Computer Networks

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Chapter 4. Internetworking

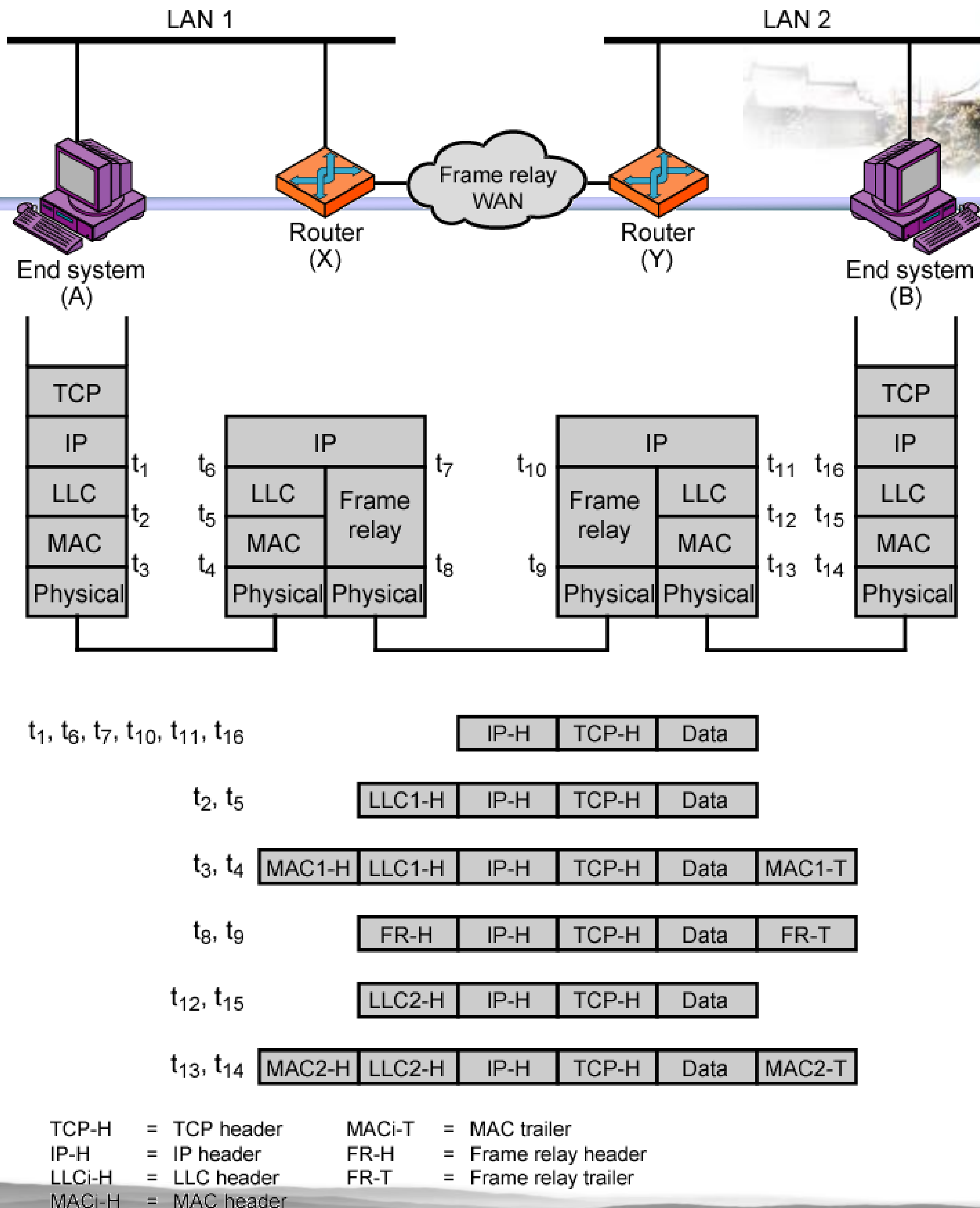
- The Internet Protocol
- IP Address
- ARP and DHCP
- ICMP
- IPv6
- Mobile IP
- Internet Routing
- BGP and OSPF
- IP Multicasting
- Multiprotocol Label Switching (MPLS)

Chapter 4.

ARP and DHCP

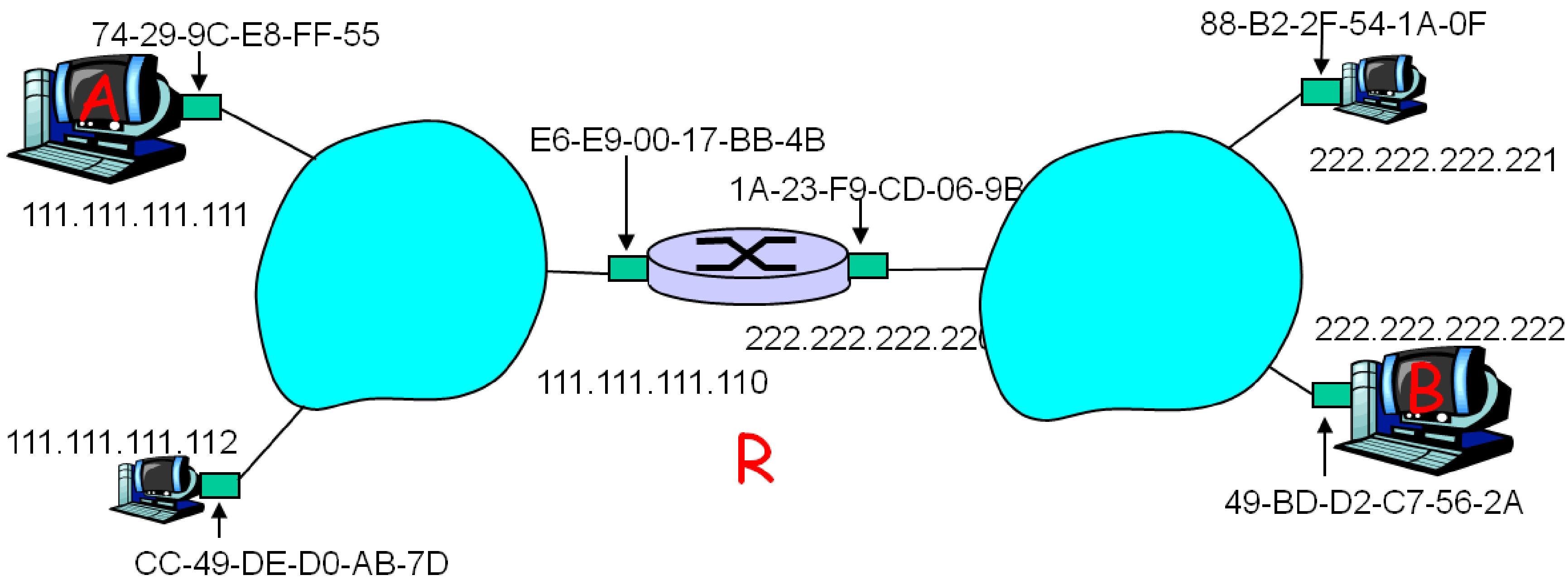
- ARP (Address Resolution Protocol)
  - Convert an IP address into a physical (MAC) address using broadcasts, typical for LAN users
- DHCP (Dynamic Host Configuration Protocol)
  - Assign dynamic IP addresses to hosts on a network, typical for dial-up and LAN users

IP Forwarding



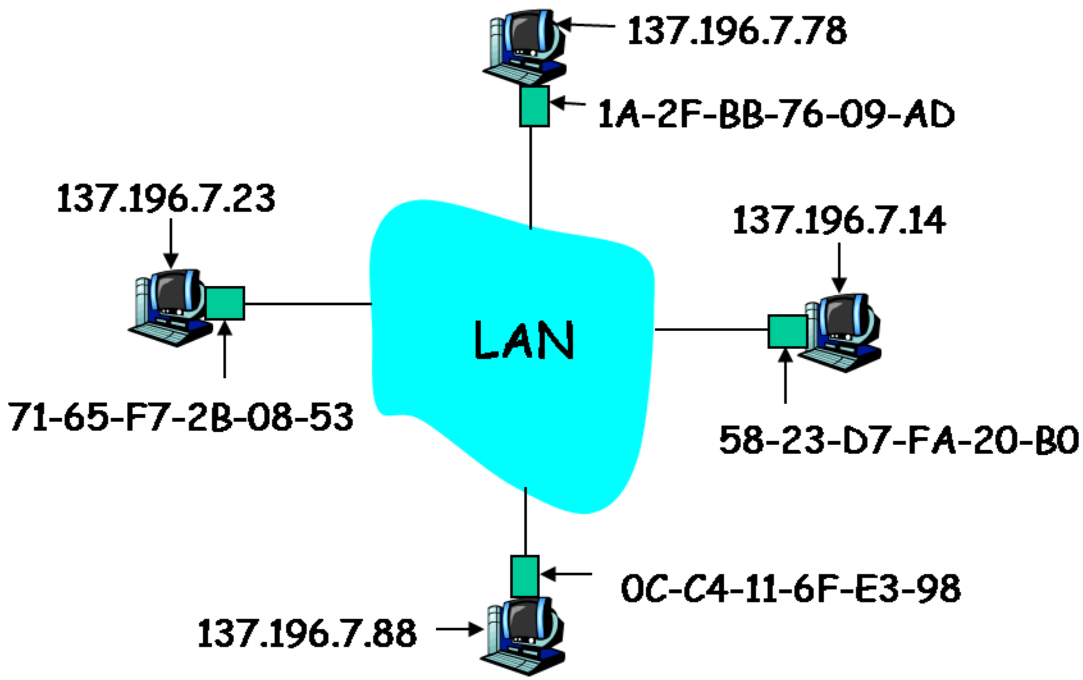
Try Handling out Addresses

- Walkthrough: send datagram from A to B via R



Address Resolution Protocol

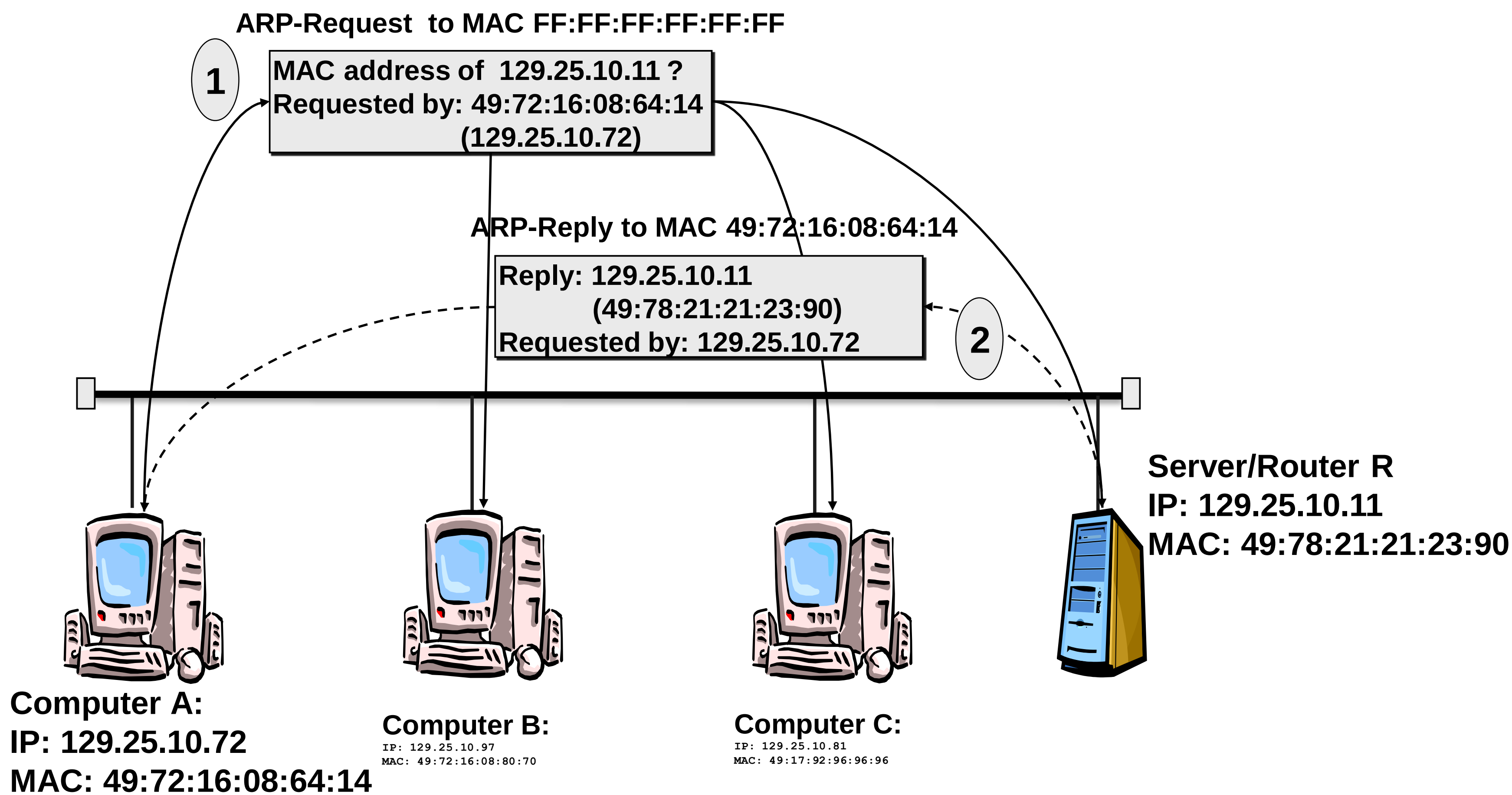
- User access bbs.nju.edu.cn
- DNS gives its IP address 202.119.32.12
- Its MAC address is needed to deliver the data
- On LAN, ARP is used get a host/router's MAC given its IP address



ARP Procedure

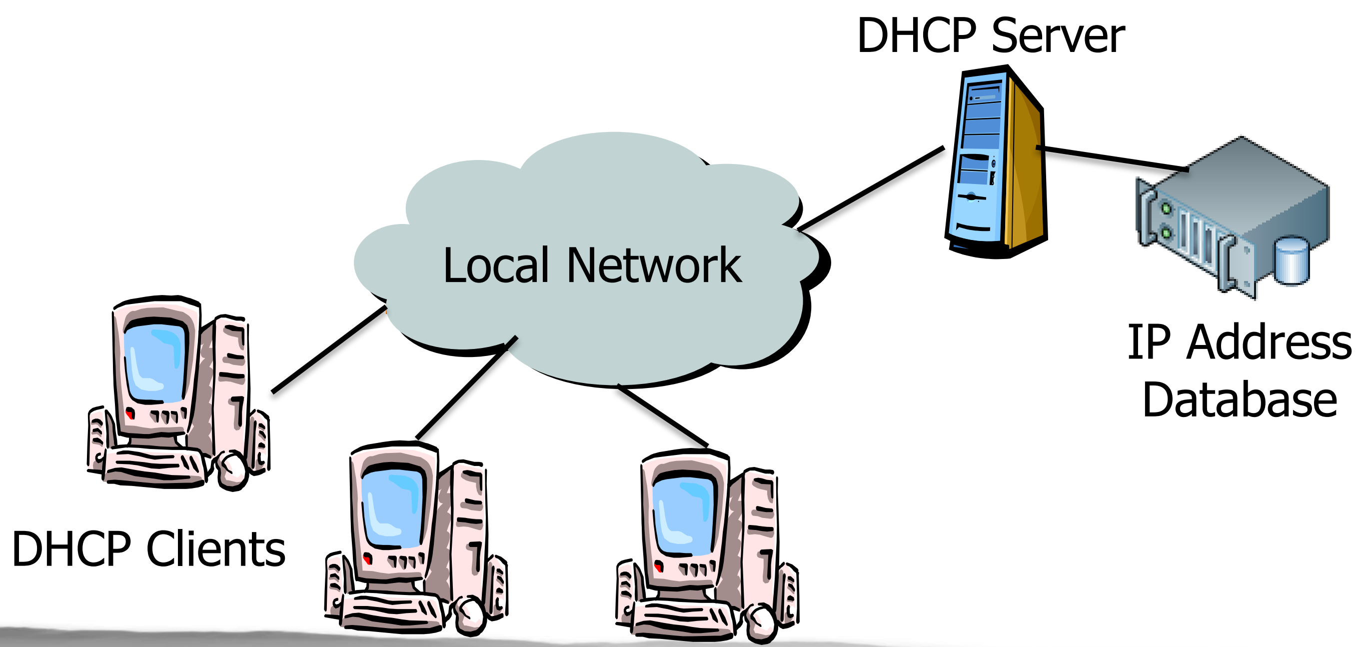
- Sender
  - Looks into local cache first, if none
  - Constructs ARP request, insert <*sender IP*, *sender MAC*, *destination IP*>
  - Broadcasts using MAC frame
  - Caches destination's <*MAC*, *IP*> pair with timestamp
- Receiver
  - Checks the destination IP, if OK
  - Constructs ARP reply, insert <*destination IP*, *destination MAC*>
  - Sends to sender MAC using MAC frame
  - Caches sender's <*MAC*, *IP*> pair with timestamp

Illustration of ARP

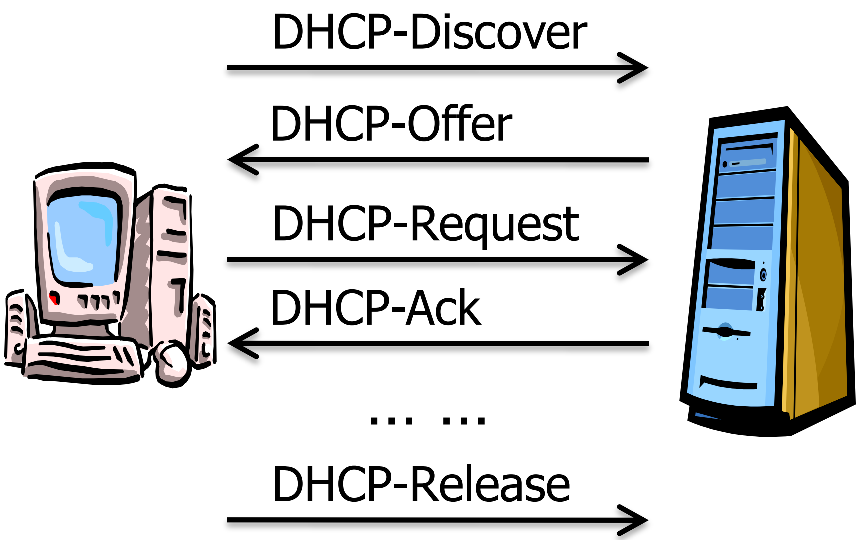


DHCP

- Dynamic Host Configuration Protocol
  - An extension of Bootstrap protocol (BOOTP), built on top of UDP (Port 67/68)
  - For passing configuration information to hosts on a TCP/IP network

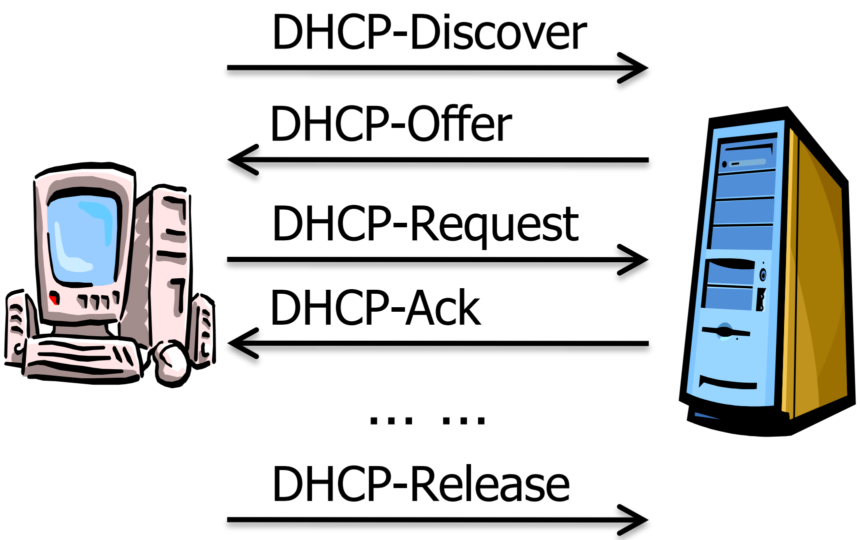


Typical Procedure of DHCP



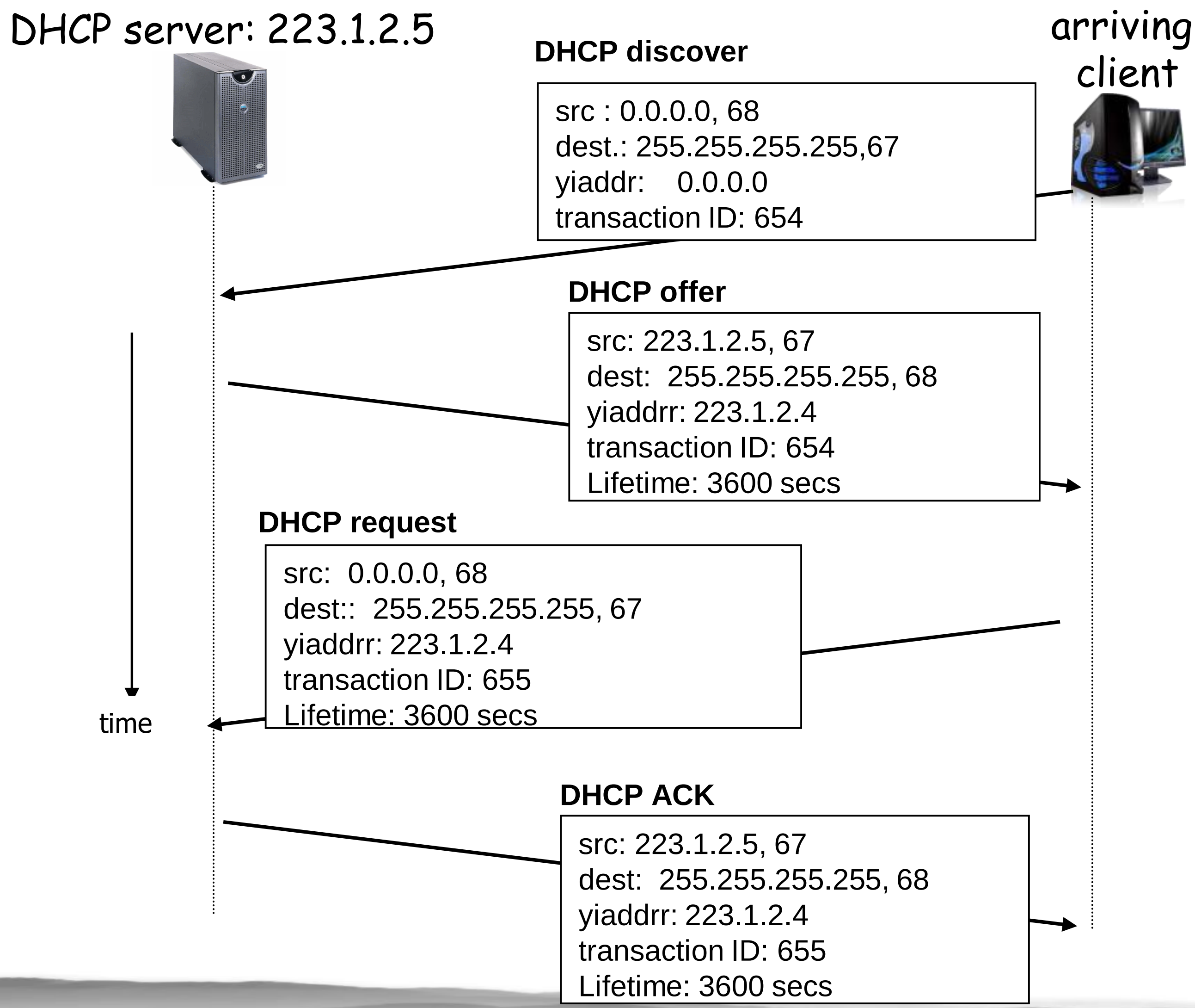
- The client broadcasts a DHCP-DISCOVER message on its subnet
- Each server may respond with a DHCP-OFFER message
- The client chooses one server, broadcasts a DHCP-REQUEST message including server IP
- The selected server commits the binding, responds with a DHCP-ACK message

Typical Procedure of DHCP



- The client set its configuration parameters within the DHCP-ACK
- The client relinquish the binding by a DHCP-RELEASE message
- The binding will be expired if the client does not renew (rebind) the binding before

DHCP Messages



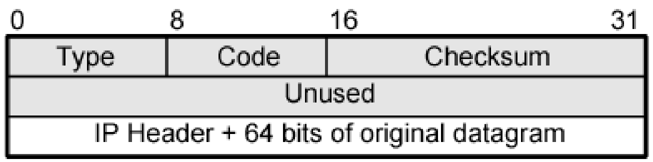
ICMP

- Internet Control Message Protocol (RFC 792)

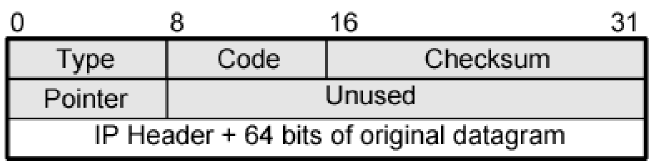
- Transfer of error and control msgs among routers and hosts
  - Echo request and reply to facilitate diagnostic
  - Feedback about problems, e.g. time to live expired, unreachable host

- Encapsulated in IP datagram
  - Protocol type = 1
  - Not reliable

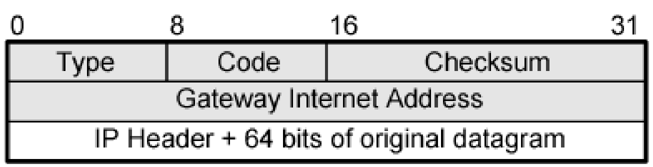
ICMP Message Formats



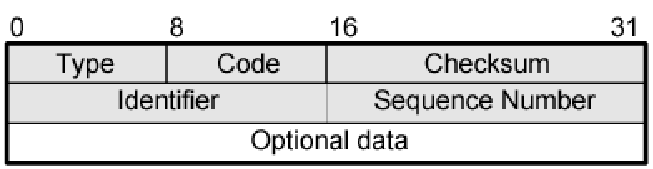
(a) Destination Unreachable; Time Exceeded; Source Quench



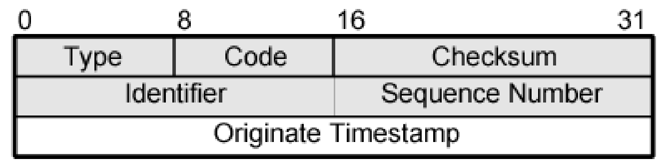
(b) Parameter Problem



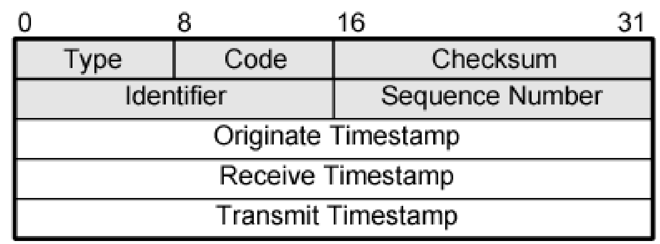
(c) Redirect



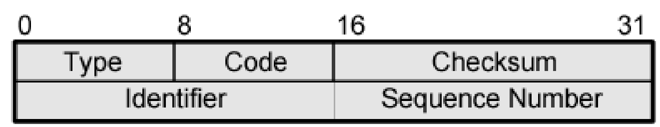
(d) Echo, Echo Reply



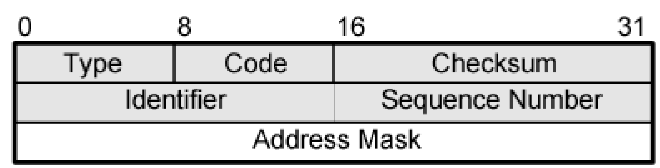
(e) Timestamp



(f) Timestamp Reply



(g) Address Mask Request



(h) Address Mask Reply

Some ICMP Message Types

Type	Code	description
0	0	echo reply (ping)
3	0	dest. network unreachable
3	1	dest host unreachable
3	2	dest protocol unreachable
3	3	dest port unreachable
3	6	dest network unknown
3	7	dest host unknown
4	0	source quench (congestion control)
8	0	echo request (ping)
9	0	route advertisement
10	0	router discovery
11	0	TTL expired
12	0	Parameter unintelligible
13	0	timestamp
14	0	timestamp reply
15	0	address mask request
16	0	address mask reply

Using ICMP – Ping

- Test destination reachability

- Source sends *echo request* to a remote host or router
- If remote system receives the ICMP packet, it sends back an *echo reply* to source

- The ping utility may further do
  - Calculate round-trip time
  - Count the number of hops to destination (use TTL)

Using ICMP – Traceroute

- Measures the number of hops required to reach a destination

- Source sends 1st IP (UDP) packet with the TTL value set to 1
- The first router decrements the TTL to 0, discards the packet, sends a TTL expired back
- Source calculates RTT, and repeat 3 times

- Source sends 2nd IP packet with the TTL set to 2
- The second router will send back a TTL expired
- Source calculates RTT, and repeat 3 times

- Source repeats this with increasing TTL until destination is reached (or host unreachable)
- May suffer from dynamic routing (how?)

Using ICMP – Path MTU

- Determines the minimum MTU along the path to destination

- Source sends a large IP packet with don't fragment bit set
- If packet too large, relevant router will send back a parameter unintelligible

- Source decrements the packet length accordingly and tries again
- Until the packet reaches destination without ICMP error message

- Also suffer from dynamic routing

IPv6

- Initial motivation: address space exhaustion
  - Rapid growth of networks and the Internet
  - 32-bit address space (esp. net address) soon to be completely allocated

- Additional motivation
  - New header format helps speed processing and forwarding
  - Header changes to facilitate QOS
  - No fragmentation at router

  - New address mode: route to “best” of several replicated servers

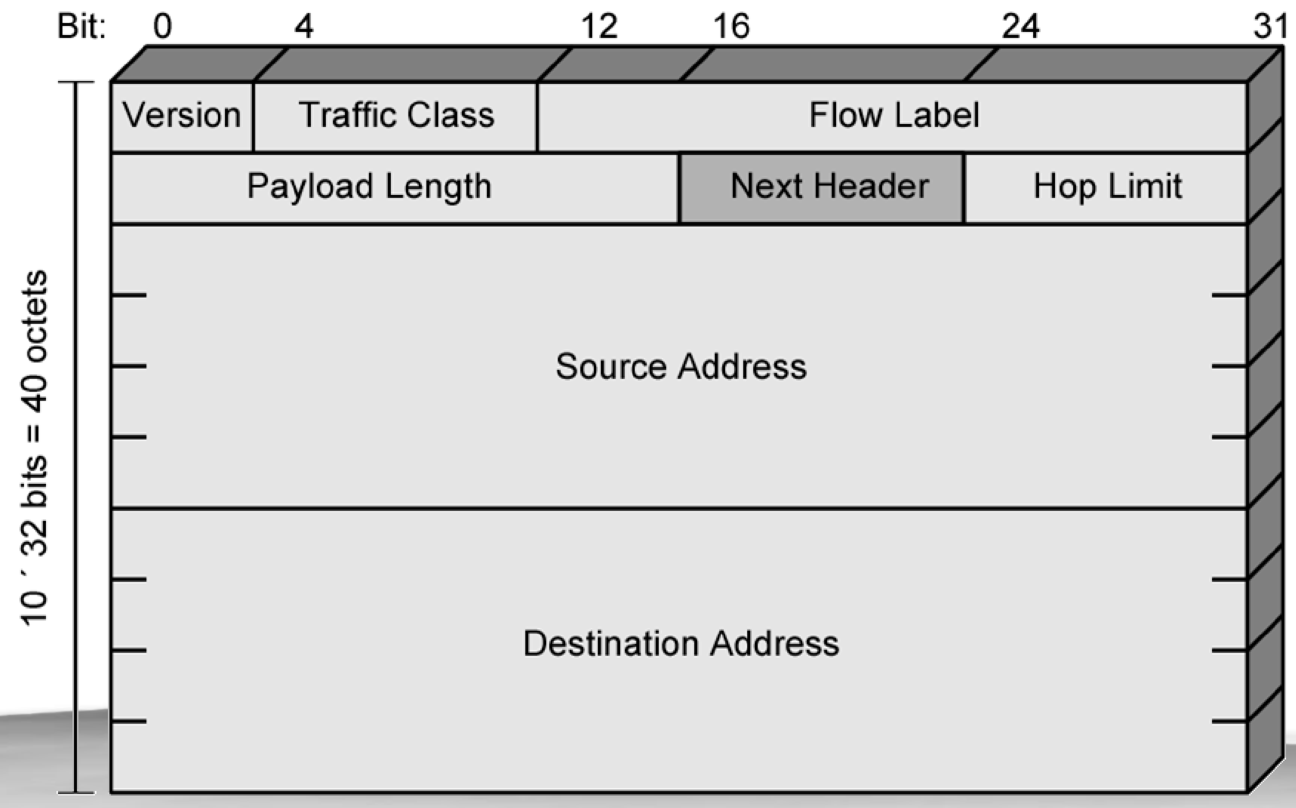
IPv6 RFCs

- 1752 – Recommendations for the IP Next Generation Protocol
- 2460 – Overall specification
- 2373 – addressing structure

- Others (www.rfc-editor.org)
  - 1981 – Path MTU Discovery for IPv6
  - 2401 – Security Architecture for the Internet Protocol
  - 2402 – IP Authentication Header
  - 2406 – IP Encapsulating Security Protocol (ESP)
  - 2463 – ICMP for IPv6
  - …

IPv6 Header

- Version (4 bits): 6
- Traffic Class (8 bits)
  - Classes or priorities of packet, identify QoS



IPv6 Header Fields

- Flow Label (20 bits)
  - Identify datagrams in the same “flow”
- Payload length (16 bits)
  - Includes all extension headers plus user data
- Next Header (8 bits)
  - Identifies type of the next header
  - Extension or next layer up
- Source / Destination Address (128 bits)

IPv6 Enhancements (1)

- Expanded address space: 128 bit
- Improved option mechanism
  - Separate optional headers between IPv6 header and transport layer header
  - Most are not examined by intermediate routers
  - Easier to extend options
- Checksum removed to further reduce processing time at each router

IPv6 Enhancements (2)

- Increased addressing flexibility
  - *Anycast* – delivered to one of a set of nodes
  - Scalability of multicast addresses
  - Address auto-configuration
- Support for resource allocation
  - Uses traffic class
  - Grouping packets to particular traffic flow
  - Allows QoS handling other than best-effort, e.g. real-time video

IPv6 Flow

- A sequence of packets sent from a particular source to a particular destination
- From hosts point of view
  - Generated from one application and have the same transfer service requirements
  - May comprise a single or multiple TCP connections
  - One application may generate a single flow or multiple flows
- From routers point of view
  - Share attributes that affect how these packets are handled by the router
  - e.g. routing, resource allocation, discard requirements, accounting, and security

Flow Label

- A flow is uniquely identified by the combination of
  - Source and destination address
  - A non-zero 20-bit Flow Label
- Flow requirements are defined prior to flow commencement
  - Then a unique Flow Label is assigned to the flow
- Router decide how to route and process the packet by
  - Simply looking up the Flow Label in a table and without examining the rest of the header

IPv6 Addresses

- 128 bits long, assigned to interface

FEDC : BA98 : 7654 : 3210 : FEDC : BA98 : 7654 : 3210
1080 : 0 : 0 : 0 : 8 : 800 : 200C : 417A

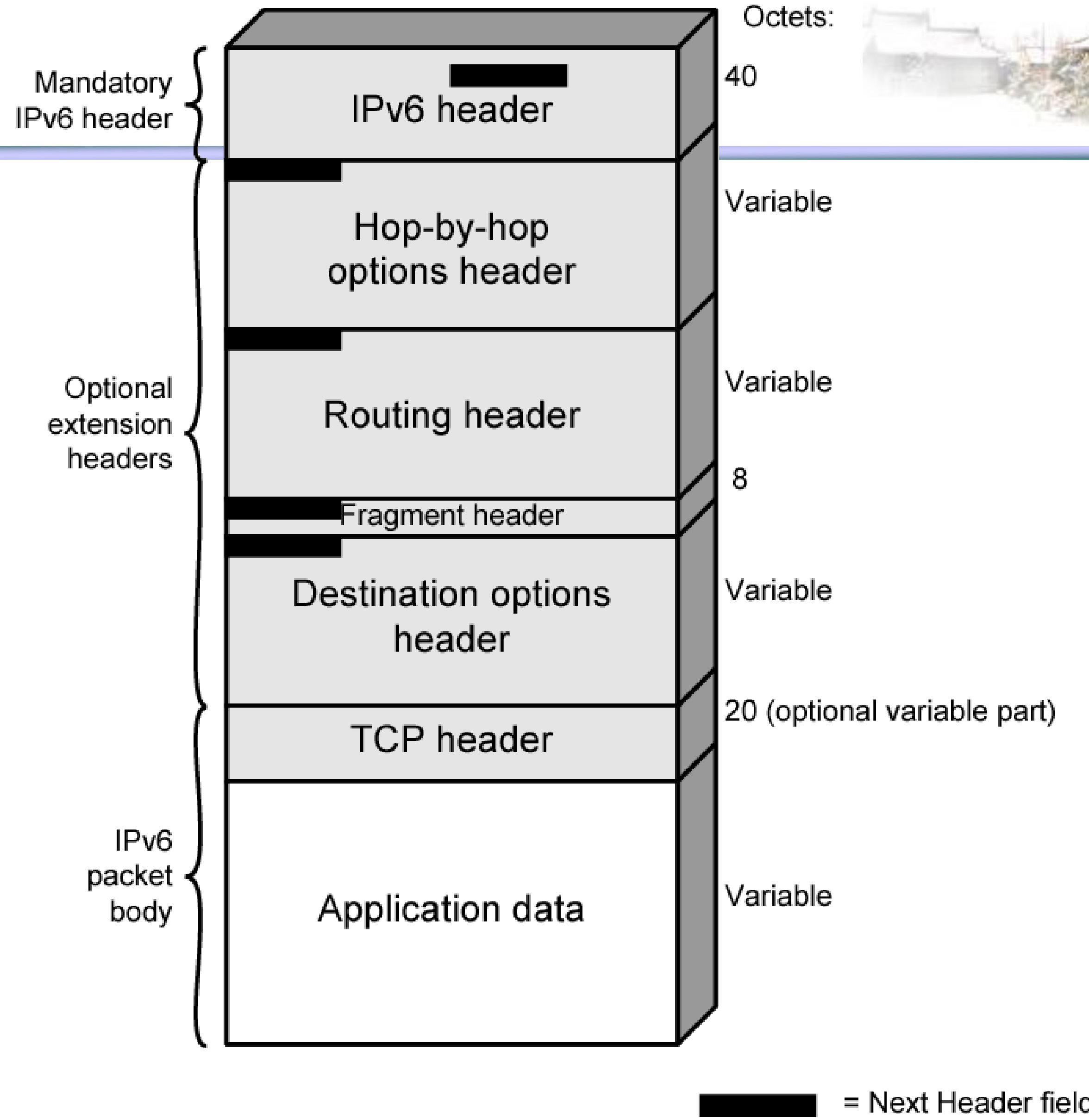
- Single interface may have multiple unicast addresses

- 3 types of address defined
  - Unicast, Multicast, Anycast

Example IPv6 Addresses

- Different IPv6 addresses
  - A unicast address
    - 1080:0:0:0:8:800:200C:417A, simplified as 1080::8:800:200C:417A
  - A multicast address
    - FF01:0:0:0:0:0:0:101, simplified as FF01::101
  - The loopback address
    - 0:0:0:0:0:0:0:1, simplified as ::1
  - Unspecified addresses
    - 0:0:0:0:0:0:0:0, simplified as ::
- IPv4 address → IPv6 address
  - x:x:x:x:x:x:d.d.d.d, 2 possible ways
  - 0:0:0:0:0:0:13.1.68.3, simplified as ::13.1.68.3
  - 0:0:0:0:0:FFFF:129.144.52.38, simplified as ::FFFF:129.144.52.38

IPv6 Header Structure



Extension Headers

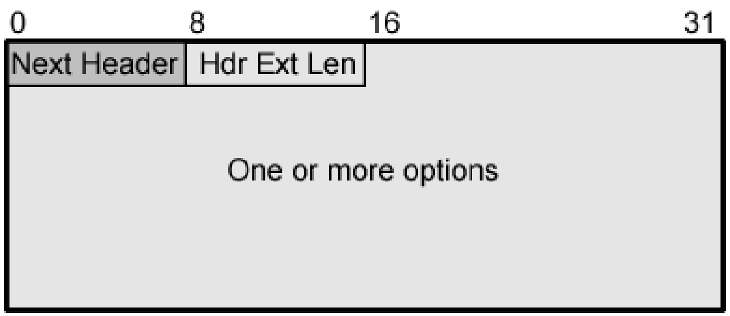
Appeared in order

- Hop-by-Hop Options: Require processing at each router
- Routing: Source routing
- Fragment: source fragmentation

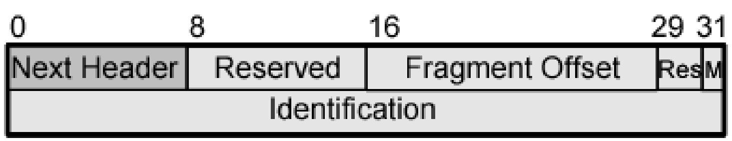
- Authentication
- Encapsulating security payload

- Destination options: handle at destination

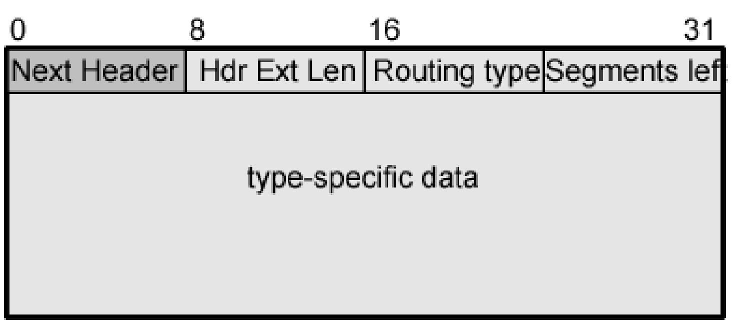
IPv6 Extension Headers



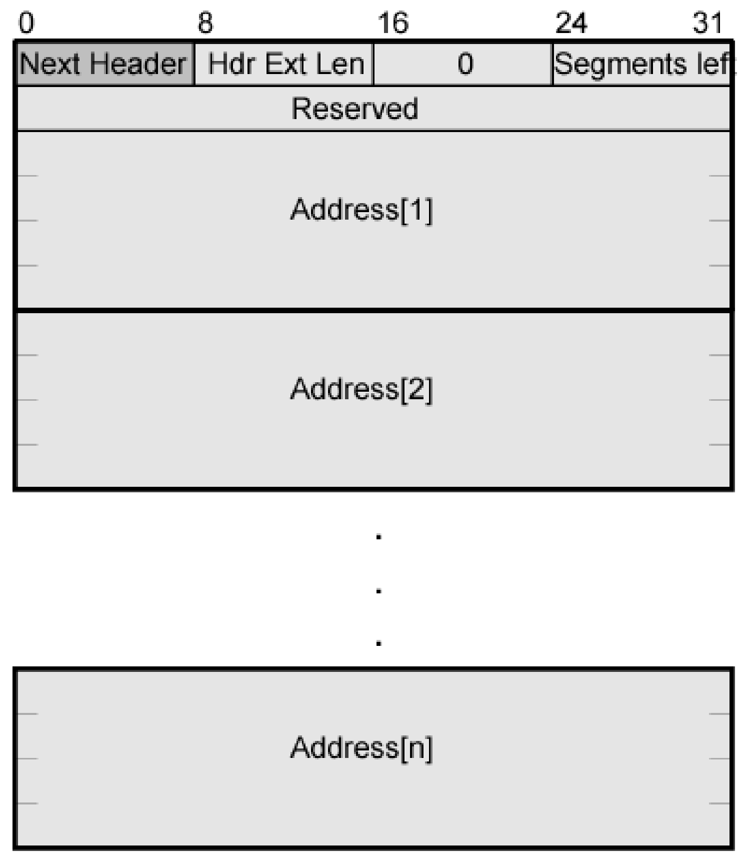
(a) Hop-by-hop options header;
destination options header



(b) Fragment header



(c) Generic routing header



(d) Type 0 routing header

Routing Header

- List of one or more intermediate nodes to be visited
- Next Header (8 bits)
- Header extension length (8 bits)
  - In 64 bits (8 octets) unit, excluding first 8 octets
- Routing type (8 bits)
  - Only type 0 defined now
- Segments left (8 bits)
  - Number of nodes still to be visited

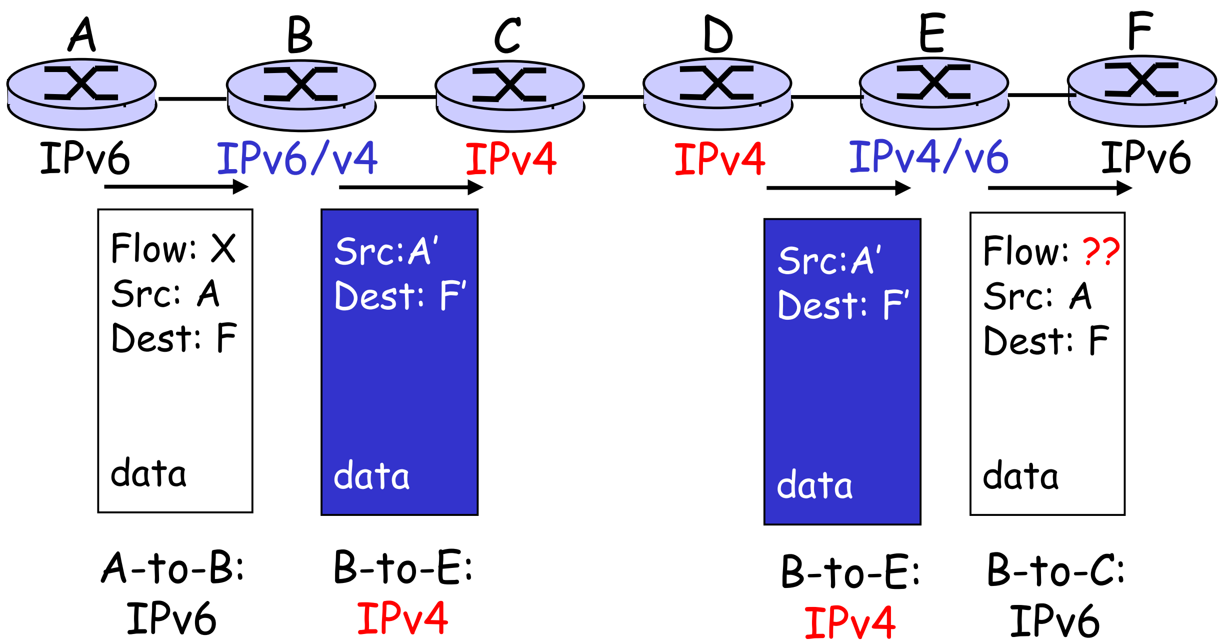
Operation of Type 0 Routing Header

- As the packet travels from S to I1:
  Source Address = S
  Destination Address = I1
  Hdr Ext Len = 6
  Segments Left = 3
  Address[1] = I2
  Address[2] = I3
  Address[3] = D
- As the packet travels from I1 to I2:
  Source Address = S
  Destination Address = I2
  Hdr Ext Len = 6
  Segments Left = 2
  Address[1] = I1
  Address[2] = I3
  Address[3] = D
- As the packet travels from I2 to I3:
  Source Address = S
  Destination Address = I3
  Hdr Ext Len = 6
  Segments Left = 1
  Address[1] = I1
  Address[2] = I2
  Address[3] = D
- As the packet travels from I3 to D:
  Source Address = S
  Destination Address = D
  Hdr Ext Len = 6
  Segments Left = 0
  Address[1] = I1
  Address[2] = I2
  Address[3] = I3

Transition From IPv4 To IPv6

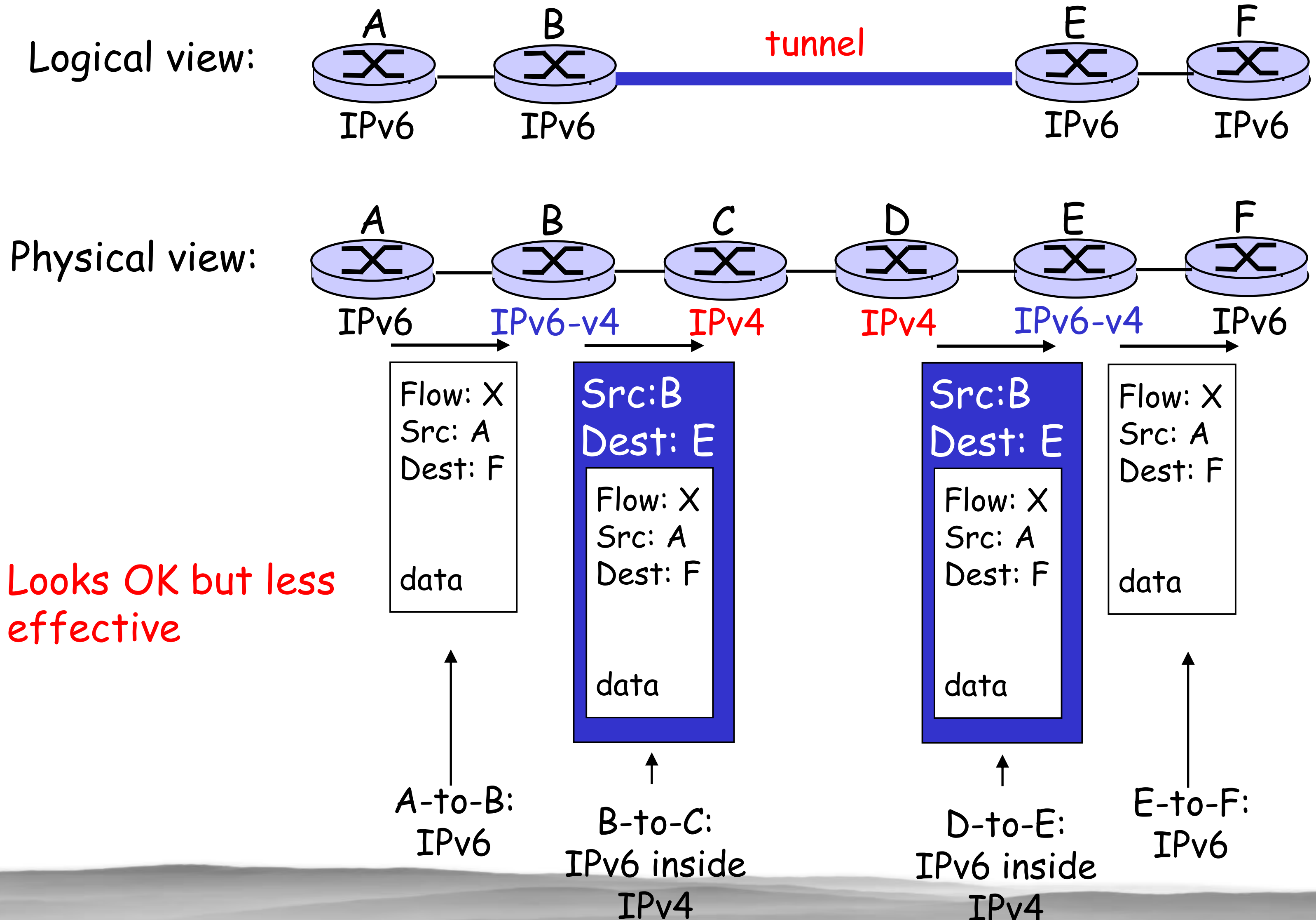
- Not all routers can be upgraded simultaneously
  - How will the network operate with mixed IPv4 and IPv6 routers
- Two proposed approaches
  - Dual Stack – some routers with dual stack (IPv6, IPv4) can translate between formats
  - Tunneling – IPv6 carried as payload in IPv4 datagram among IPv4 routers

Dual Stack Approach



- Address translation between IPv4 and IPv6 is needed
- Some IPv6 features is lost

Tunneling



Looks OK but less effective

Mobile IP

- Mobile IP standard
  - Approved by the Internet Engineering Steering Group (IESG) in June 1996
  - Published as a proposed standard by the Internet Engineering Tasks force (IETF) in November 1996

- Developed in order to cope with the increasing popularity of PDA’s and Laptop’s

Mobile Devices

Need for Mobile IP

- Datagram moved from one network to the other by routers, which use destination's IP addresses
- IP address is divided into two parts: <netID, hostID>

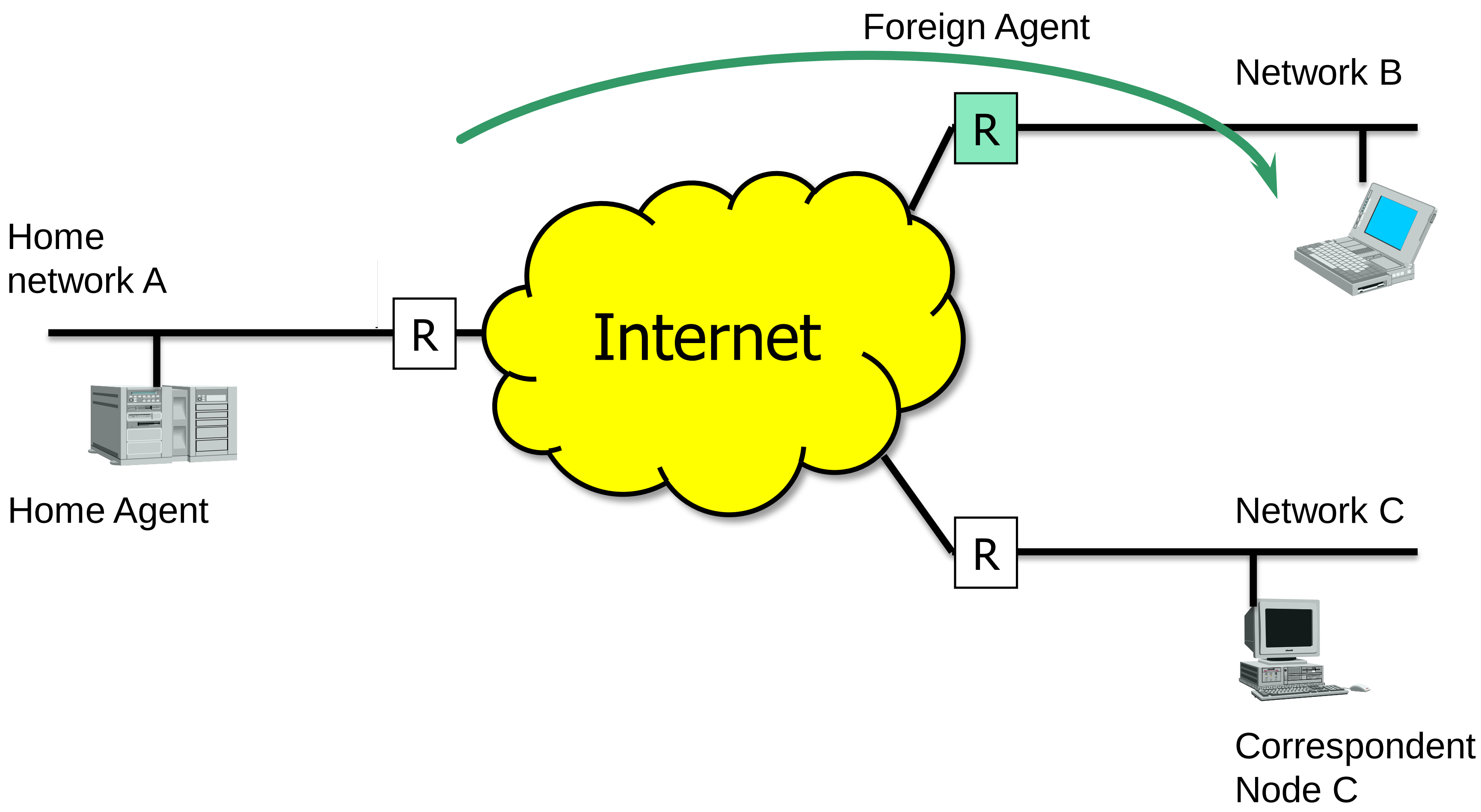
- Most applications over the Internet are supported by TCP connections
- TCP uses IP address and port number for routing and delivery

Need for Mobile IP

- As a mobile device moves from one network to the other, its IP address changes dynamically
- Thus the TCP connection needs to restart any ongoing communications each time it moves

- Mobile IP is to deal with the problem of dynamically varying IP addresses
- No need to change the TCP, i.e. IP address of the mobile device is pretend to be unchanged

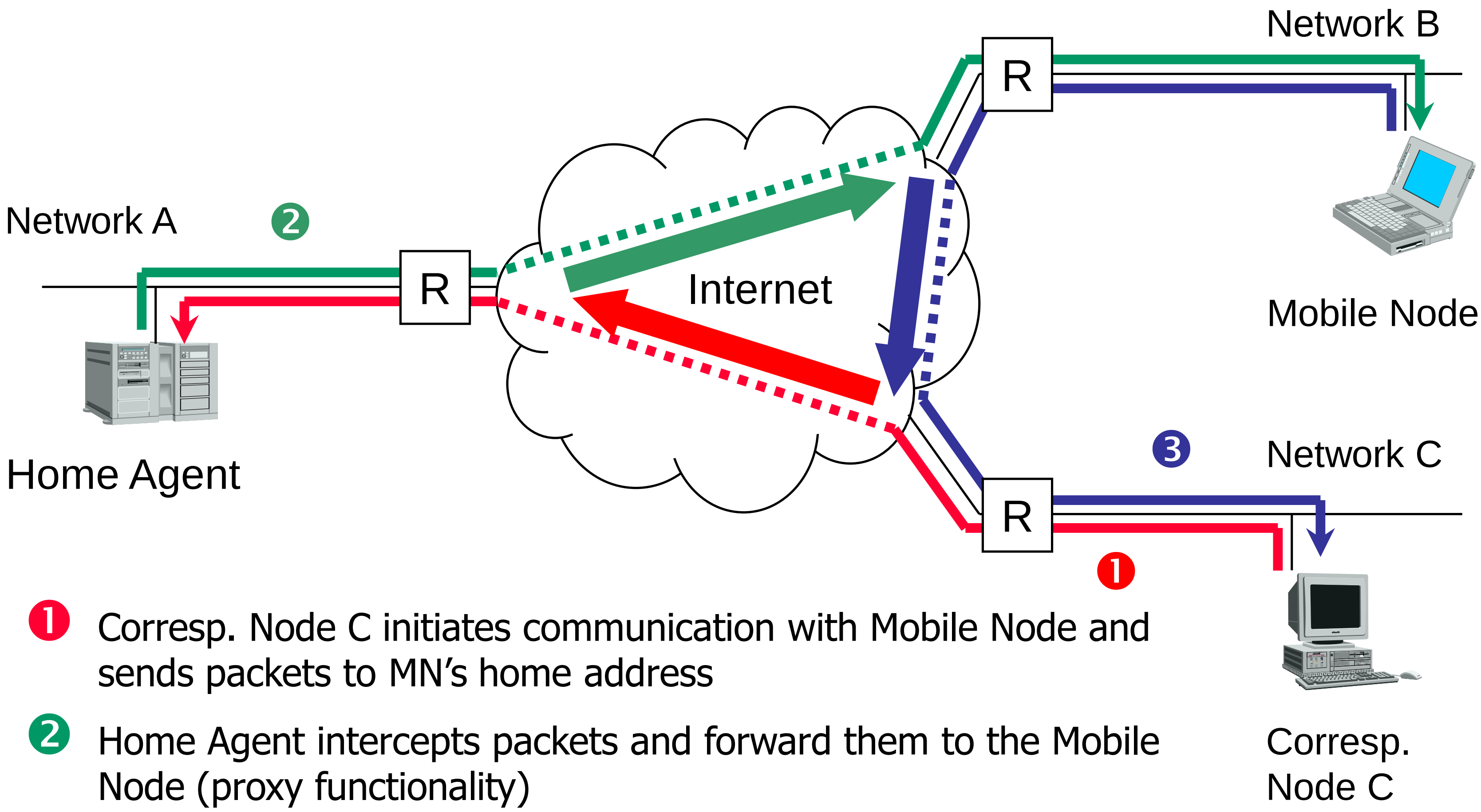
An Illustration



Different Entities

- Mobile Node
  - A host that may change its point of attachment from one network to the other
- Correspondent Node
  - A host that sends a packet addressed to a mobile node
- Home Agent
  - A node on the home network that maintains a list of registered mobile nodes
- Foreign Agent
  - A router on a foreign network that assists a mobile node in delivering datagram

Triangle Routing



1. Corresp. Node C initiates communication with Mobile Node and sends packets to MN's home address
2. Home Agent intercepts packets and forward them to the Mobile Node (proxy functionality)
3. Mobile Node replies directly to Corresp. Node C

The Protocol

- Mobile IP includes 3 capabilities
  - Discovery
  - Registration
  - Tunneling

Discovery

- Mobile (Foreign) Agents
  - Send ICMP router advertisements with mobility agent advertisement extension periodically informing its presence
- Mobile node
  - Optionally request an advertisement from an agent
  - Or simply wait for the next advertisement

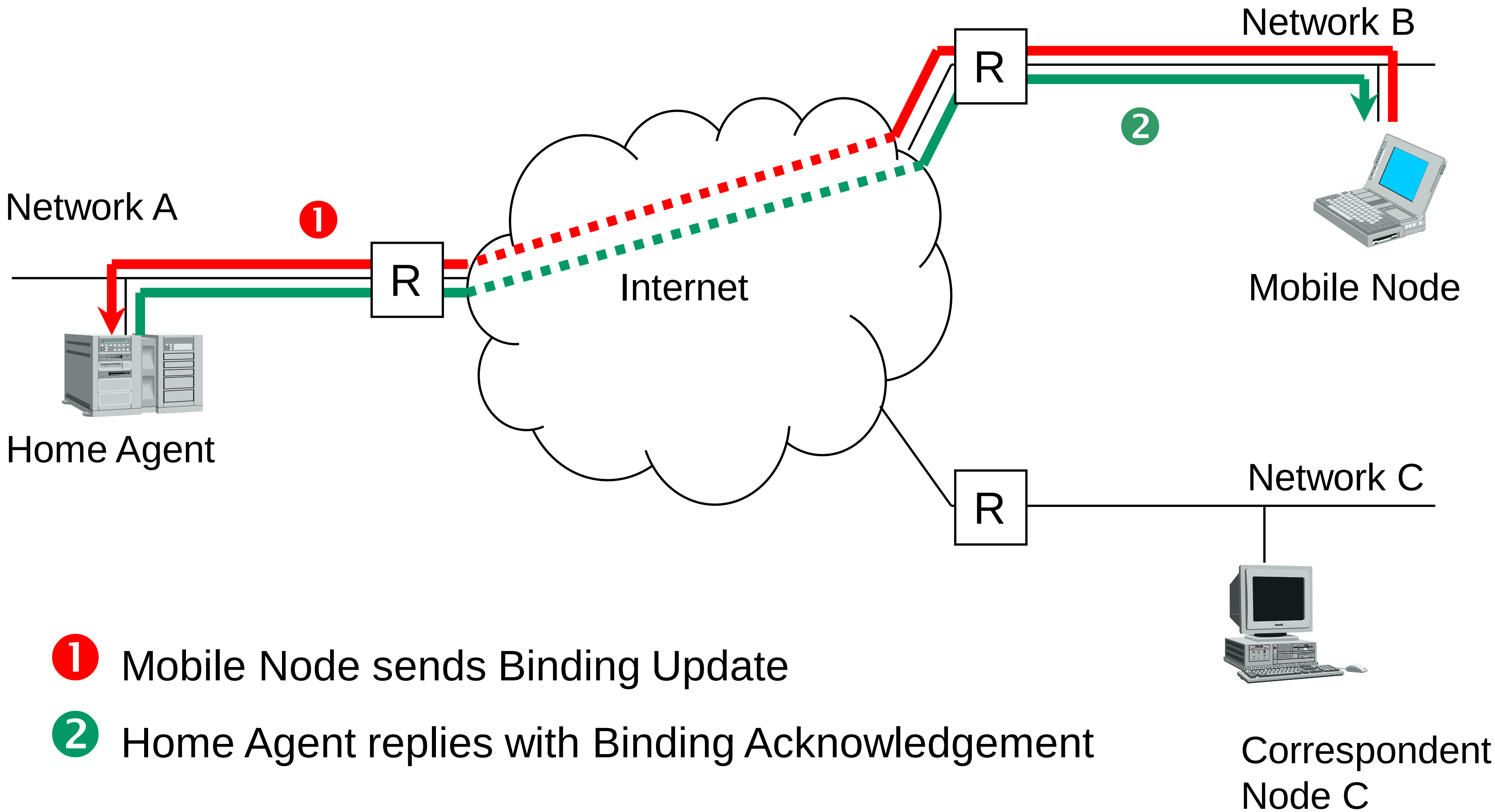
Registration

- Mobile node
  - Acquires a Care-of-Address from the foreign agent
  - Requests its home agent to forward its data packets to the foreign agent

- 4 steps
  - Mobile node sends registration request to the foreign agent
  - Foreign agent relays this request to the home agent

  - Home agent sends registration reply to the foreign agent
  - Foreign agent relays this reply to the mobile node

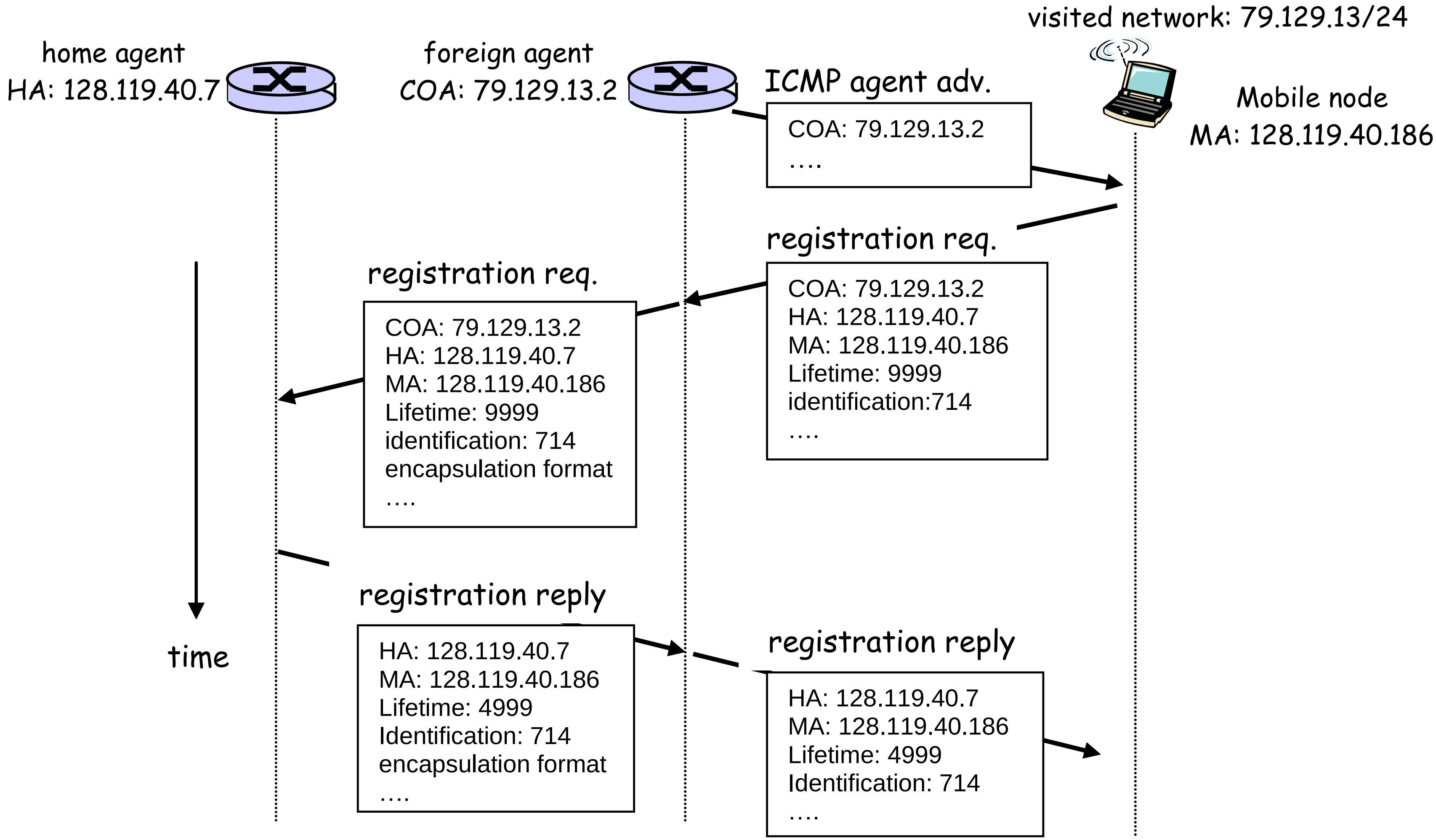
Registration of Mobile Node



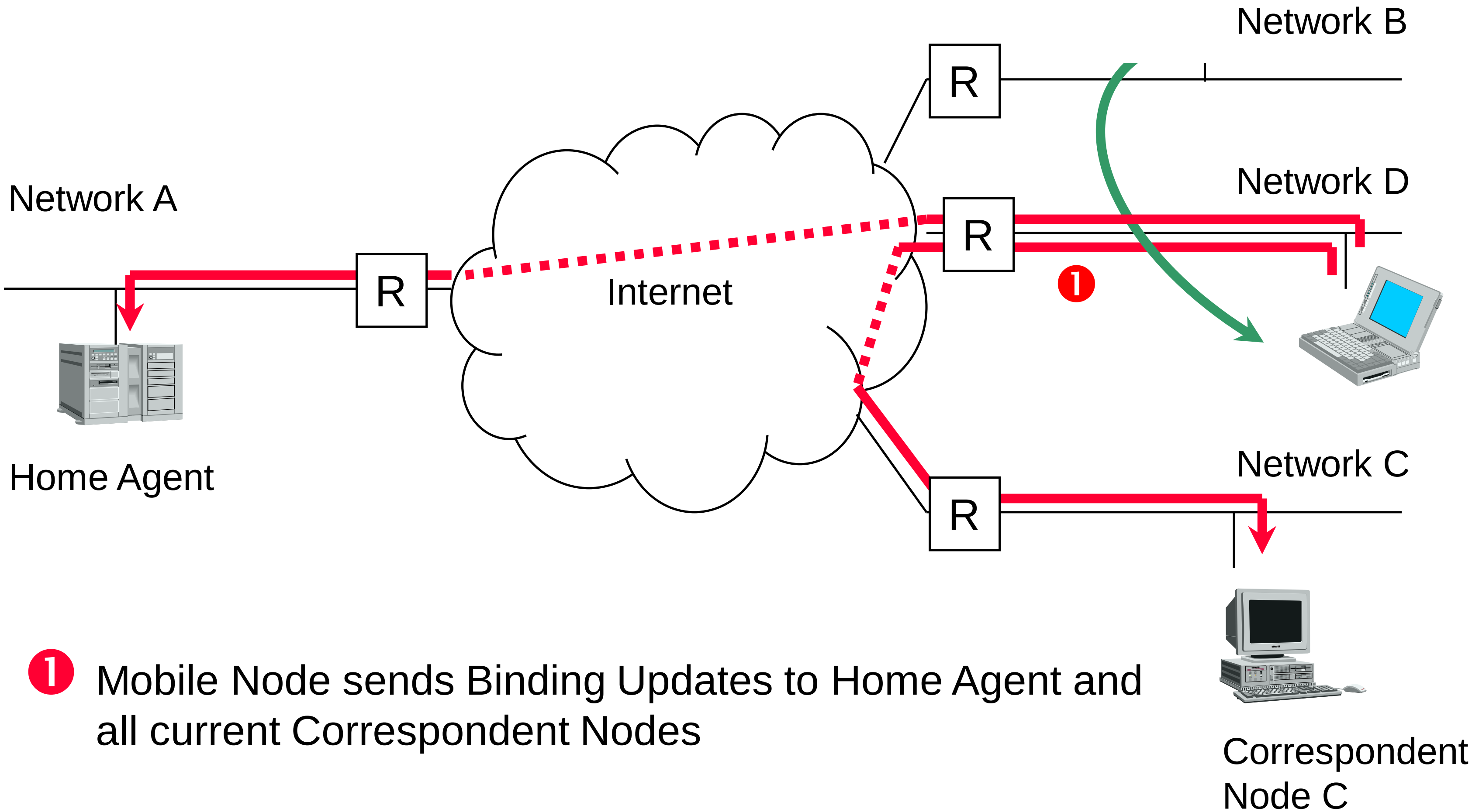
❶ Mobile Node sends Binding Update

❷ Home Agent replies with Binding Acknowledgement

A Registration Example



Mobile Roaming (IPv6)



❶ Mobile Node sends Binding Updates to Home Agent and all current Correspondent Nodes

Tunneling

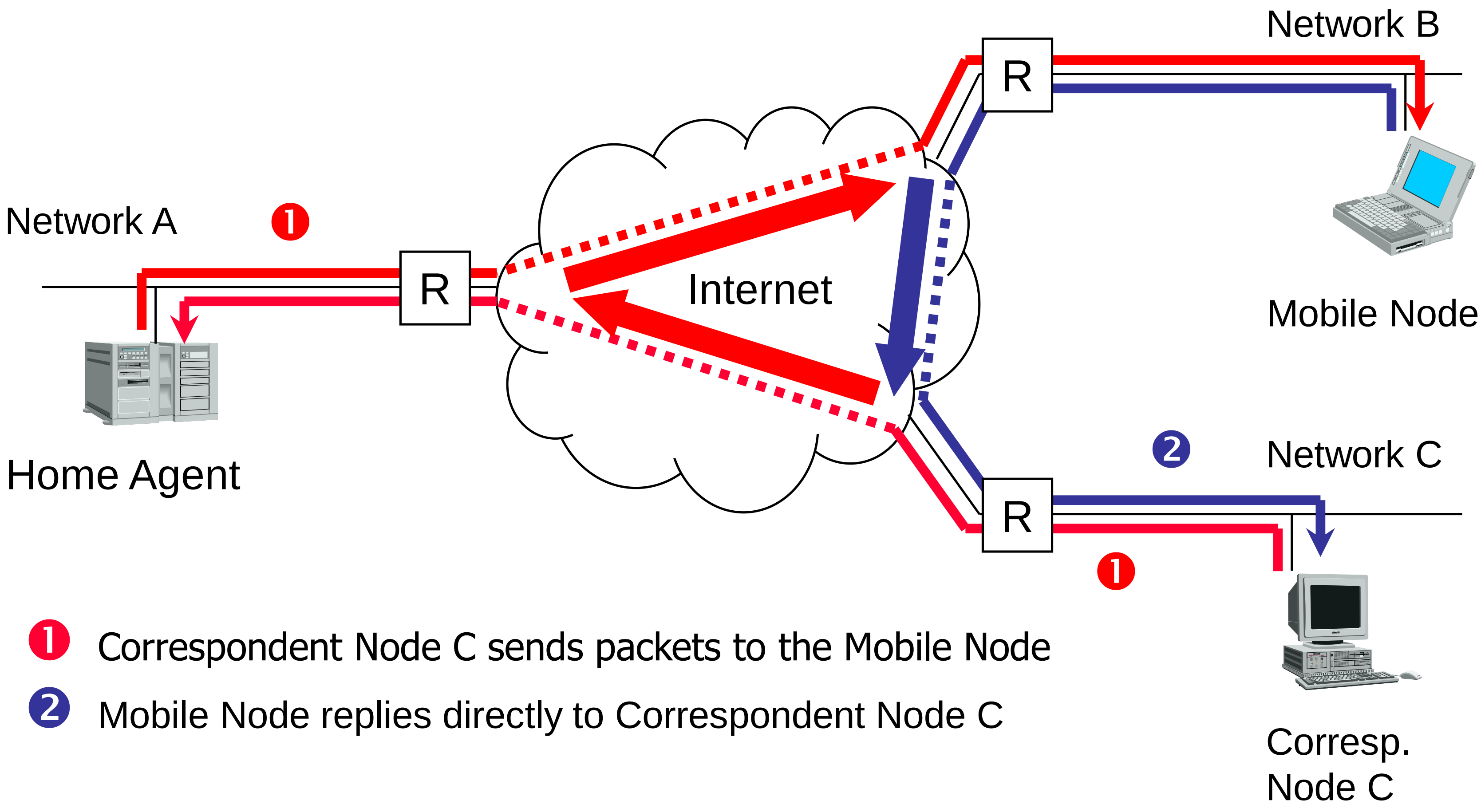
- After registration, an IP tunnel is set up
  - Between the home agent and care-of-address of the mobile node
  - Home agent broadcasts gratuitous ARP request which binds the mobile nodes IP address to the home agents MAC address
  - Thus home agent receives packets destined to the mobile node, and forwards the packets to the foreign agent through the IP tunnel

Tunneling

- For a correspondent node
  - Assumes the reply from the mobile node is coming from its home network
  - Continues to send the packet to the home agent

- Thus the TCP connection is maintained without changing the MN's IP address

IP Tunneling



❶ Correspondent Node C sends packets to the Mobile Node

❷ Mobile Node replies directly to Correspondent Node C

Indirect Routing