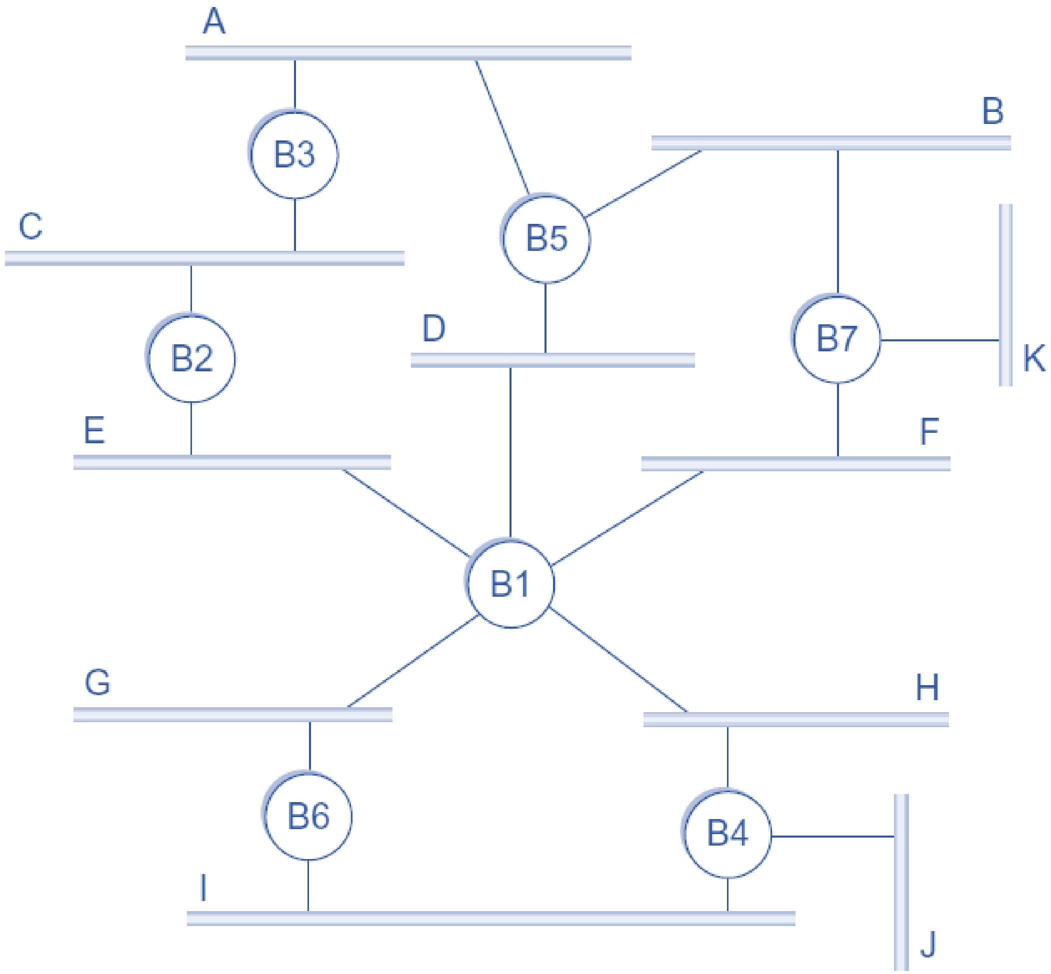
CS120: Computer Networks

Lecture 9. Internet Protocol

Zhice Yang



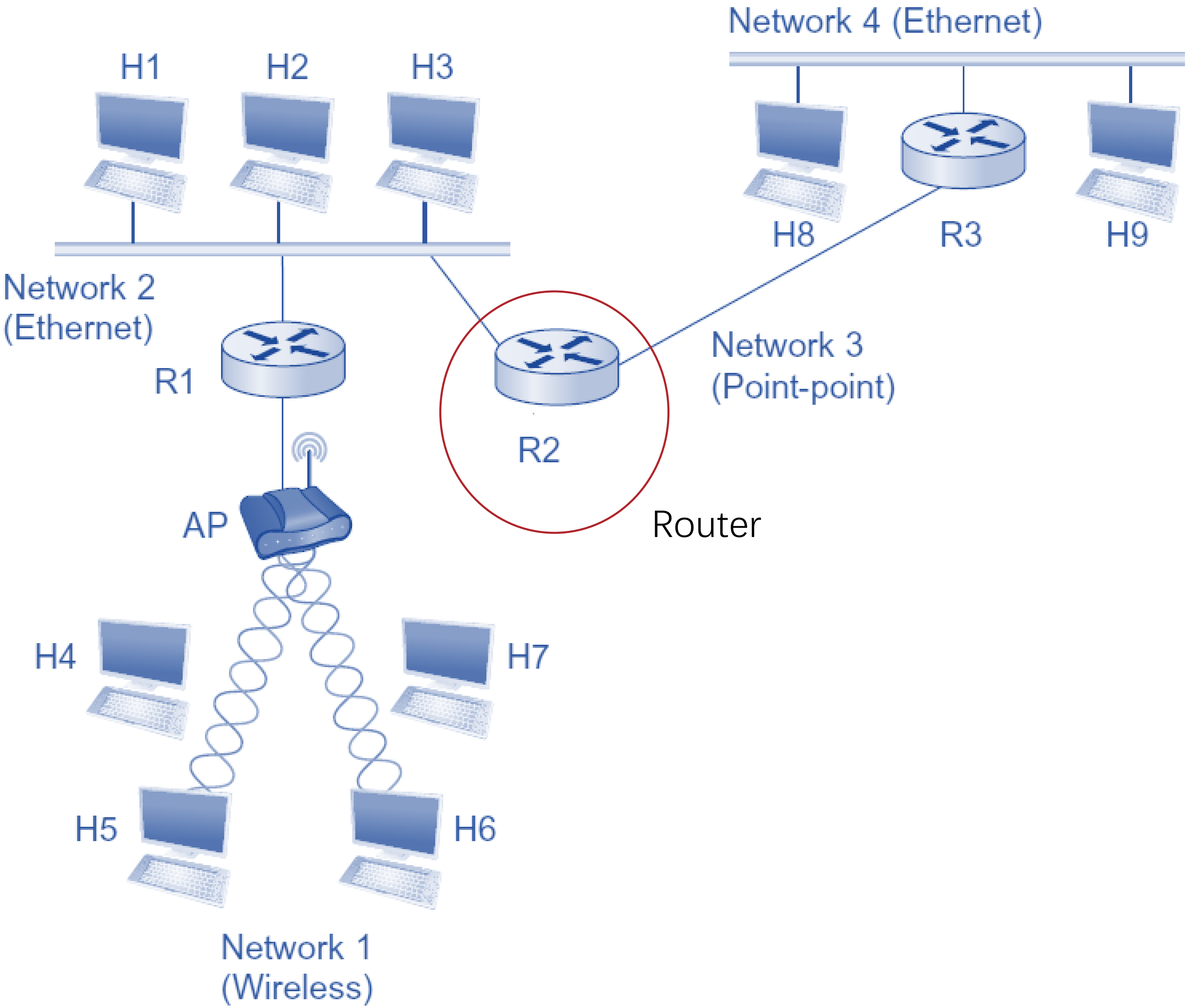
How to Further Extend the Network ?

Limitation of Extended Ethernet

- Addressing Scalability
  - Spanning Tree does not scale
    - Large network
      - Switches store too many forwarding entries
      - Huge broadcasting overhead
- Network Heterogeneity
  - Cannot communicate with other networks
    - Cannot addressing nodes in other networks

Internet Protocol (IP)

- Goal:
- Scalable Addressing Scheme
  - Support Heterogeneous Networks
- Service Model: Datagram (Connectionless)
  - Packets can be lost
  - Packets can be delivered out of order
  - Duplicate copies of a packet can be delivered
  - Packets can be delayed for a long time


Network 4 (Ethernet)
H1
H2
H3
H8
R3
H9
Network 2
(Ethernet)
R1
R2
Network 3
(Point-point)
Router
AP
H4
H7
H5
H6
Network 1
(Wireless)

Outline

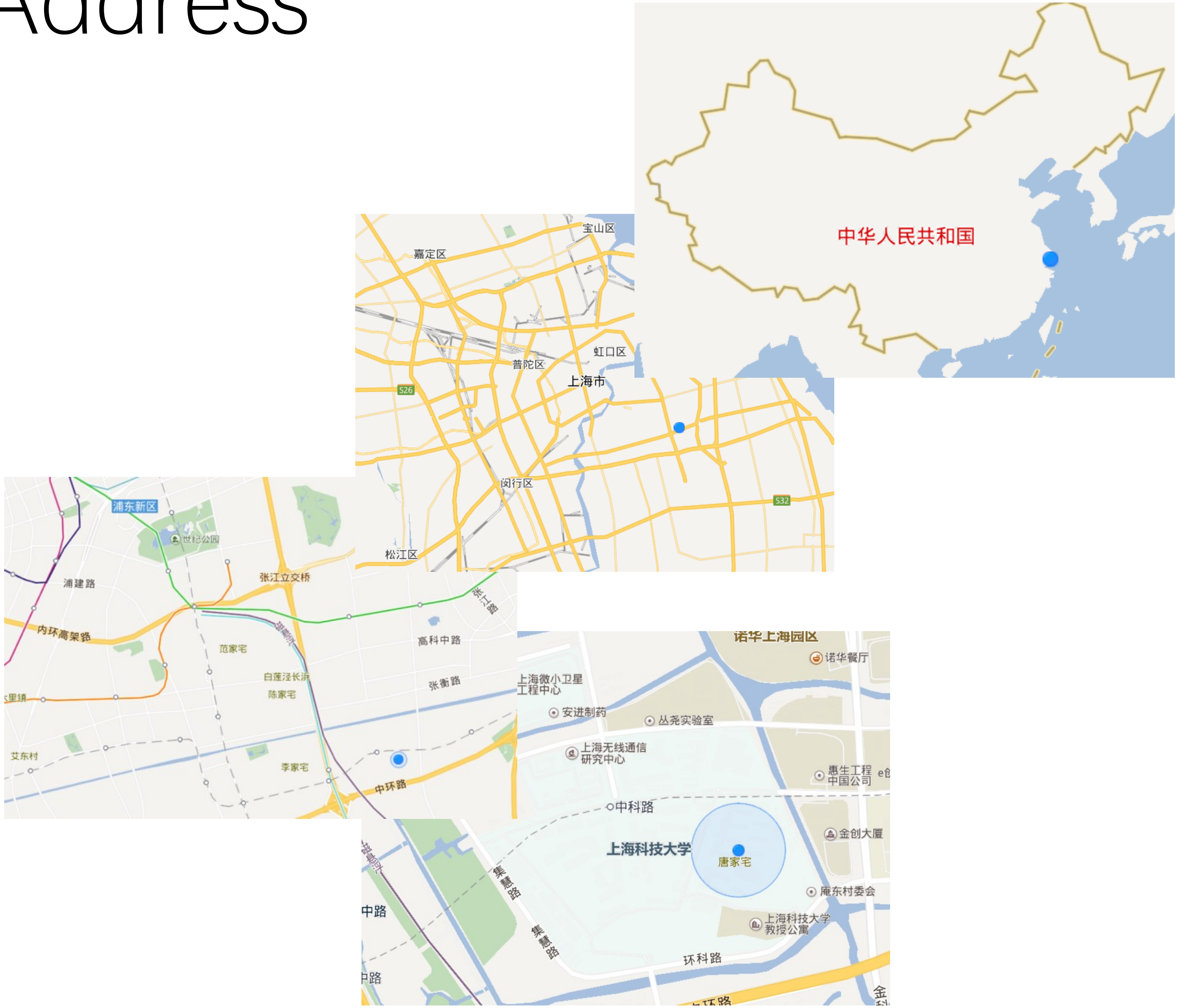
- IP Addressing
  - IP Address
  - Subnet
  - Routing Aggregation
  - IP Distribution: DHCP
  - IP and Switching: ARP
- IP Packet
  - Fragmentation

Addressing in Postal Service

- NAME => Ethernet MAC Address
  - Unique
  - but less informative in finding route to deliver
- In practice we use: Location Address + NAME

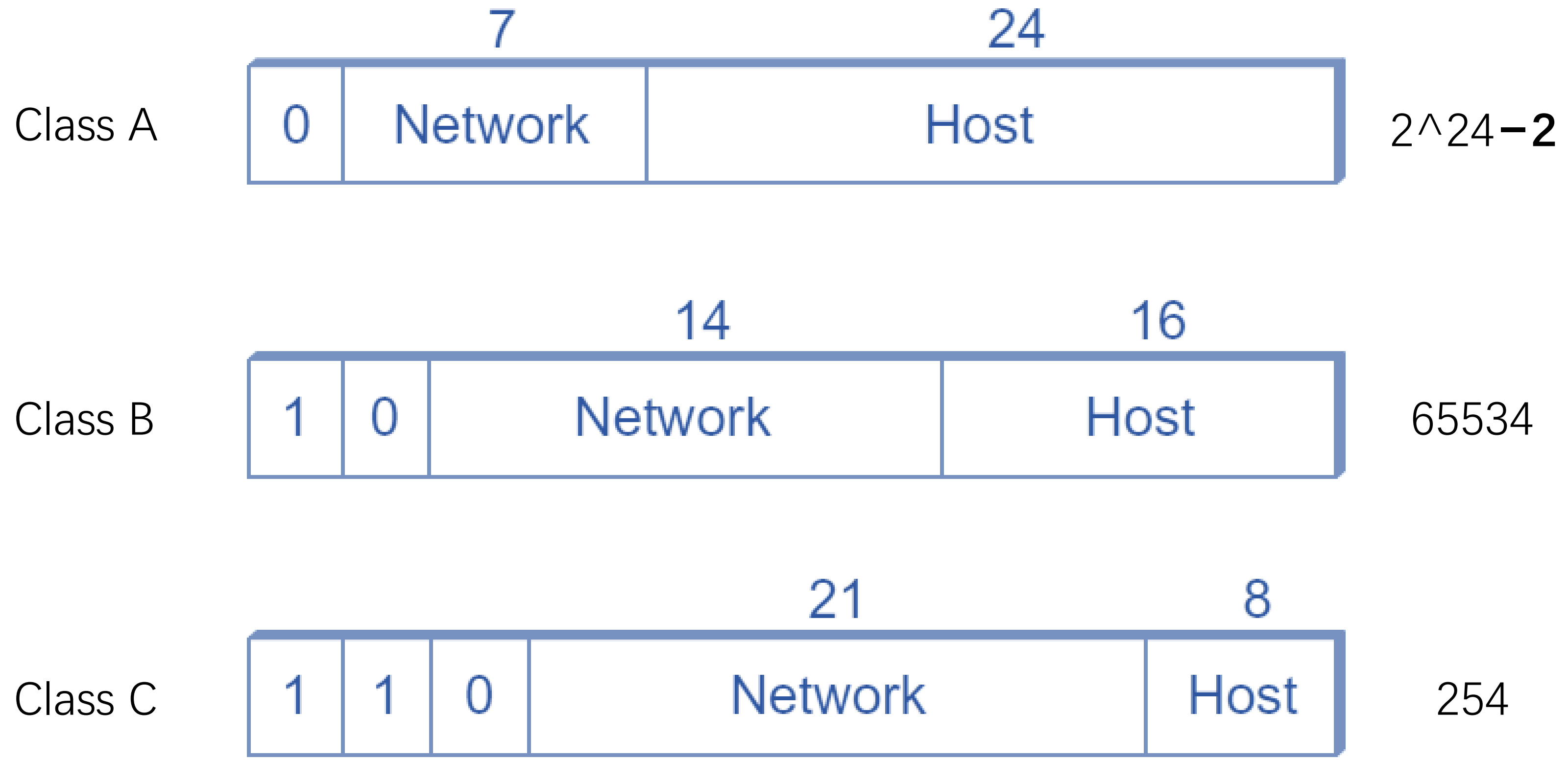
Hierarchical Address

- China
- Shanghai
- Pudong
- ShanghaiTech



IP Address

- IP Address: 32-bit identifier for host or router ports
  - Globally unique (original goal)
  - Hierarchical: network + host (original goal)



IP Address

- Dot notation
    - 10.3.2.4
    - 128.96.33.15
    - 192.12.69.77

10000000 01100000 00100010 00001111

128. 96. 33. 15

Assigning IP Address

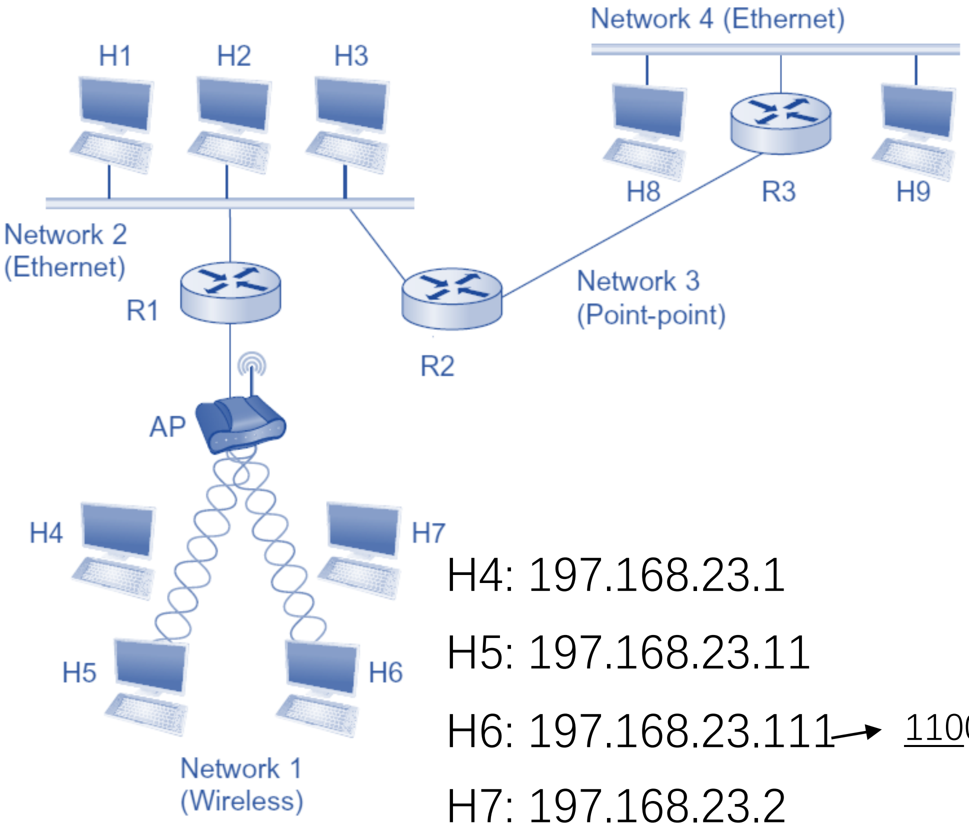
- Each host has a unique IP address
- Hosts in the same physical network have the same network part

H1: 200.155.11.5

H2: 200.155.11.3

H3: 200.155.11.2

11001000.10011011.00001011.XXXXXXXX



H8: 210.168.1.10

H9: 210.168.1.200

11010010.10101000.00000001.XXXXXXXX

H4: 197.168.23.1

H5: 197.168.23.11

H6: 197.168.23.111 → 11000101.10101000.00010111.XXXXXXXX

H7: 197.168.23.2

Assigning IP Address

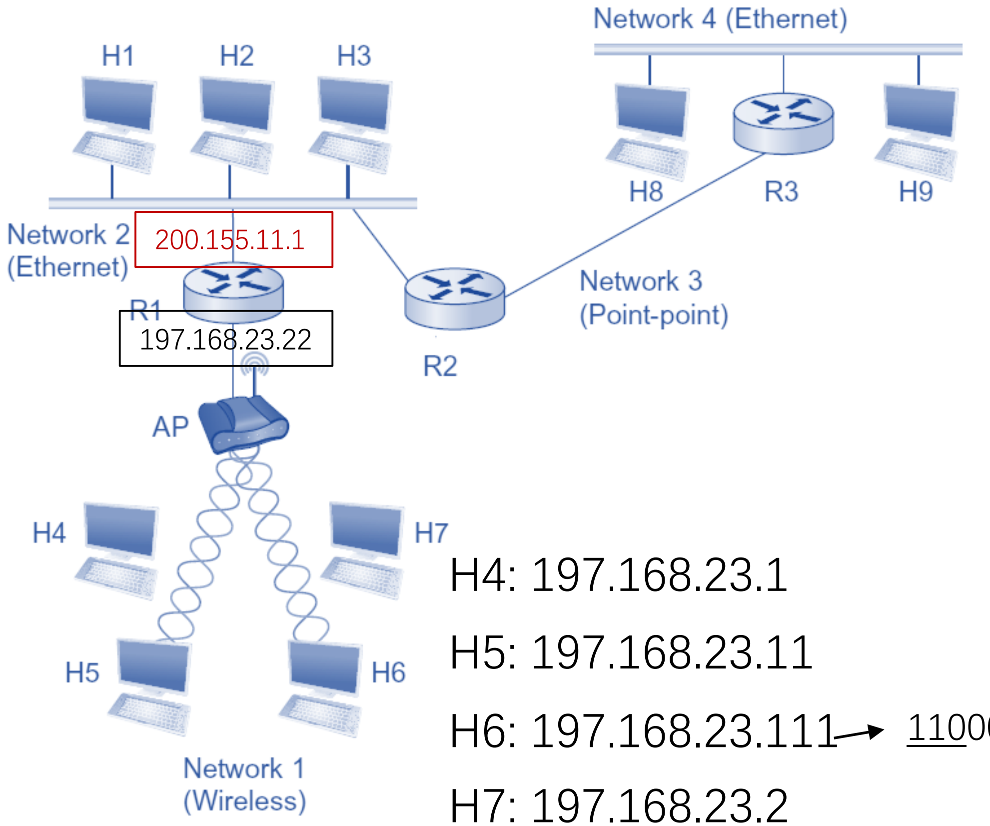
- Each router contains multiple network interfaces
- Each port has the IP address of the connected network

H1: 200.155.11.5

H2: 200.155.11.3

H3: 200.155.11.2

11001000.10011011.00001011.XXXXXXXX



H8: 210.168.1.10

H9: 210.168.1.200

11010010.10101000.00000001.XXXXXXXX

H4: 197.168.23.1

H5: 197.168.23.11

H6: 197.168.23.111 → 11000101.10101000.00010111.XXXXXXXX

H7: 197.168.23.2

Forwarding with IP Address

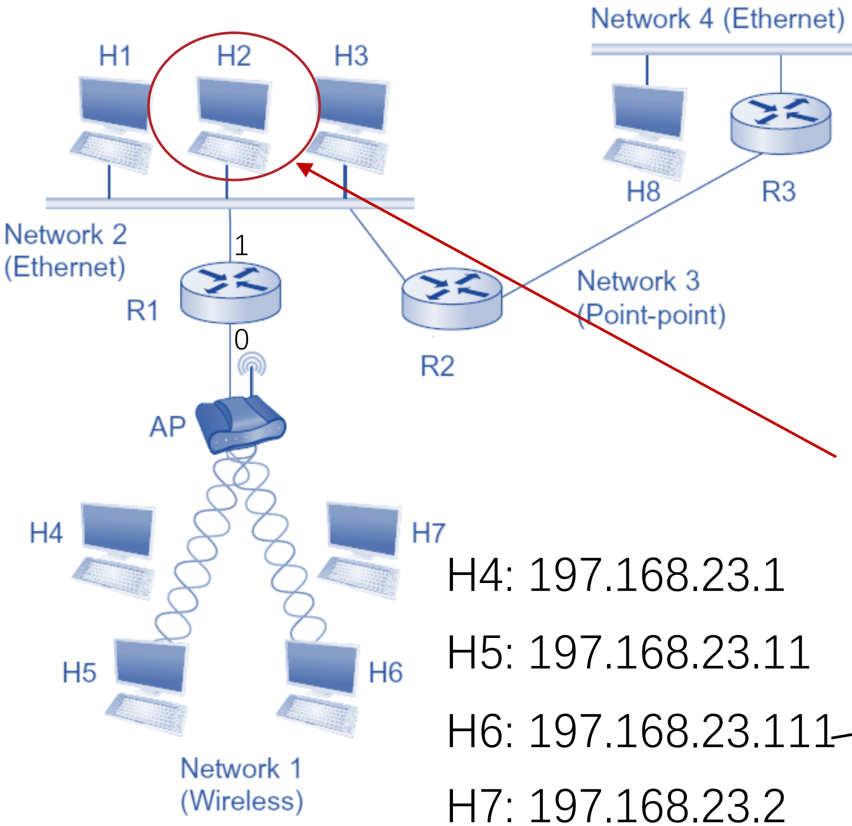
- Host Behavior
  - if IP.network == MyIP.network
    - forward to the host via L2 (How? ARP: IP->MAC)
  - else
    - forward to some router

H1: 200.155.11.5

H2: 200.155.11.3

H3: 200.155.11.2

11001000.10011011.00001011.XXXXXXXX



H8: 210.168.1.10

H9: 210.168.1.200

11010010.10101000.00000001.XXXXXXXX

IP	Next
200.155.11.5 200.155.11.2	H1 H3
Others	R1

H4: 197.168.23.1

H5: 197.168.23.11

H6: 197.168.23.111 → 11000101.10101000.00010111.XXXXXXXX

H7: 197.168.23.2

Forwarding with IP Address

- Router Behavior
  - if IP.network == PortX.IP.network
    - forward to the host connected to PortX
  - else
    - forward to the router (Which? given by routing alg.)

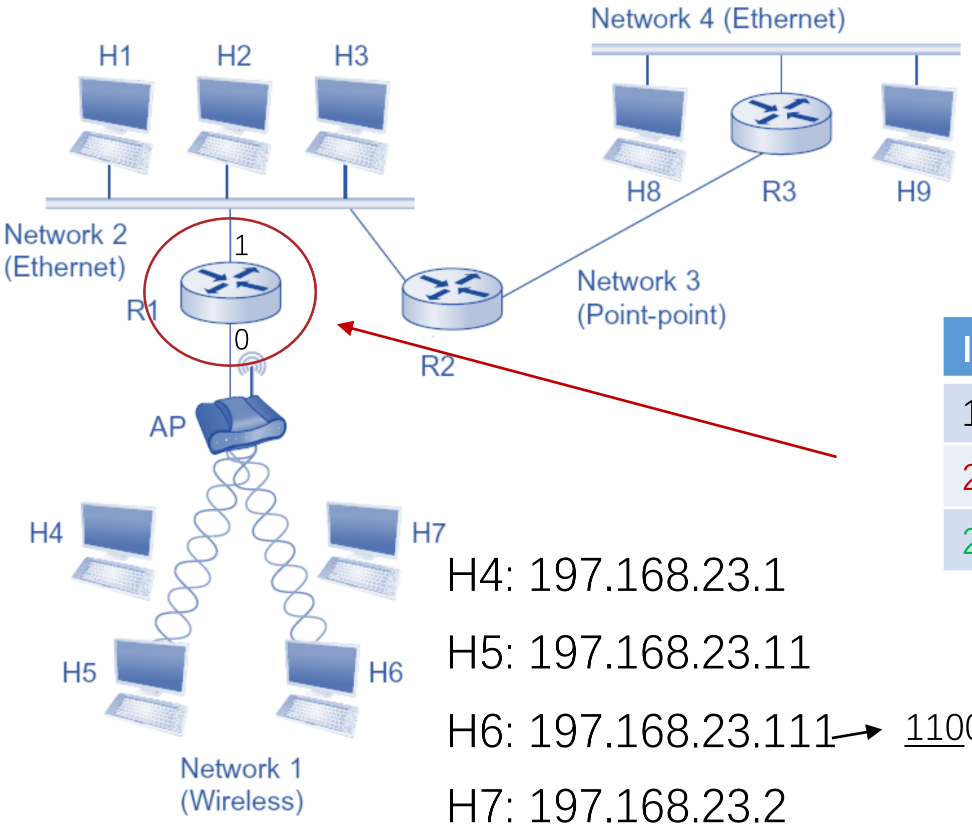
NO need to check the host part

H1: 200.155.11.5

H2: 200.155.11.3

H3: 200.155.11.2

11001000.10011011.00001011.XXXXXXXX



H8: 210.168.1.10

H9: 210.168.1.200

11010010.10101000.00000001.XXXXXXXX

IP	Next
197.168.23.*	Interface 0
200.155.11.*	Interface 1
210.168.1.*	R2

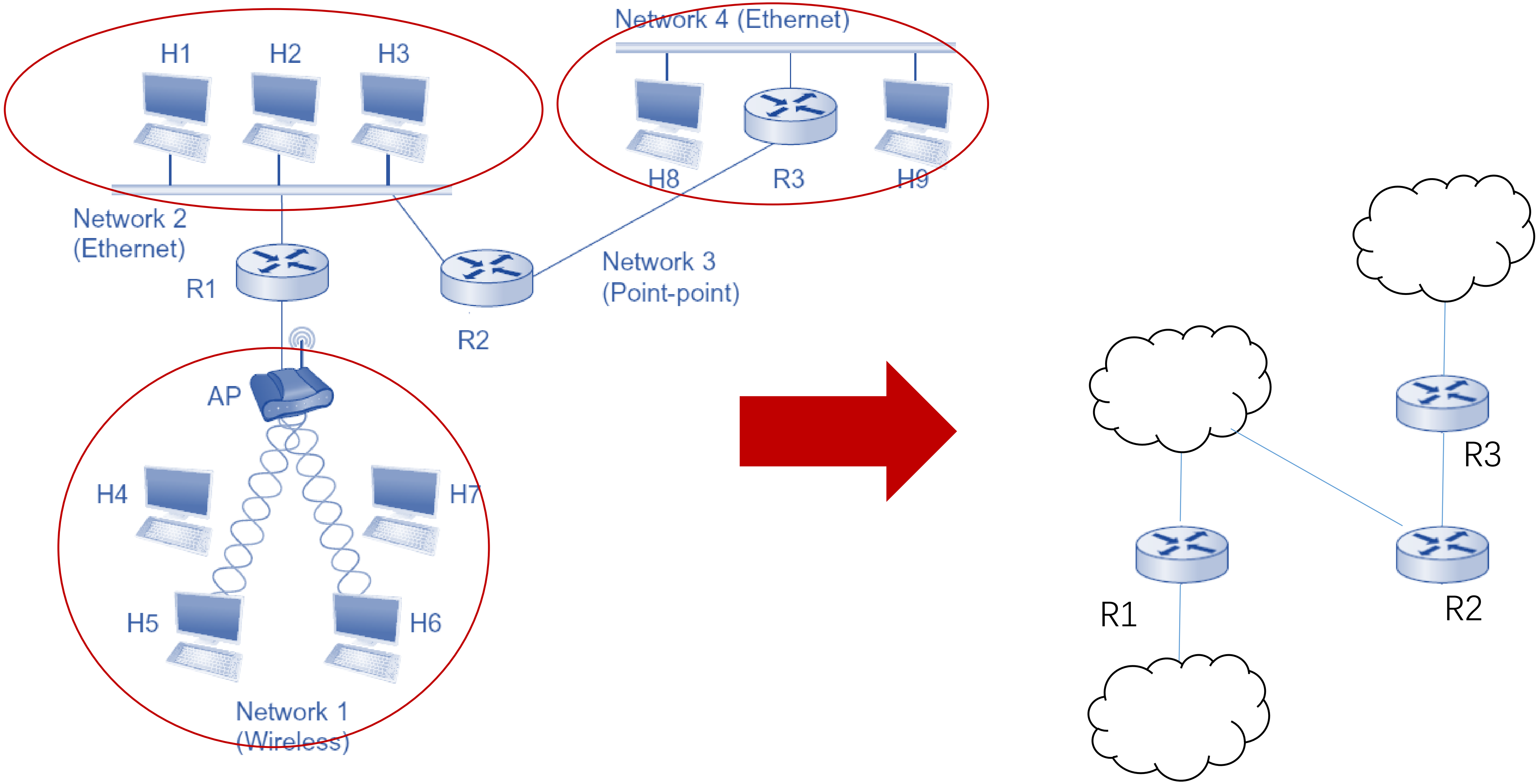
H4: 197.168.23.1

H5: 197.168.23.11

H6: 197.168.23.111 → 11000101.10101000.00010111.XXXXXXXX

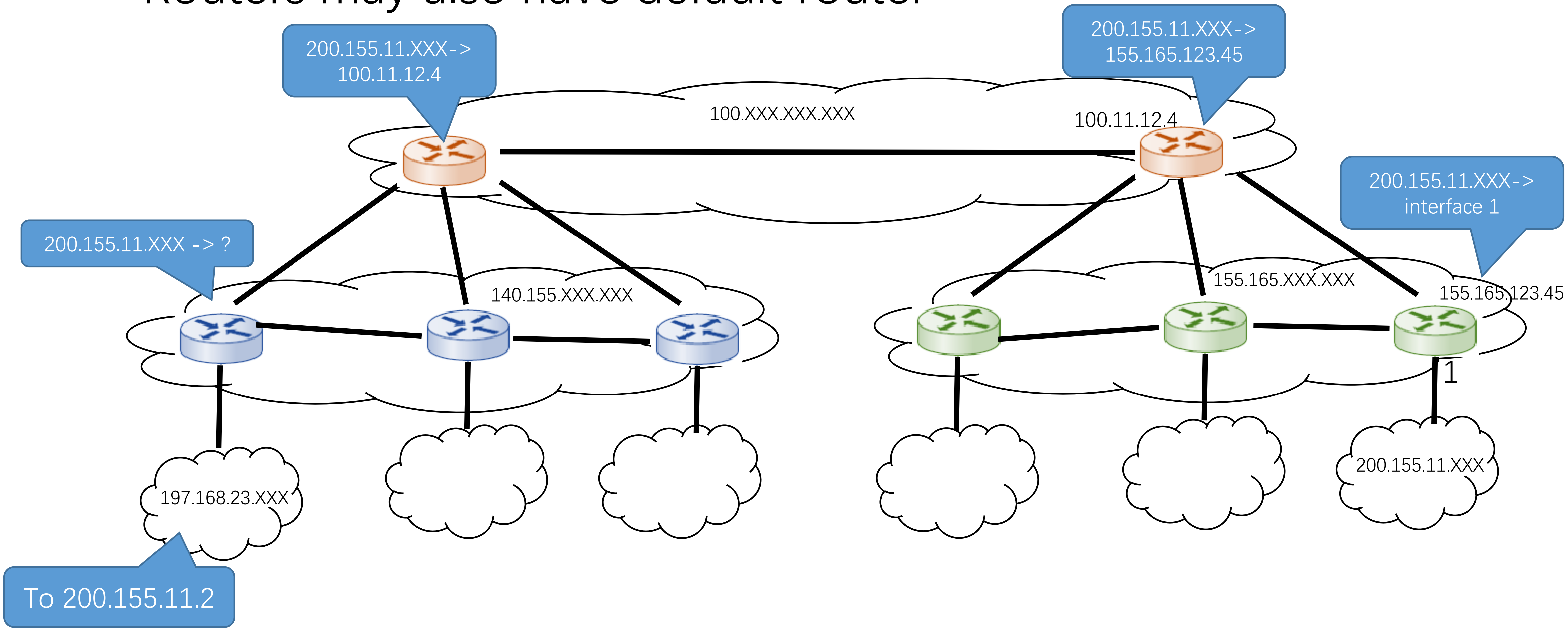
H7: 197.168.23.2

Forwarding with IP Address



Forwarding with IP Address

- Each host has a default router
- Routers may also have default router

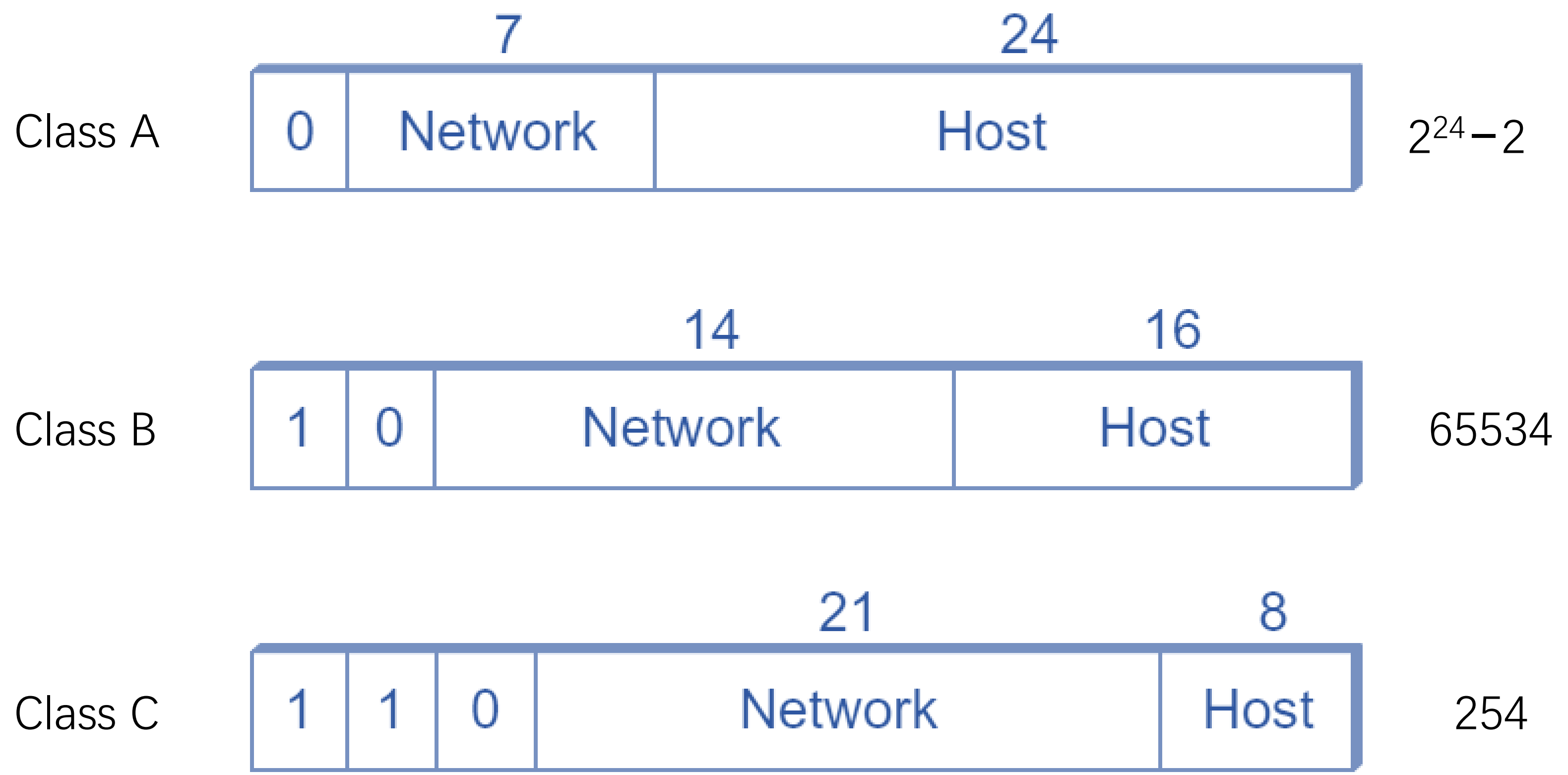


Class Addressing

- Limitation
  - Address utilization is not efficient
    - 255 hosts
      - Class C: not enough
      - Class B: too many addresses are wasted
  - Forwarding table is still large
    - Proportional to the number of networks

IP Address

- IP Address: 32-bit identifier for host, router ports
  - Globally unique (original goal)
  - Hierarchical: network + host (original goal)



Subnet Mask

- "and" IP address with network mask to determine the Subnet

Network   Host

141.155.0.1   10001101.10011011.00000000.00000001

141.155.255.254   10001101.10011011.11111111.11111110

....

Network   Subnet   Host

10001101.10011011.00000000.00000001

10001101.10011011.00000001.11111110

11111111.11111111.11111110.00000000

Subnet Mask

Network   Subnet   Host

10001101.10011011.00000010.00000001

10001101.10011011.00000011.11111110

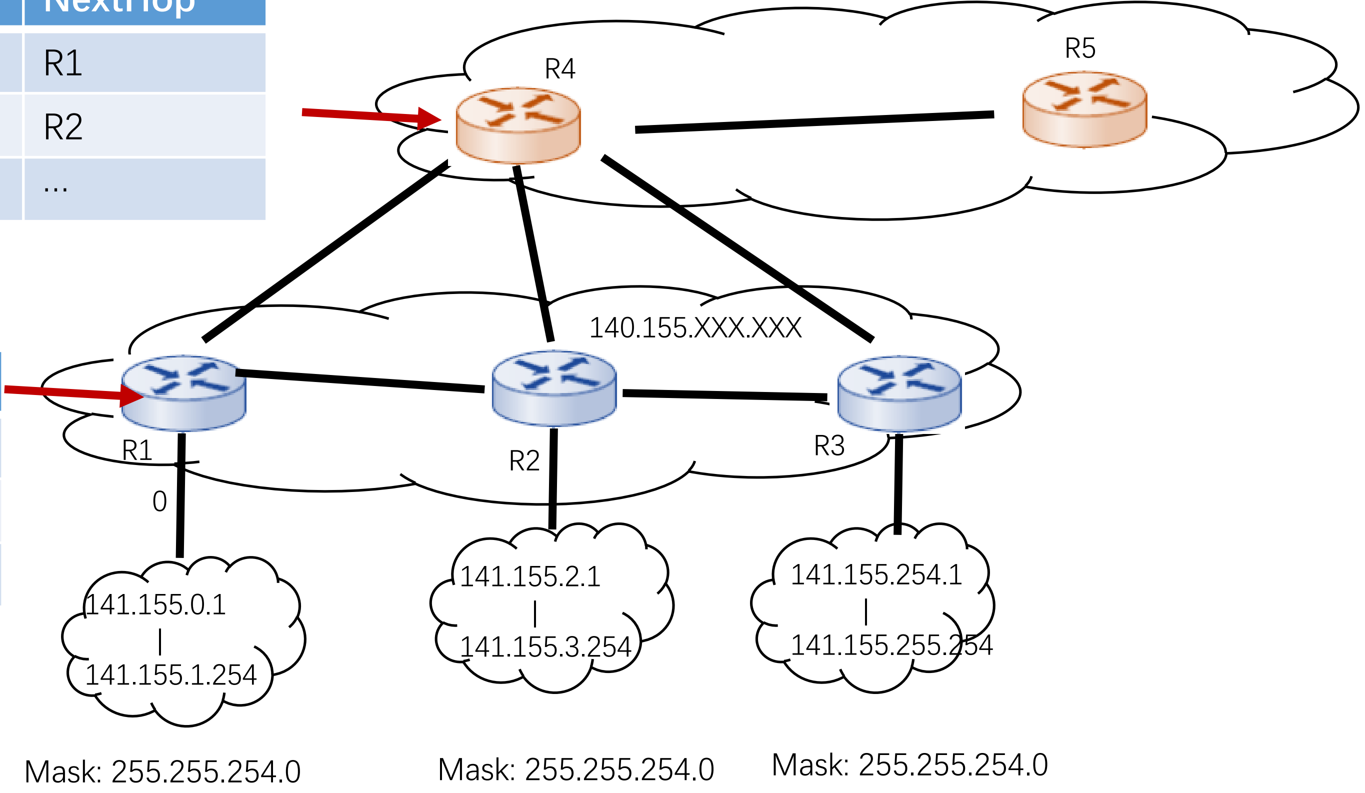
11111111.11111111.11111110.00000000   255.255.254.0

Subnet Mask

- Divide a Large Network Address into Small Subnet Addresses

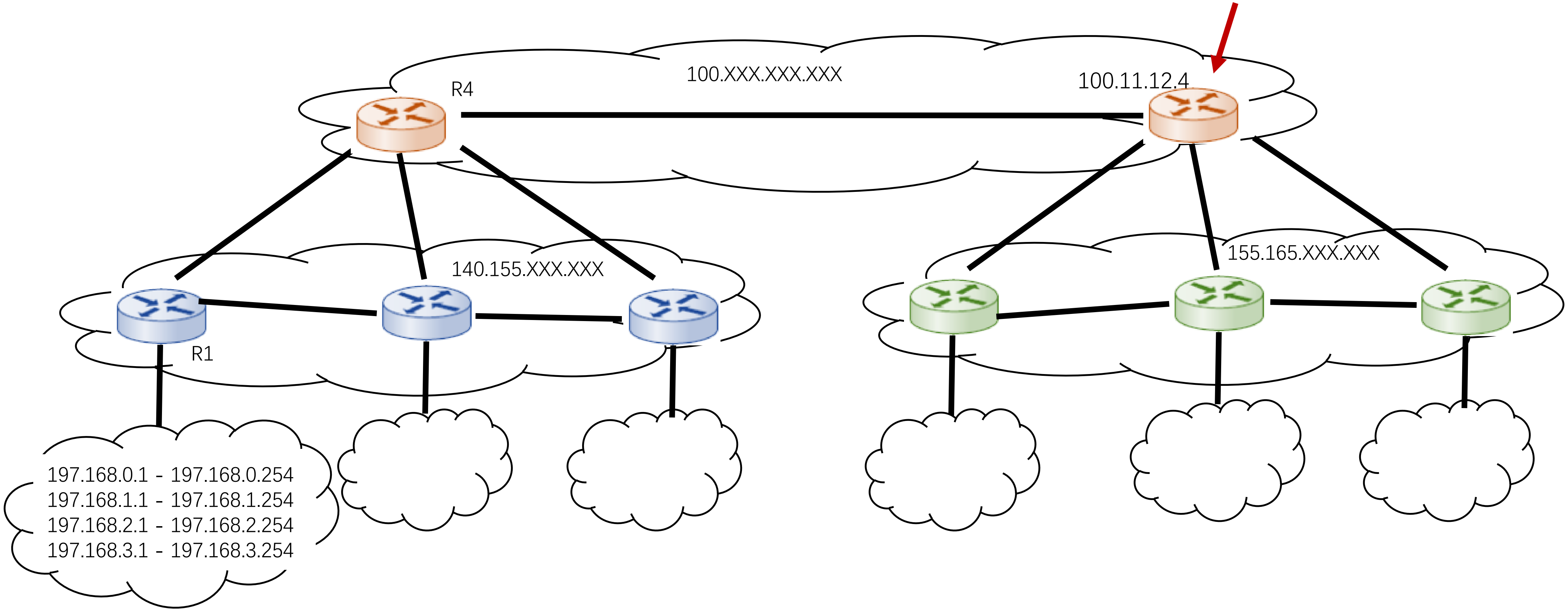
SubnetNum	SubnetMask	NextHop
141.155.0.0	255.255.254.0	R1
141.155.2.0	255.255.254.0	R2
…	…	…

SubnetNum	SubnetMask	NextHop
141.155.0.0	255.255.254.0	Interface 0
141.155.2.0	255.255.254.0	R2
…	…	…



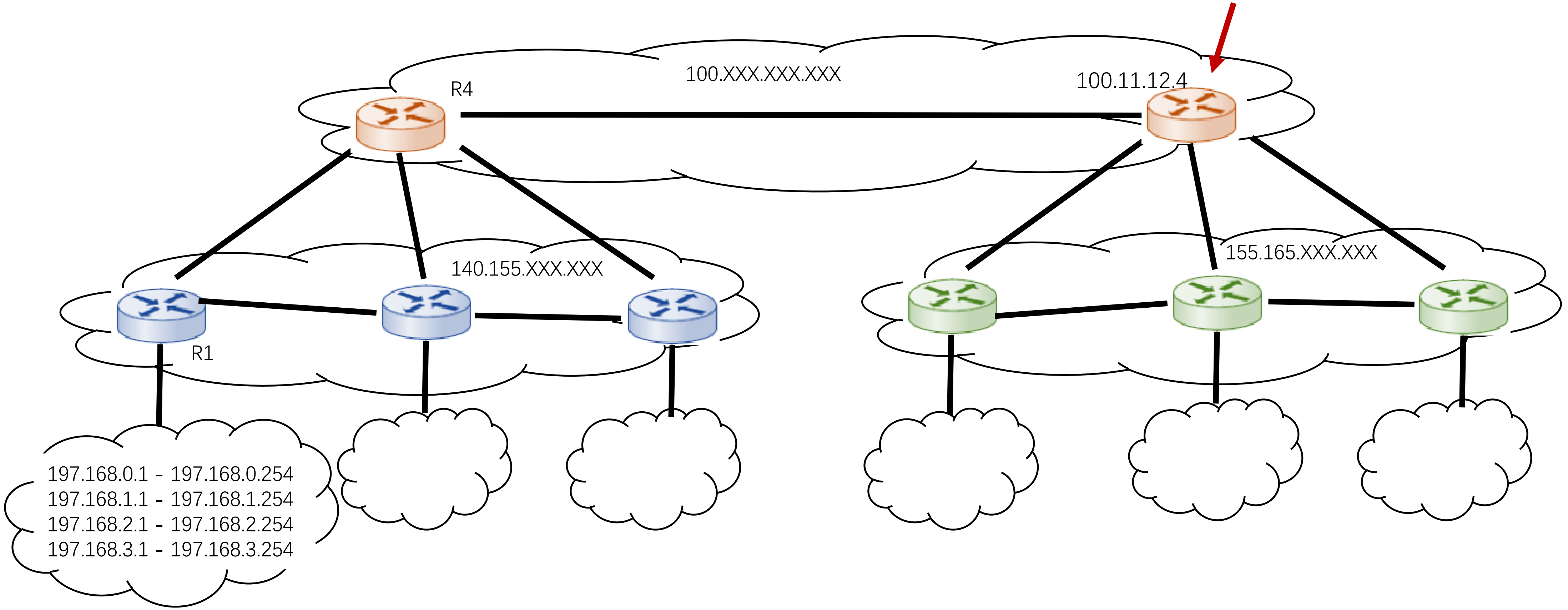
Route Aggregation

SubnetNum	SubnetMask	NextHop
197.168.0.0	255.255.255.0	R4
197.168.1.0	255.255.255.0	R4
197.168.2.0	255.255.255.0	R4
197.168.3.0	255.255.255.0	R4



Route Aggregation

SubnetNum	SubnetMask	NextHop
197.168.0.0	255.255.252.0	R4



Classless InterDomain Routing (CIDR)

- Subnet portion of address is of arbitrary length
- Address format: a.b.c.d/x, where x is # bits in subnet portion of address

141.155.0.1 10001101.10011011.00000000.00000001

| |

141.155.1.254 10001101.10011011.00000001.11111110

Subnet Host

10001101.10011011.00000000.00000001

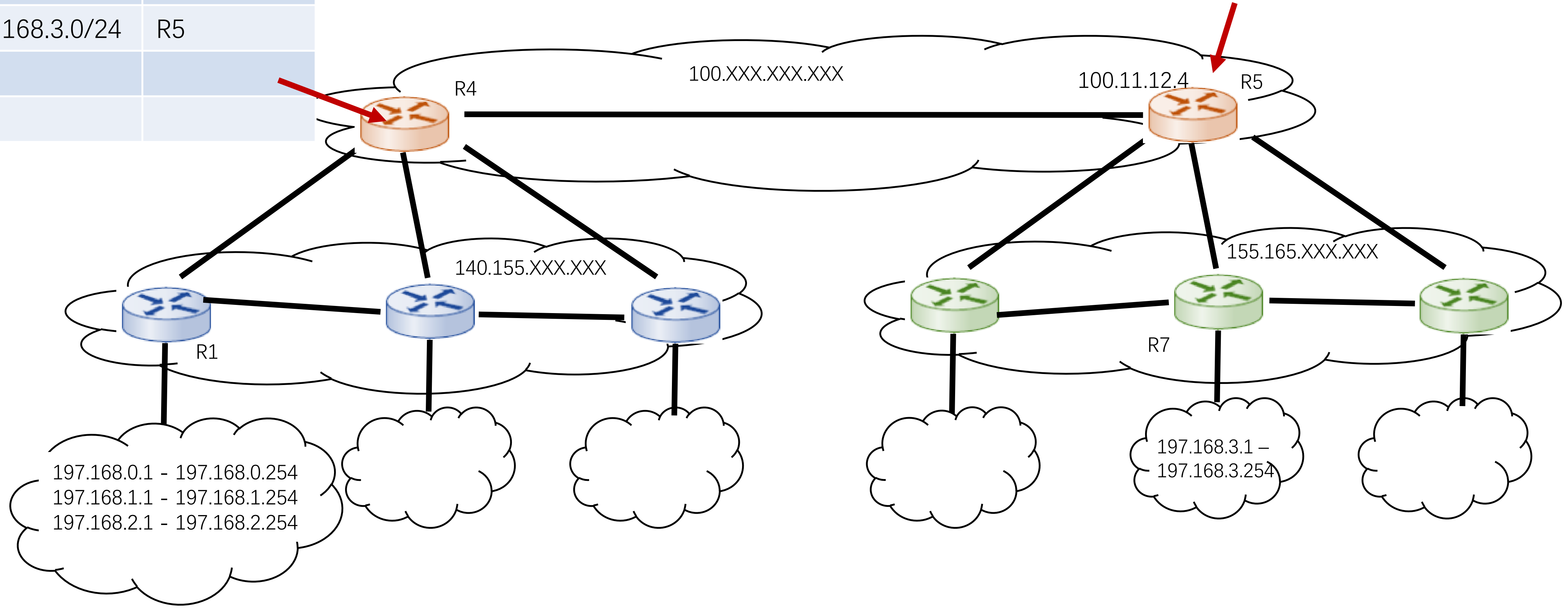
141.155.0.0/23 11111111.11111111.11111110.00000000 Subnet Mask

10001101.10011011.00000001.11111110

Specific Routes ?

SubnetNum	NextHop
197.168.0.0/22	R1
197.168.3.0/24	R5

SubnetNum	NextHop
197.168.0.0/22	R4
197.168.3.0/24	R7



Longest Prefix Matching

- When looking for forwarding table entry for given destination address, use longest address prefix that matches destination address.

SubnetNum	NextHop	
197.168.0.0/22	R4	11000101.10101000.000000**.********
197.168.3.0/24	R7	11000101.10101000.00000011.********
197.168.4.0/22	R9	11000101.10101000.000001**.********

197. 168. 3. 215
11000101.10101000.00000011.11010111 → R7

197. 168. 7. 215
11000101.10101000.00000111.11010111 → R9

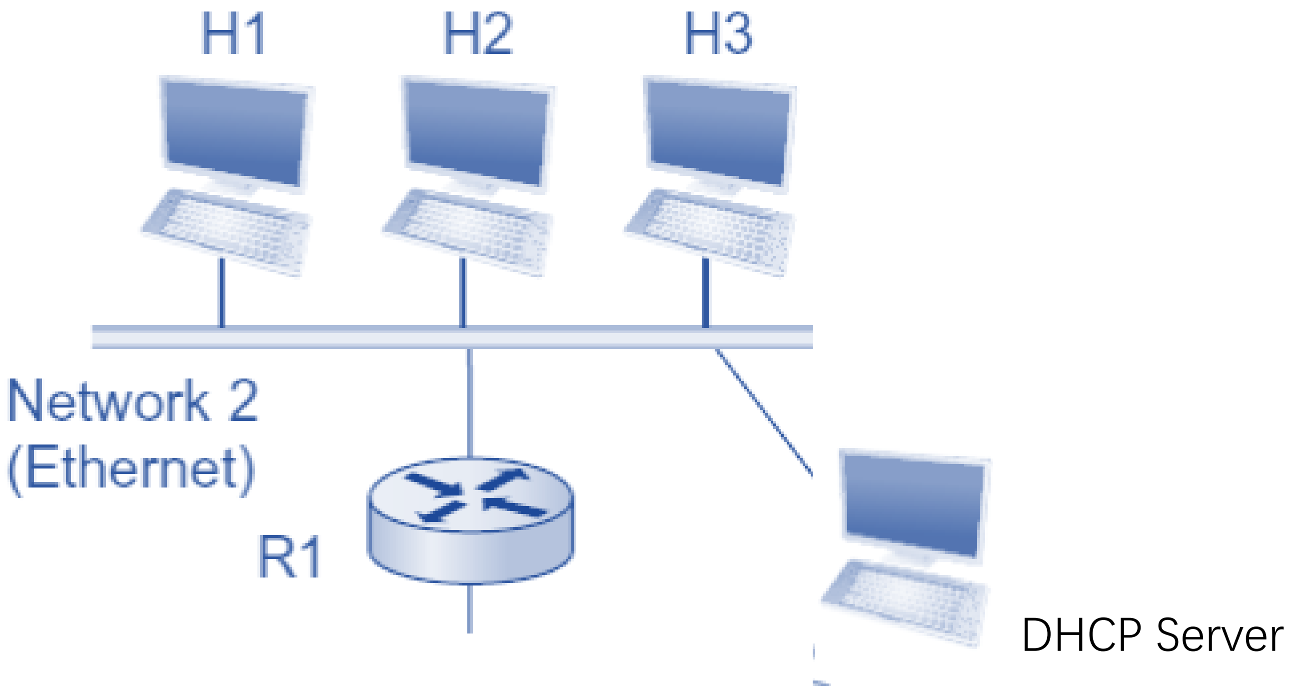
How to Assign IP Addresses ?

- Hard-coded
- Dynamic Host Configuration Protocol (DHCP)
  - Dynamically get IP address from network server

Dynamic Host Configuration Protocol (DHCP)

- Goal: allow host to dynamically obtain its IP address from network server when it joins the network
  - Reuse IP addresses
    - Release IP of unconnected host, e.g. power-off
    - Support for mobile hosts who want to join the network

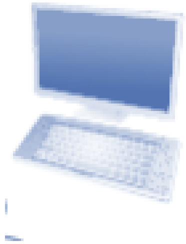
DHCP



DHCP

DHCP Server
223.1.2.1

Client



discover

src MAC: MAC of client
dest MAC: FF:FF:FF:FF:FF:FF
src IP: 0.0.0.0
dest. IP: 255.255.255.255
yiaddr: 0.0.0.0

offer

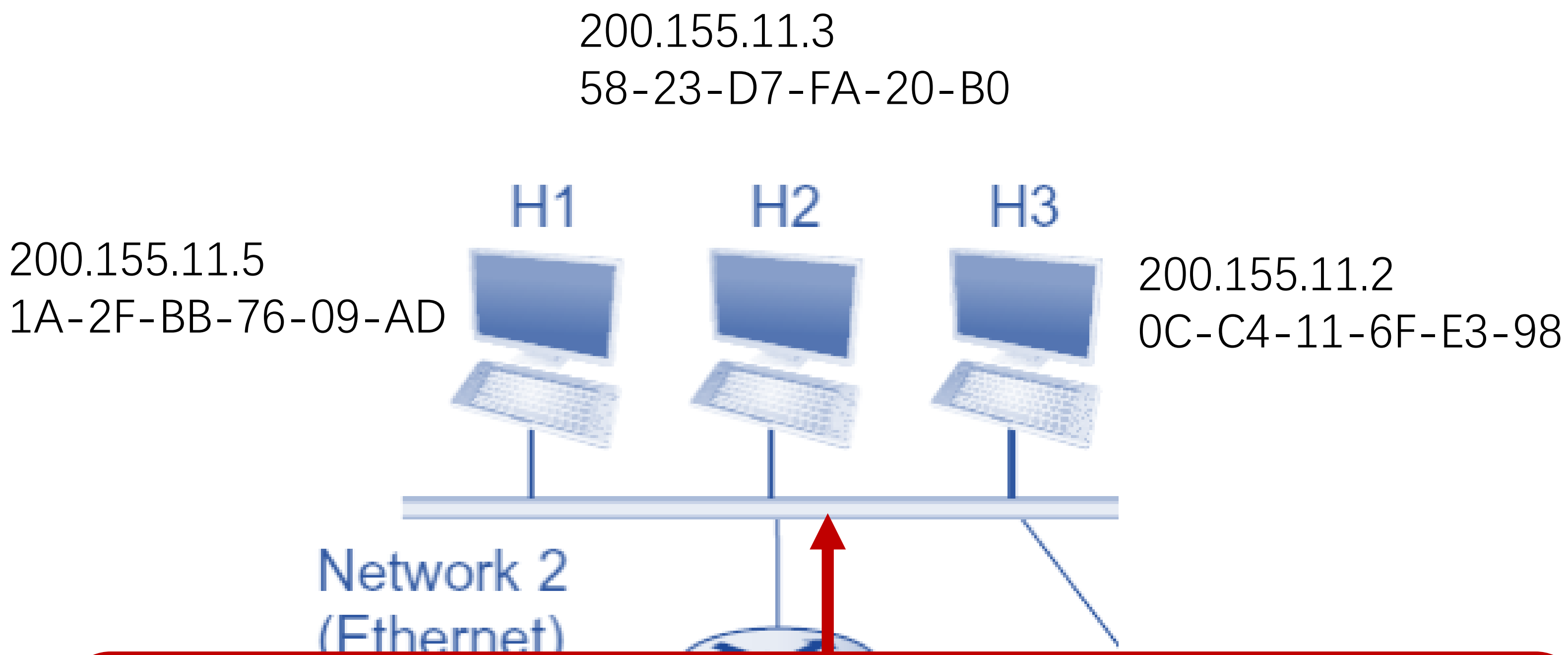
src MAC: MAC of server
dest MAC: MAC of client
src IP: 223.1.2.1
dest. IP : 255.255.255.255
yiaddr: 223.1.2.4

request

src MAC: MAC of client
dest MAC: FF:FF:FF:FF:FF:FF
src IP: 0.0.0.0
dest. IP : 255.255.255.255
ciaddr:223.1.2.4

ack

src MAC: MAC of server
dest MAC: MAC of client
src : 223.1.2.1
dest.: 255.255.255.255
yiaddr: 223.1.2.4



How to Determine the Interface's MAC Address, Knowing its IP address?

Address Resolution Protocol (ARP)

- A wants to send datagrams to B
  - if B’s IP address is in the same subnet and B’s MAC address not in A’s ARP table
    - A broadcasts ARP query packet, containing B's IP address
    - B receives ARP packet, replies to A with its (B's) MAC address
      - Frame is sent to A’s MAC address (unicast)
    - A caches (saves) IP-to-MAC address pair in its ARP table until information becomes old (times out)

Address Resolution Protocol (ARP)

- ARP table: each IP node (host, router) on LAN has table IP/MAC address mappings for some LAN nodes
  - < IP address; MAC address; TTL>
- TTL (Time To Live)
  - Time after which address mapping will be forgotten

200.155.11.3; 58-23-D7-FA-20-B0
200.155.11.5; 1A-2F-BB-76-09-AD
200.155.11.2; 0C-C4-11-6F-E3-98


Addressing: from one
LAN to Another

Demo

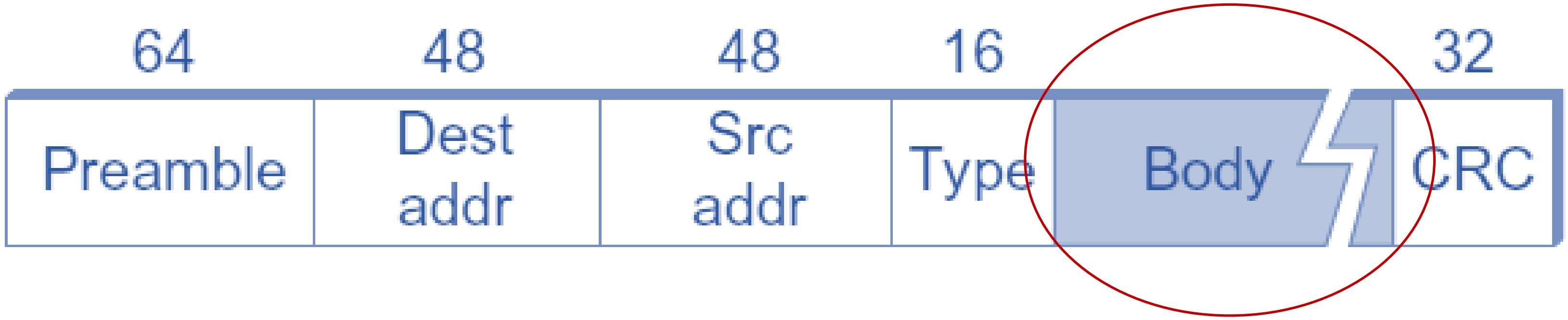
- DHCP
  - Four handshake messages
    - `ipconfig /release`
    - `ipconfig /renew`
- ARP
  - Show arp table: `arp -a`
- Forwarding Table
  - Show Forwarding Table: `route print`

Outline

- IP Addressing
  - IP Address
  - Subnet
  - Routing Aggregation
  - IP Distribution: DHCP
  - IP and Switching: ARP
- ➢IP Packet
  - Fragmentation

Ethernet Frame

- Type
  - IPV4, ARP, RoCE, etc.
  - Length
- Body 46-1500 B
- CRC 32
- NO ACK



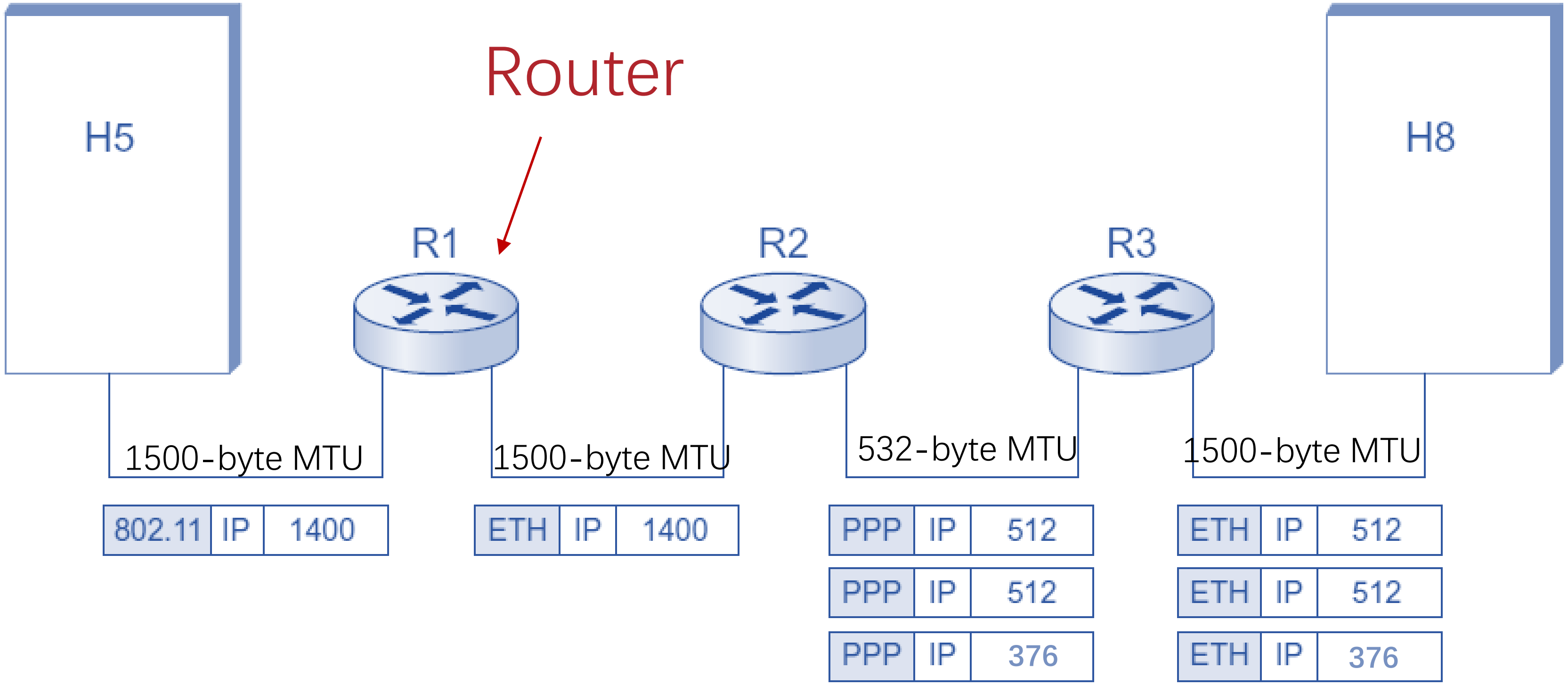
Packet Format

- Version (4): currently 4
- Hlen (4): number of 32-bit words in header
- TOS (8): type of service
- Length (16): number of bytes in this datagram
- Ident (16): used by fragmentation
- Flags/Offset (16): used by fragmentation
- TTL (8): number of hops this datagram has traveled
- Protocol (8): demux key (TCP=6, UDP=17)
- Checksum (16): of the header only
- DestAddr & SrcAddr (32)

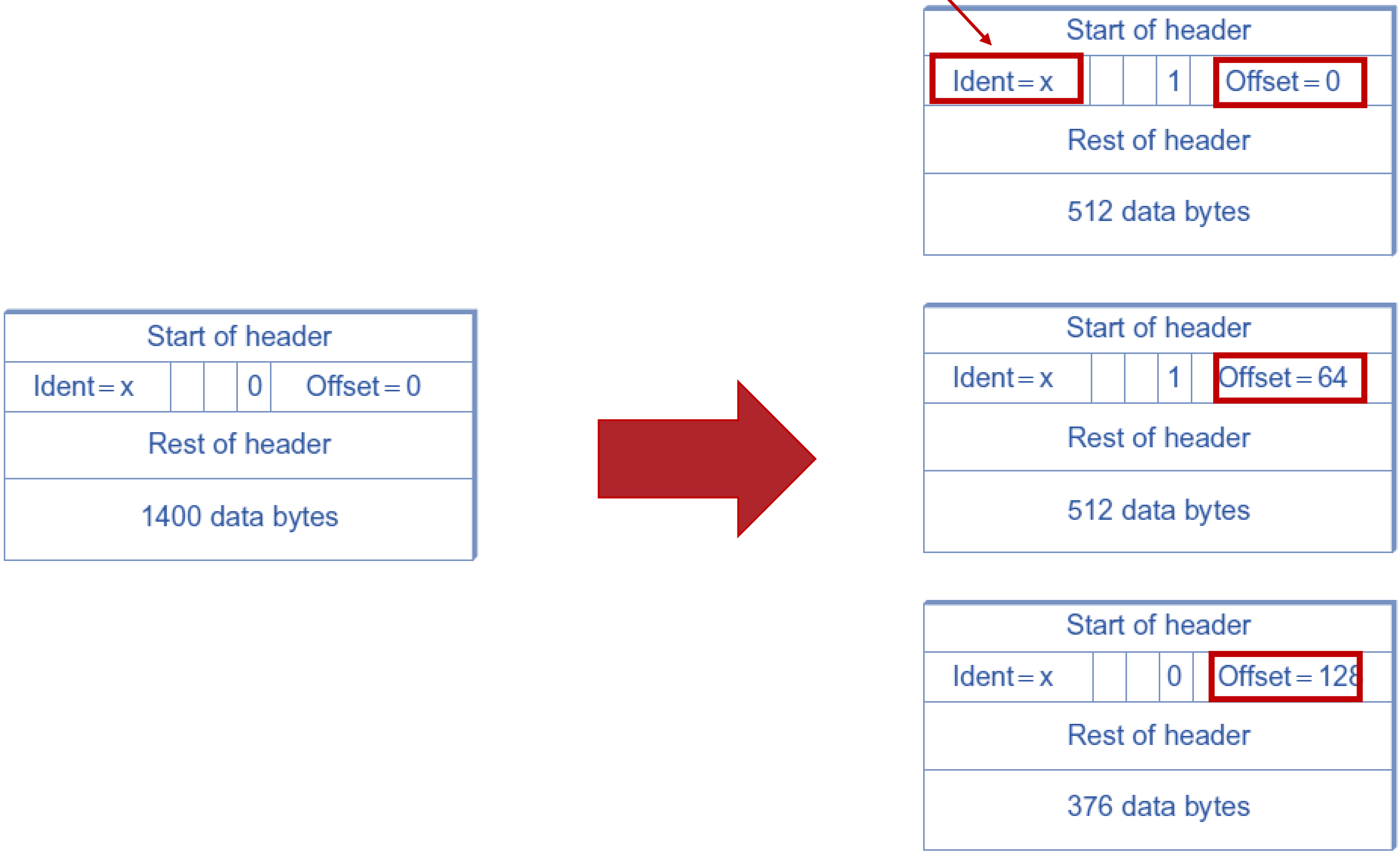
Fragmentation and Reassembly

- Network links have MTU (max.transfer size) - largest possible link-level frame
  - Different link types, different MTUs
- Large datagram is divided (“fragmented”) within net
  - One datagram becomes several datagrams
  - “Reassembled” only at final destination

Fragmentation and Reassembly



Identify the group of the fragments



Reference

- Textbook 3.2