Similar to the receiver ID, which is unique.
- ➢IP address: Similar to the physical address or postal code.
  - A receiver may stay at different locations.
  - Similarly, an MAC address may be configured with different IP addresses.
- ➢ARP: Address Resolution Protocol to map the MAC addresses with IP addresses.

❑How does the data get delivered to the destination?

- ➢Routing among different networks via the routing table.

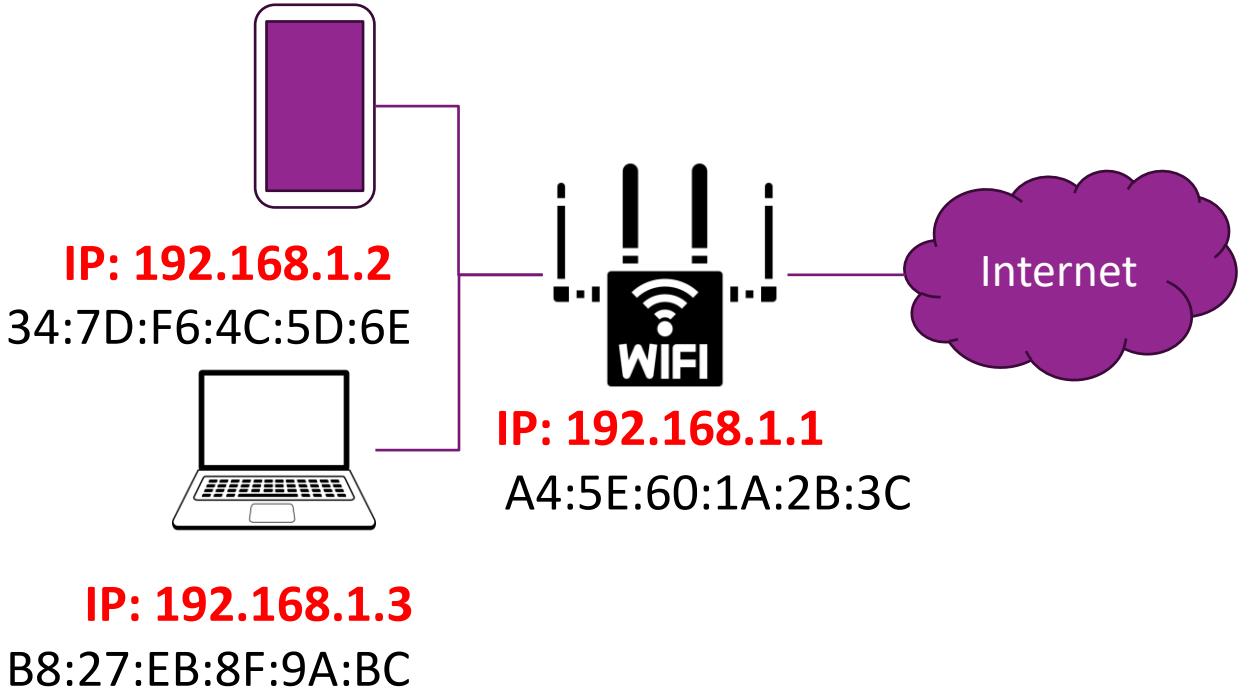
MAC (Media Access Control) Address

- Each network interface controller (NIC) has a unique MAC address.
- A MAC address has 48 bits (Similar to citizen ID).
  - 24 bits: manufacturer specific
  - 24 bits: manufacturer's organizationally unique identifier
- Designed for local network communications.



IP (Internet Protocol) Address

- Each device can be configured with one or several IP addresses.
- An IPv4 address is 32 bits long, and it is usually written as four decimal numbers separated by dots, *e.g.*, 192.168.1.1.
- IPv6 address has 128 bits, and it can support more addresses.



IP Address and Networks

❑An IP address has two parts.

- ➢**Network part:** The left n bits that identify the network.
- ➢**Host part**: The rest bits identifies the device on that network.

❑How to determine the network part?

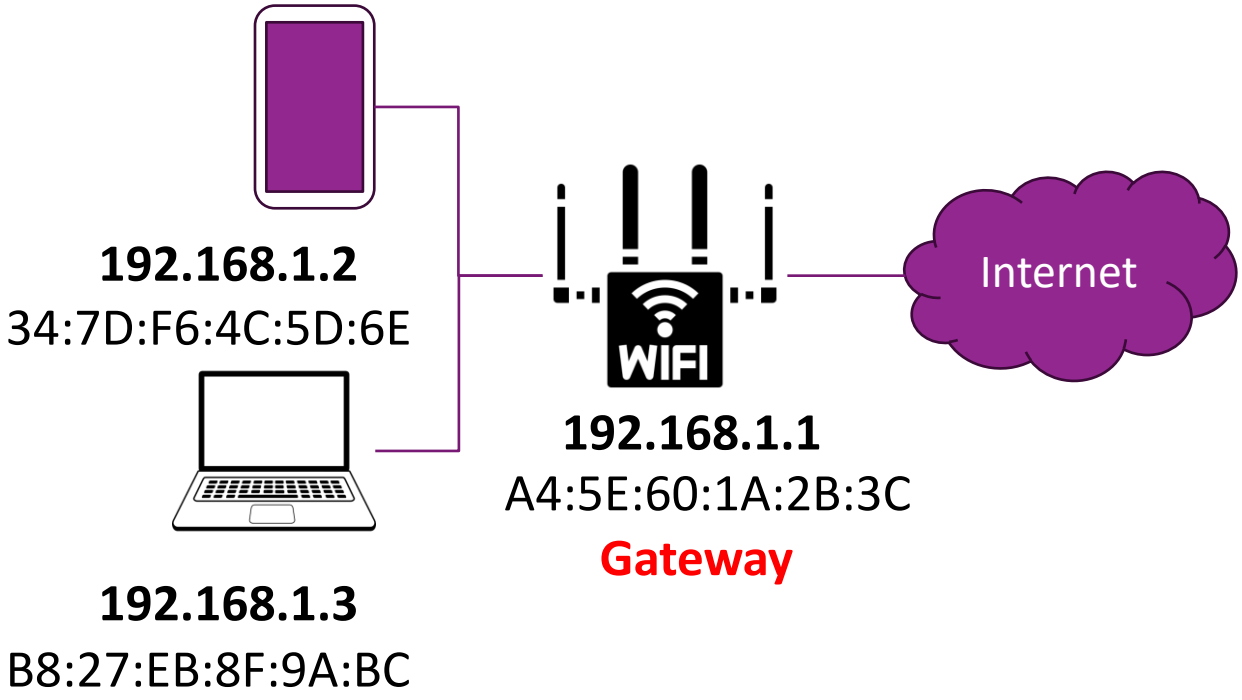
- ➢CIDR notation, e.g., 192.168.1.1 / 24 (number of prefix bits).
- ➢Uses subnet masks, e.g., 192.168.1.1 / 255.255.255.0.

❑IP Addresses within the same network must share the same network prefix.

- ➢e.g., 192.168.1.1 / 24 and 192.168.1.100 / 24 are within the same network.
- ➢e.g., 192.168.1.1 / 26 and 192.168.1.100 / 26 do not belong to the same network.

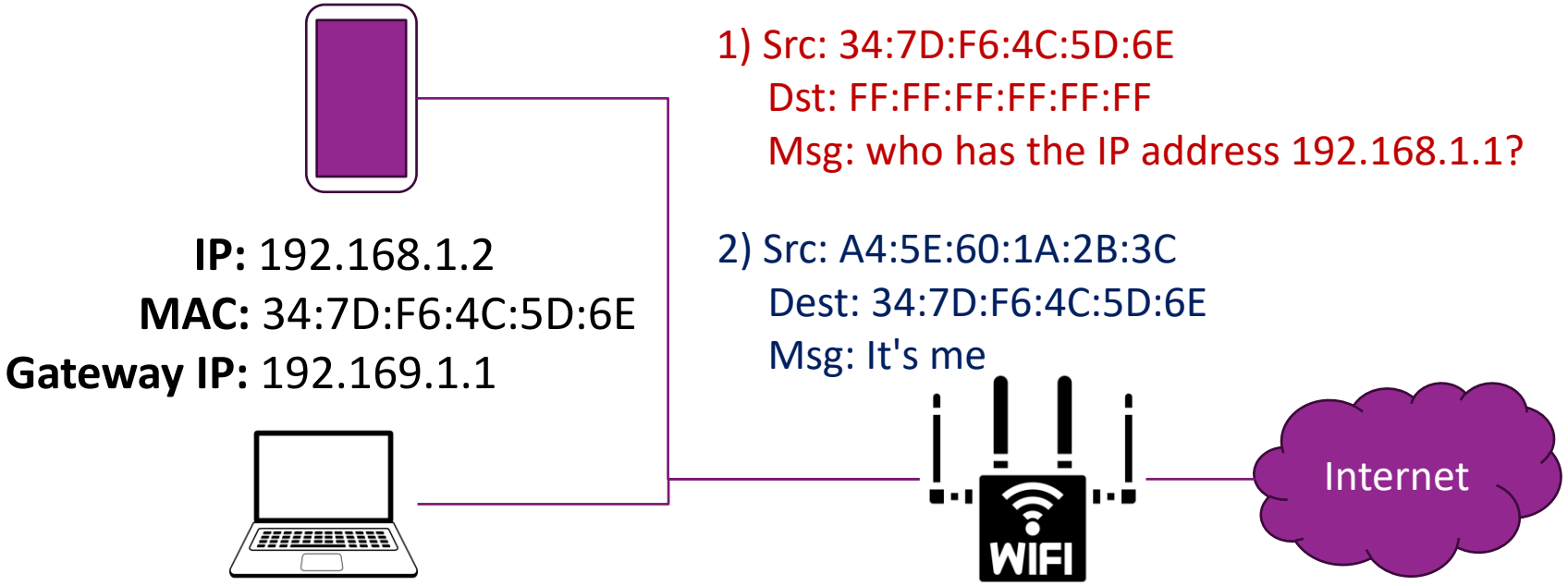
Local Area Network (LAN)

- Each device has an IP address within a local area network.
- The LAN typically uses a gateway to connect to external networks.
  - All IP addresses in the LAN can reach the outside world through this gateway.



Address Resolution Protocol (ARP)

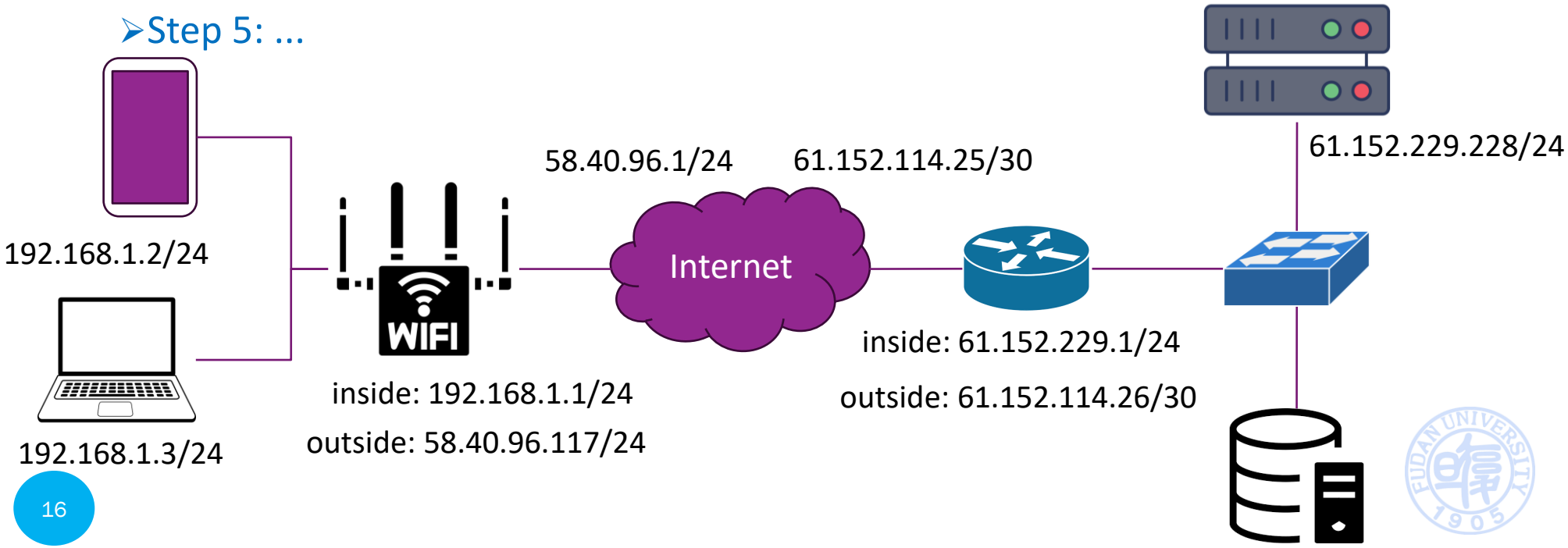
- MAC addresses are used for transmission in a LAN.
- But a host only knows the target (e.g., gateway) IP address.
- ARP translates an IP address to the MAC address.



Routing among Different Networks

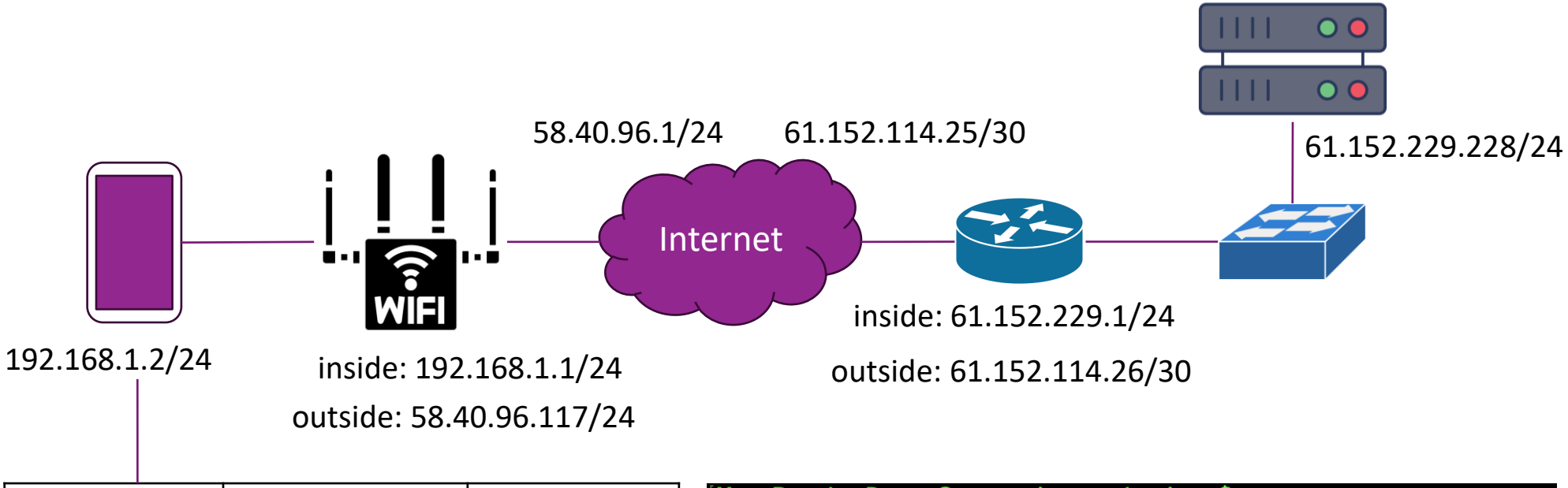
❑Suppose from 192.168.1.2 to 61.152.229.228.

- ➢Step 1: Client inquiries the MAC address of the gateway via ARP.
- ➢Step 2: Client composes a message with the destination IP: 61.152.229.228.
- ➢Step 3: Client sends the message to the gateway's MAC address.
- ➢Step 4: The gateway checks the routing table and forwards the message via the outside port to 58.40.96.1.
- ➢Step 5: ...



Routing Table

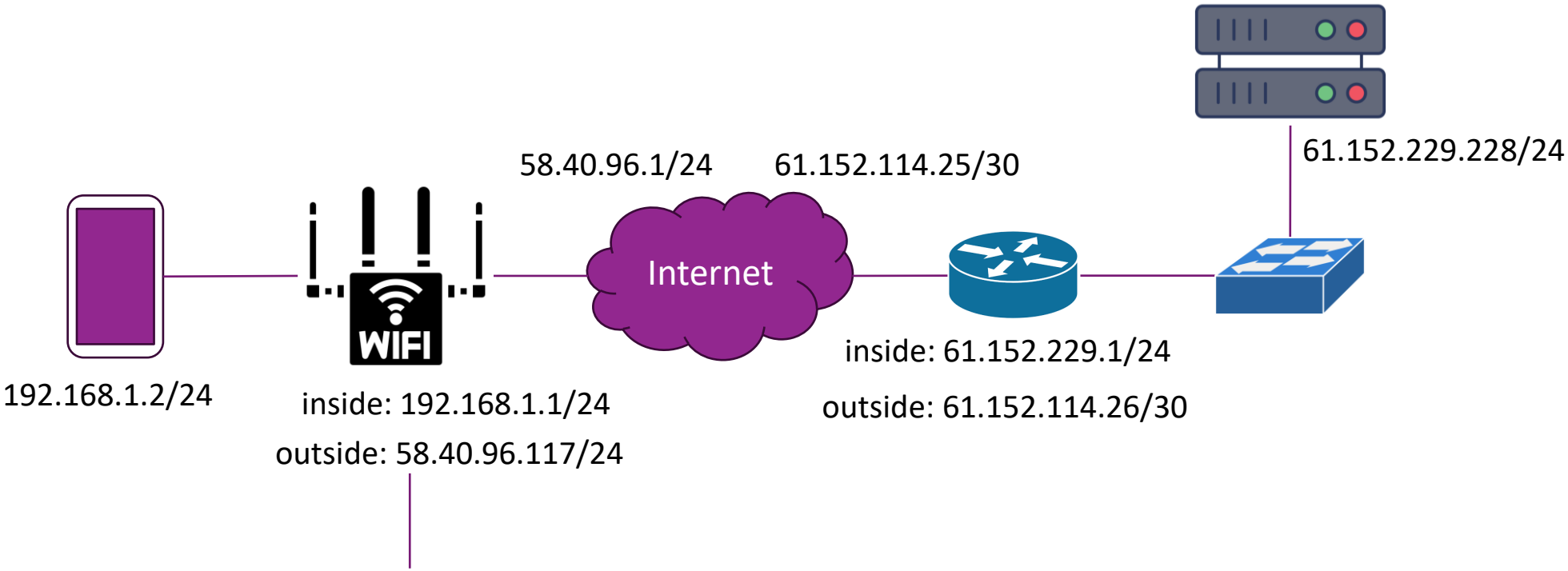
- Each device has a route table.
- The entries specify the next hop based on the destination.



Destination	Next Hop	Interface
default	192.168.1.1	eth0

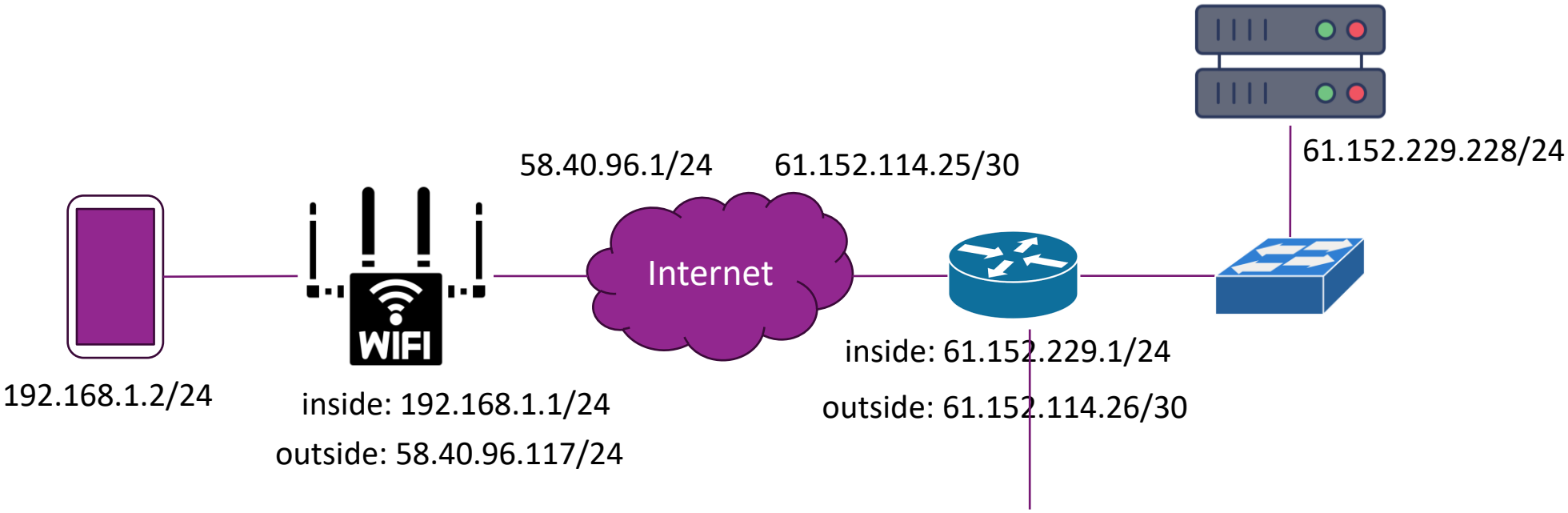
```
MacBook-Pro-2:artisan huixu$ netstat -rn
Routing tables

Internet:
Destination        Gateway            Flags
default            192.168.1.1        UGScg
127                127.0.0.1          UCS
127.0.0.1          127.0.0.1          UH
```

Routing Table



Destination	Next Hop	Interface
default	58.40.96.117	outside

Routing Table



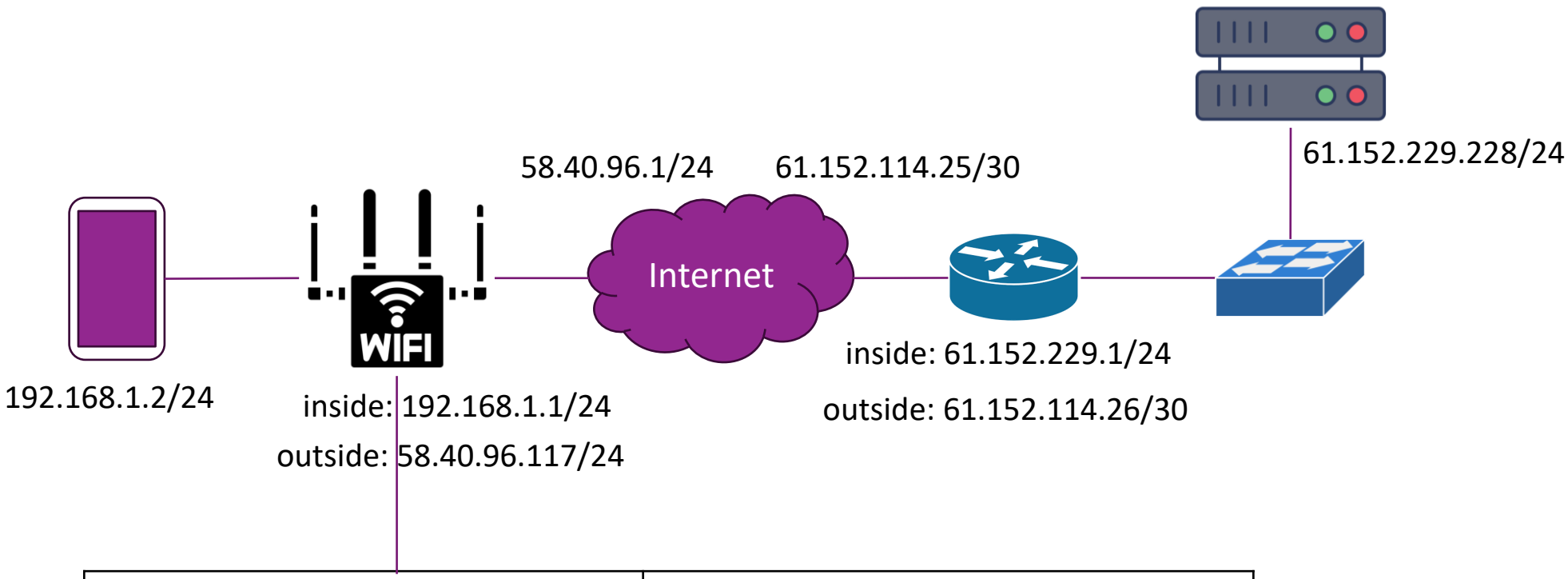
Destination	Next Hop	Interface
61.152.229.0/24	-	inside
default	61.152.114.25	outside

Private Network

- Three ranges of IP addresses are reserved for private network.
- Private addresses are not routable on the public Internet.
- Access Internet via a gateway with Network Address Translation.
- Widely used due to the limited number of IPv4 addresses.

Range	Next Hop	No. of Addresses
1	10.0.0.0 – 10.255.255.255	16777216
2	172.16.0.0 – 172.31.255.255	1048576
3	192.168.0.0 – 192.168.255.255	65536

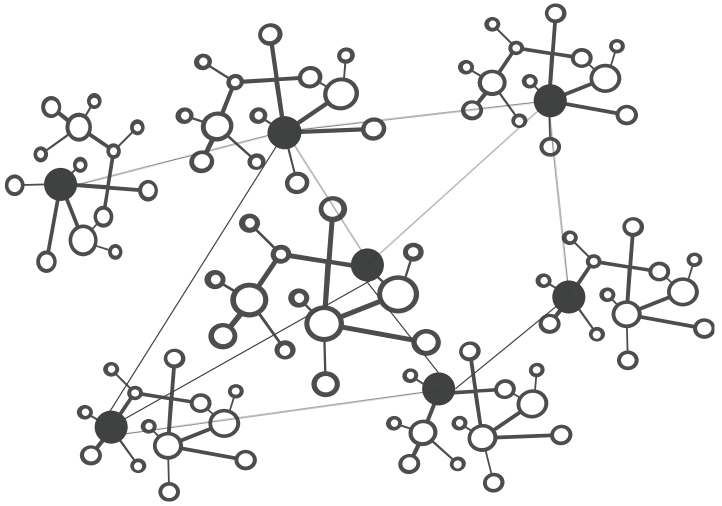
Network Address Translation (NAT)



Source Address		Translated Address	
IP	Port	IP	Port
192.168.1.2	12345	58.40.96.117	32123
192.168.1.2	12346	58.40.96.117	32124
192.168.1.2	12347	58.40.96.117	32125

Internet

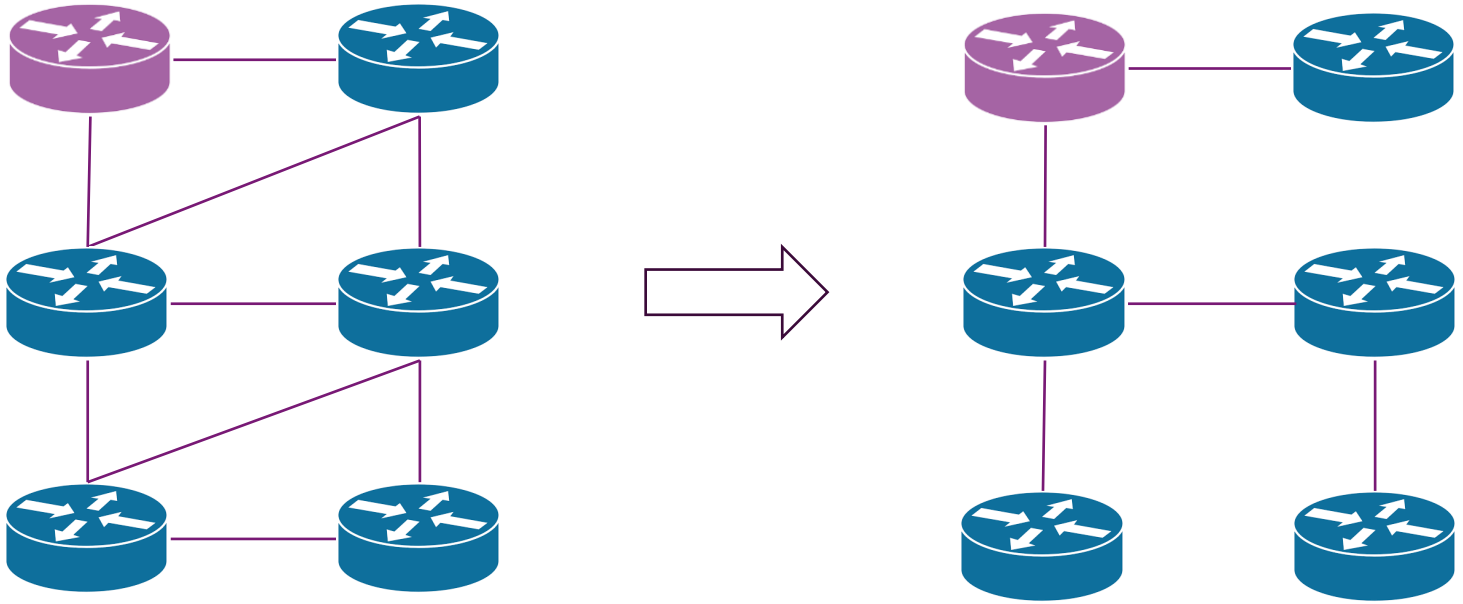
- **Composed of many autonomous systems (AS).**
- **Each AS is an independent network entity, such as**
  - Internet Service Provider (ISP)
  - Large high-tech organizations



- **Within an Autonomous System:**
  - Multiple routers manage multiple networks
  - Uses OSPF for internal routing
- **Interconnection between Autonomous Systems:**
  - Use BGP for communication between different ASes

Open Shortest Path First (OSPF)

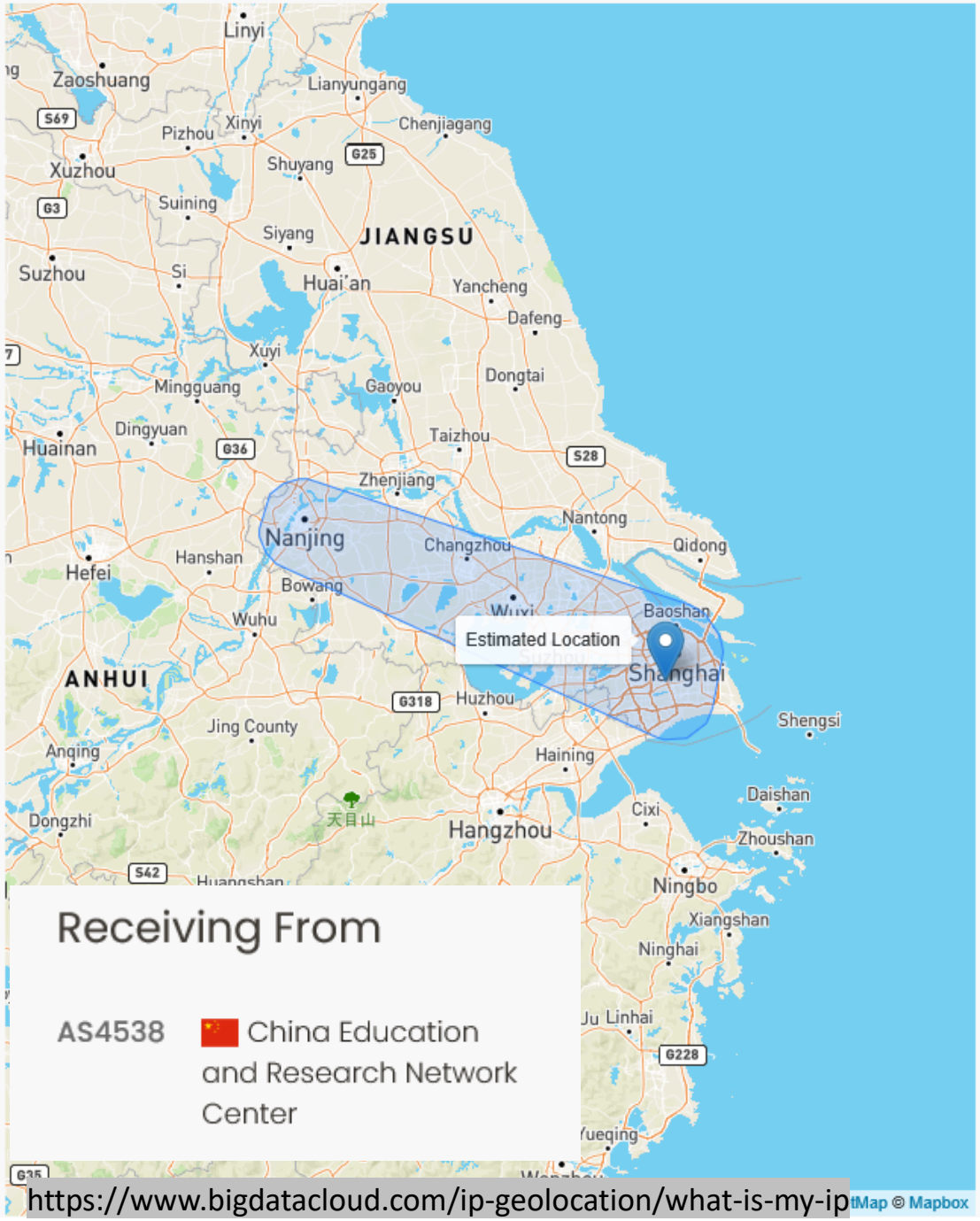
- **OSPF is a dynamic routing protocol.**
- **Build the routing table within the same autonomous systems.**
  - Find the shortest path to each destination based on Dijkstra's algorithm.
  - Convert a network topology to a spanning tree.



Example AS

Rank	AS Number	Organisation	Total IPv4 Addresses
1	AS749	DoD Network Information Center	224,675,888
2	AS4134	No.31,Jin-rong Street Beijing 100032	102,264,959
3	AS7018	AT&T Services, Inc.	92,705,503
4	AS7922	Comcast Cable Communications, LLC	69,615,412
5	AS8075	Microsoft Corporation	63,707,003
6	AS4837	CHINA UNICOM China169 Backbone	56,944,270
7	AS16509	Amazon.com, Inc.	48,741,833
8	AS4766	Korea Telecom	46,124,863
9	AS17676	SoftBank Mobile Corp. Tokyo Port City Takeshiba ..	40,782,687
10	AS701	Verizon Business	40,144,718

https://www.bigdatacloud.com/insights/as-rank



Ip Details	JSON View	JSON Raw

Security Risk	unknown
Registered For	Fudan University Network and Information Engineering Center 5th Floor, Yifu Building 220 Handan Road
UN Region	Asia/Eastern Asia
World Bank Region	East Asia & Pacific
World Bank Income Level	Upper middle income
Country	China
ISO ALPHA-2	CN
ISO ALPHA-3	CHN
Principal Subdivision	上海市
ISO 3166-2	CN-SH
City	
Postal Code	
Latitude	31.05
Longitude	121.4
Timezone	(CST) China Standard Time
Local Time	Sunday, September 27, 2020 10:38 am
Confidence	moderate
Carrier	CERNET2 IX at Shanghai Jiaotong University
ASN	AS24364
BGP Prefix	202.120.234.0/23

https://www.bigdatacloud.com/ip-geolocation/what-is-my-ip

AS 4538

Receiving From

AS174	Cogent Communications	AS4134	No.31Jinrong Street
AS4637	Telstra International Limited	AS4789	NAP1 at CERNET
AS4837	CHINA UNICOM China169 Backbone	AS6453	TATA COMMUNICATIONS AMERICA INC
AS6939	Hurricane Electric LLC	AS7497	Computer Network Information Center
AS9808	China Mobile	AS23911	China Next Generation Internet Beijing IX

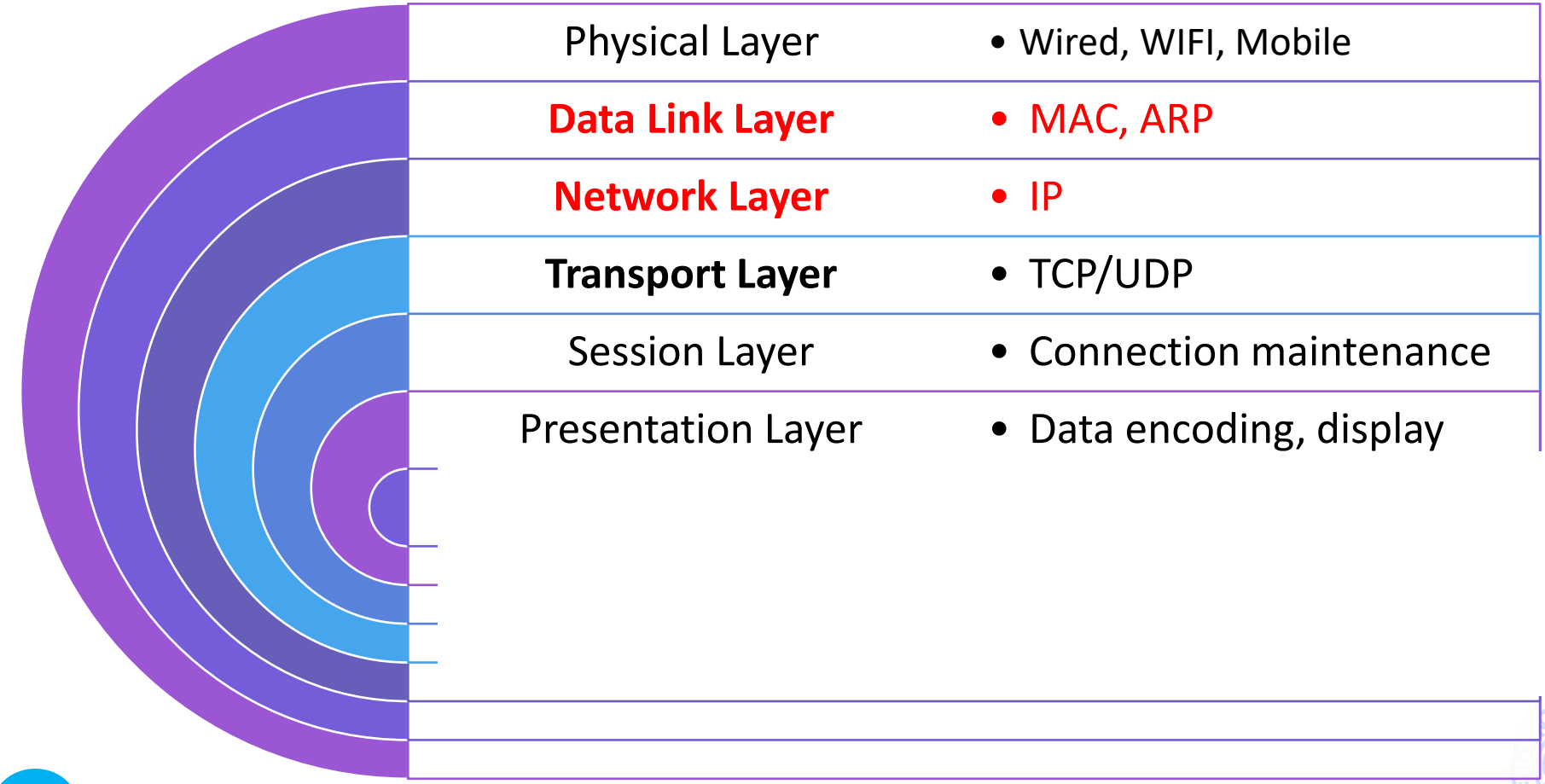
Transit To

AS9405	Test platform Service Center	AS23910	China Next Generation Internet CERNET2
AS23911	China Next Generation Internet Beijing IX	AS24348	CERNET2 IX at Tsinghua University
AS24349	CERNET2 IX at Peking University	AS24350	CERNET2 IX at Beijing University of Posts and Telecommunications
AS24353	CERNET2 IX at Xian Jiaotong University	AS24355	CERNET2 IX at University of Electronic Science and Technology of China
AS24357	CERNET2 IX at South China University of Technology	AS24358	CERNET2 IX at Huazhong University of Science and Technology
AS24361	CERNET2 IX at Southeast University	AS24362	CERNET2 IX at University of Science and Technology of China
AS24363	CERNET2 IX at Shandong University	AS24364	CERNET2 IX at Shanghai Jiaotong University

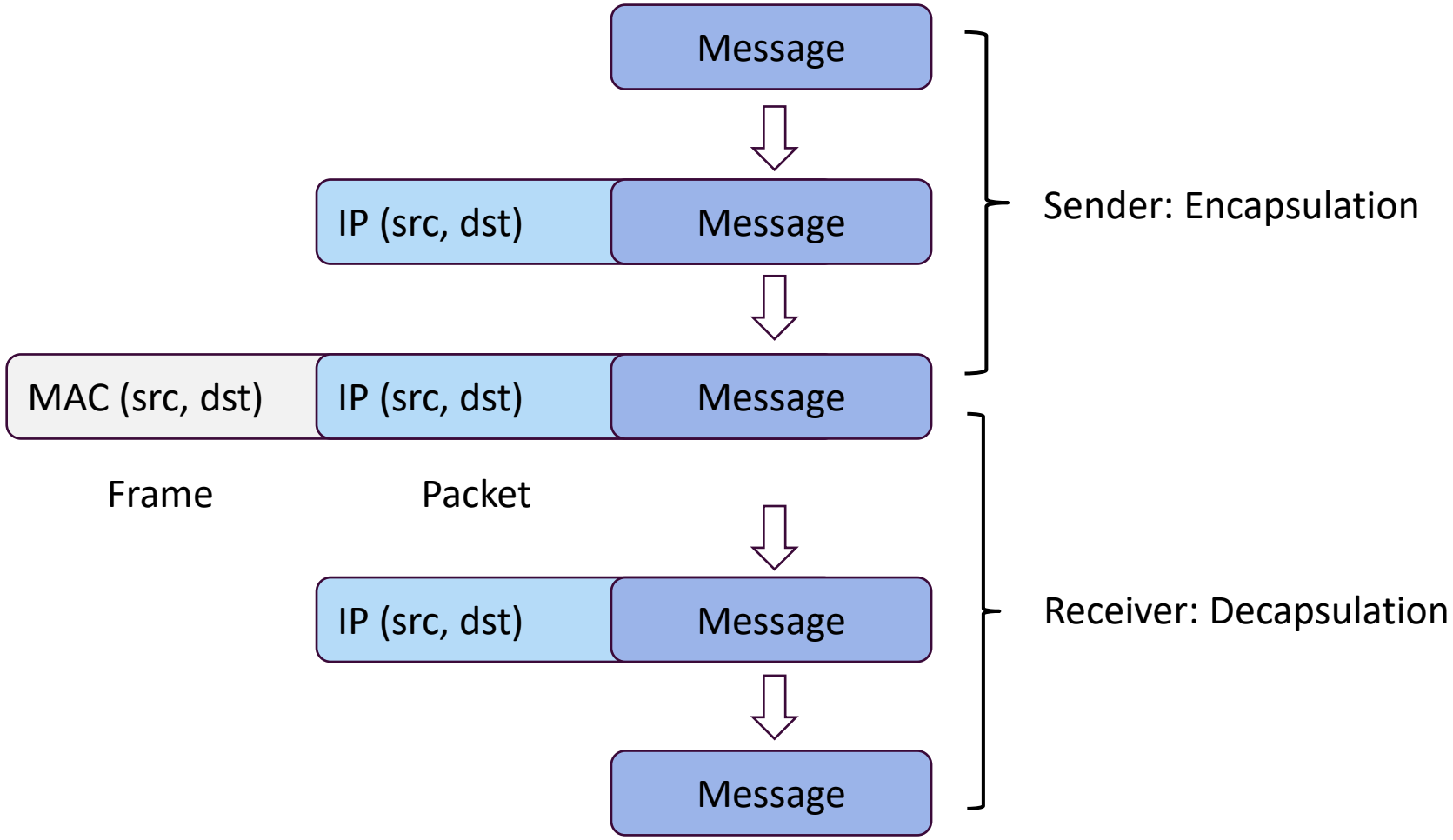
2. Messaging

The OSI Model

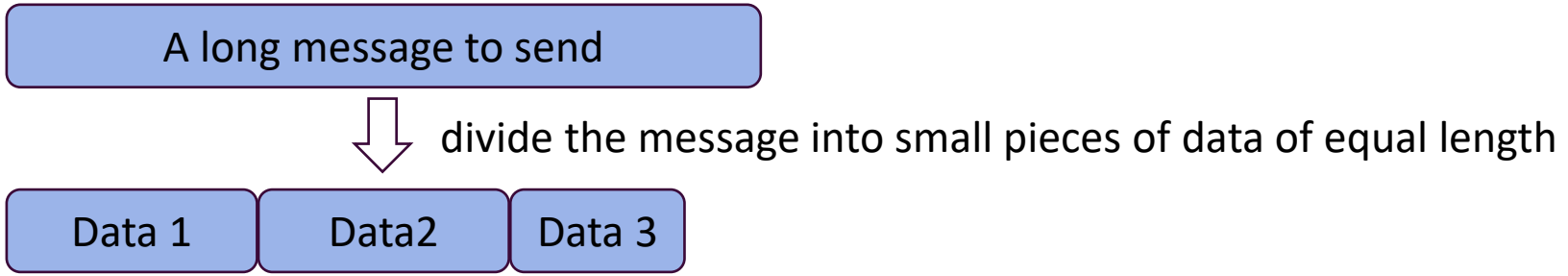
- A 7-layer framework for understanding network communication.
- Developed by ISO to standardize networking.



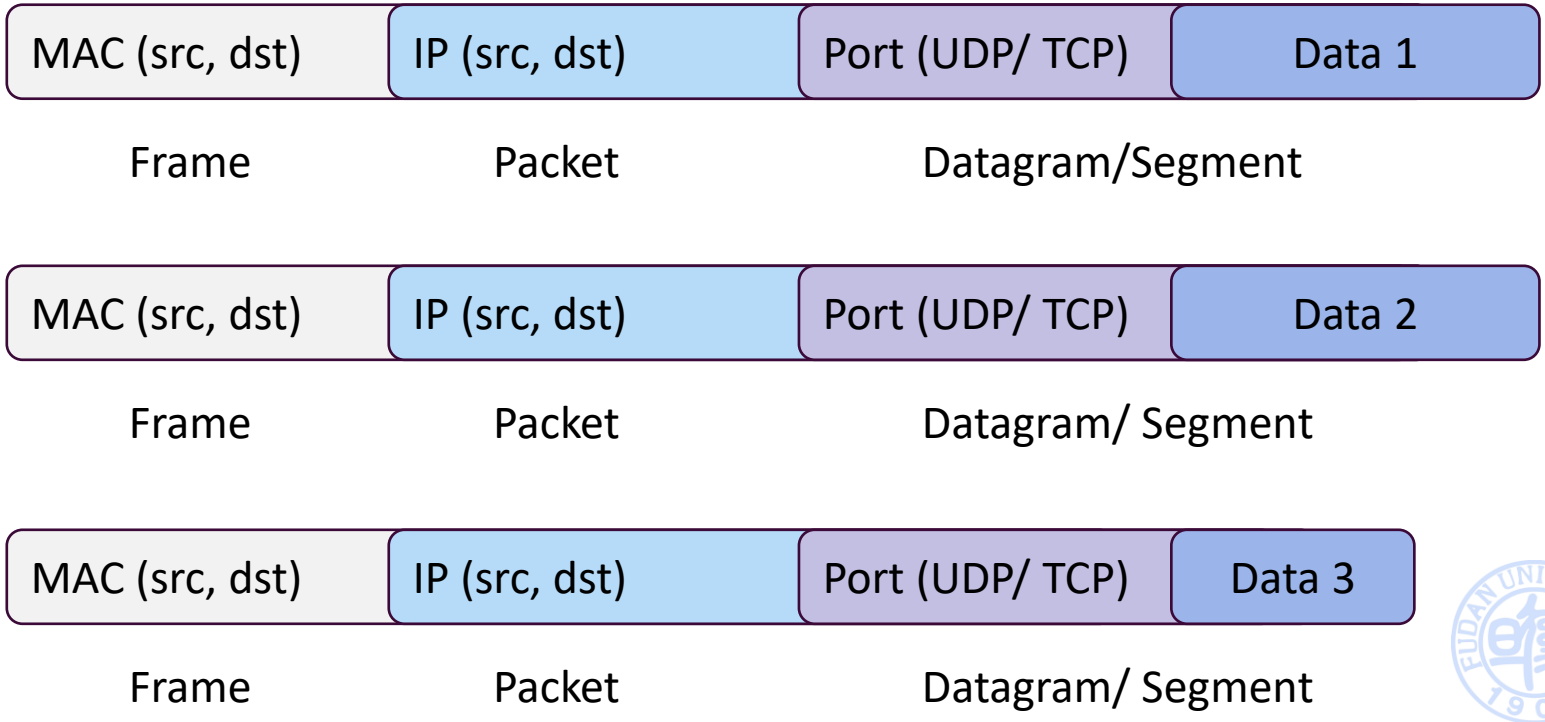
Message Encapsulation/Decapsulation



Message Encapsulation



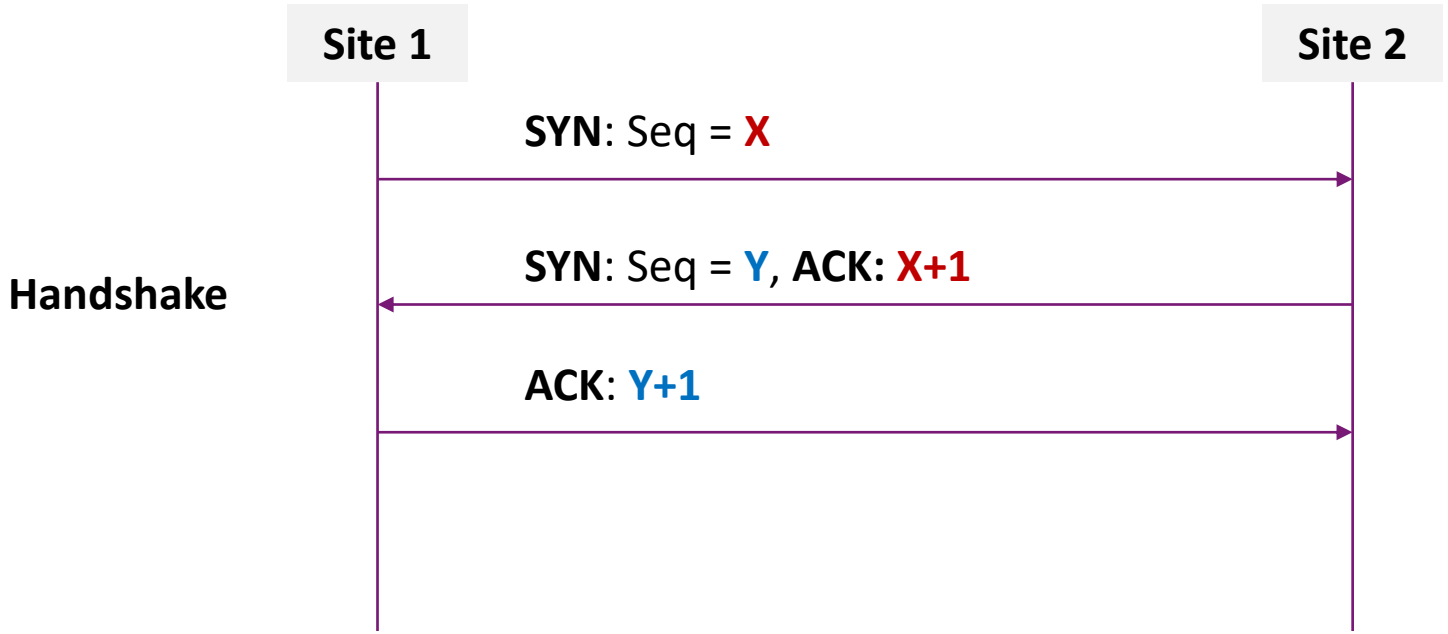
Encapsulate each piece of data:



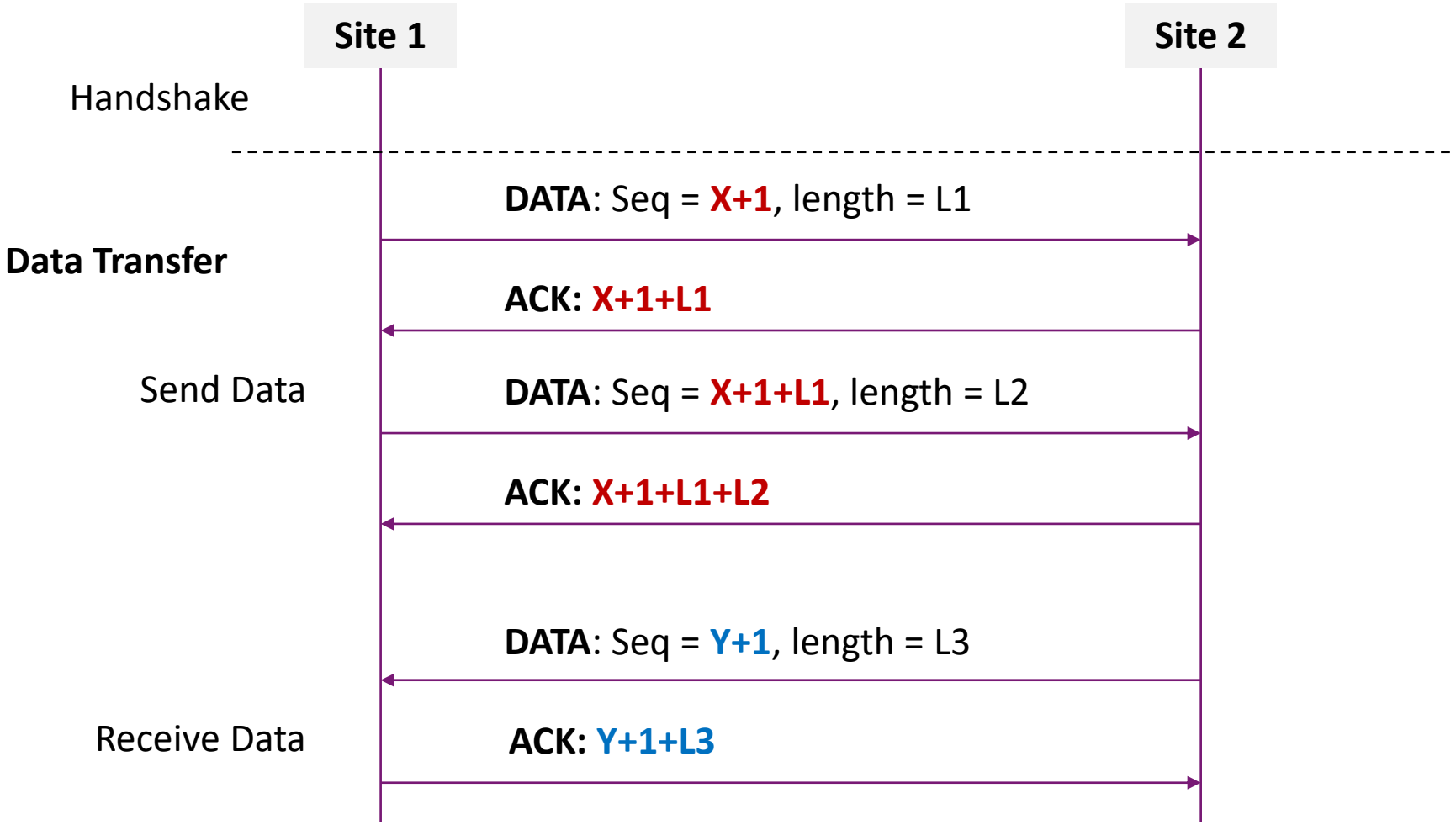
Transmission Control Protocol (TCP)

- **Data can be lost during transmission over the network.**
- **TCP provides reliable, ordered, error-checked delivery of data.**
- **Turn the Internet's "best effort" IP service into a virtual connection.**
- **Three phases:**
  - Handshake: Establish the connection between sender and receiver
  - Data Transfer: Send and receive data reliably
  - Termination: Close the connection gracefully

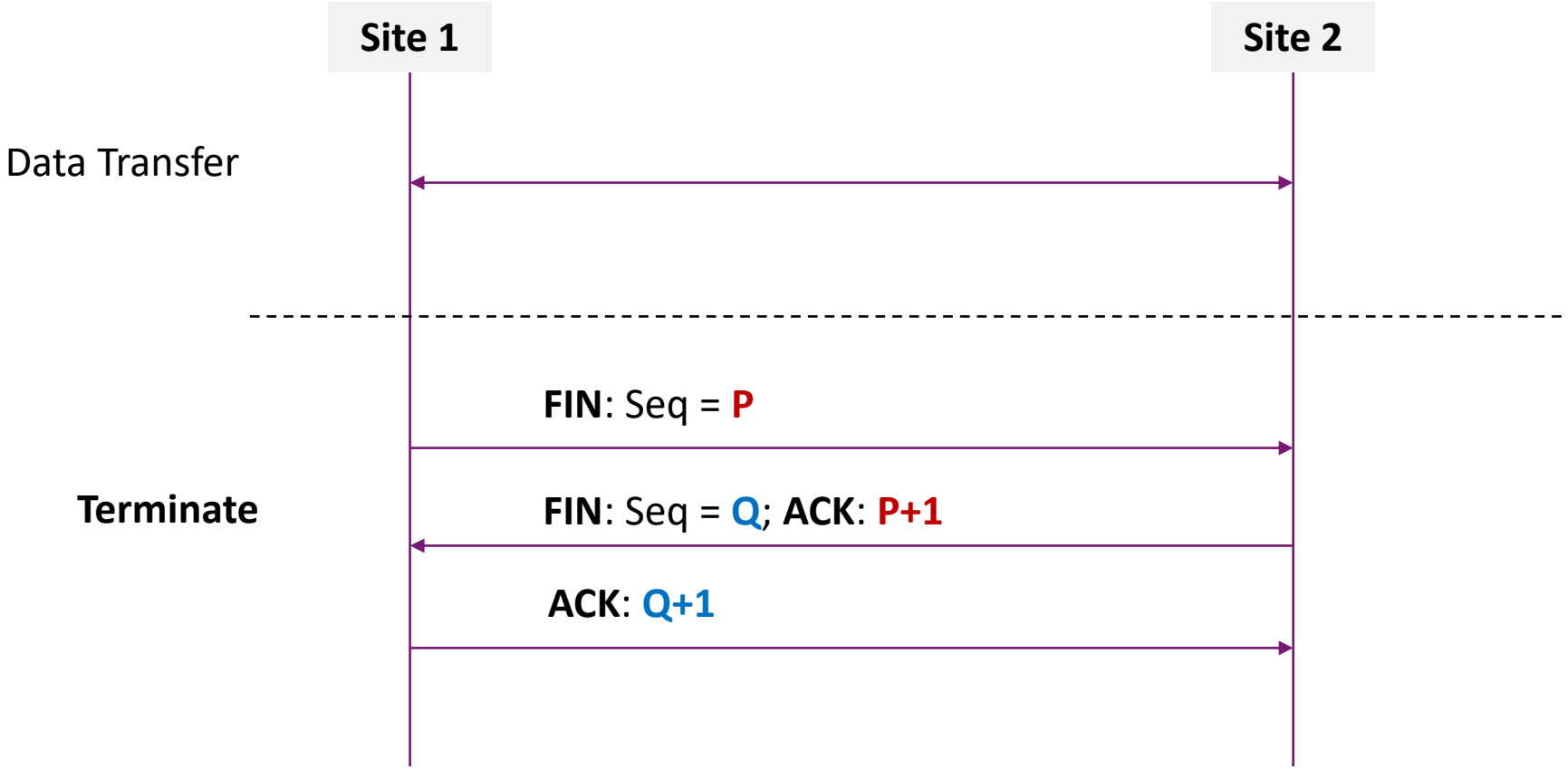
TCP: Three-Way Handshake



TCP: Data Transfer



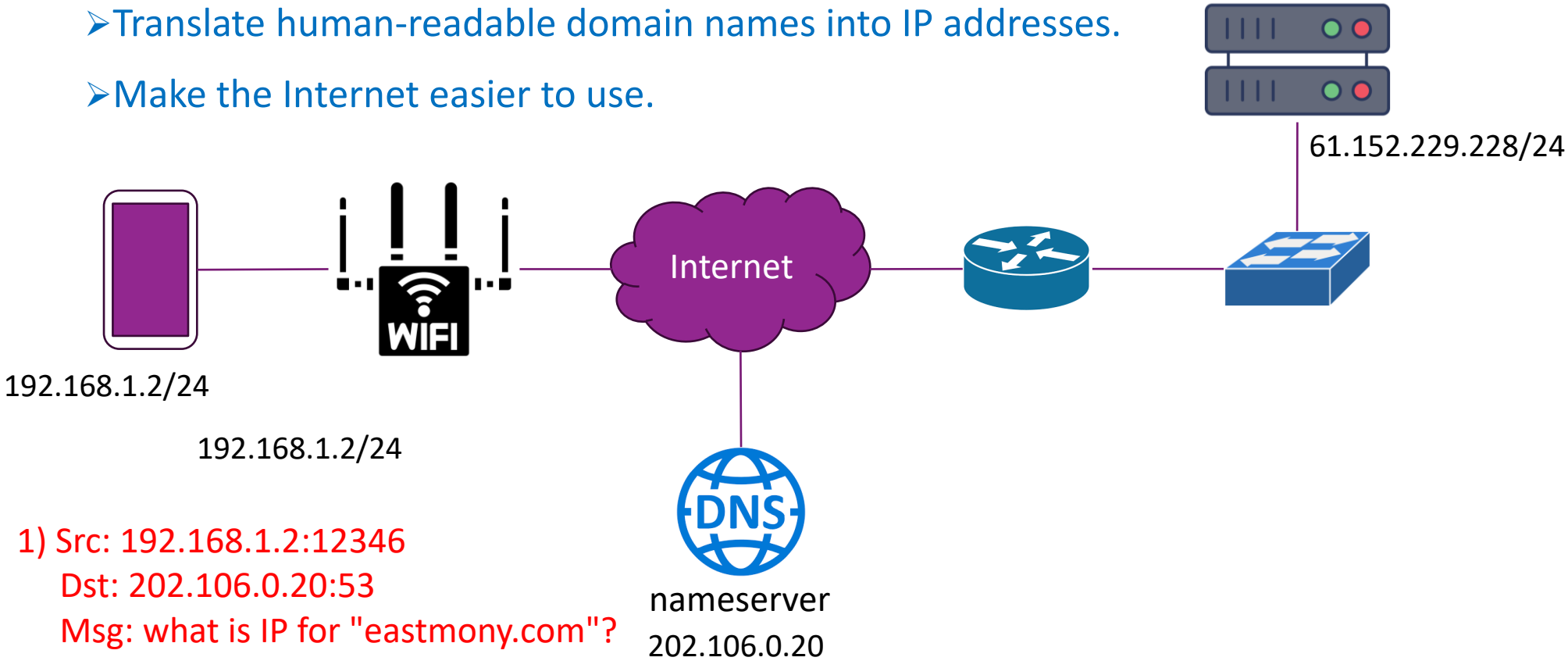
TCP: Close


Site 1
Site 2
Data Transfer
FIN: Seq = P
Terminate
FIN: Seq = Q; ACK: P+1
ACK: Q+1

Domain Name Service (DNS)

❑DNS acts like a phone book for the Internet.

- ➢Translate human-readable domain names into IP addresses.
- ➢Make the Internet easier to use.

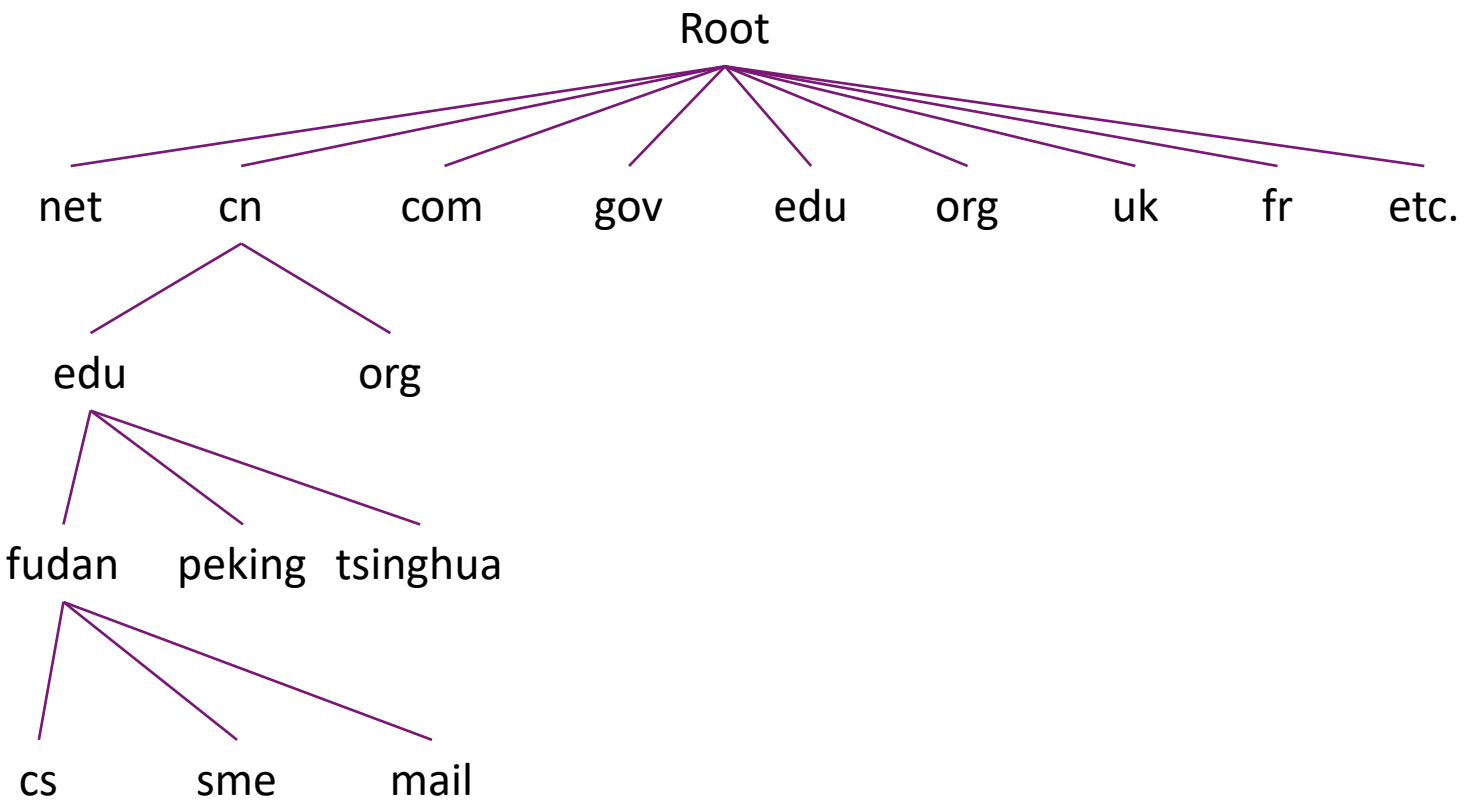


1) Src: 192.168.1.2:12346
   Dst: 202.106.0.20:53
   Msg: what is IP for "eastmony.com"?

2) Src: 202.106.0.20:53
   Dst: 58.40.96.117:32124
   Msg: It's 61.152.229.228

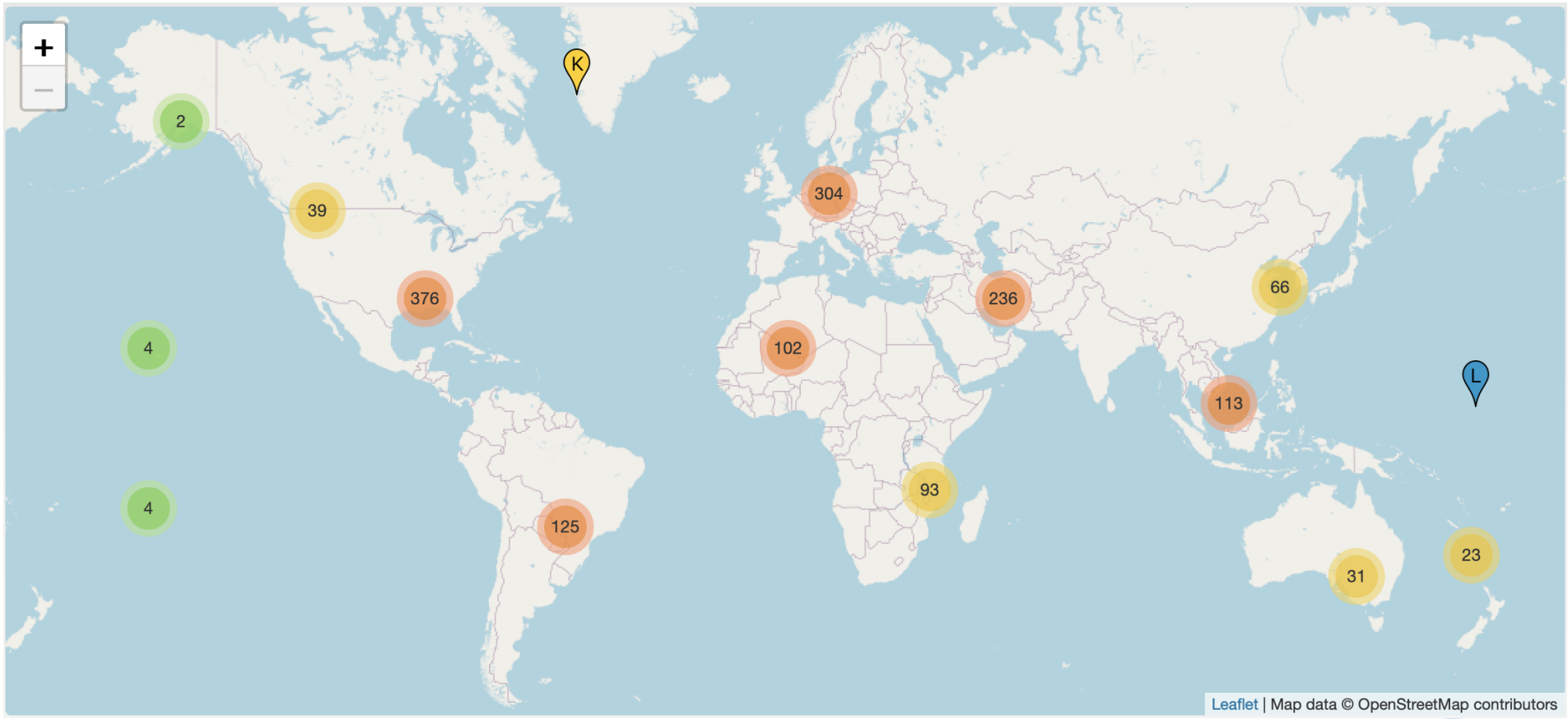
Domain Name in a Tree Structure

- Domain names are organized in a tree-like hierarchy.
- Each node is managed by an organization.



Root DNS Server

- 13 root servers (A-M) and hundreds of mirrors around the world.



https://root-servers.org/

Hypertext Transfer Protocol (HTTP)

- **An application-layer protocol used by web browsers and servers.**
  - Work on top of TCP/IP.
  - Transfer web pages, images, and other resources over the Internet.
- **Define how browsers request and servers respond with content.**
  - Request (from client):
    - URL: the address of the resource
    - Method: GET, POST, PUT, DELETE, etc.
    - Headers: additional info (e.g., browser type, cookies)
  - Response (from server):
    - Status code: 200 OK, 404 Not Found, 500 Internal Server Error
    - Headers: content type, length, cookies, etc.
    - Body: the actual content (HTML, JSON, image…)

HTTP: An Example

1) Client (browser) sends a request.

```
GET /about HTTP/1.1
Host: www.example.com
User-Agent: Firefox/141.0
```

2) Server processes it and sends back a response.

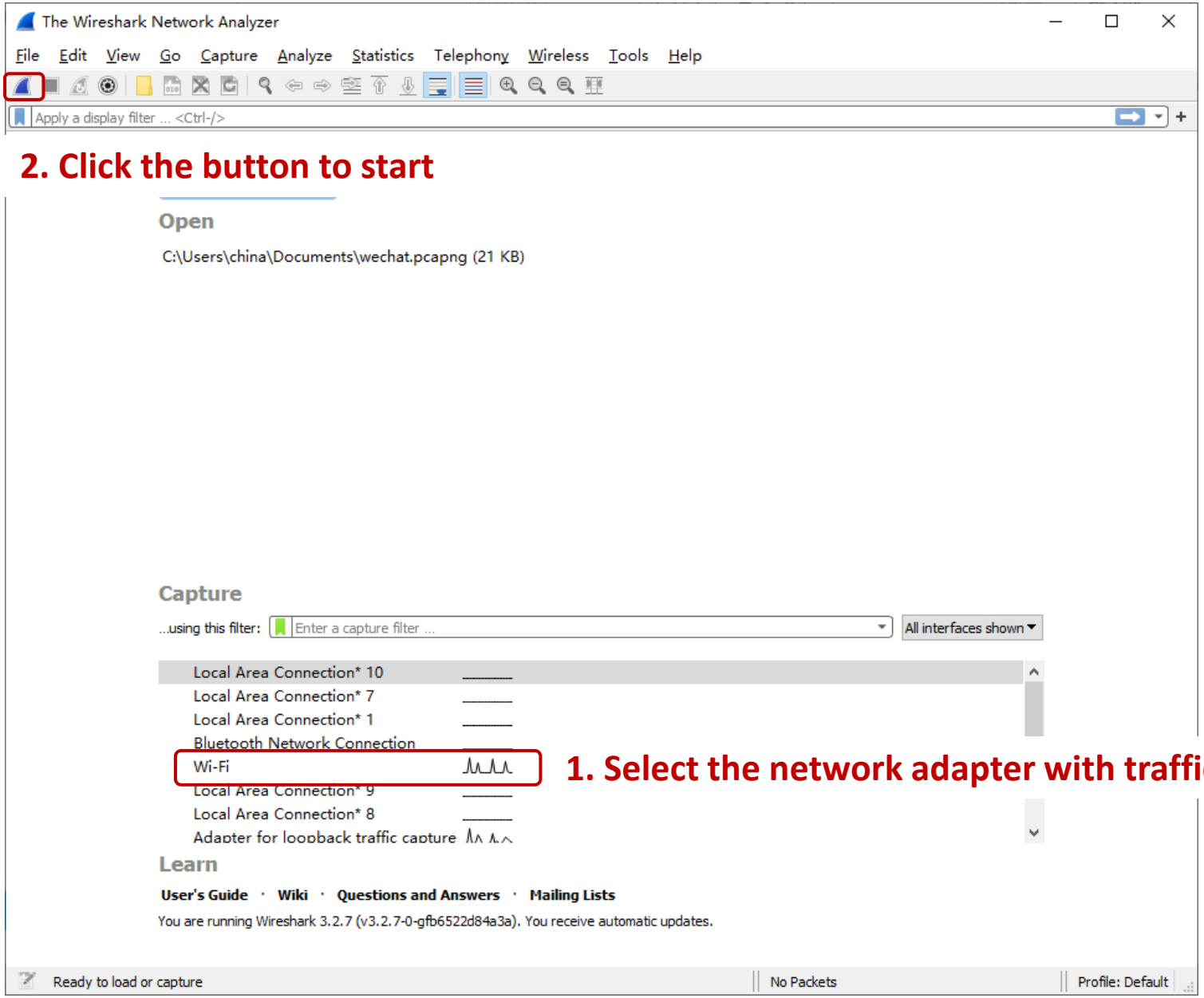
```
HTTP/1.1 200 OK
Content-Type: text/html
<html>
    <h1>Hello, world!</h1>
</html>
```

3. Practice: Packet Analysis

Practice: Network Traffic Analysis with Wireshark

- **Download and install Wireshark.**
  - https://www.wireshark.org/download.html
- **Access a website (e.g., www.fudan.edu.cn) and capture the network traffic with Wireshark.**
  - Filter related packets.
  - Interpret the meaning of each related packets.

Start Capture with Wireshark



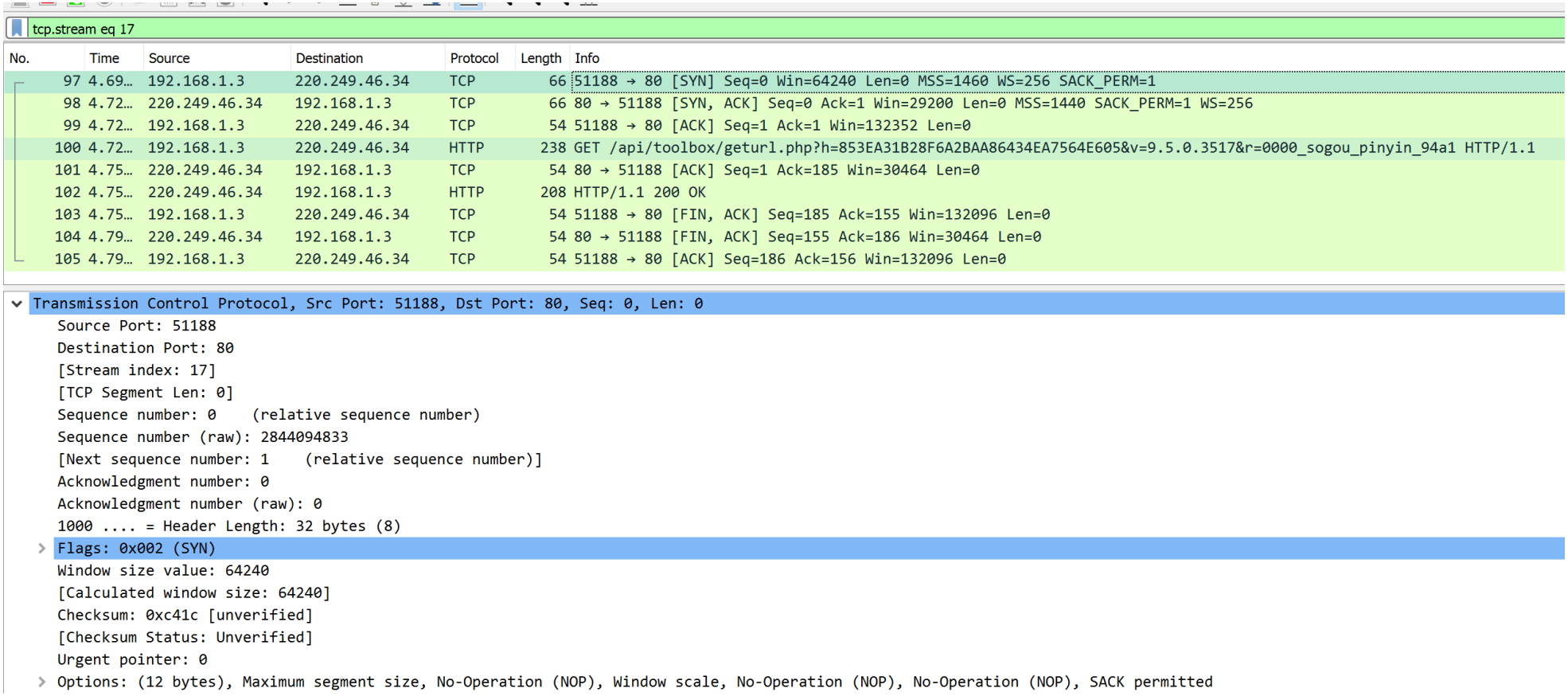
ARP

```
888 73.928771 Chongqin_… Broadcast  ARP    60 Who has 192.168.1.100? Tell 192.168.1.107
889 73.928779 IntelCor_… Chongqin_… ARP    42 192.168.1.100 is at 50:eb:71:bd:fc:f4
```

```
Ethernet II, Src: Chongqin_4f:6c:98 (ec:5c:68:4f:6c:98), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
  > Destination: Broadcast (ff:ff:ff:ff:ff:ff)
  > Source: Chongqin_4f:6c:98 (ec:5c:68:4f:6c:98)
    Type: ARP (0x0806)
    Padding: 000000000000000000000000000000000000
Address Resolution Protocol (request)
    Hardware type: Ethernet (1)
    Protocol type: IPv4 (0x0800)
    Hardware size: 6
    Protocol size: 4
    Opcode: request (1)
    Sender MAC address: Chongqin_4f:6c:98 (ec:5c:68:4f:6c:98)
    Sender IP address: 192.168.1.107
    Target MAC address: 00:00:00_00:00:00 (00:00:00:00:00:00)
    Target IP address: 192.168.1.100
```

```
Ethernet II, Src: IntelCor_bd:fc:f4 (50:eb:71:bd:fc:f4), Dst: Chongqin_4f:6c:98 (ec:5c:68:4f:6c:98)
  > Destination: Chongqin_4f:6c:98 (ec:5c:68:4f:6c:98)
  > Source: IntelCor_bd:fc:f4 (50:eb:71:bd:fc:f4)
    Type: ARP (0x0806)
Address Resolution Protocol (reply)
    Hardware type: Ethernet (1)
    Protocol type: IPv4 (0x0800)
    Hardware size: 6
    Protocol size: 4
    Opcode: reply (2)
    Sender MAC address: IntelCor_bd:fc:f4 (50:eb:71:bd:fc:f4)
    Sender IP address: 192.168.1.100
    Target MAC address: Chongqin_4f:6c:98 (ec:5c:68:4f:6c:98)
    Target IP address: 192.168.1.107
```

TCP Handshake: SYN



tcp.stream eq 17

No.	Time	Source	Destination	Protocol	Length	Info
97	4.69…	192.168.1.3	220.249.46.34	TCP	66	51188 → 80 [SYN] Seq=0 Win=64240 Len=0 MSS=1460 WS=256 SACK_PERM=1
98	4.72…	220.249.46.34	192.168.1.3	TCP	66	80 → 51188 [SYN, ACK] Seq=0 Ack=1 Win=29200 Len=0 MSS=1440 SACK_PERM=1 WS=256
99	4.72…	192.168.1.3	220.249.46.34	TCP	54	51188 → 80 [ACK] Seq=1 Ack=1 Win=132352 Len=0
100	4.72…	192.168.1.3	220.249.46.34	HTTP	238	GET /api/toolbox/geturl.php?h=853EA31B28F6A2BAA86434EA7564E605&v=9.5.0.3517&r=0000_sogou_pinyin_94a1 HTTP/1.1
101	4.75…	220.249.46.34	192.168.1.3	TCP	54	80 → 51188 [ACK] Seq=1 Ack=185 Win=30464 Len=0
102	4.75…	220.249.46.34	192.168.1.3	HTTP	208	HTTP/1.1 200 OK
103	4.75…	192.168.1.3	220.249.46.34	TCP	54	51188 → 80 [FIN, ACK] Seq=185 Ack=155 Win=132096 Len=0
104	4.79…	220.249.46.34	192.168.1.3	TCP	54	80 → 51188 [FIN, ACK] Seq=155 Ack=186 Win=30464 Len=0
105	4.79…	192.168.1.3	220.249.46.34	TCP	54	51188 → 80 [ACK] Seq=186 Ack=156 Win=132096 Len=0

```
Transmission Control Protocol, Src Port: 51188, Dst Port: 80, Seq: 0, Len: 0
    Source Port: 51188
    Destination Port: 80
    [Stream index: 17]
    [TCP Segment Len: 0]
    Sequence number: 0    (relative sequence number)
    Sequence number (raw): 2844094833
    [Next sequence number: 1    (relative sequence number)]
    Acknowledgment number: 0
    Acknowledgment number (raw): 0
    1000 .... = Header Length: 32 bytes (8)
  > Flags: 0x002 (SYN)
    Window size value: 64240
    [Calculated window size: 64240]
    Checksum: 0xc41c [unverified]
    [Checksum Status: Unverified]
    Urgent pointer: 0
  > Options: (12 bytes), Maximum segment size, No-Operation (NOP), Window scale, No-Operation (NOP), No-Operation (NOP), SACK permitted
```

TCP Handshake: SYN-ACK

tcp.stream eq 17

No.	Time	Source	Destination	Protocol	Length	Info
97	4.69…	192.168.1.3	220.249.46.34	TCP	66	51188 → 80 [SYN] Seq=0 Win=64240 Len=0 MSS=1460 WS=256 SACK_PERM=1
98	4.72…	220.249.46.34	192.168.1.3	TCP	66	80 → 51188 [SYN, ACK] Seq=0 Ack=1 Win=29200 Len=0 MSS=1440 SACK_PERM=1 WS=256
99	4.72…	192.168.1.3	220.249.46.34	TCP	54	51188 → 80 [ACK] Seq=1 Ack=1 Win=132352 Len=0
100	4.72…	192.168.1.3	220.249.46.34	HTTP	238	GET /api/toolbox/geturl.php?h=853EA31B28F6A2BAA86434EA7564E605&v=9.5.0.3517&r=
101	4.75…	220.249.46.34	192.168.1.3	TCP	54	80 → 51188 [ACK] Seq=1 Ack=185 Win=30464 Len=0
102	4.75…	220.249.46.34	192.168.1.3	HTTP	208	HTTP/1.1 200 OK
103	4.75…	192.168.1.3	220.249.46.34	TCP	54	51188 → 80 [FIN, ACK] Seq=185 Ack=155 Win=132096 Len=0
104	4.79…	220.249.46.34	192.168.1.3	TCP	54	80 → 51188 [FIN, ACK] Seq=155 Ack=186 Win=30464 Len=0
105	4.79…	192.168.1.3	220.249.46.34	TCP	54	51188 → 80 [ACK] Seq=186 Ack=156 Win=132096 Len=0

```
Transmission Control Protocol, Src Port: 80, Dst Port: 51188, Seq: 0, Ack: 1, Len: 0
    Source Port: 80
    Destination Port: 51188
    [Stream index: 17]
    [TCP Segment Len: 0]
    Sequence number: 0    (relative sequence number)
    Sequence number (raw): 911860538
    [Next sequence number: 1    (relative sequence number)]
    Acknowledgment number: 1    (relative ack number)
    Acknowledgment number (raw): 2844094834
    1000 .... = Header Length: 32 bytes (8)
  > Flags: 0x012 (SYN, ACK)
    Window size value: 29200
    [Calculated window size: 29200]
    Checksum: 0x336c [unverified]
    [Checksum Status: Unverified]
    Urgent pointer: 0
  > Options: (12 bytes), Maximum segment size, No-Operation (NOP), No-Operation (NOP), SACK permitted, No-Operation (NOP), Window scale
```

TCP Connection Termination: FIN

tcp.stream eq 17

No.	Time	Source	Destination	Protocol	Length	Info
97	4.69…	192.168.1.3	220.249.46.34	TCP	66	51188 → 80 [SYN] Seq=0 Win=64240 Len=0 MSS=1460 WS=256
98	4.72…	220.249.46.34	192.168.1.3	TCP	66	80 → 51188 [SYN, ACK] Seq=0 Ack=1 Win=29200 Len=0 MSS=1
99	4.72…	192.168.1.3	220.249.46.34	TCP	54	51188 → 80 [ACK] Seq=1 Ack=1 Win=132352 Len=0
100	4.72…	192.168.1.3	220.249.46.34	HTTP	238	GET /api/toolbox/geturl.php?h=853EA31B28F6A2BAA86434EA7
101	4.75…	220.249.46.34	192.168.1.3	TCP	54	80 → 51188 [ACK] Seq=1 Ack=185 Win=30464 Len=0
102	4.75…	220.249.46.34	192.168.1.3	HTTP	208	HTTP/1.1 200 OK
103	4.75…	192.168.1.3	220.249.46.34	TCP	54	51188 → 80 [FIN, ACK] Seq=185 Ack=155 Win=132096 Len=0
104	4.79…	220.249.46.34	192.168.1.3	TCP	54	80 → 51188 [FIN, ACK] Seq=155 Ack=186 Win=30464 Len=0
105	4.79…	192.168.1.3	220.249.46.34	TCP	54	51188 → 80 [ACK] Seq=186 Ack=156 Win=132096 Len=0

```
Transmission Control Protocol, Src Port: 51188, Dst Port: 80, Seq: 185, Ack: 155, Len: 0
    Source Port: 51188
    Destination Port: 80
    [Stream index: 17]
    [TCP Segment Len: 0]
    Sequence number: 185    (relative sequence number)
    Sequence number (raw): 2844095018
    [Next sequence number: 186    (relative sequence number)]
    Acknowledgment number: 155    (relative ack number)
    Acknowledgment number (raw): 911860693
    0101 .... = Header Length: 20 bytes (5)
  > Flags: 0x011 (FIN, ACK)
    Window size value: 516
    [Calculated window size: 132096]
    [Window size scaling factor: 256]
```

Summary

❑The OSI model has seven layers, including:

- ➢The application layer: *e.g.,* HTTP, DNS
- ➢The transport layer: TCP ensures reliable transmission.
- ➢The network layer: IP addresses are used for routing over the Internet.
- ➢The data link layer: A MAC address is unique to each device.