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Computer Networks

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Material with thanks to James F. Kurose, Mosharaf Chowdhury, and other colleagues.

Chapter 3. Network Layer

- NAT
- ARP
- DHCP
- ICMP
- Mobile IP
- IPv6

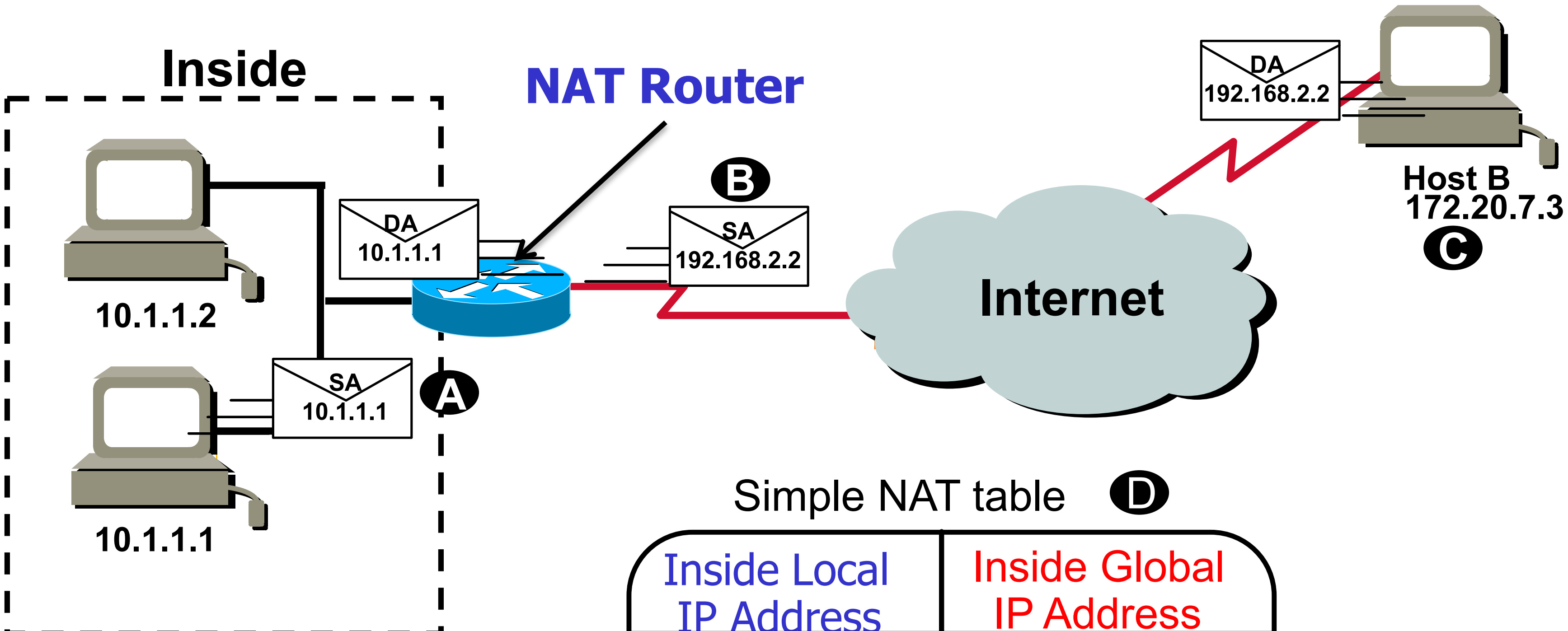
Network Address Translation

- NAT
  - Enables different sets of IP addresses for internal and external traffic
  - The IP address translations occur where the Intranet interfaces with the broader Internet
- Purposes
  - Acts as a firewall by hiding internal IP addresses
  - Enables an enterprise (organization) to use more internal IP addresses
  - Isolate the (organization / ISP) changes

3 Types of NAT

- Static NAT
  - A private IP address is mapped to one reserved public IP address
  - Usually for server hosts in Intranet
- Dynamic NAT
  - The NAT router keeps a pool of registered IP addresses, and assign to private IP addresses on demand
  - Usually for client PCs in Intranet
- Single-Address NAT/Overloading/Masquerading/Network Address Port Translation (NAPT)

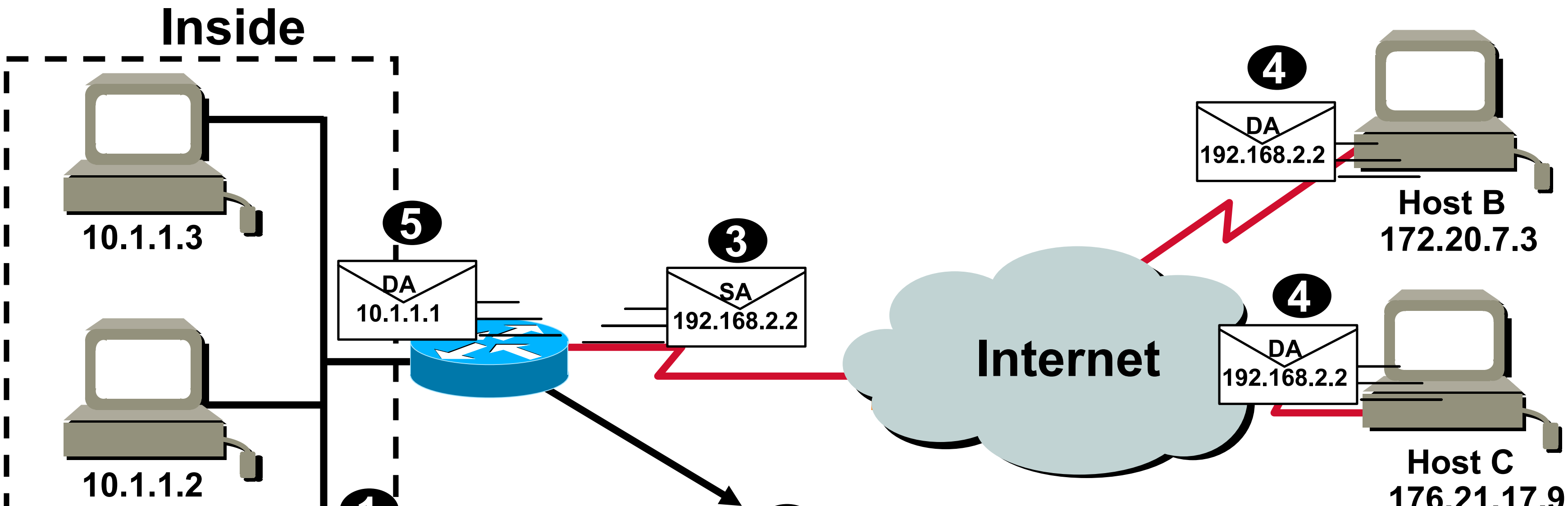
Illustration of NAT



Simple NAT table D

Inside Local IP Address	Inside Global IP Address
A 10.1.1.2	B 192.168.2.3
10.1.1.1	192.168.2.2

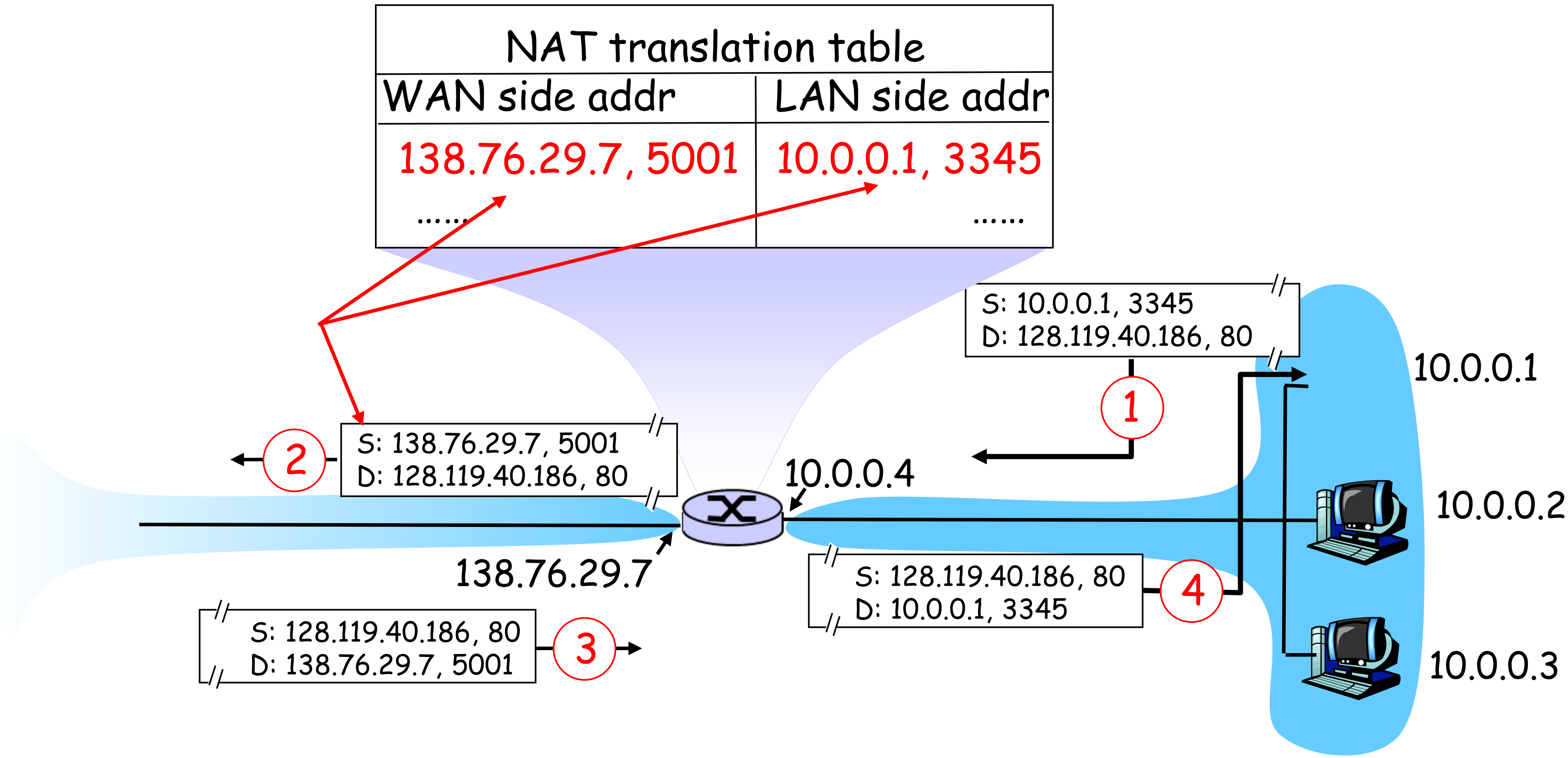
Overloading Global Address



2 NAT table

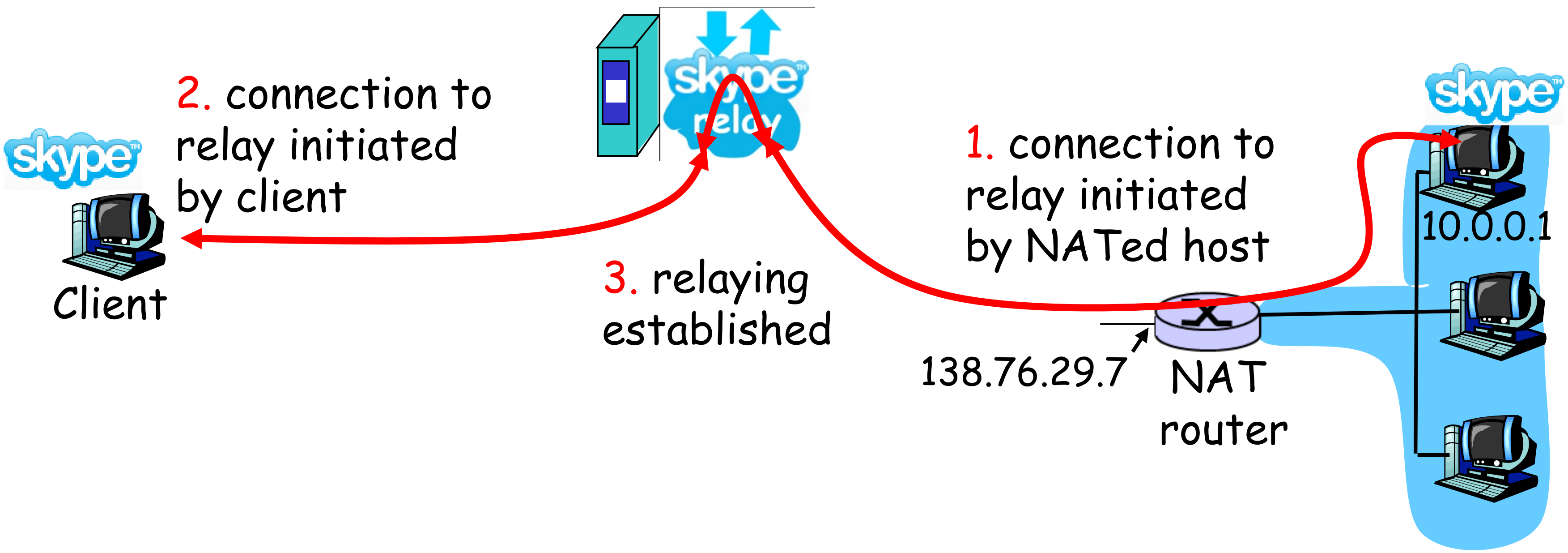
Protocol 10.1.1.1	Inside Local IP Address: Port	Inside Global IP Address: Port	Outside Global IP Address: Port
TCP	10.1.1.3:1723	192.168.2.2:1492	176.21.17.9:23
TCP	10.1.1.2:1723	192.168.2.2:1723	176.21.17.9:23
TCP	10.1.1.1:1024	192.168.2.2:1024	172.20.7.3:23

Network Address Translation



NAT is Controversial

- Addresses changes from time to time
  - E.g. must be taken into account by P2P applications
- Relaying in Skype
  - NATed supernodes establishes connection to relay
  - External client connects to relay
  - Relay bridges packets between 2 connections



IP protocol suits

- ARP (Address Resolution Protocol)
- DHCP (Dynamic Host Configuration Protocol)
- ICMP (Internet Control Message Protocol)
- Mobile IP (IP Mobility Support Protocol)
- IPv6 (Internet Protocol Version 6)

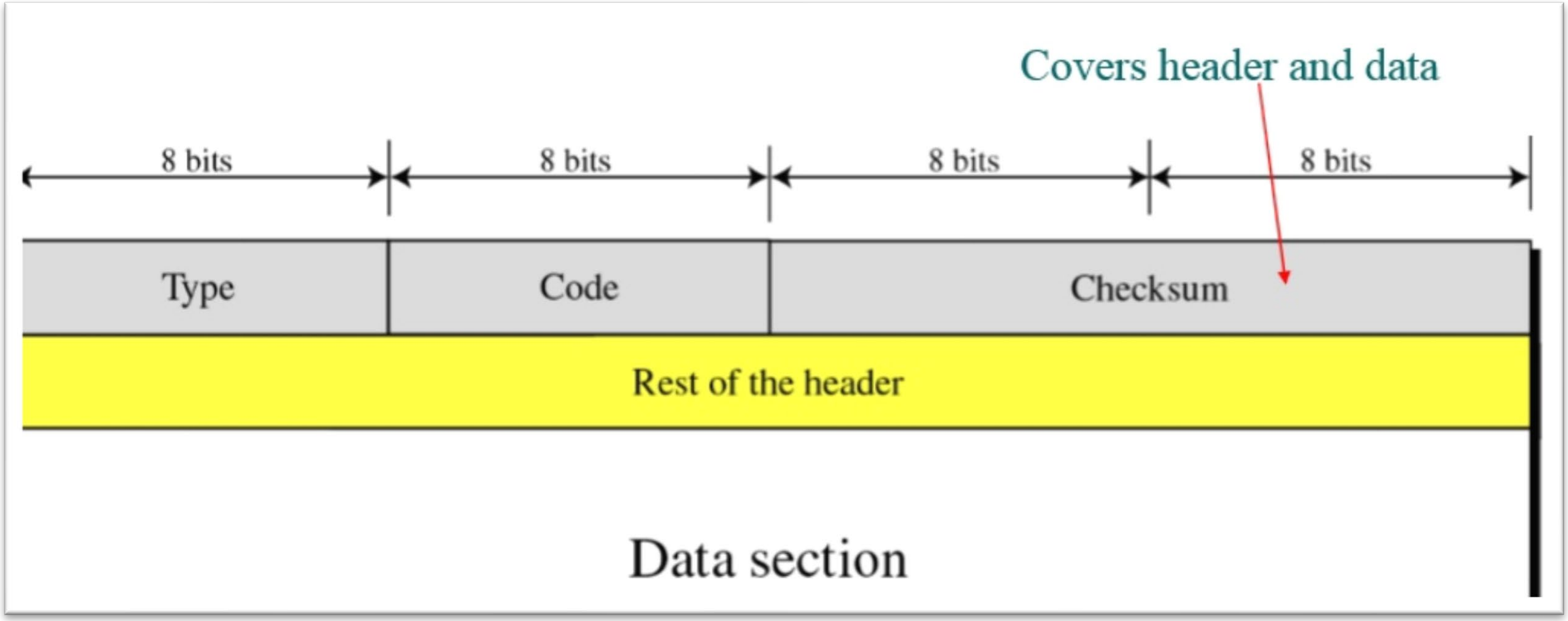
ICMP

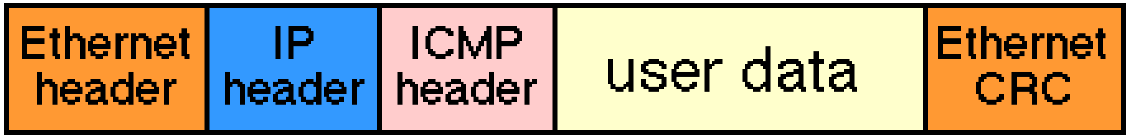
- Internet Control Message Protocol (RFC 792)

- 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 Format





ICMP Message Types

- ICMP Messages
  - Error Reports
    - Destination unreachable
    - Source quench (congestion control)
    - Parameters problem
    - Redirection
  - Request/Reply
    - Echo request/reply
    - Timestamp request/reply
    - Assress mask request/reply
    - Router discovery/advertisement

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

Some ICMP Message Formats

0	8	16	31
Type	Code	Checksum	
Unused			
IP Header + 64 bits of original datagram			

(a) Destination Unreachable; Time Exceeded; Source Quench

0	8	16	31
Type	Code	Checksum	
Pointer	Unused		
IP Header + 64 bits of original datagram			

(b) Parameter Problem

0	8	16	31
Type	Code	Checksum	
Gateway Internet Address			
IP Header + 64 bits of original datagram			

(c) Redirect

0	8	16	31
Type	Code	Checksum	
Identifier		Sequence Number	
Optional data			

(d) Echo, Echo Reply

0	8	16	31
Type	Code	Checksum	
Identifier		Sequence Number	
Originate Timestamp			

(e) Timestamp

0	8	16	31
Type	Code	Checksum	
Identifier		Sequence Number	
Originate Timestamp			
Receive Timestamp			
Transmit Timestamp			

(f) Timestamp Reply

0	8	16	31
Type	Code	Checksum	
Identifier		Sequence Number	

(g) Address Mask Request

0	8	16	31
Type	Code	Checksum	
Identifier		Sequence Number	
Address Mask			

(h) 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)

Traceroute

www.traceroute.org

traceroute: gaia.cs.umass.edu to www.eurecom.fr

Three delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

trans-oceanic link

* means no response (probe lost, router not replying)

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

Mobile IP

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>

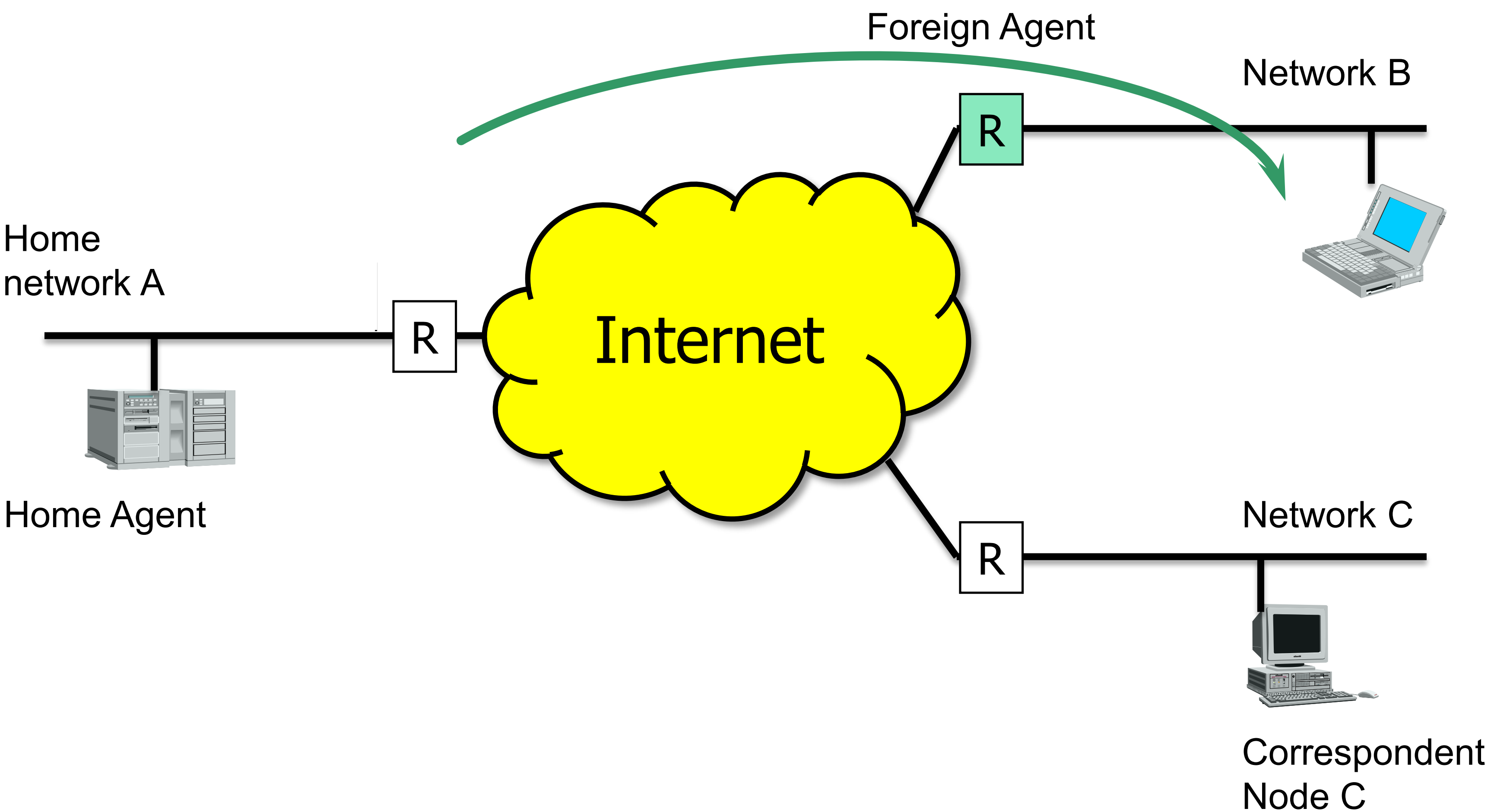
- Most applications over the Internet are supported by TCP connections
- TCP uses IP address and port number for routing and delivery

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

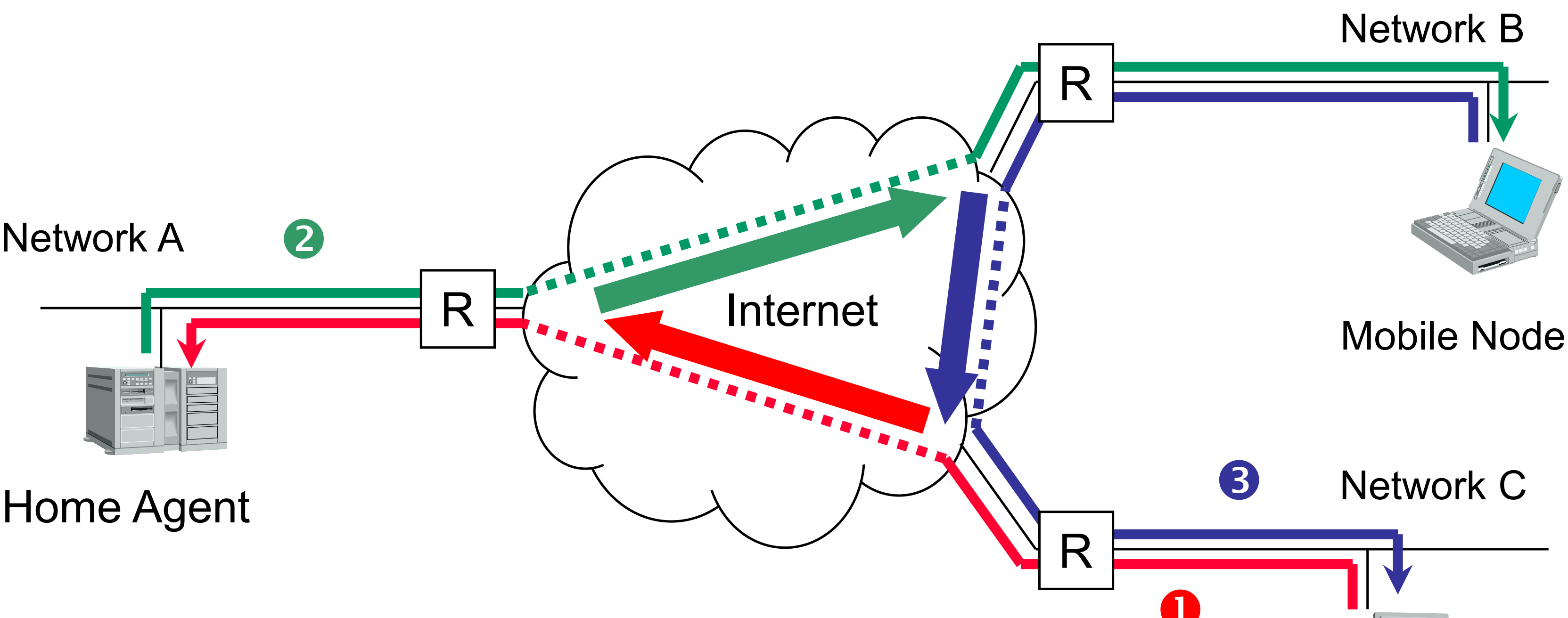


Different Entities

移动节点
通信节点
归属代理
外部代理

- 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



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

The Protocol

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

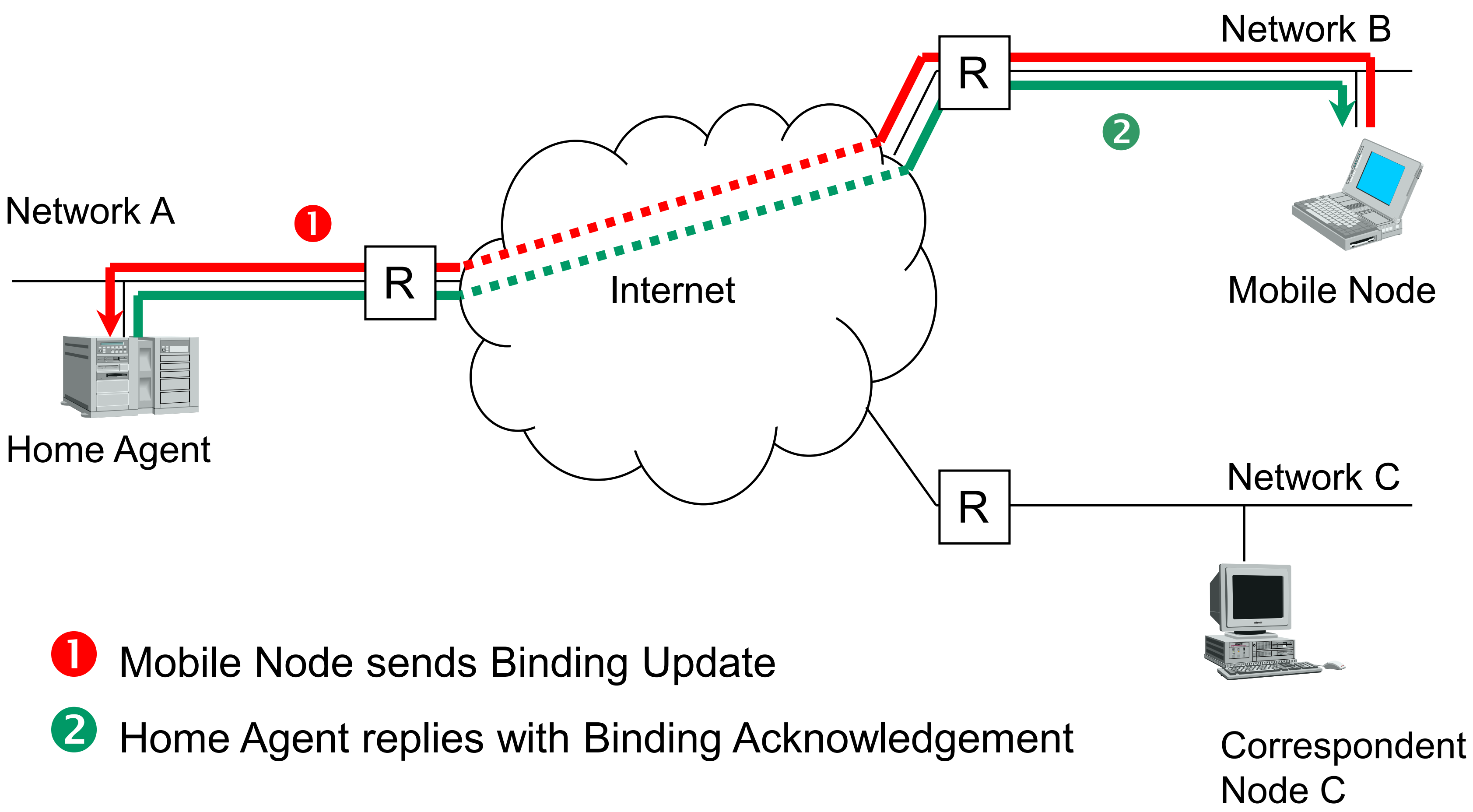
Discovery

- 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

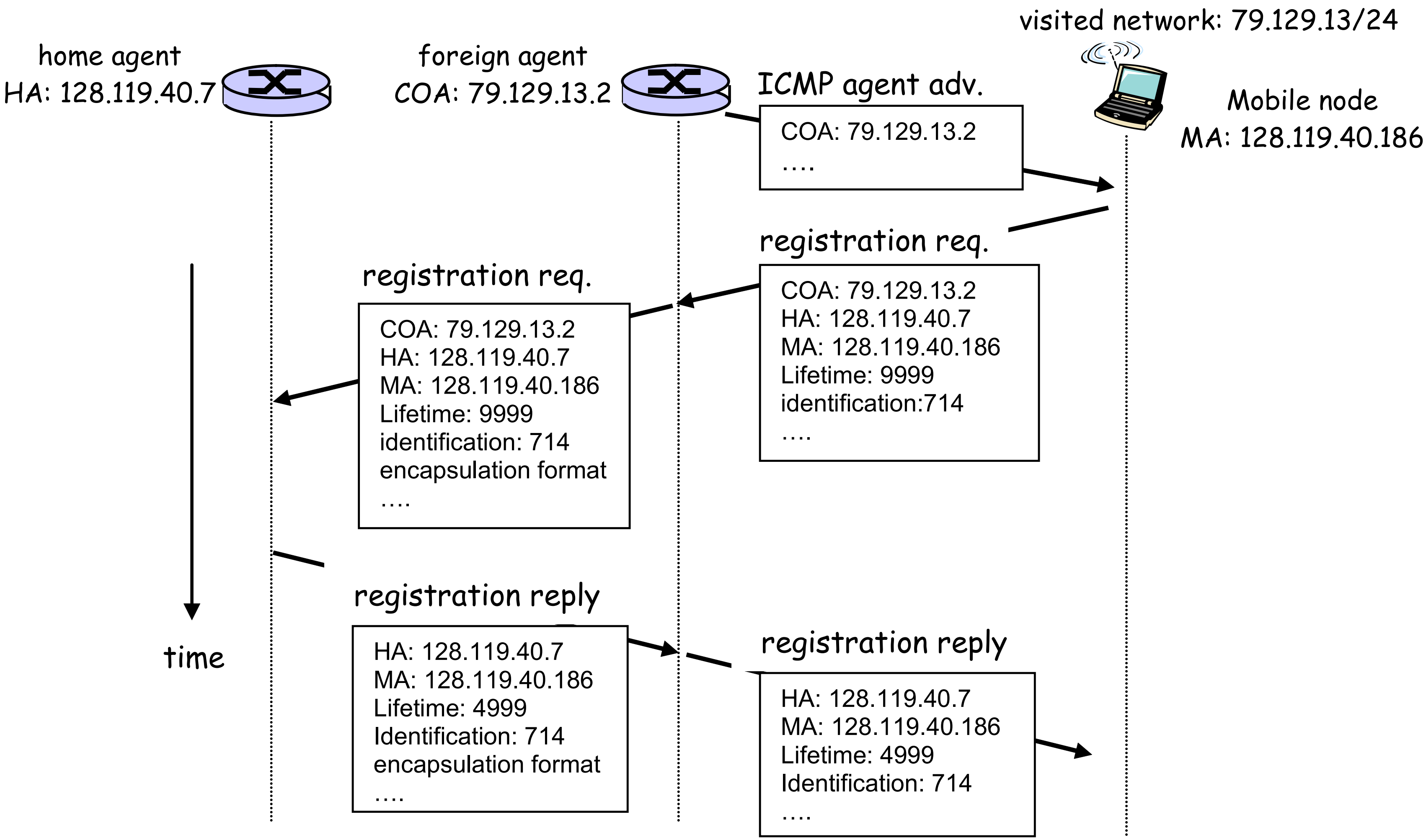
Registration of Mobile Node



❶ Mobile Node sends Binding Update

❷ Home Agent replies with Binding Acknowledgement

A Registration Example



Tunneling

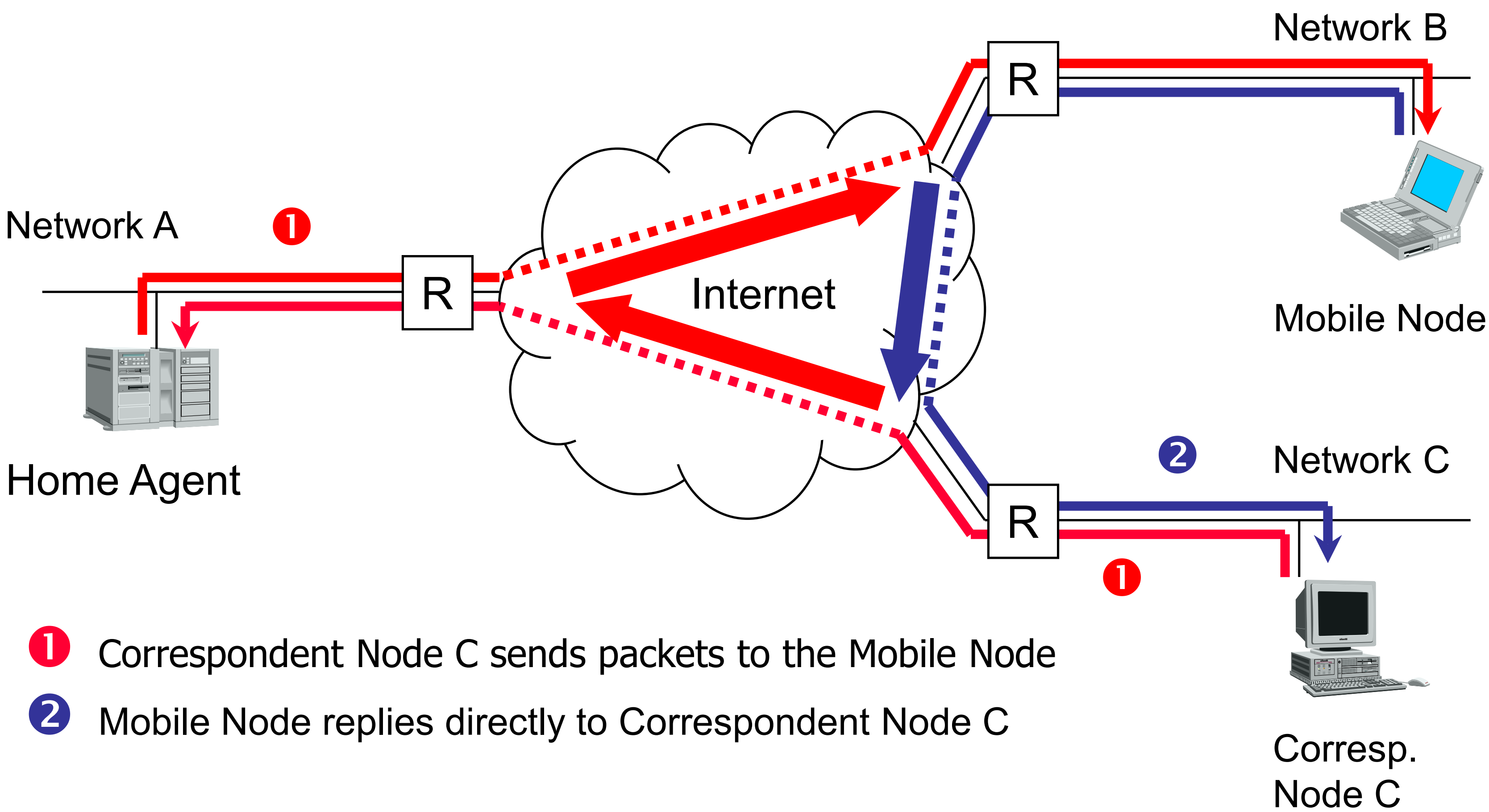
- After registration, an IP tunnel is set up
  - Between the home agent and care-of-address of the mobile node
  - Home agent broadcasts gratuitous ARP request which binds the mobile nodes IP address to the home agents MAC address
  - Thus home agent receives packets destined to the mobile node, and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

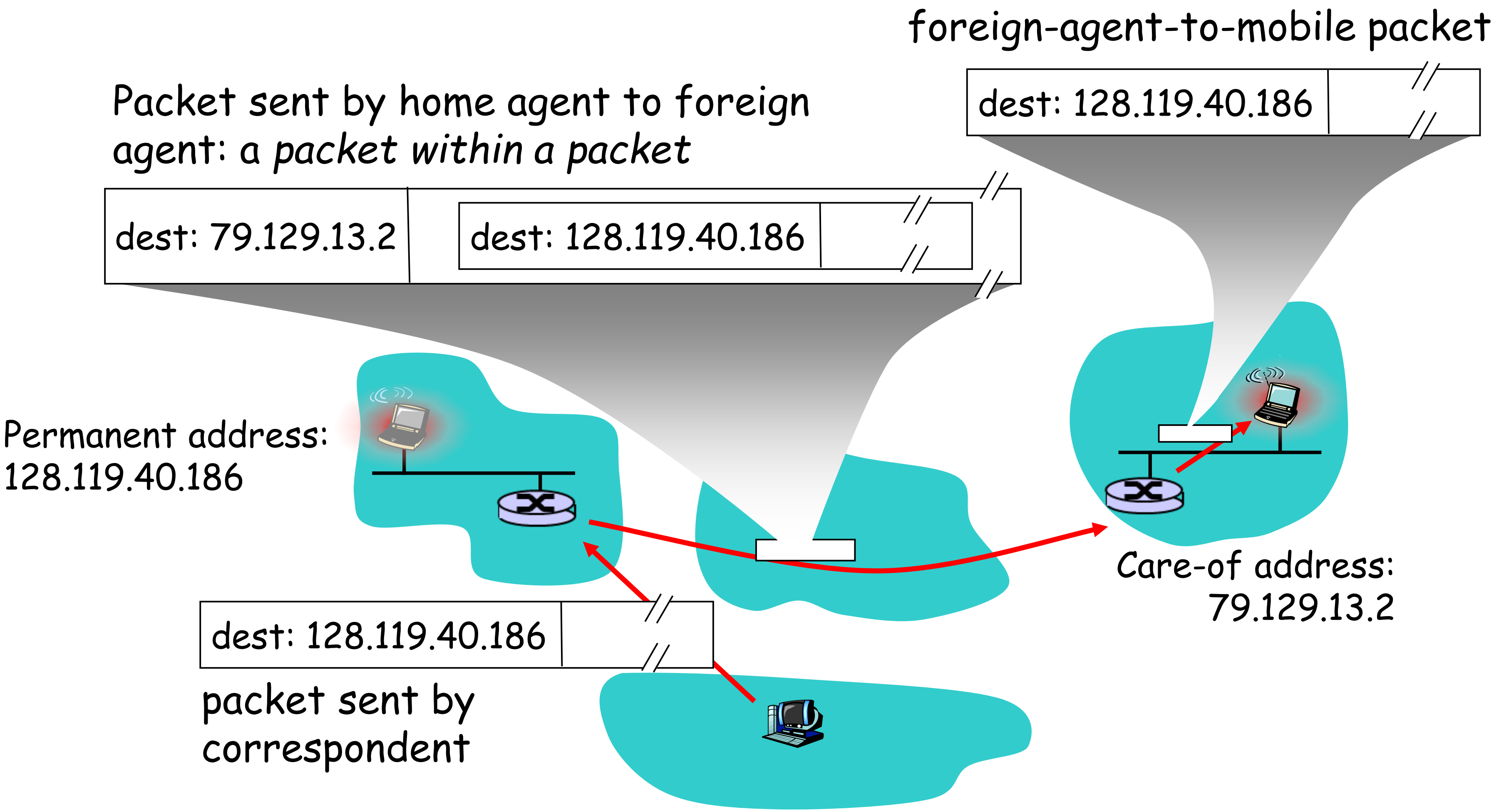
IP Tunneling



❶ Correspondent Node C sends packets to the Mobile Node

❷ Mobile Node replies directly to Correspondent Node C

Indirect Routing



IPv6

IPv6

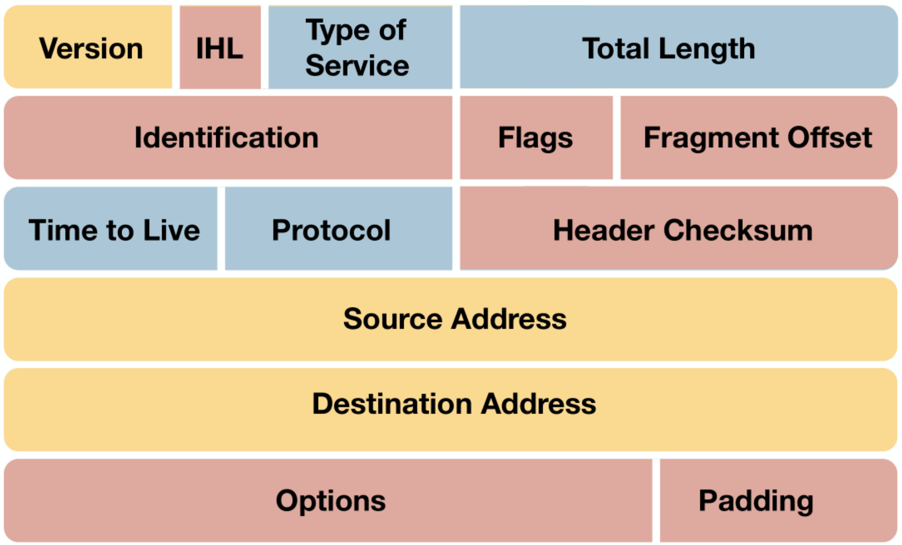
- Initial motivation: address space exhaustion
  - Rapid growth of networks and the Internet
  - 32-bit address space (esp. net address) soon to be completely allocated
- Additional motivation
  - New header format helps speed processing and forwarding
  - Header changes to facilitate QOS
  - No fragmentation at router
  - New address mode: route to "best" of several replicated servers

IPv6 RFCs

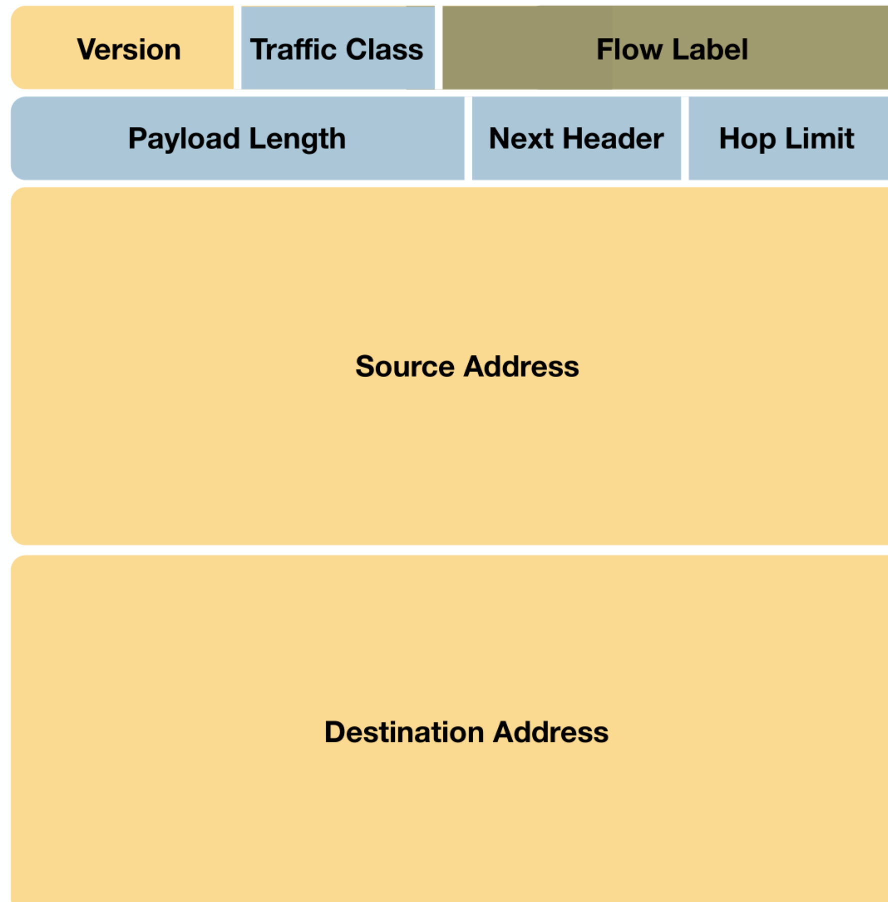
- 1752 – Recommendations for the IP Next Generation Protocol
- 2460 – Overall specification
- 2373 – addressing structure
- Others (www.rfc-editor.org)
  - 1981 – Path MTU Discovery for IPv6
  - 2401 – Security Architecture for the Internet Protocol
  - 2402 – IP Authentication Header
  - 2406 – IP Encapsulating Security Protocol (ESP)
  - 2463 – ICMP for IPv6
  - …

IPv6 Header VS IPv4 Header

IPv4 Header



IPv6 Header



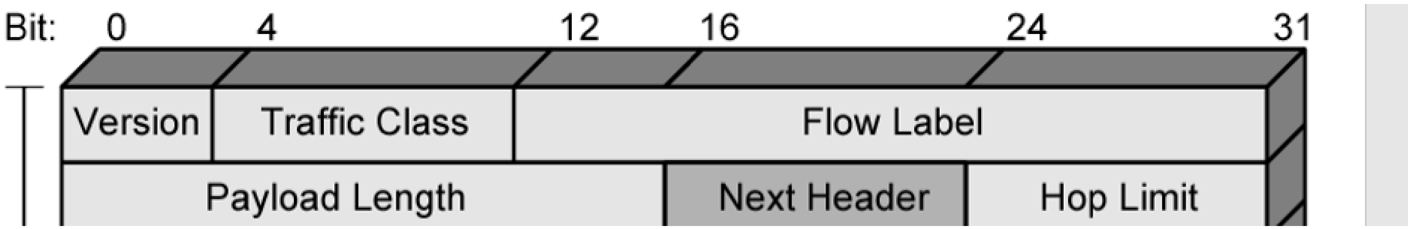
LEGEND

- Field’s name kept from IPv4 to IPv6
- Field not kept in IPv6
- Name and position changed in IPv6
- New field in IPv6

IPv6 Header Fields

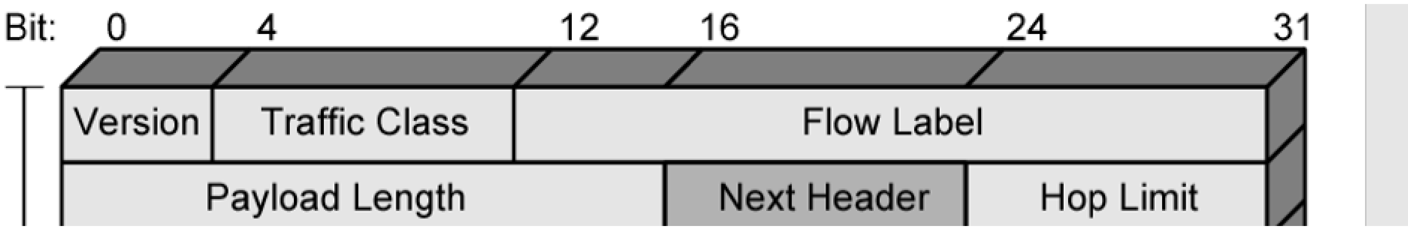
- Version (4 bits): 6
- Traffic Class (8 bits)
  - Classes or priorities of packet, identify QoS
- Flow Label (20 bits)
  - Identify datagrams in the same "flow"
- Payload length (16 bits)
  - Includes all extension headers plus user data
- Next Header (8 bits)
  - Identifies type of the next header
  - Extension or next layer up
- Source / Destination Address (128 bits)

Traffic Class



- The 8-bit field in the IPv6 header is available for use by originating nodes and/or forwarding routers to identify and distinguish between different classes or priorities of IPv6 packets.
  - E.g., used as the codepoint in DiffServ
- General requirements
  - Service interface must provide means for upper-layer protocol to supply the value of traffic class
  - Value of traffic class can be changed by source, forwarder, receiver
  - An upper-layer protocol should not assume the value of traffic class in a packet has not been changed.

IPv6 Flow



- A sequence of packets sent from a particular source to a particular destination

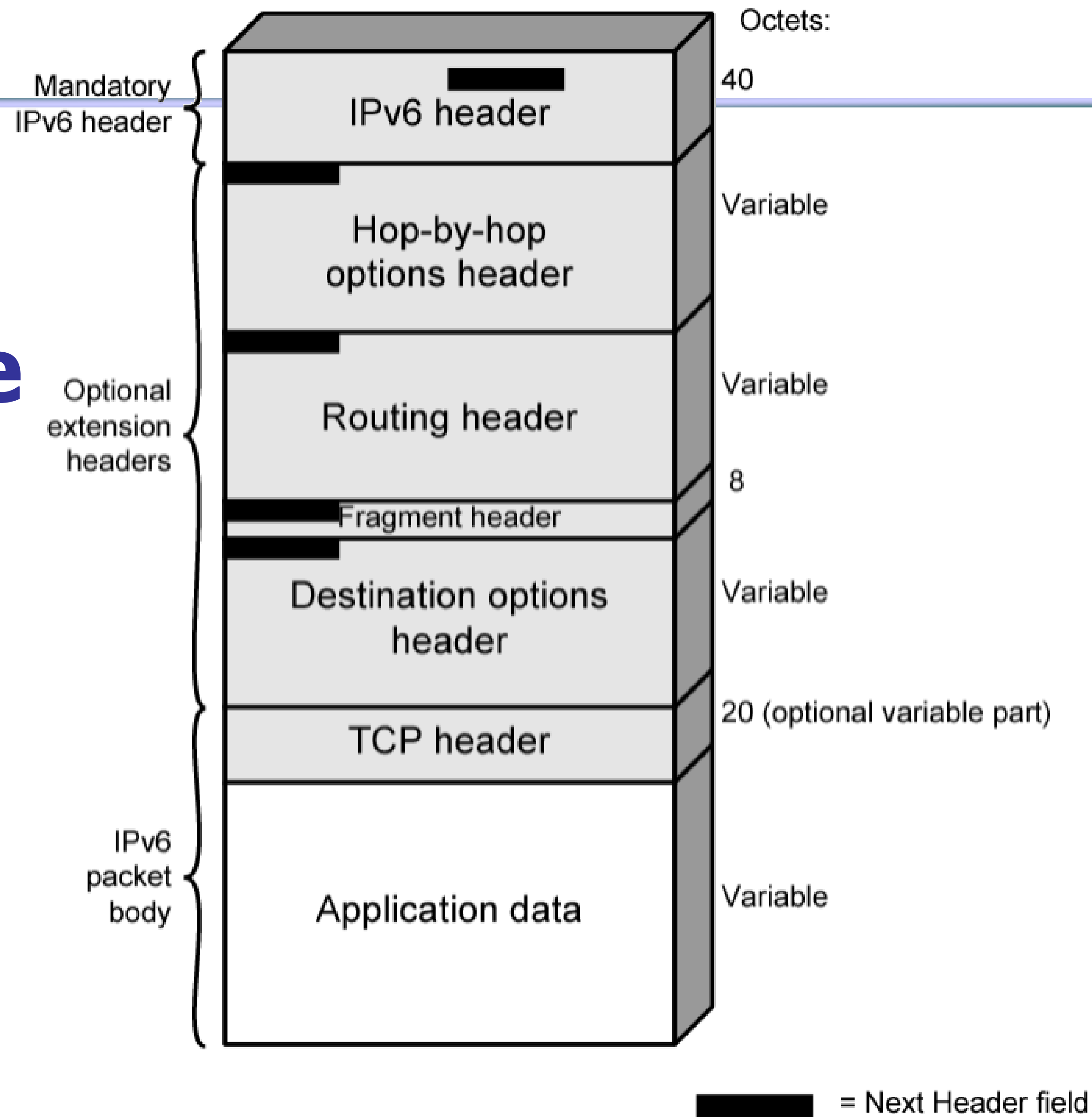
- From hosts point of view
  - Generated from one application and have the same transfer service requirements
  - May comprise a single or multiple TCP connections
  - One application may generate a single flow or multiple flows

- 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

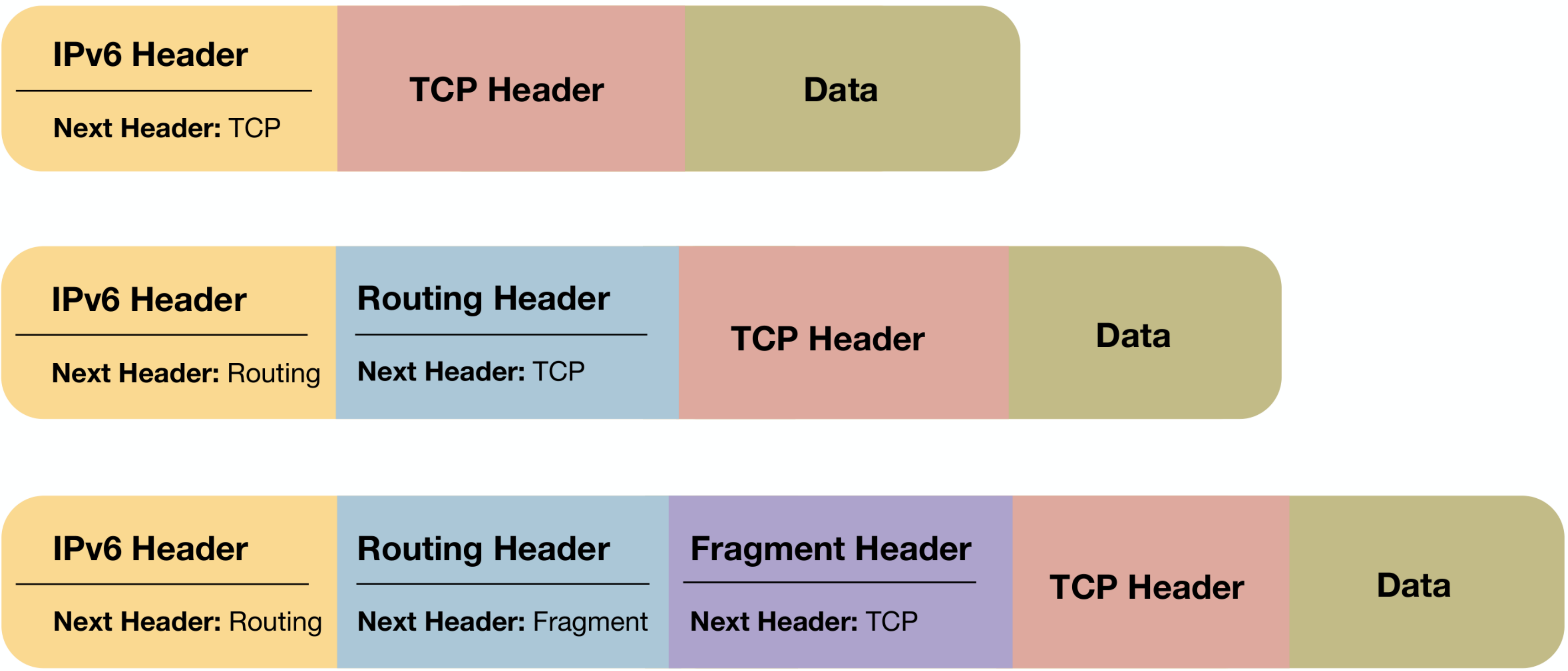
- A flow is uniquely identified by the combination of
  - Source and destination address
  - A non-zero 20-bit Flow Label
- Flow requirements are defined prior to flow commencement
  - Then a unique Flow Label is assigned to the flow
- Router decide how to route and process the packet by
  - Simply looking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

IPv6 Header Structure



Extension Headers

- Optional fields go into extension headers
- Daisy-chained after the main header



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

Fragmentation

- Routers don't fragment packets with IPv6
  - More efficient handling of packets in the core
  - Fragmentation is being done by host
- If a packet is too big for next hop:
  - "Packet too big" error message
  - This is an ICMPv6 message
  - Filtering ICMPv6 causes problems

Broadcast

- IPv6 has no broadcast
- There is an “all nodes” multicast group
  - ff02::1

- Disadvantages of broadcast:
  - It wakes up all nodes
  - Only a few devices are involved
  - Can create broadcast storms

Neighbor Discovery

- IPv6 has no ARP
- Replacement is called Neighbor Discovery
  - Uses ICMPv6
  - Uses Multicast

- Neighbor Discovery is used by nodes:
  - For address resolution
  - To find neighboring routers
  - To track address changes
  - To check neighbor reachability
  - To do Duplicate Address Detection

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

Summary of Header Changes

- 40 bytes
- Address increased from 32 to 128 bits
- Fragmentation and options fields removed from base header
- Header checksum removed
- Header length is only payload (because fixed length header
- New flow label field
- TOS→> Traffic Class
- Protocol -> Next Header(extension headers)
- Time To Live-> Hop Limit
- Alignment changed to 64 bits

Advantages of IPv6 over IPv4

- Expanded addressing capabilities
  - 128 bit
  - Scalability of *multicast* addresses
  - *Anycast* – delivered to one of a set of nodes
  - Address auto-configuration
- 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

Advantages of IPv6 over IPv4

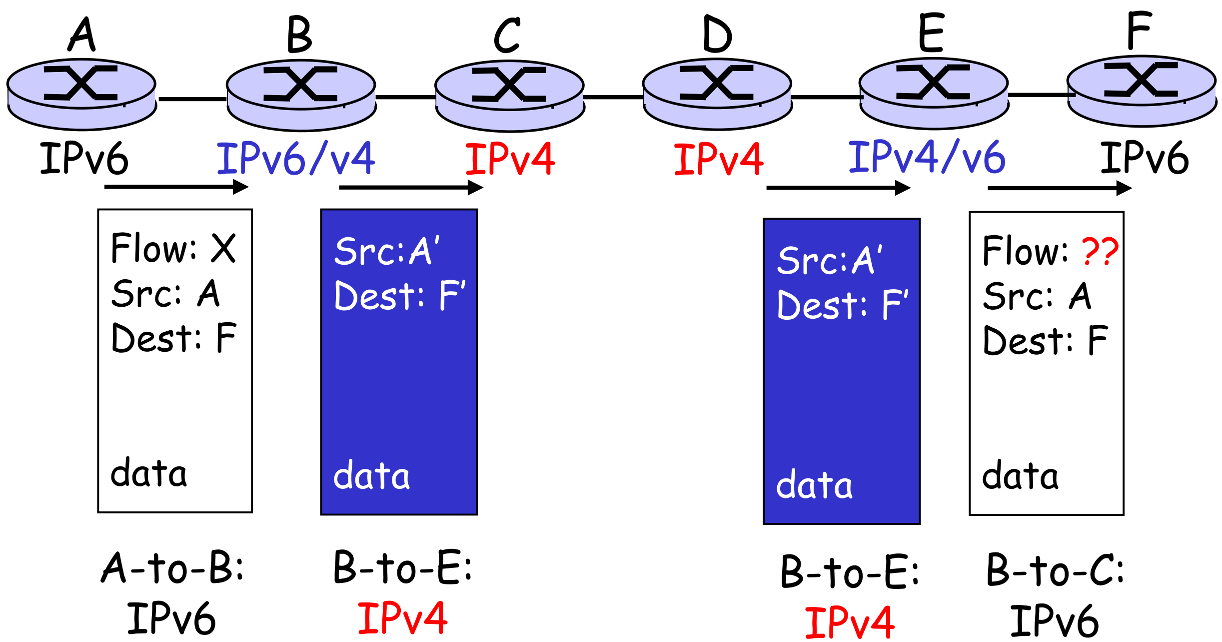
- Support for resource allocation
  - Uses traffic class
  - Grouping packets to particular traffic flow
  - Allows QoS handling other than best-effort, e.g. real-time video
- More efficient and robust mobility mechanism
- More security: Built-in, strong IP-layer encryption and authentication

Transition From IPv4 To IPv6

- Not all routers can be upgraded simultaneously
  - How will the network operate with mixed IPv4 and IPv6 routers

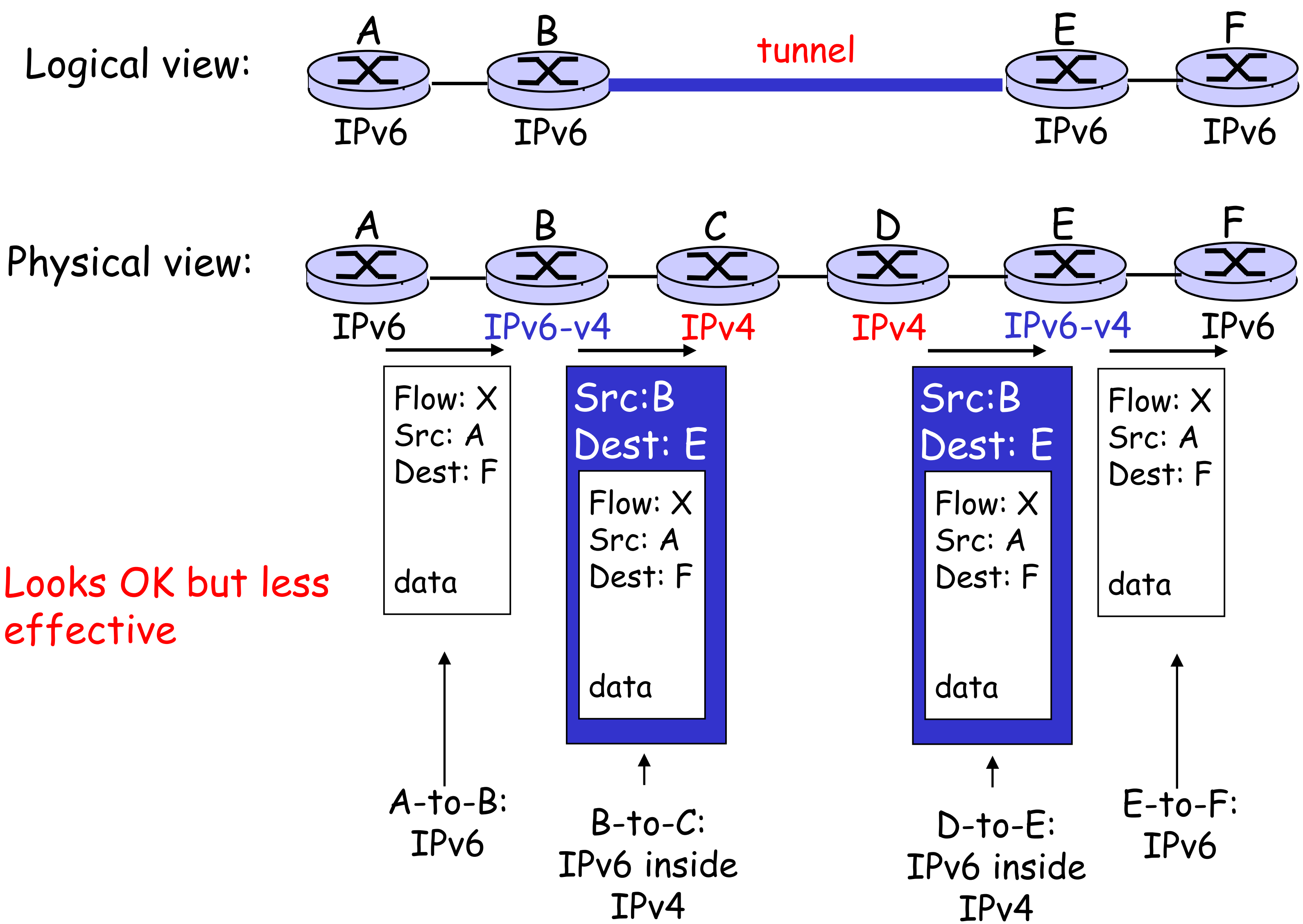
- Two proposed approaches
  - Dual Stack – some routers with dual stack (IPv6, IPv4) can translate between formats
  - Tunneling – IPv6 carried as payload in IPv4 datagram among IPv4 routers

Dual Stack Approach



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

Tunneling



Looks OK but less effective

Summary

- NAT原理及优缺点
- ARP地址解析原理和流程
- DHCP动态地址获取的过程
- ICMP
  - 用于发送出错信息
  - Ping和traceroute的实现原理
- Mobile IP
  - 移动终端，归属代理，外部代理，隧道
  - 三角路由
- IPv6
  - 地址格式
  - 和IPv4的异同，优缺点？
  - V4和V6的融合

Homework

- 第四章：R14, R19, R20, P22