Student Online Teaching Advice Notice

The materials and content presented within this session are intended solely for use in a context of teaching and learning at Trinity.

Any session recorded for subsequent review is made available solely for the purpose of enhancing student learning.

Students should not edit or modify the recording in any way, nor disseminate it for use outside of a context of teaching and learning at Trinity.

Please be mindful of your physical environment and conscious of what may be captured by the device camera and microphone during videoconferencing calls.

Recorded materials will be handled in compliance with Trinity's statutory duties under the Universities Act, 1997 and in accordance with the University's policies and procedures.

Further information on data protection and best practice when using videoconferencing software is available at https://www.tcd.ie/info_compliance/data-protection/.

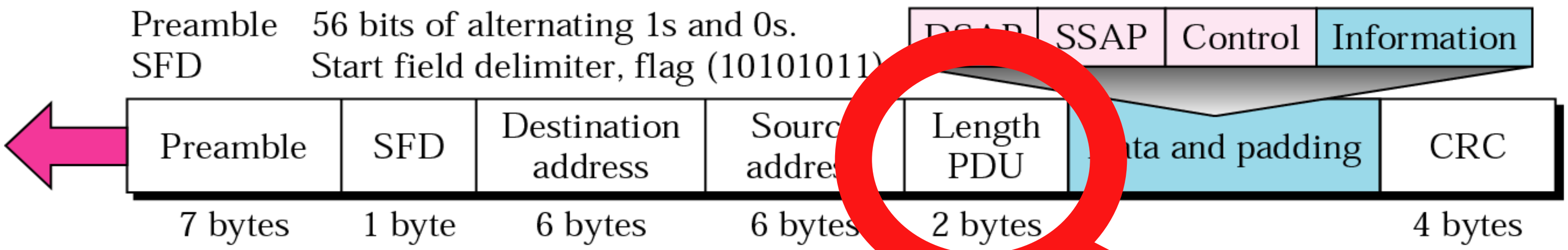
Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

CSU33031 Computer Networks

Ethernet & IPv4

Stefan Weber
email: sweber@tcd.ie
Office: Lloyd 1.41

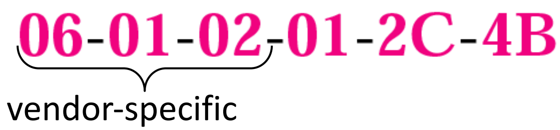
802.3 Ethernet



Length: Up to 0x0600
Type: eg. 0x0800 IP
0x0806 ARP

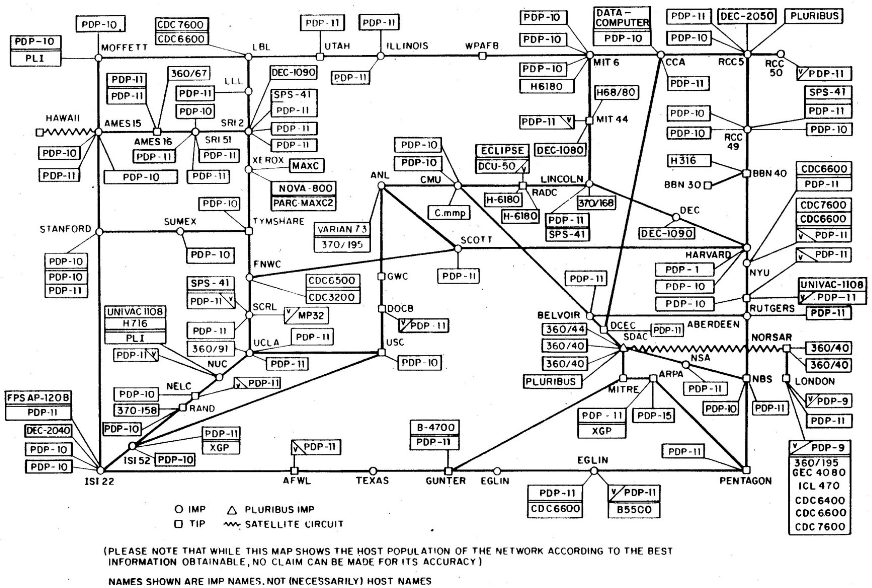
- Types of Addresses:
  - Unicast – delivered to one station
    - 00-10-4B 3Com 3C905-TX PCI
    - 00-A0-C9 Intel (PRO100B and PRO100+)

  (omitted Ethernet Multicast)
  - Broadcast – delivered to all stations
    - FF-FF-FF-FF-FF-FF



* Figure is courtesy of B. Forouzan

From ARPANET to IPv4



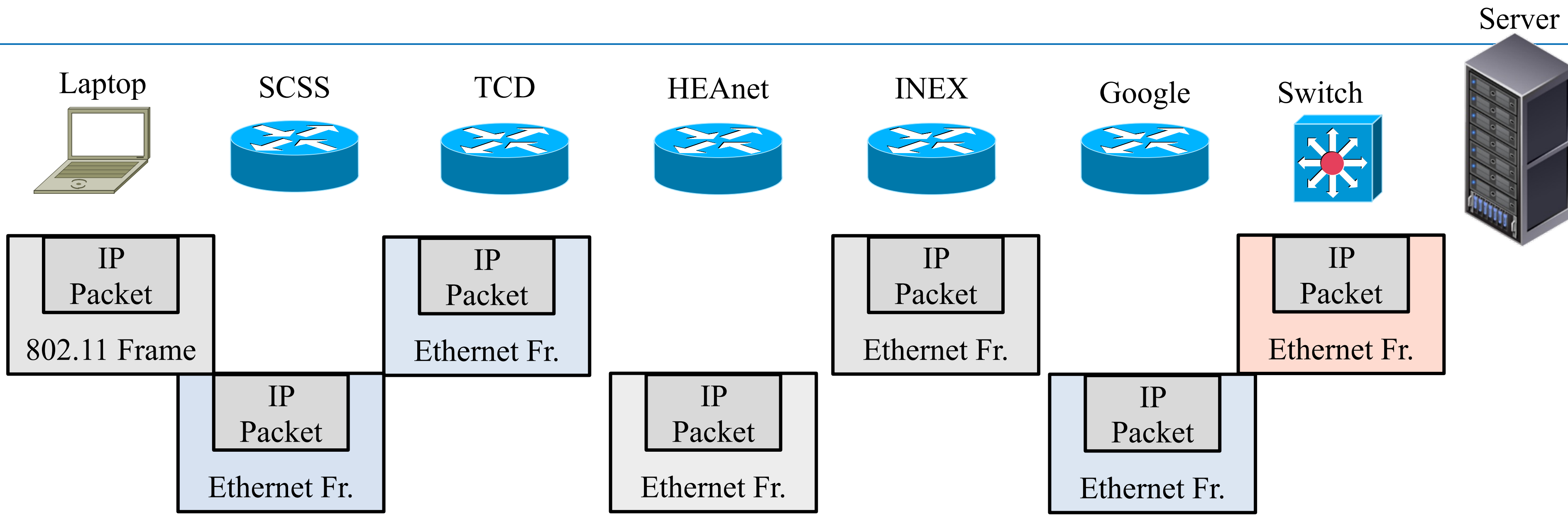
- 32-bit number
  - 4.294.967.296 addresses

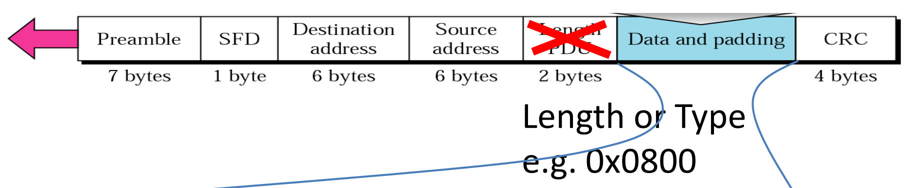
10000000 00001011 00000011 00011111

128.11.3.31

- IP addresses are unique and universal
  - with some exceptions
- Dotted decimal notation:
  - Bytes of binary notation represented as decimal separated by dot

IP Packet Encapsulation in Ethernet

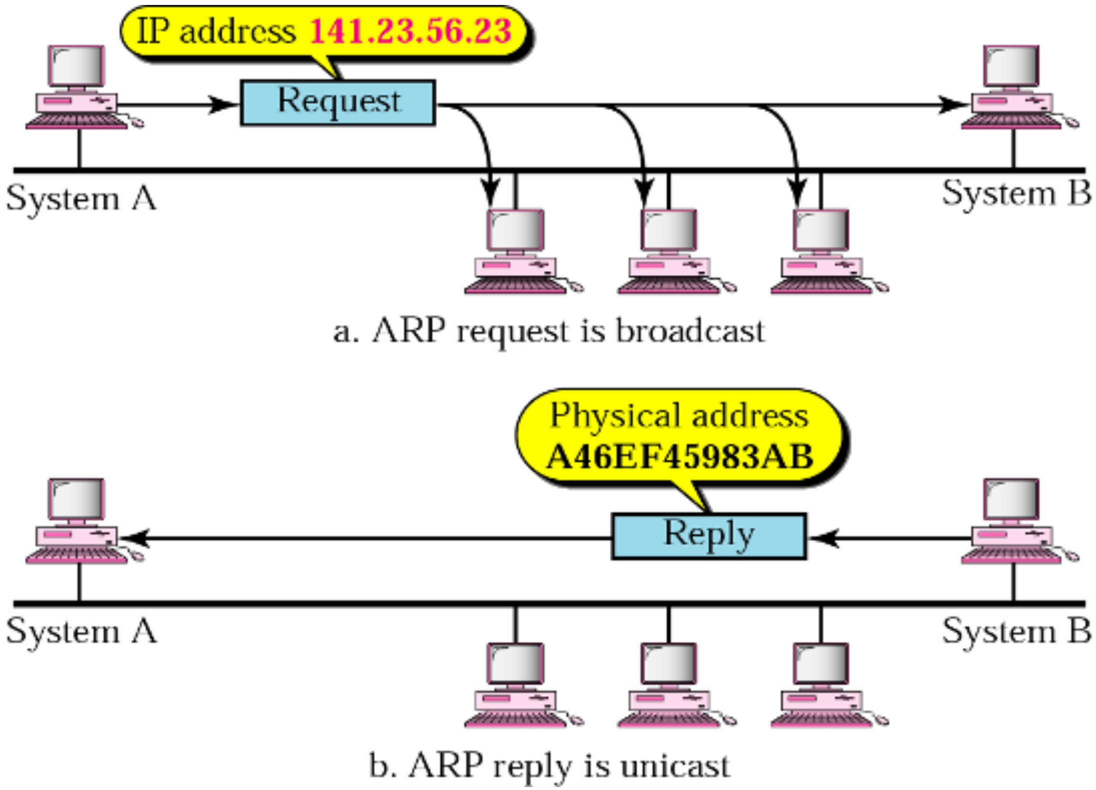




VER 4 bits	HLEN 4 bits	DS 8 bits	Total length 16 bits	
Identification 16 bits			Flags 3 bits	Fragmentation offset 13 bits
Time to live 8 bits		Protocol 8 bits	Header checksum 16 bits	
Source IP address				
Destination IP address				
Option				

Address Resolution Protocol (ARP)

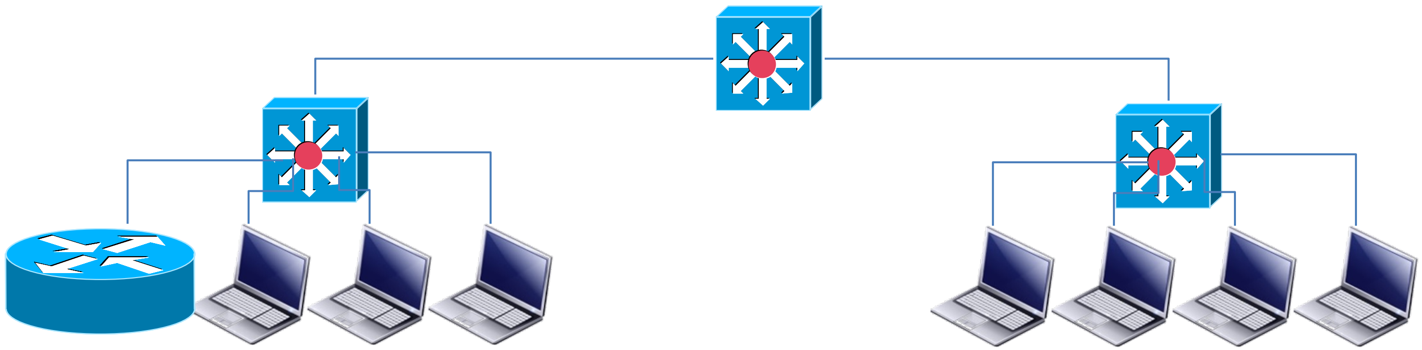
Ethernet all the way



- Association between hardware address and IP address

* Figure is courtesy of B. Forouzan

Packet from .0.2 to .0.3



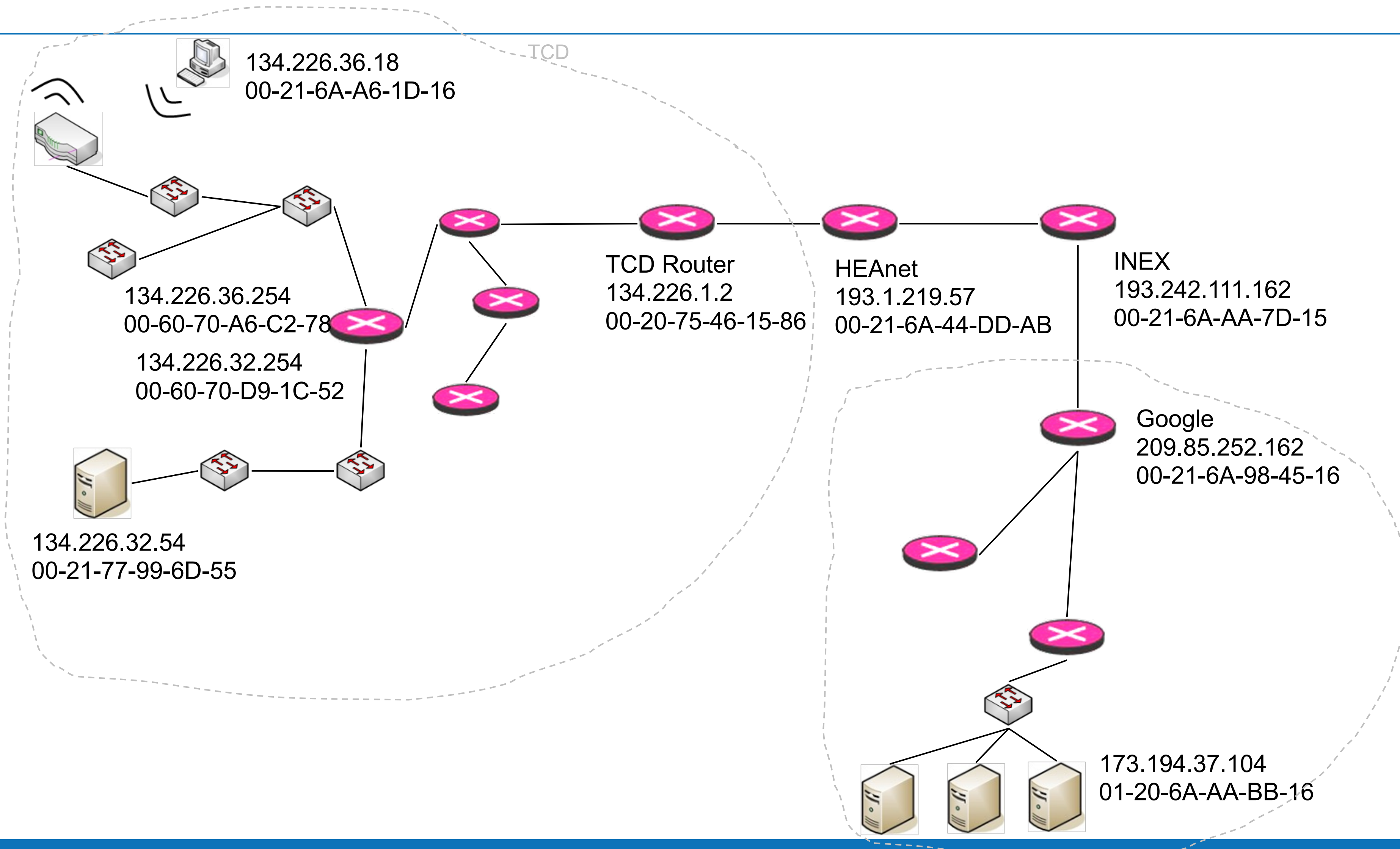
IP: 172.20.0.2
MAC: AA:BB:CC:12:34:56

172.20.0.3
MAC: AA:BB:CC:78:90:12

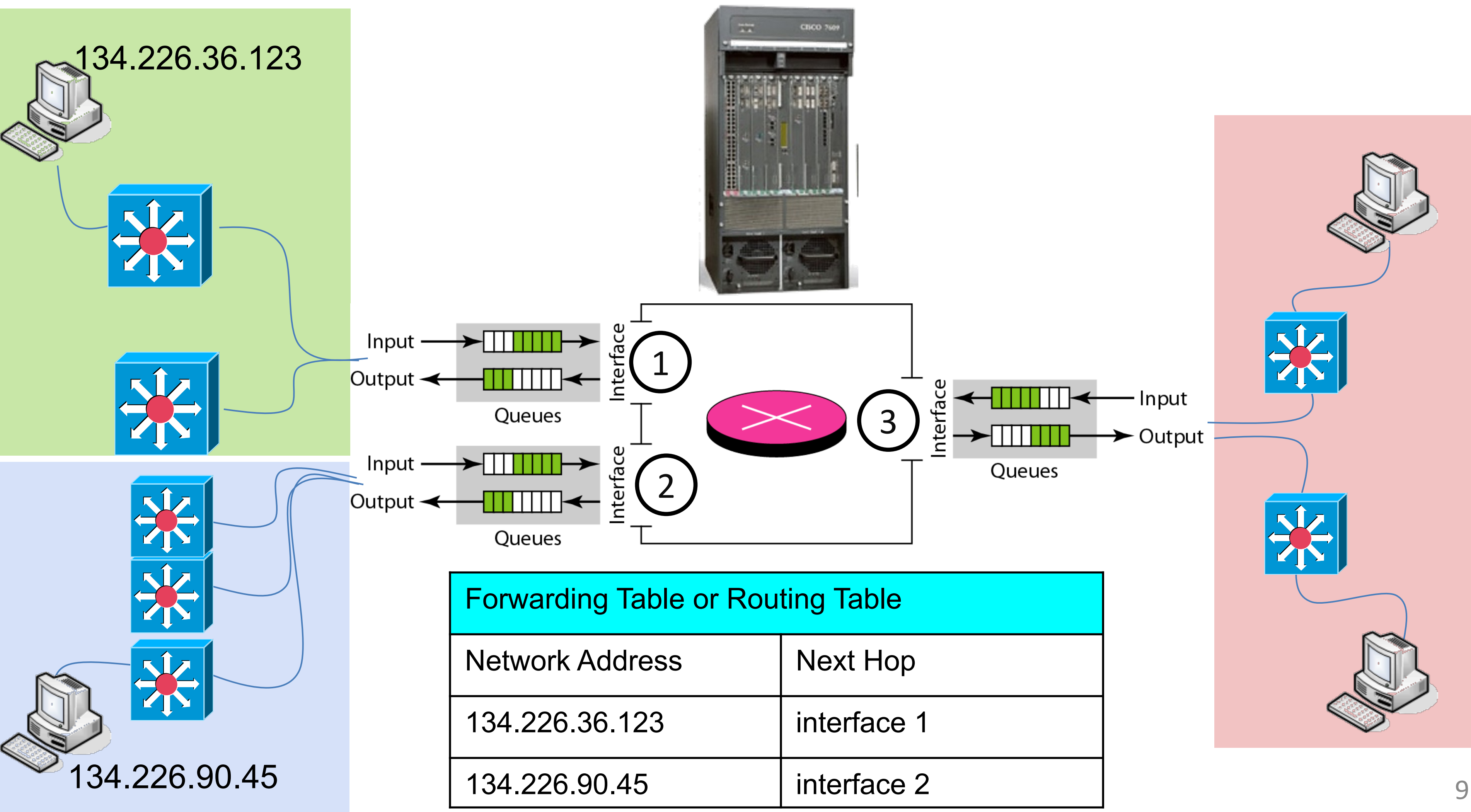
Ethernet Frame
From: AA:BB:CC:12:34:56
To: AA:BB:CC:78:90:12

IP Packet
From: 172.20.0.2
To: 172.20.0.3

Network Layer Scenario I

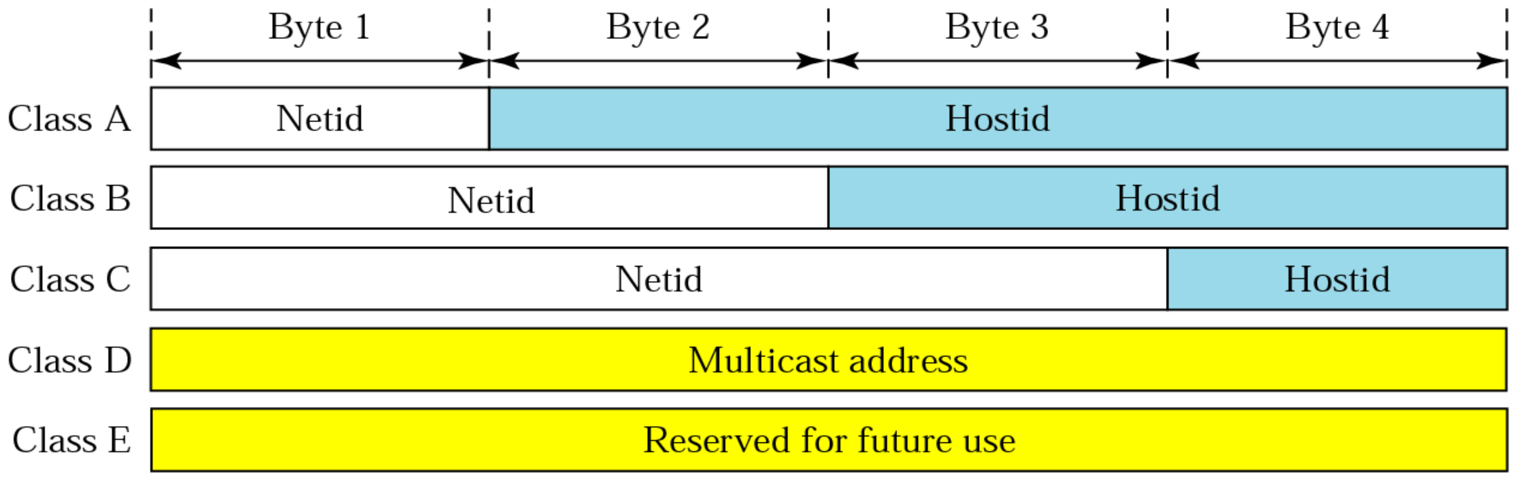


Routers (or Network Elements)



Forwarding Table or Routing Table	
Network Address	Next Hop
134.226.36.123	interface 1
134.226.90.45	interface 2

Classful Addresses – Making routing manageable



- Class A (international organisations)
  - 126 networks with 16,277,214 hosts each
- Class B (large companies)
  - 16,384 networks with 65,354 hosts each
- Class C (smaller companies)
  - 2,097,152 networks with 254 hosts each

Private Address Ranges:

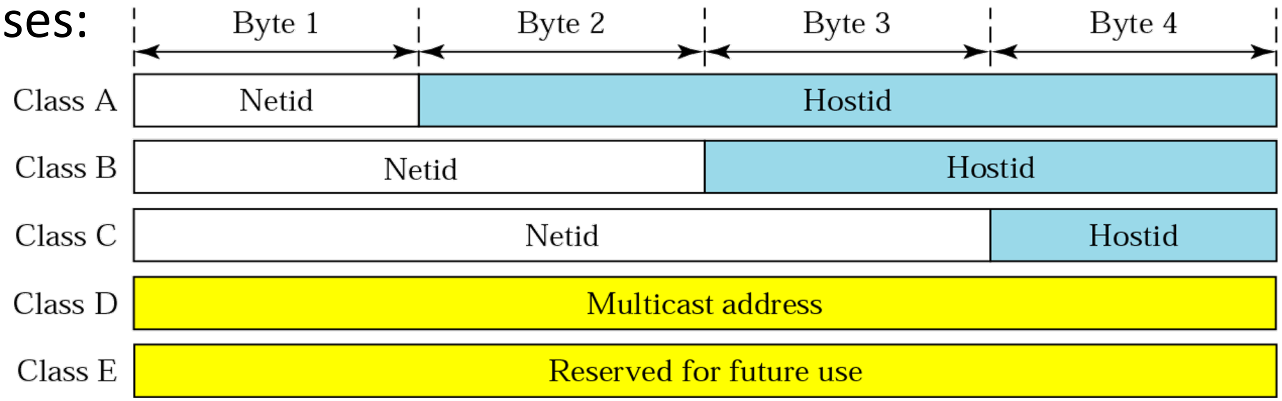
Not unique but also not on the Internet

Range			*Total*
10.0.0.0	to	10.255.255.255	2^{24}
172.16.0.0	to	172.31.255.255	2^{20}
192.168.0.0	to	192.168.255.255	2^{16}

* Figure is courtesy of B. Forouzan

Inefficiency of Classful Addresses

- Classful Addresses:



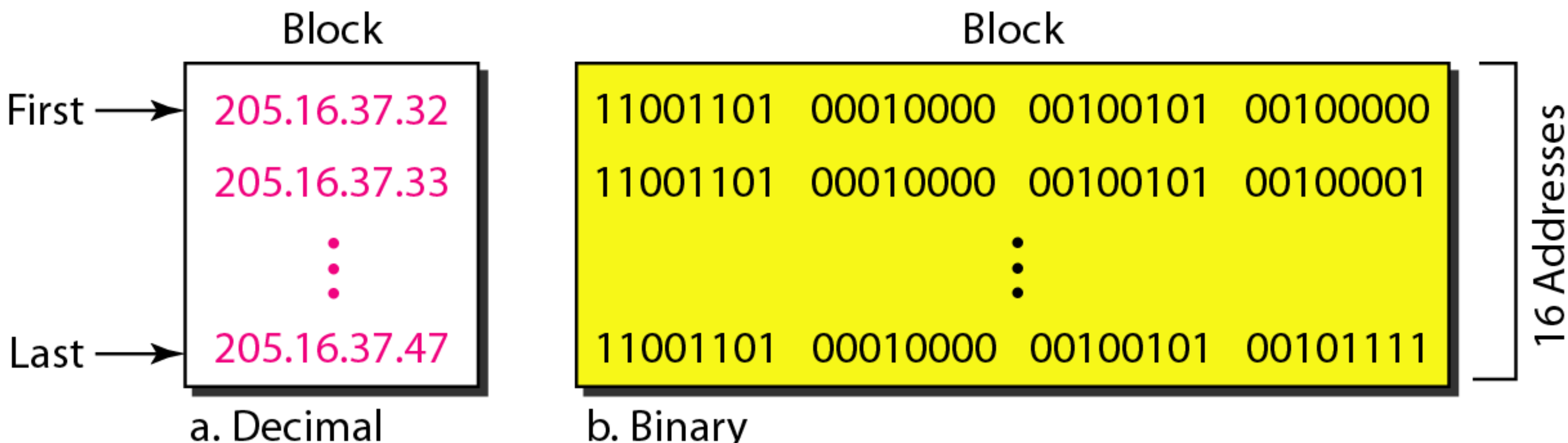
- Inefficient use of Hierarchical Address Space
  - Class C with 2 hosts (2/254 = 0.78% efficient)
  - Class B with 256 hosts (256/65534 = 0.39% efficient)

Class	Networks	Addresses
A	126	16,777,214
B	16,382	65,534
C	2,097,152	254

* Figure is courtesy of B. Forouzan

Classless Inter-Domain Routing(CIDR)

- Allow address space to be divided into blocks of addresses
    - only limited to the power of 2
- Notation as decimal number of the significant bits e.g. 134.226.36.0 /29
- 205.16.37.32/28
    - 32 bits – 28 bits are static - 4 bits are varied



* Figure is courtesy of B. Forouzan

Classless Inter-Domain Routing(CIDR)

- Aggregation: For example, class C networks can be combined to larger networks
- /21 = 8 class C = 8 * 256 addresses = 2048 addresses

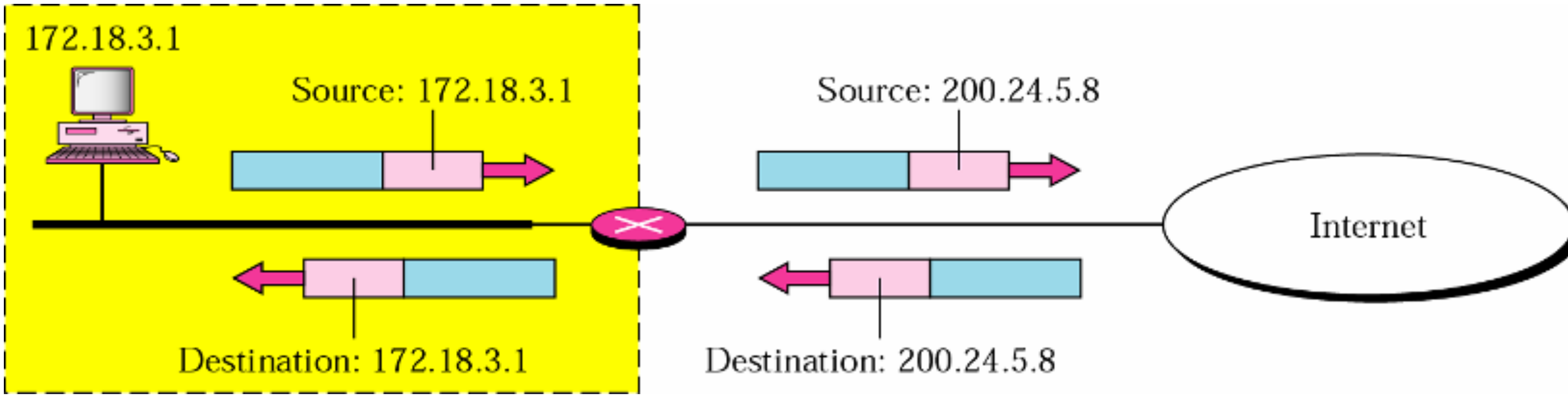
	Dotted Decimal	32-bit binary equivalent
Lowest	128.211.168.0	10000000 11010011 10101000 00000000
Highest	128.211.175.255	10000000 11010011 10101111 11111111

= 128.211.168.0/21

* Figure is courtesy of B. Forouzan

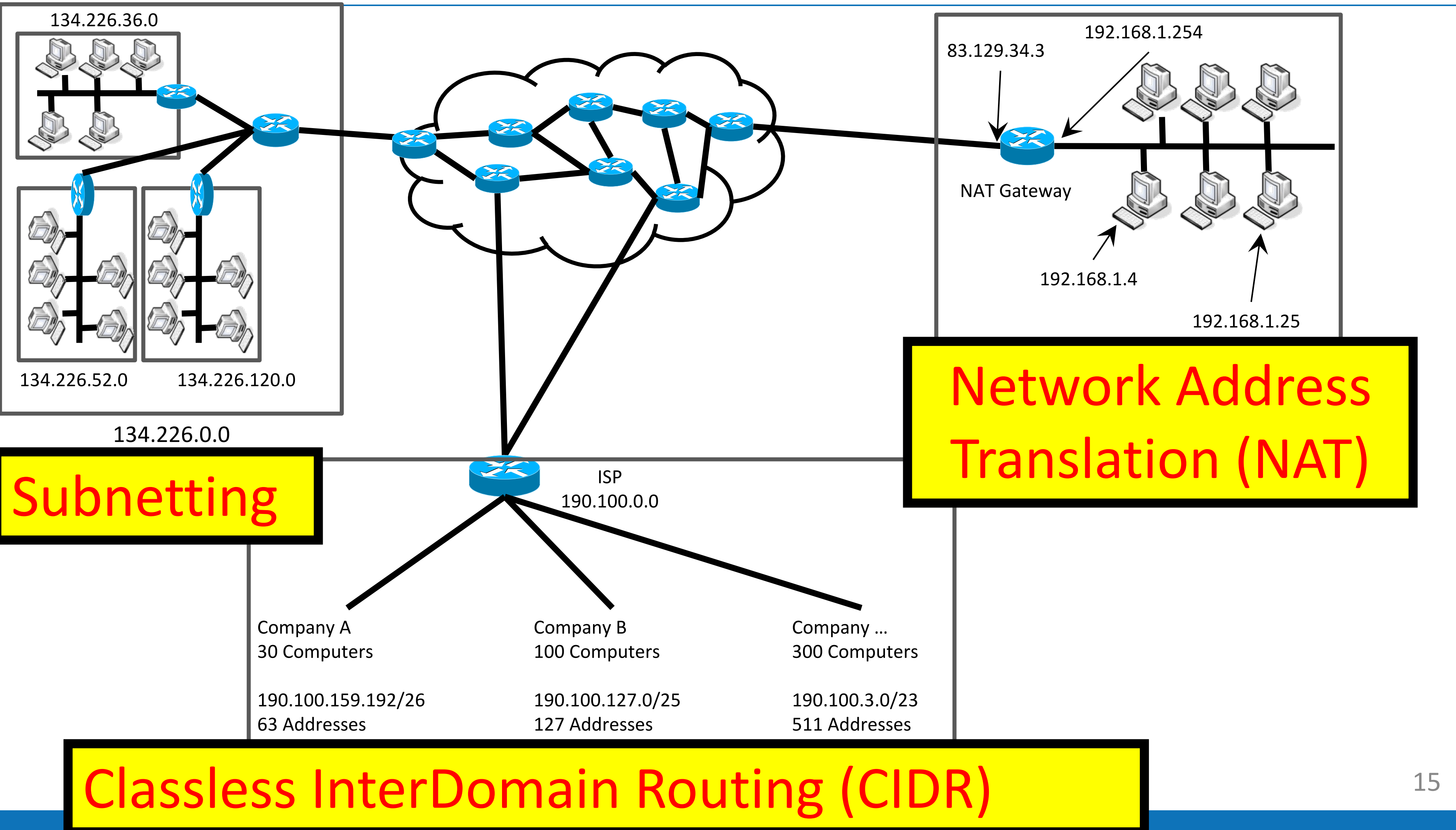
Network Address Translation (NAT)

- Gateway maintains table to match incoming and outgoing packets; including IDs for applications



Private Address	Private Port	External Address	External Port	Transport Protocol
172.18.3.1	1400	25.8.3.2	80	TCP
172.18.3.2	1401	25.8.3.2	80	TCP
...	...	...	...	...

Summary IP Addresses



Summary: Addresses

- 32-bit number / Dotted decimal notation
- IP addresses are unique and universal
  - Exception: Private Addresses

- Classful addresses
  - Classes A, B, and C for networks, D for multicast
  - Routing on Network IDs
- Subnetting + Netmasks
  - Dealing with scale in local networks
- Classless Inter-Domain Routing (CIDR)
  - / notation – significant bits of address
- Network Address Translation (NAT)

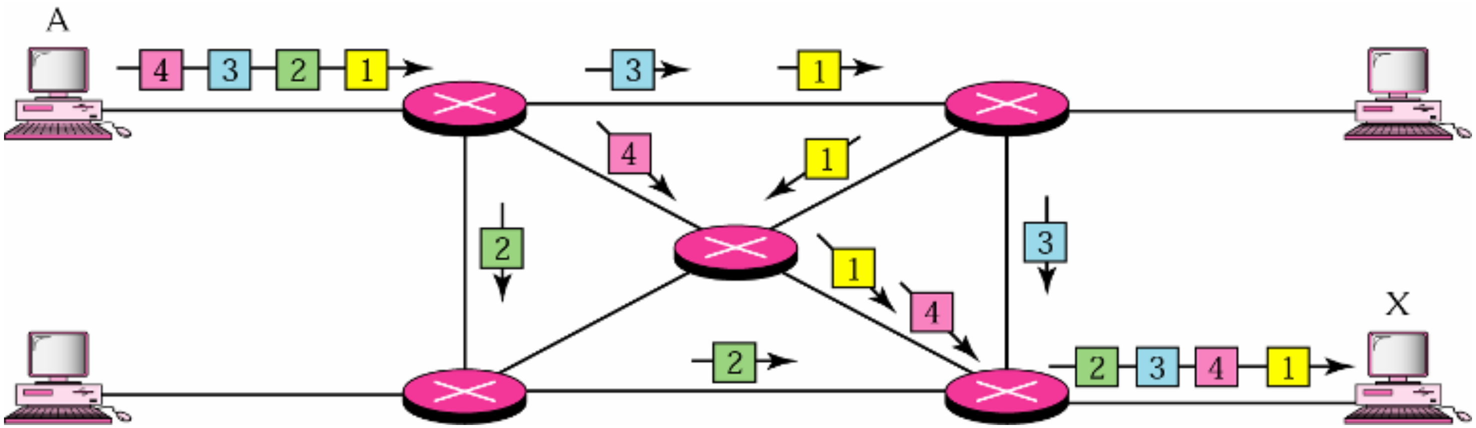
Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

CSU33031 Computer Networks

IPv4 Fragmentation

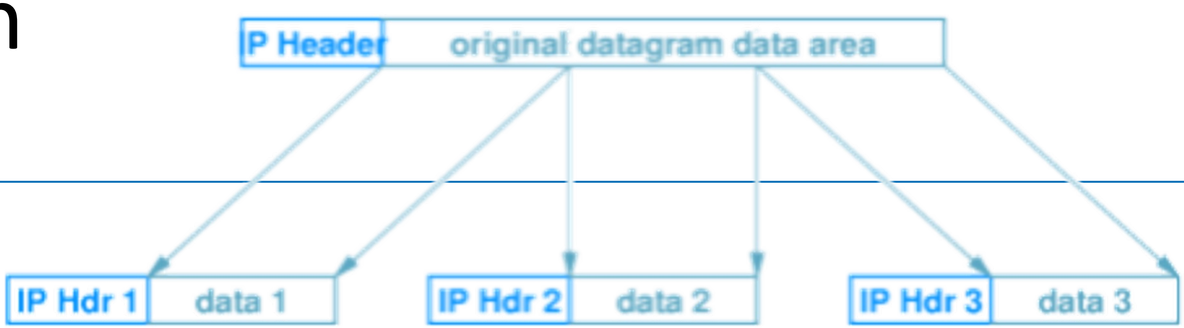
Stefan Weber
email: sweber@tcd.ie
Office: Lloyd 1.41

IP Service Model



- Best-effort delivery (unreliable service)
  - Packets may be lost
  - Packets may be delivered out of order
  - Duplicate copies of a packet may be delivered
  - Packets can be delayed for a long time

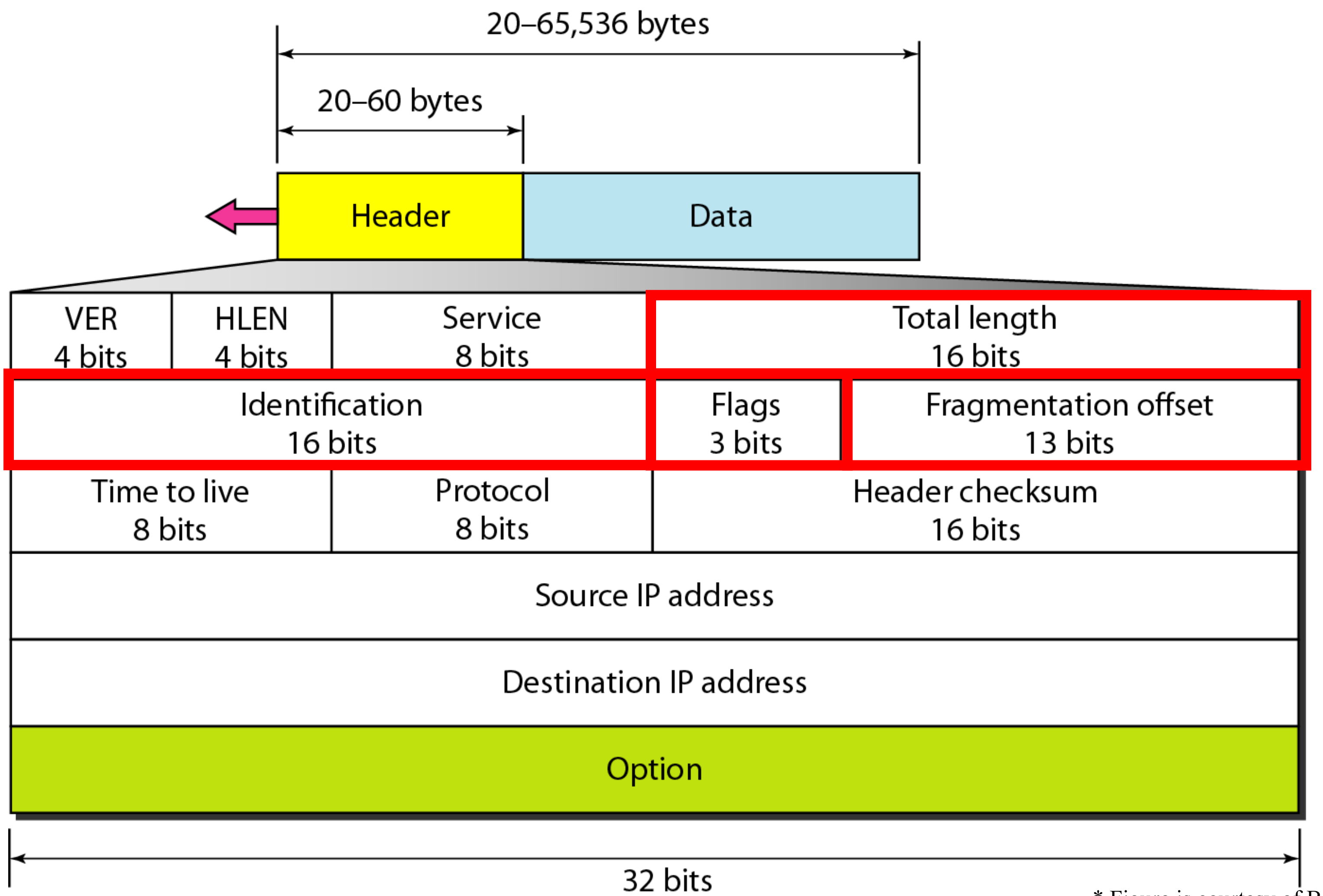
Fragmentation



- Possible techniques
  - Limit packet size to smallest MTU of any network
  - Adjust packet size as packet progresses through networks
    - Router detects packet larger than network MTU and splits into fragments

- IP Strategy
  - Fragment when necessary (Datagram > MTU)
  - Try to avoid fragmentation at source host
  - Re-fragmentation is possible
  - Delay reassembly until destination host
  - Do not recover from lost fragments
    - If one fragment is lost all fragments are discarded

Fragmentation & IPv4 Header

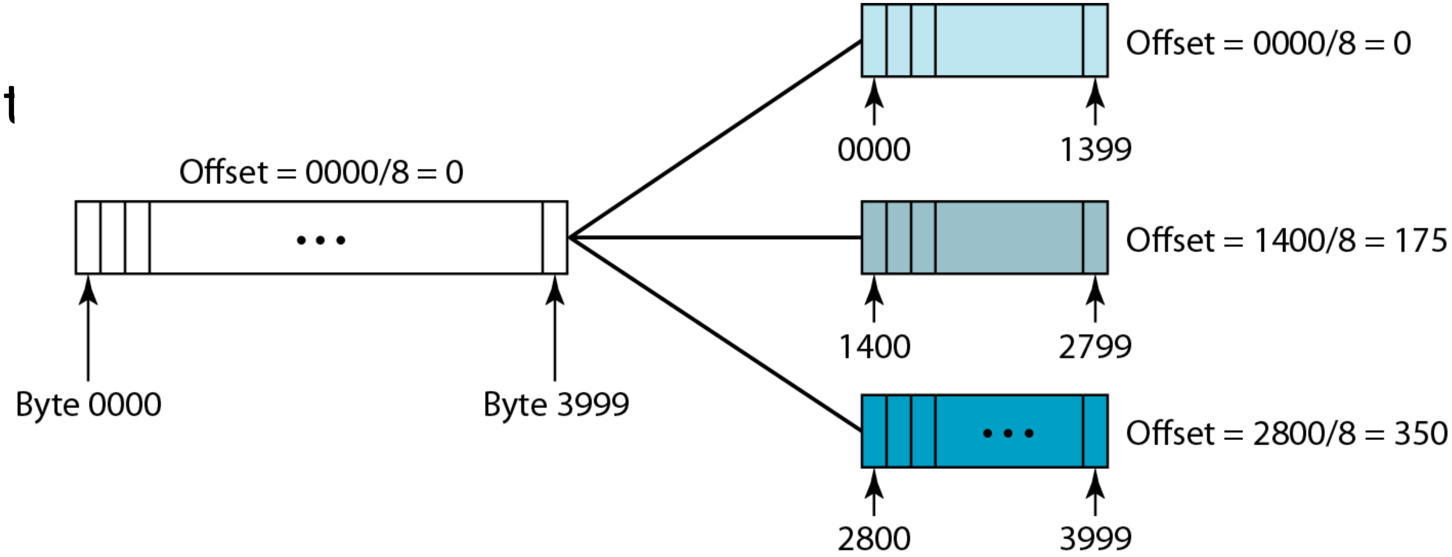


* Figure is courtesy of B. Forouzan

Header Fields

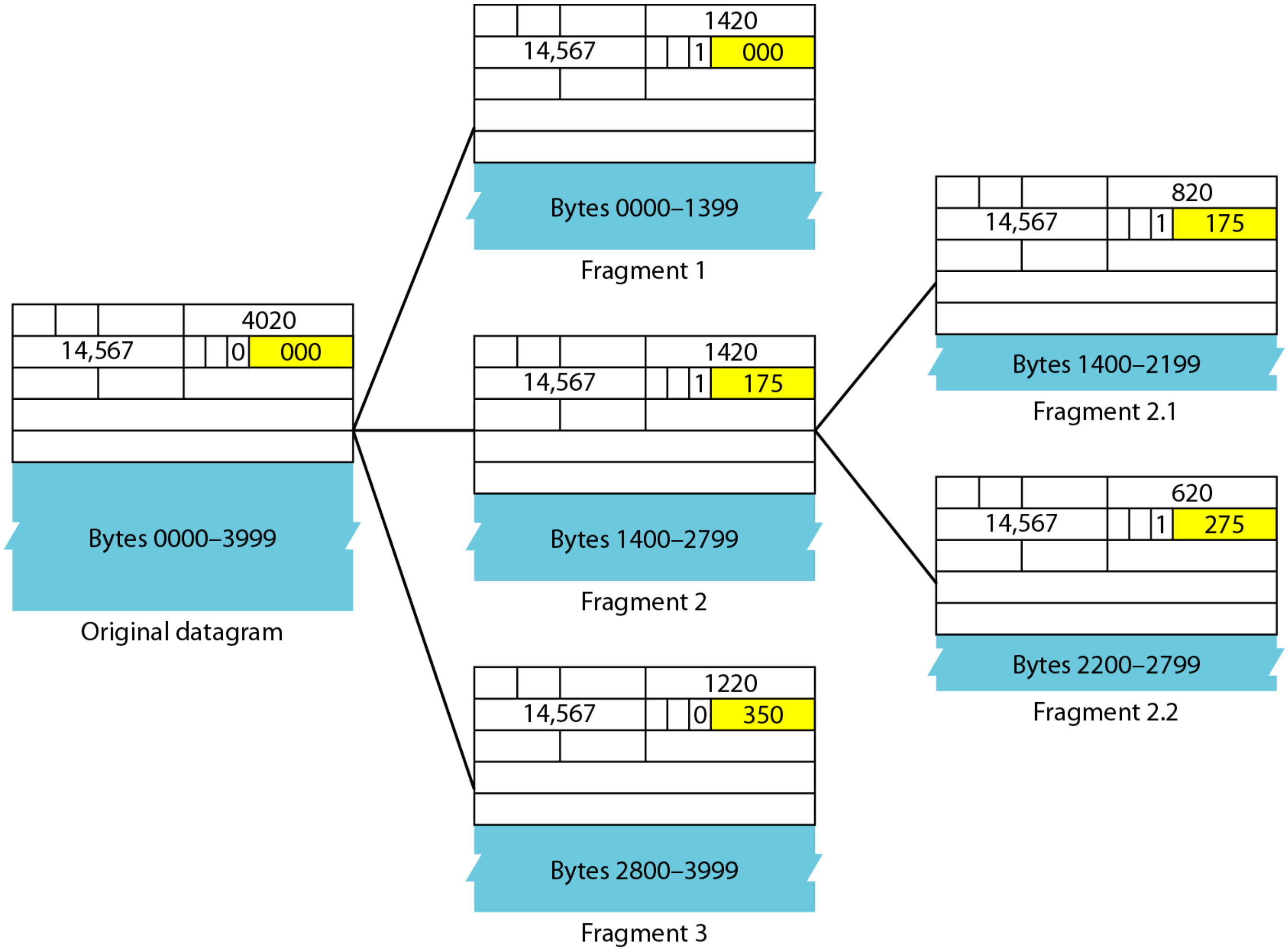
- “Do not fragment”-Request
- More Fragments

- Offset



* Figure is courtesy of B. Forouzan

Fragmentation Example I



Summary: Internet Protocol

- IP Service Model
  - Connection-less, no order guaranteed
- IP Header
  - 20 bytes + options
- Fragmentation
  - Datagrams split into fragments to fit MTUs
  - Only re-assembled at destination
- Internet Control Message Protocol (ICMP)
  - Error Reporting e.g. source quench
  - Querying e.g. Ping

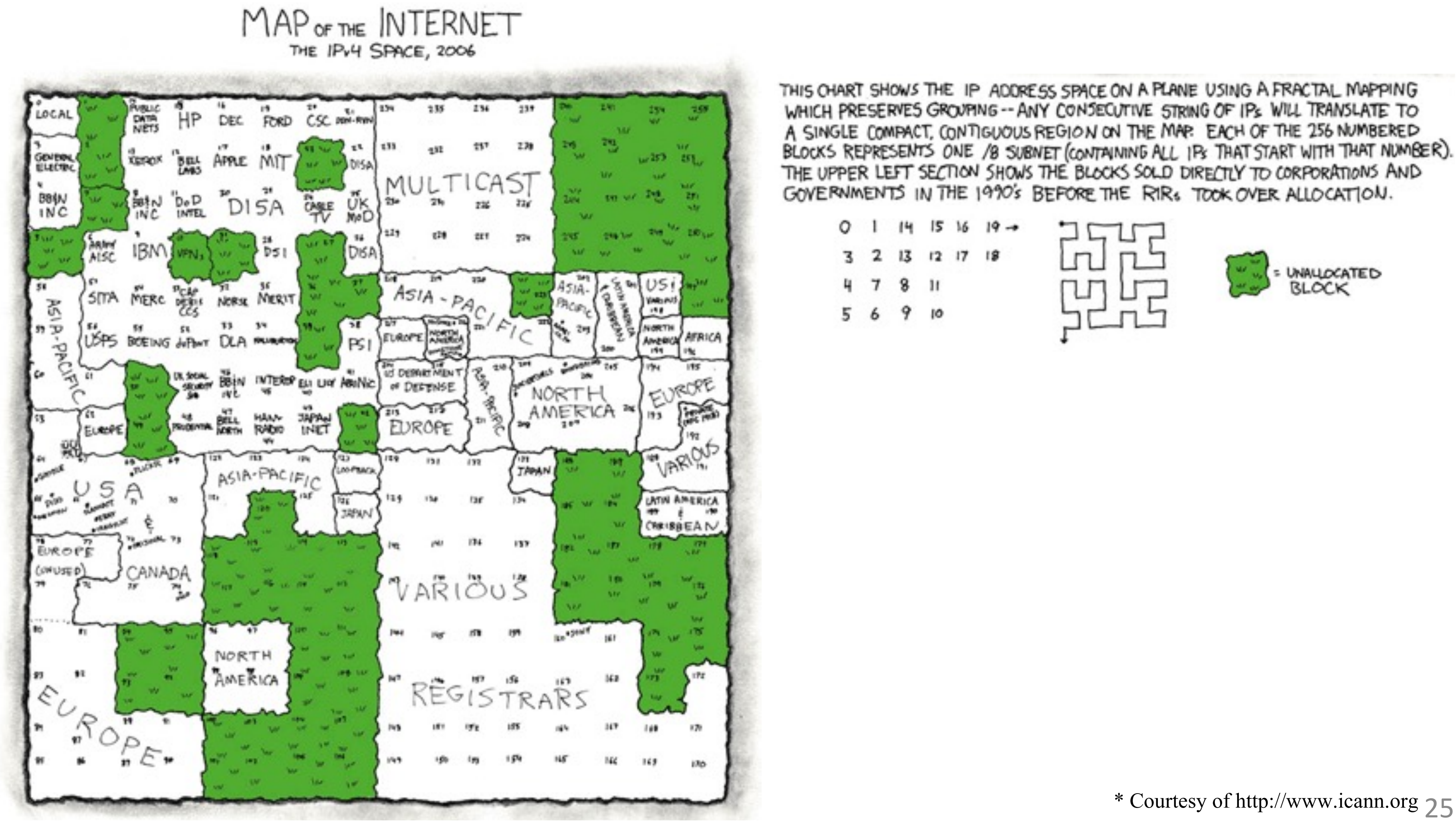
Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

CSU33031 Computer Networks

IPv6

Stefan Weber
email: sweber@tcd.ie
Office: Lloyd 1.41

2004 Allocation Map



* Courtesy of http://www.icann.org

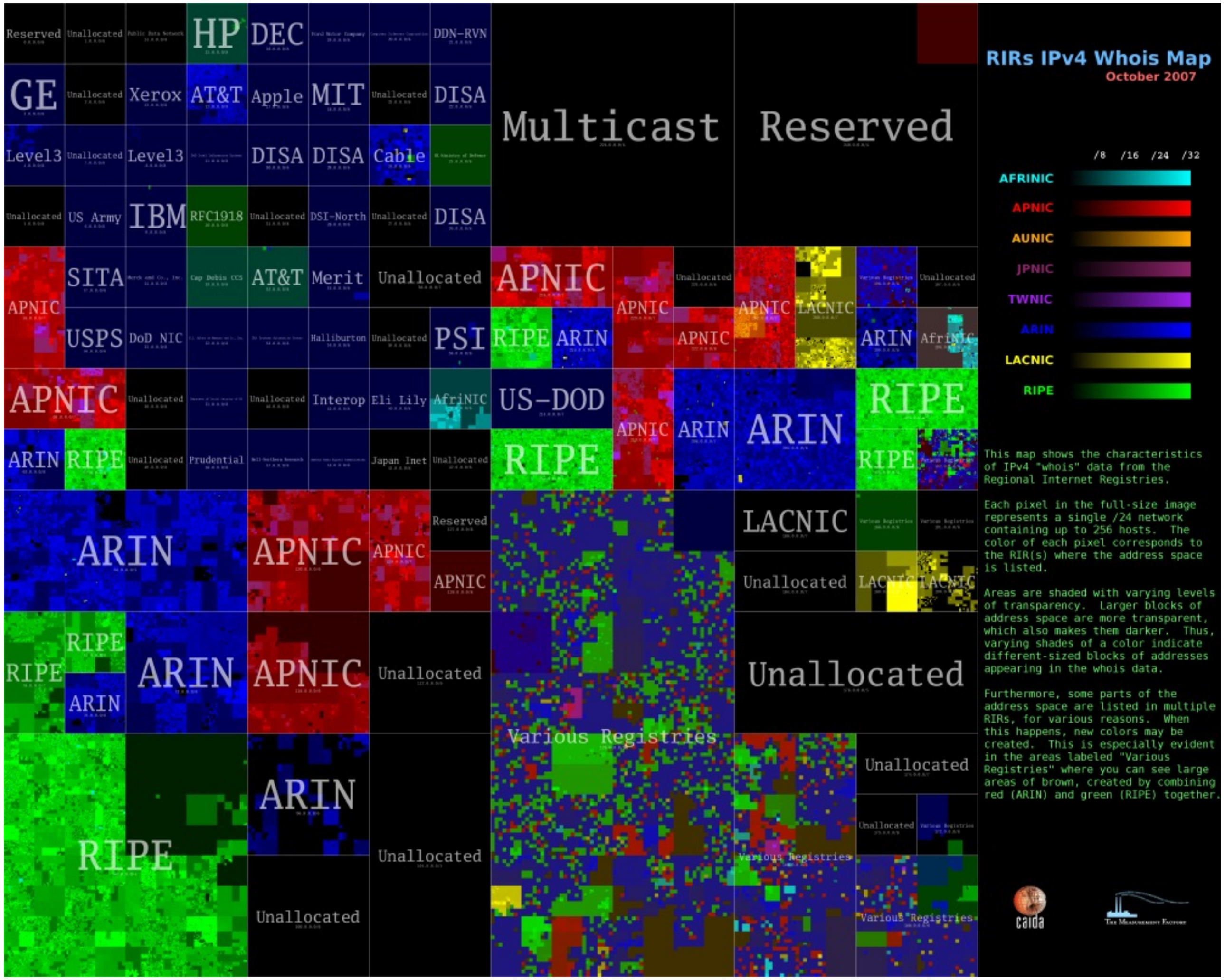
IANA & RIR Regions

AfriNIC	APNIC	ARIN	LACNIC	RIPE NCC
African Network Information Centre	Asia Pacific Network Information Centre	American Registry for Internet Numbers	Latin American and Caribbean IP Address Regional Registry	RIPE Network Coordination Centre
2005	1993	1997	2001	1992

Internet Assigned Numbers Authority (IANA)

Courtesy of http://www.nro.net

Address Allocation 2007



* Courtesy of http://www.caida.org

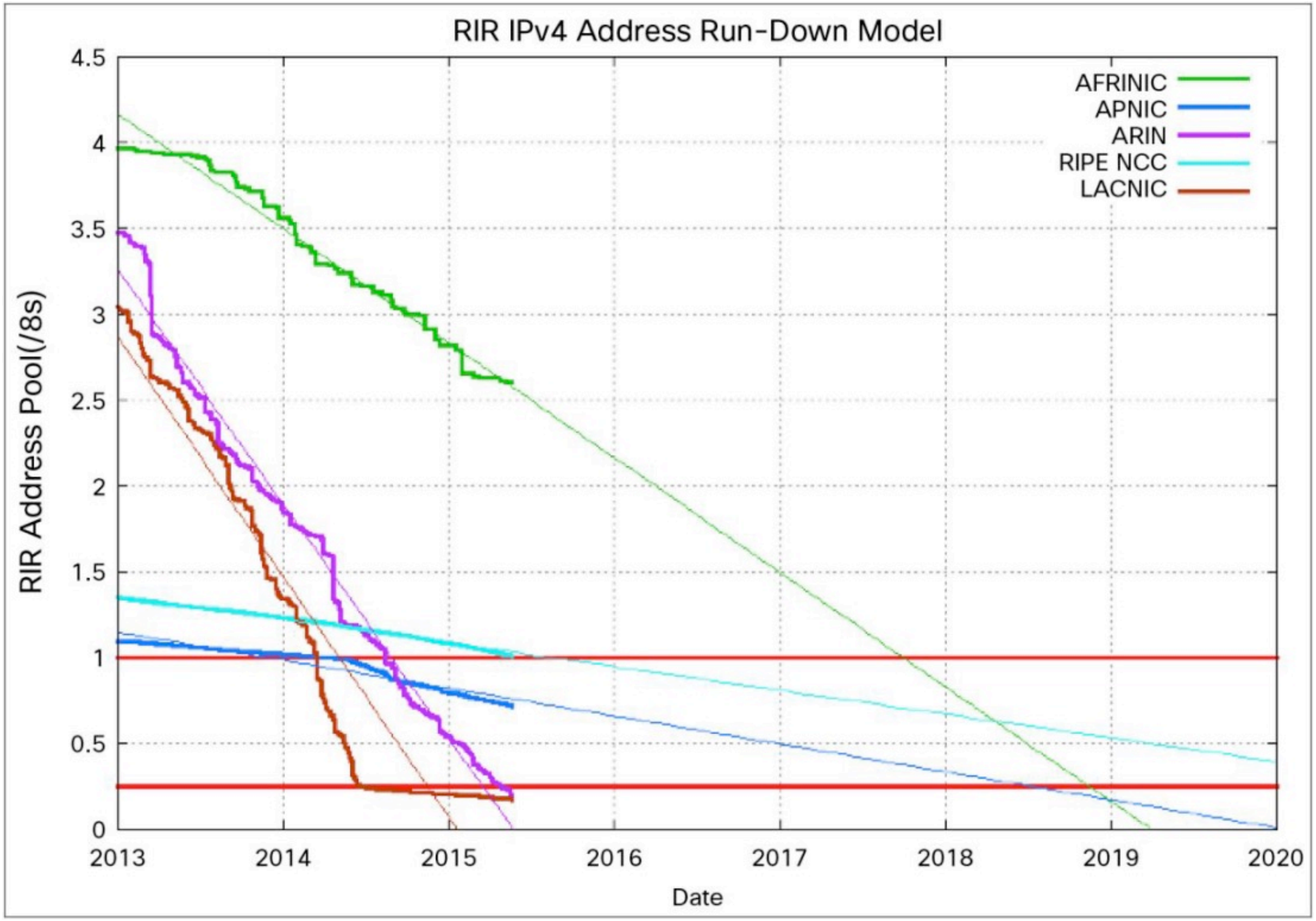
IPv4 Address Exhaustion

IANA Unallocated Address Pool Exhaustion: 03-Feb-2011

RIR	Proj. Exh. Date	Rem. Addr. in RIR Pool (/8s)
APNIC:	19-Apr-2011	1.2052
RIPENCC:	30-Jun-2012	3.9161
ARIN:	08-Jun-2013	5.9107
LACNIC:	04-Mar-2014	4.2732
AFRINIC:	12-Jul-2014	4.3815

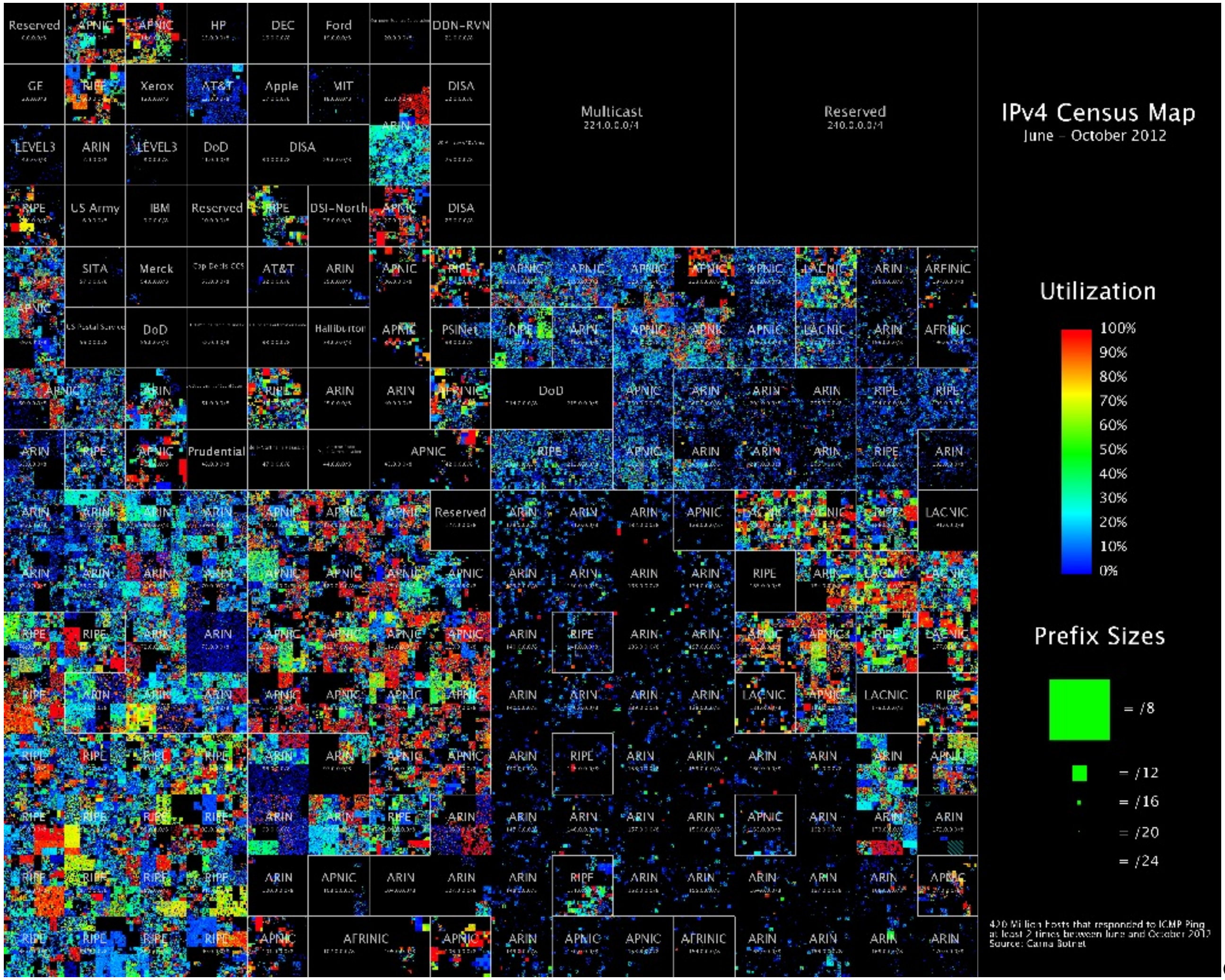
•Courtesy of http://www.potaroo.net 31 Oct 2011

Recent IPv4 Depletion Graph



•Courtesy of Cisco Whitepaper "IPv6 for the Enterprise 2015

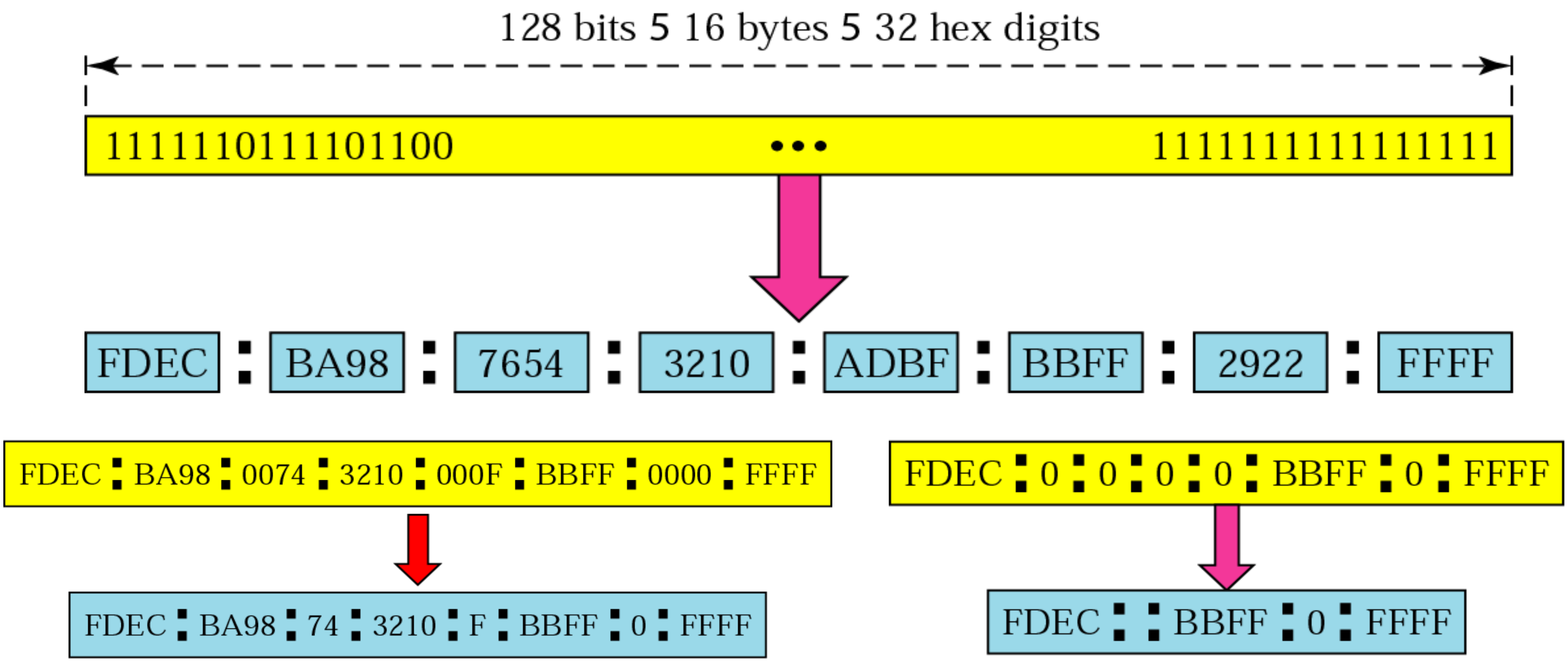
2012 Heatmap of Ping replies



Courtesy of http://www.caida.org

IPv6 Addresses

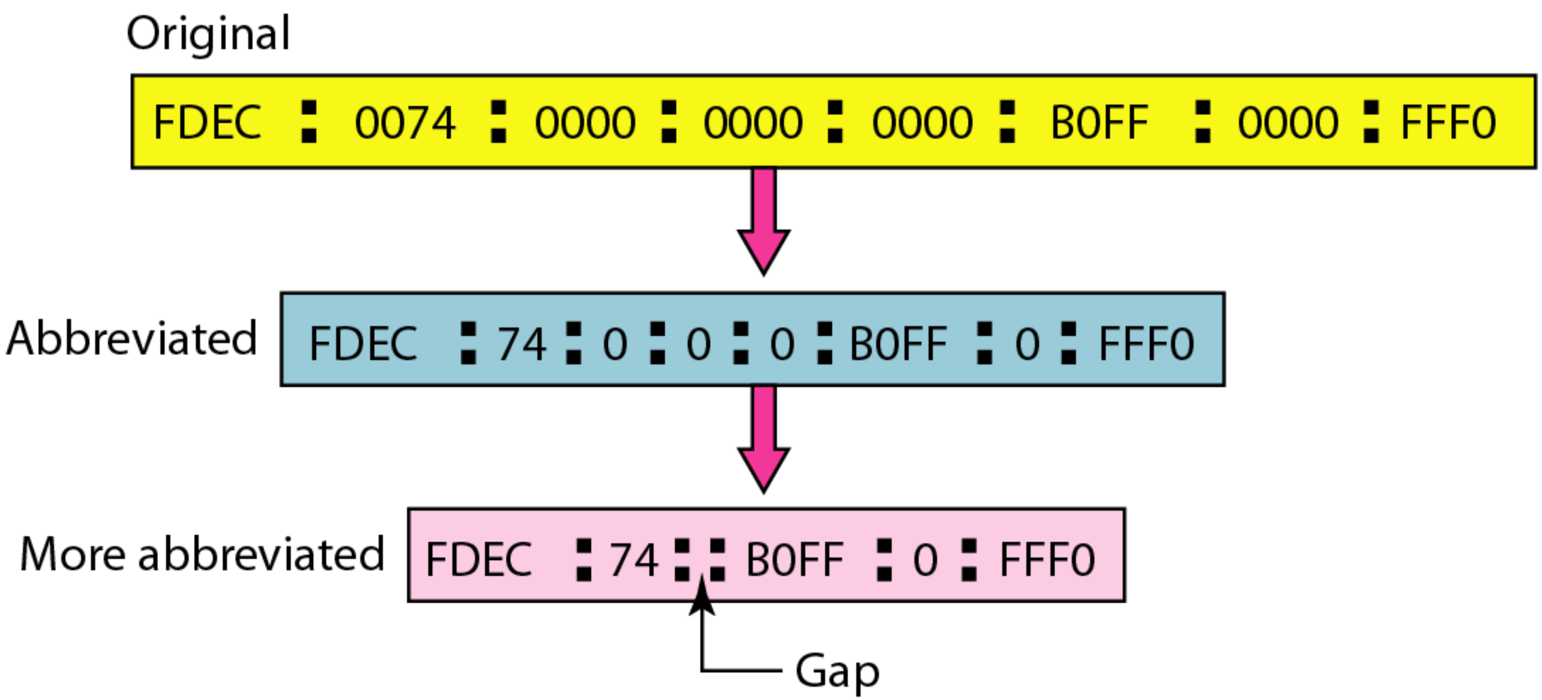
- Standard representation is set of eight 16-bit values separated by colons



* Figure is courtesy of B. Forouzan

Address Abbreviation

- Sequences of zeros can be replaced with series of colons



* Figure is courtesy of B. Forouzan

Non-Global Unicast Addresses

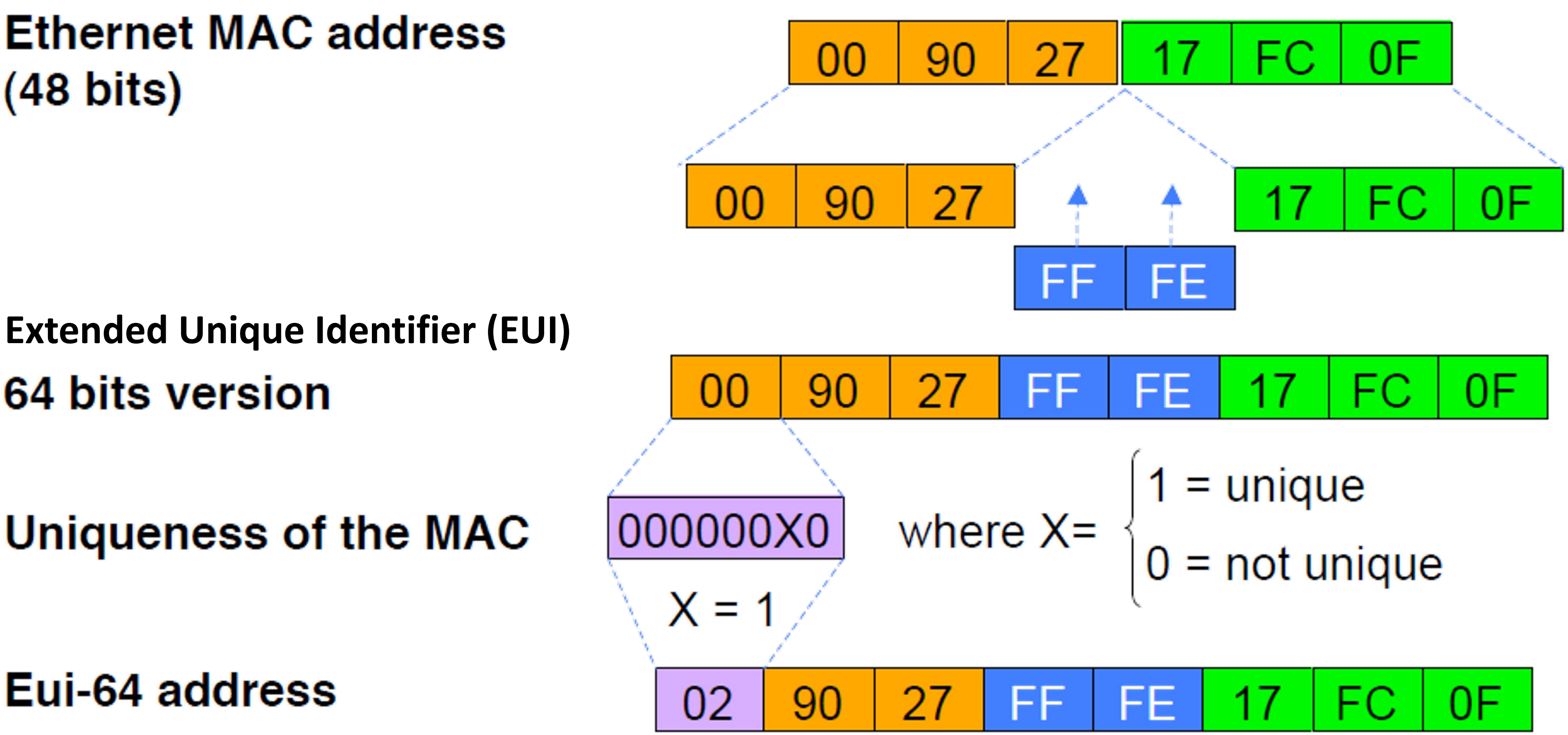
- Link-local unicast addresses are meaningful only in a single link zone, and may be re-used on other links

1111111010	0	interface ID
10 bits	54 bits	64 bits

- Site-local unicast addresses are meaningful only in a single site zone, and may be re-used in other sites

1111111011	0	subnet ID	interface ID
10 bits	38 bits	16 bits	64 bits

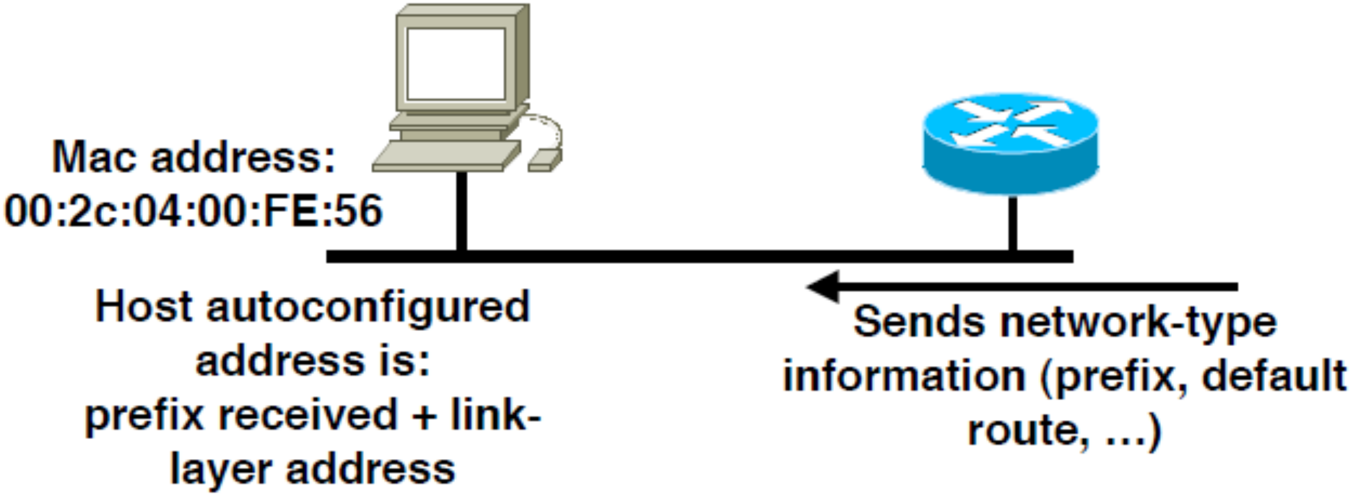
64-bit EUI Address



- EUI-64 address is formed by inserting FFFE and OR'ing a bit identifying the uniqueness of the MAC address

* Figure is courtesy of P. Smith, Cisco

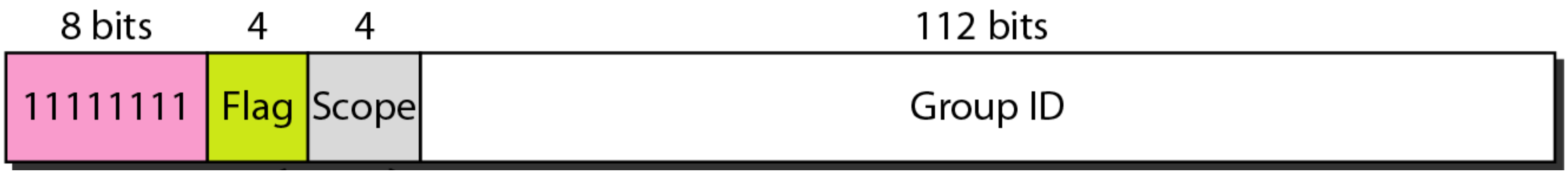
IPv6 Auto-Configuration



- Client sends router solicitation (RS) messages
- Router responds with router advertisement (RA)

  This includes prefix and default route
- Client configures its IPv6 address by concatenating prefix received with its EUI-64 address

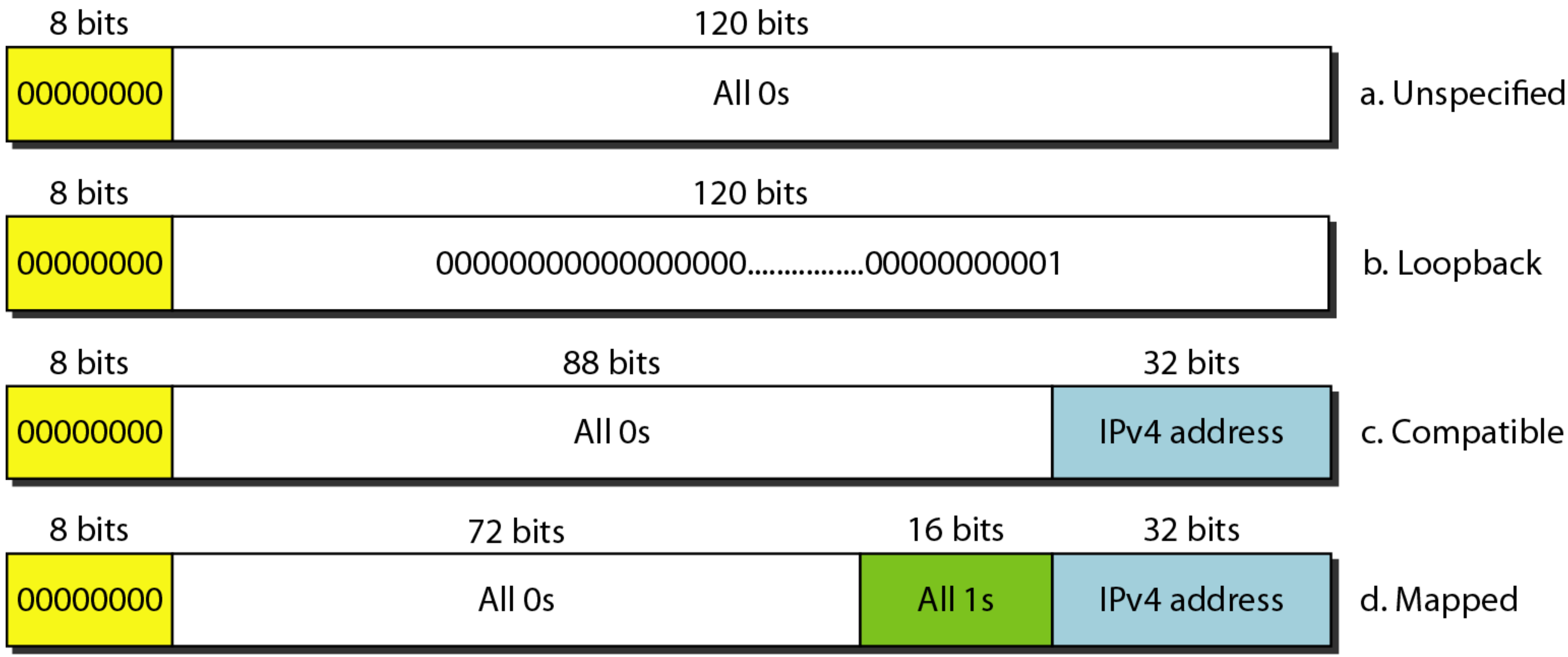
Multicast Addresses



- Low-order flag indicates permanent / transient group; three other flags reserved
- Scope field:
  - 1 - interface-local (for multicast loopback)
  - 2 - link-local (same as unicast link-local)
  - 3 - subnet-local
  - 4 - admin-local
  - 5 - site-local (same as unicast site-local)
  - 8 - organization-local
  - B - community-local
  - E - global (same as unicast global)
  - (all other values reserved)

* Figure is courtesy of B. Forouzan

Reserved Addresses



* Figure is courtesy of B. Forouzan

Different Types of Addresses

Type	Binary	Hex
Unspecified	000…0	::/128
Loopback	000…1	::1/128
Global Unicast Address	0010	2000::/3
Link Local Unicast Address	1111 1110 10	FE80::/10
Unique Local Unicast Address	1111 1100 1111 1101	FC00::/7
Multicast Address	1111 1111	FF00::/8

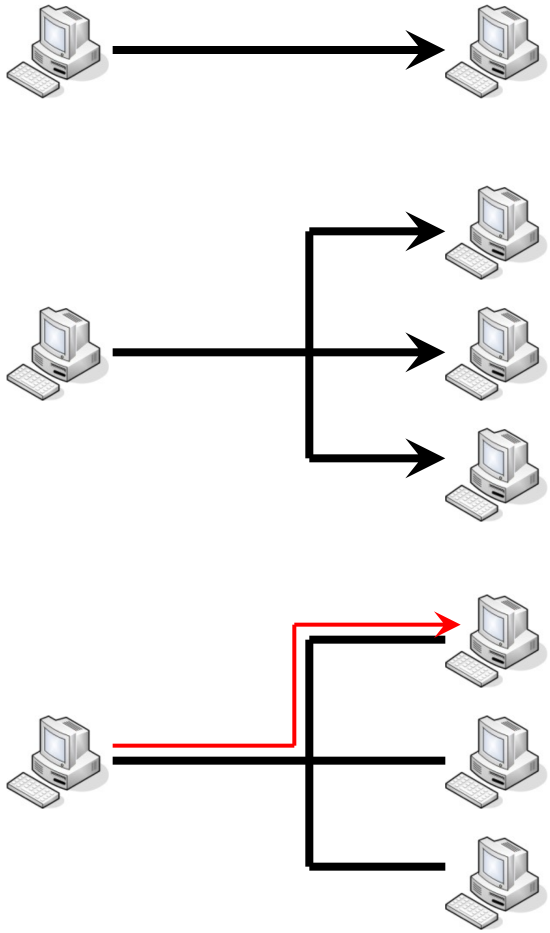
* Figure is courtesy of P. Smith, Cisco

Many Addresses

- An interface on an IPv6 node can, and usually will, have many addresses
  - Link-Local
  - Site-Local
  - Auto-configured 6to4
  - Solicited-Node Multicast
  - All-Nodes Multicast
  - Global anonymous
  - Global published

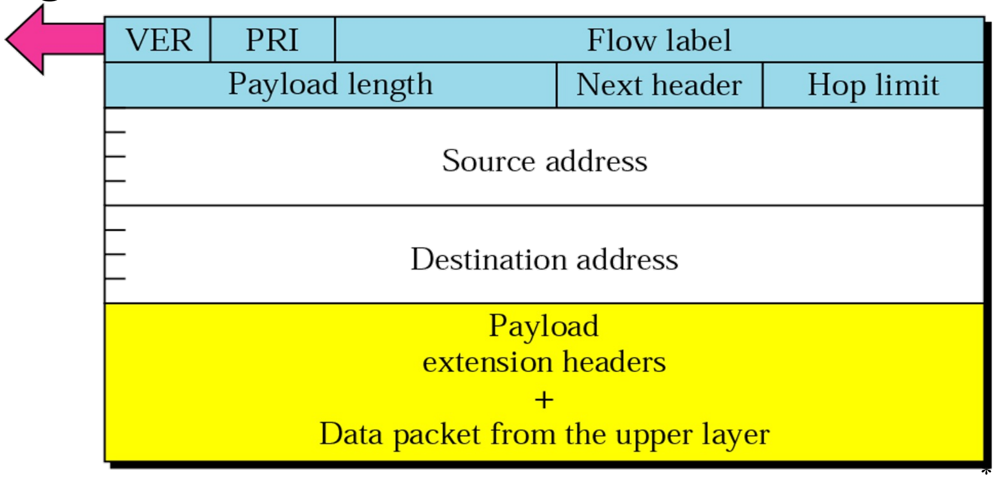
Communication Types

- Unicast
  - One-to-one communication
- Multicast
  - One-to-many communication
- Anycast
  - One-to-nearest communication
  - Delivered to any one interface



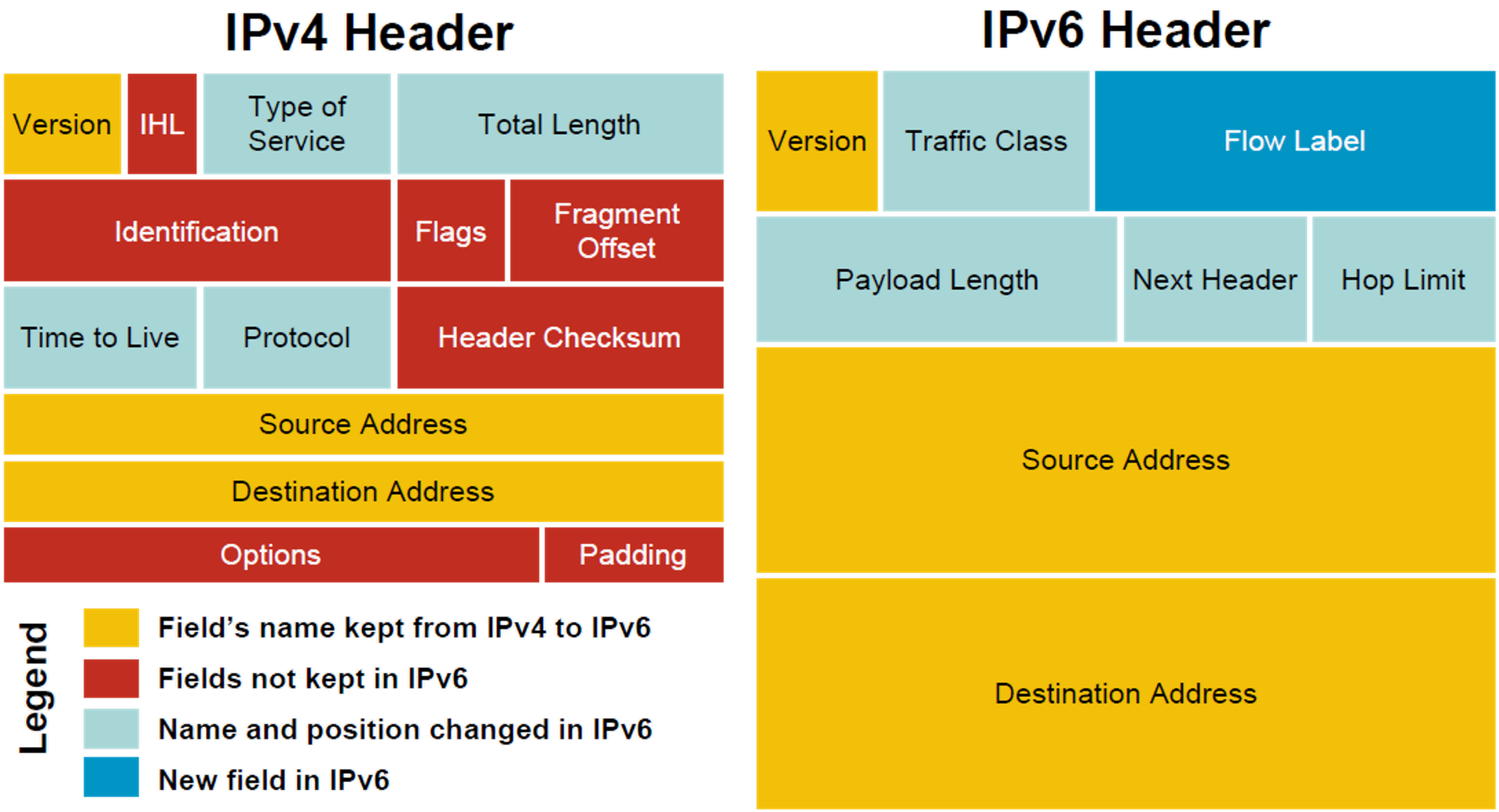
IPv6 Header

- Fixed length of all fields, header length irrelevant
- Remove Header Checksum – other layers are responsible
- No hop-by-hop fragmentation – fragment offset irrelevant
  - MTU discovery before sending or minimum MTU=1280
- Extension headers – next header type
- Basic Principle: Routers along the way should do minimal processing



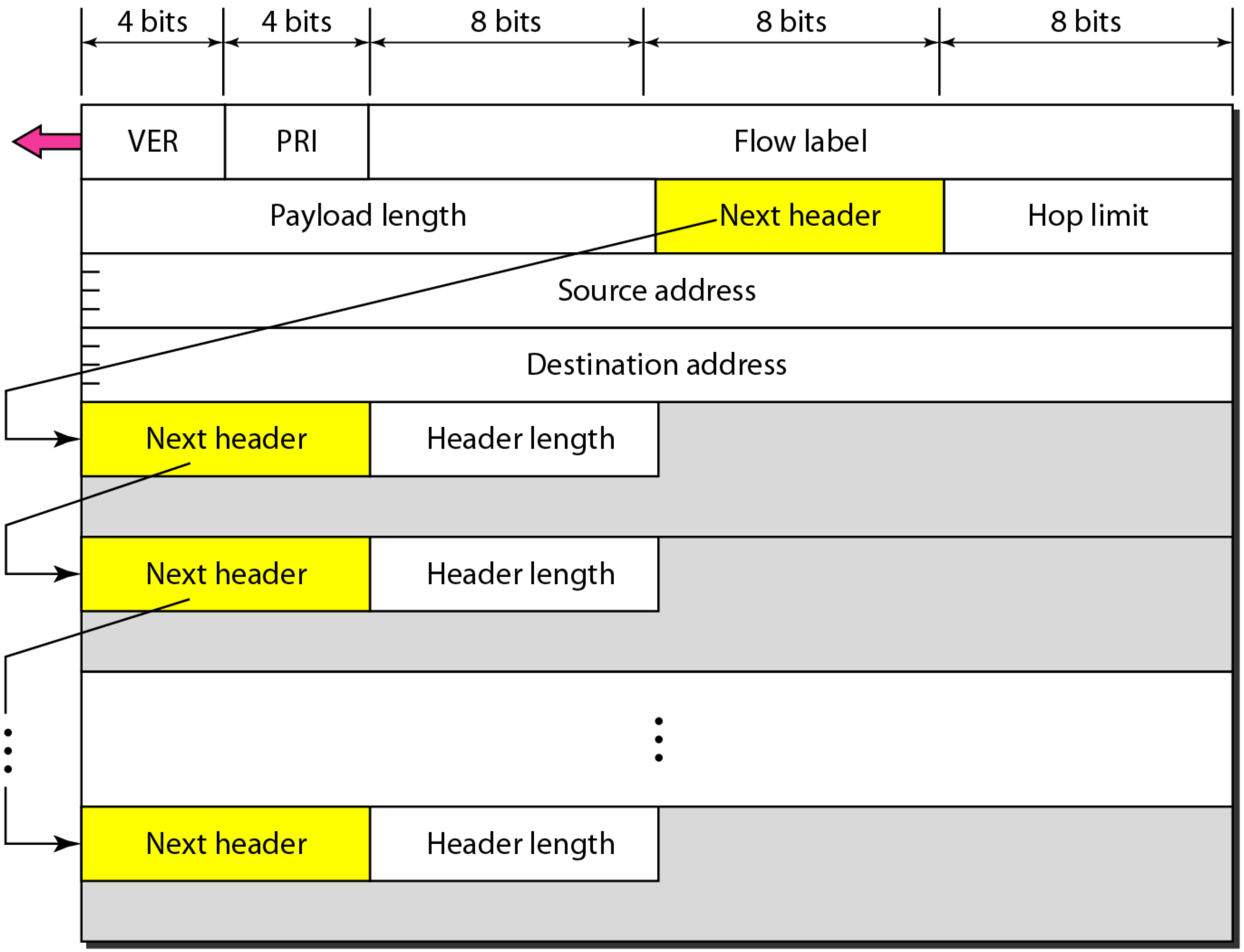
* Figure is courtesy of B. Forouzan

Header Comparison



* Figure is courtesy of P. Smith, Cisco

Extension Headers



* Figure is courtesy of B. Forouzan

Extension Headers

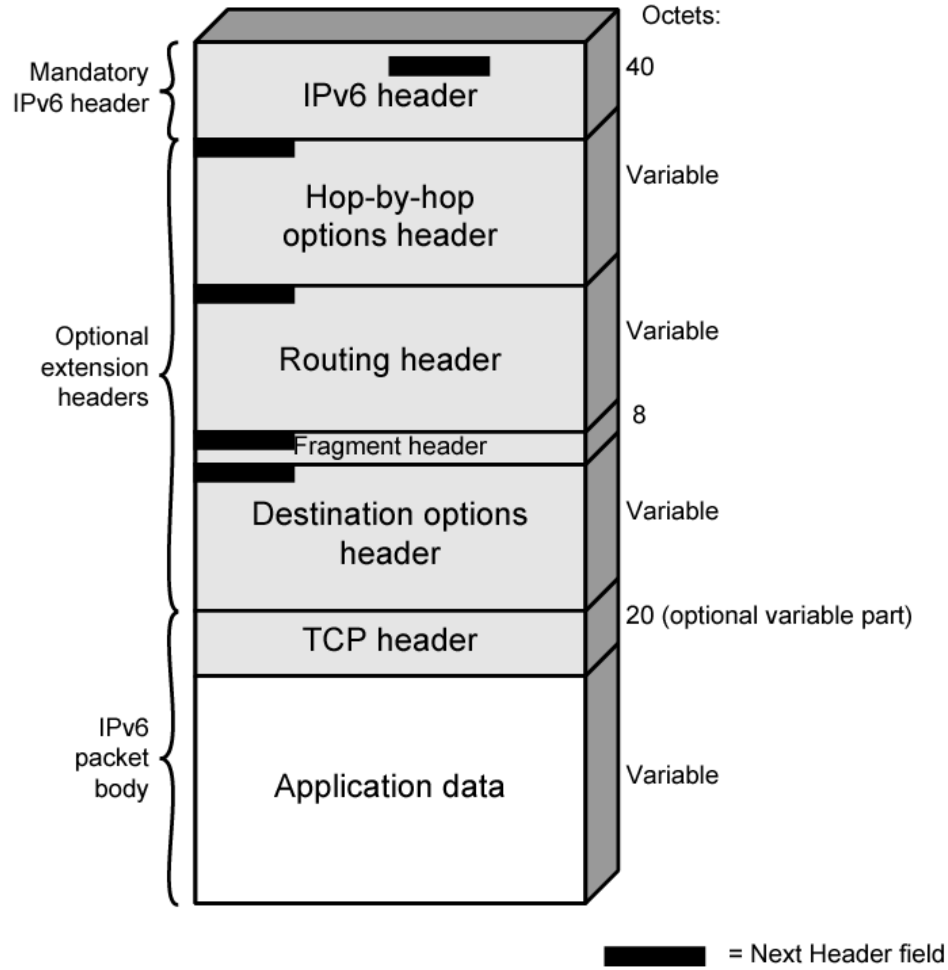
Extension header	Description
Hop-by-hop options	Miscellaneous information for routers
Destination options	Additional information for the destination
Routing	Loose list of routers to visit
Fragmentation	Management of datagram fragments
Authentication	Verification of the sender's identity
Encrypted security payload	Information about the encrypted contents

- Hop-by-Hop Options
  - Require processing at each router
- Routing
  - Similar to v4 source routing
- Fragment
- Authentication
- Encapsulating security payload
- Destination options
  - For destination node

* Figure is courtesy of A. Tanenbaum

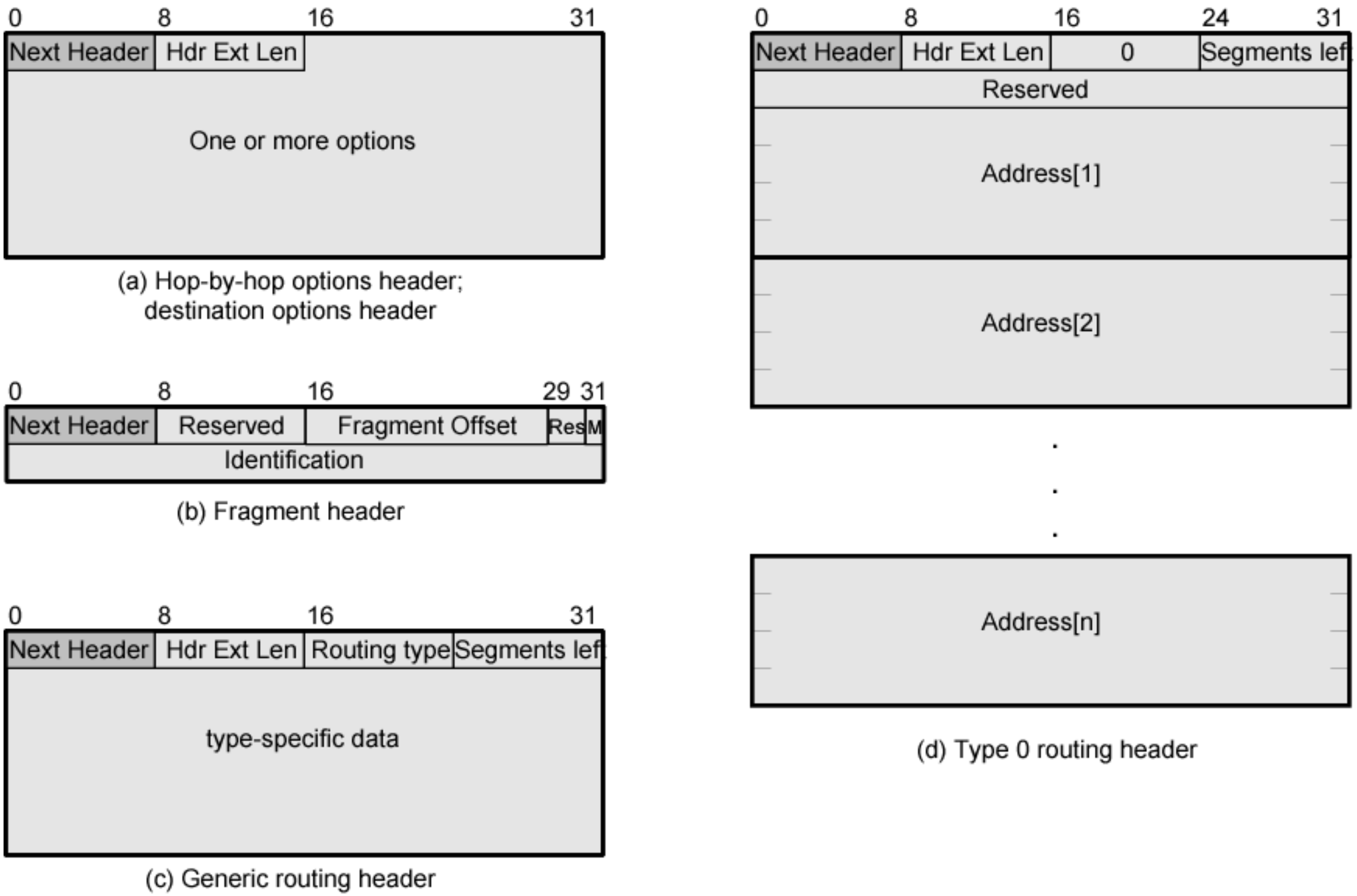
IPv6 Structure

- Every additional header is identified by “next header” field
  - including TCP and UDP header



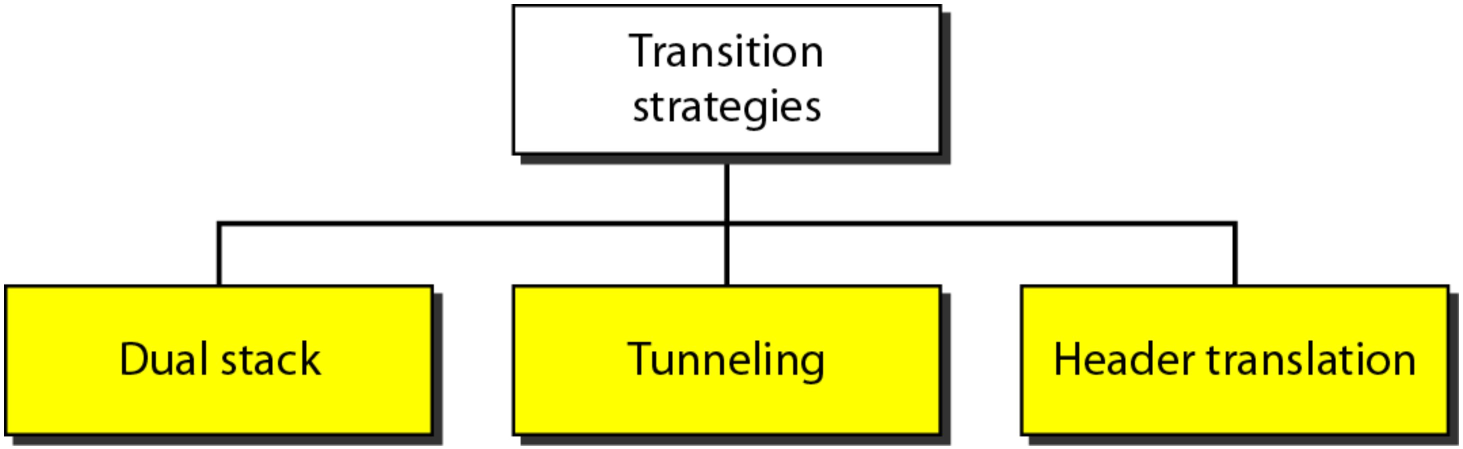
* Figure is courtesy of W. Stallings

IPv6 Extension Headers



* Figure is courtesy of W. Stallings

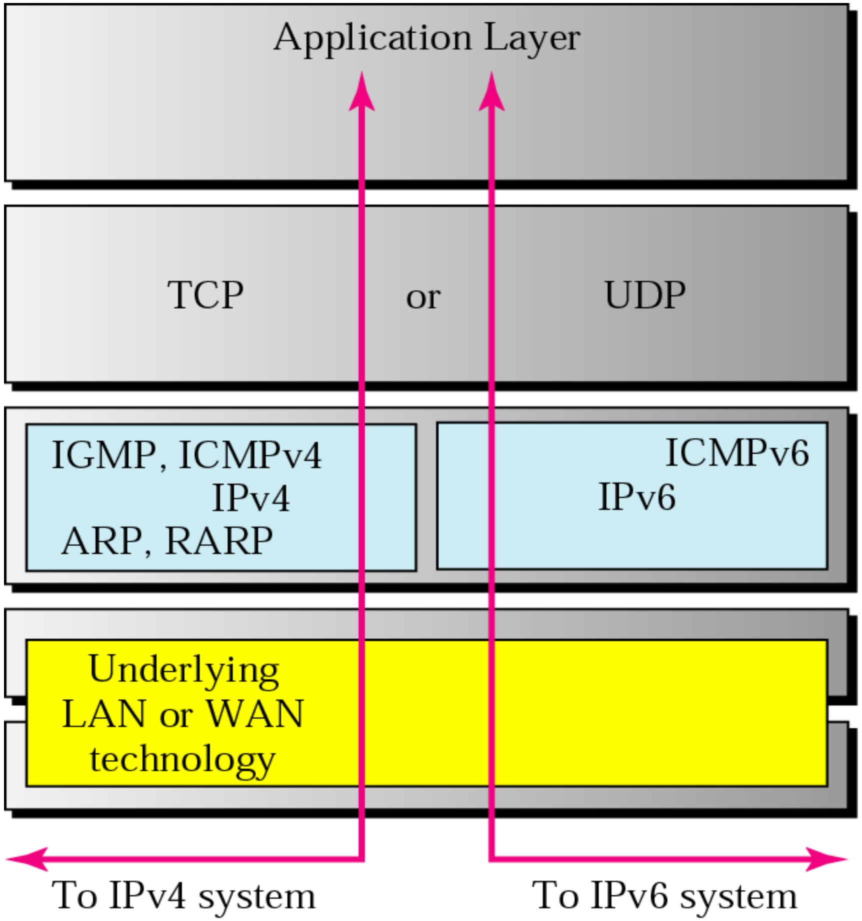
Transition from IPv4 to IPv6



* Figure is courtesy of B. Forouzan

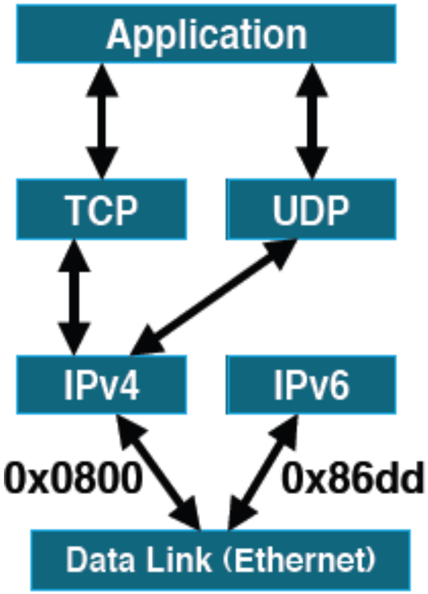
IPv4-IPv6 Transition

- Dual-Stack
  - Stack implements support for both IPv4 and IPv6
  - Allow IPv4 and IPv6 to co-exist in the same devices and networks



* Figure is courtesy of B. Forouzan

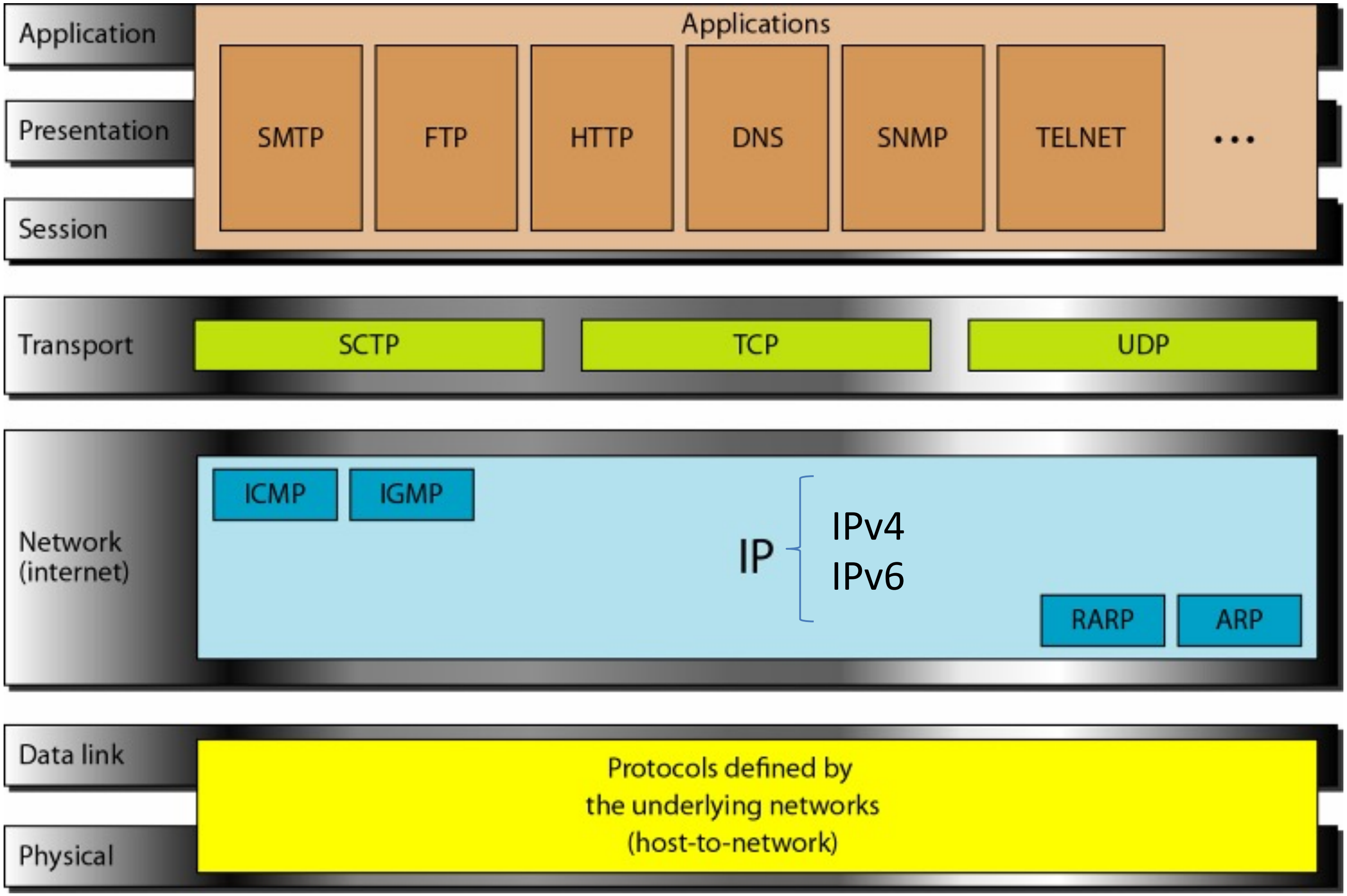
Dual-Stack Example I



- Dual stack node means:
  - Both IPv4 and IPv6 stacks enabled
  - Applications can talk to both
  - Choice of the IP version is based on name lookup and application preference

* Figure is courtesy of P. Smith, Cisco

Protocols in the OSI Model

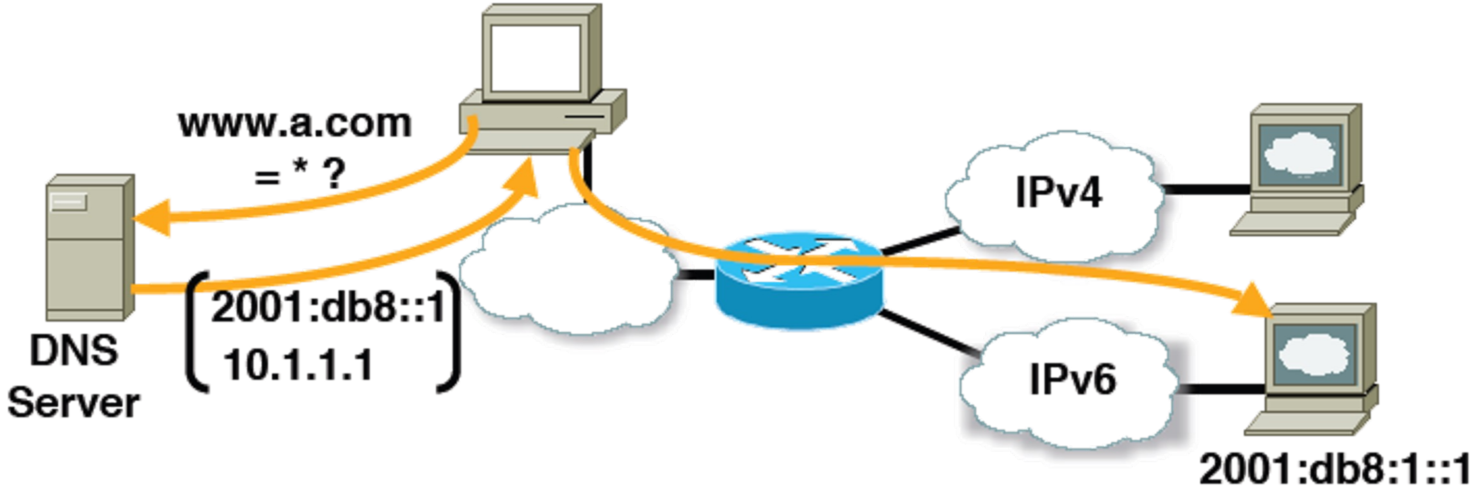


* Figure is courtesy of B. Forouzan

IPv6 and DNS

	IPv4	IPv6
Hostname to IP address	**A record:** www.abc.test. A 192.168.30.1	**AAAA record:** www.abc.test AAAA 2001:db8:c18:1::2
IP address to hostname	**PTR record:** 1.30.168.192.in-addr.arpa. PTR www.abc.test.	**PTR record:** 2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.1.0.0.0.8.1.c.0. 8.b.d.0.1.0.0.2.ip6.arpa PTR www.abc.test.

Dual-Stack Example II

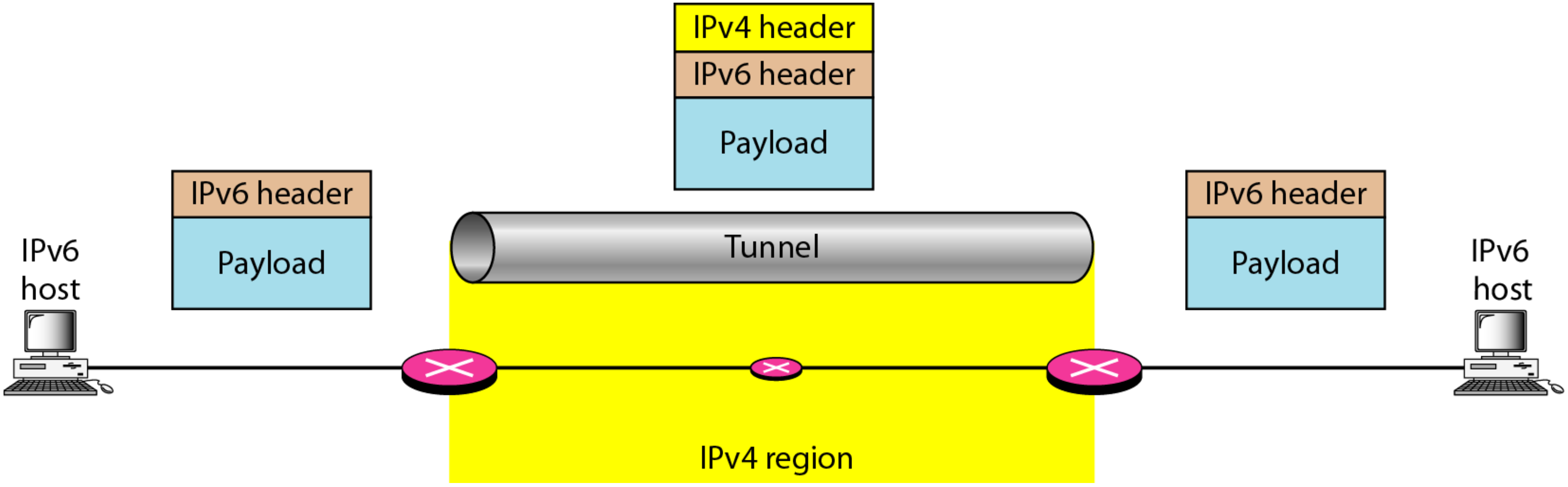


- On a system running dual stack, an application that is both IPv4 and IPv6 enabled will:
  - Ask the DNS for an IPv6 address (AAAA record)
  - If that exists, IPv6 transport will be used
  - If it does not exist, it will then ask the DNS for an IPv4 address (A record) and use IPv4 transport instead

* Figure is courtesy of P. Smith, Cisco

Tunneling

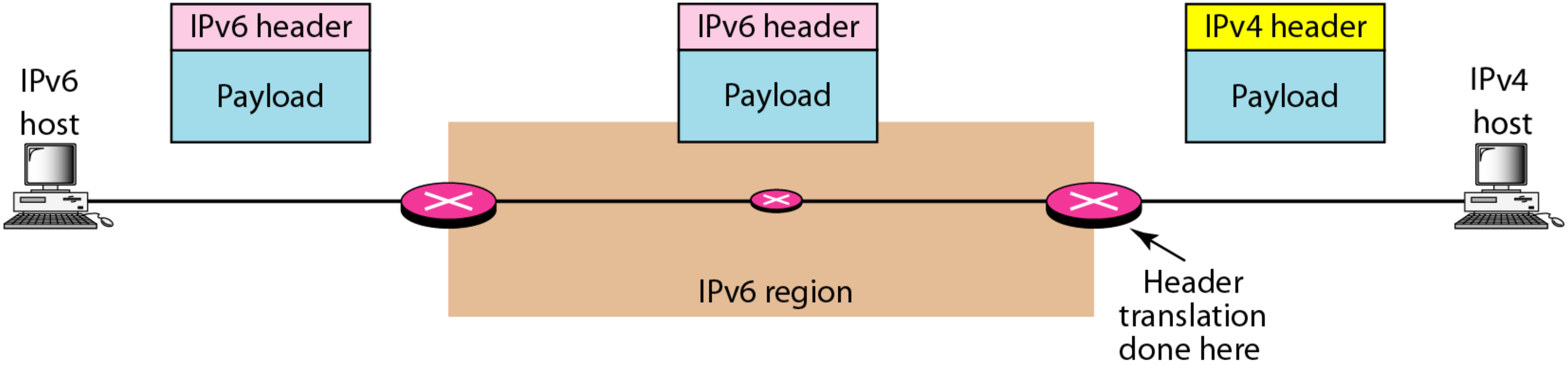
- Encapsulate IPv6 in IPv4 traffic
- Avoid order dependencies when upgrading hosts, routers, or regions



* Figure is courtesy of B. Forouzan

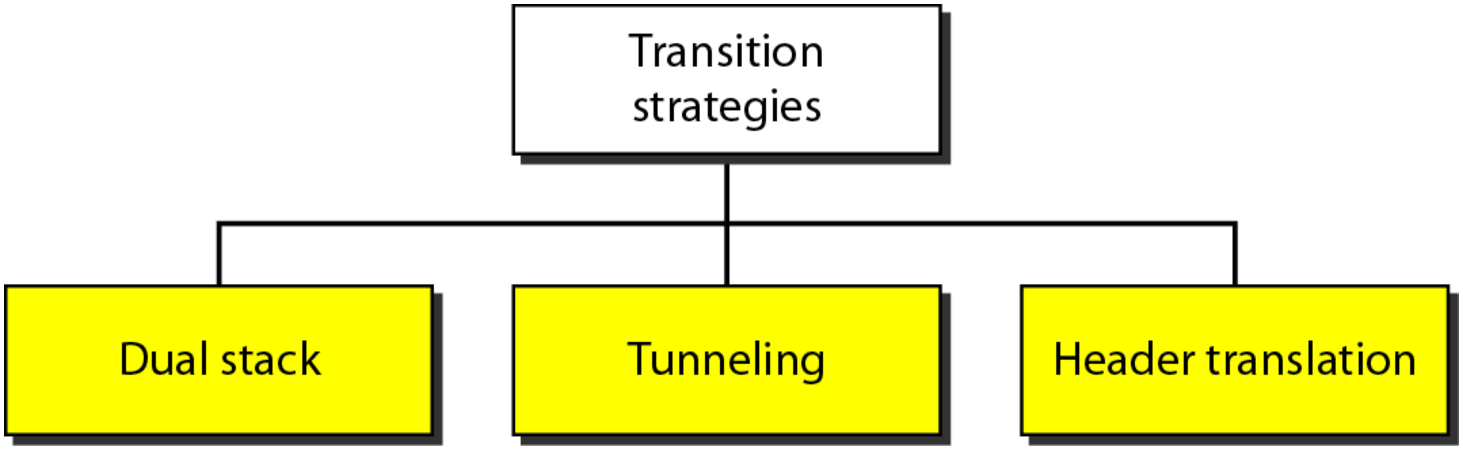
Header Translation

- Headers are translated into other format at “gateway”
- Allow IPv6-only devices to communicate with IPv4-only devices



* Figure is courtesy of B. Forouzan

Transition from IPv4 to IPv6



* Figure is courtesy of B. Forouzan

Mobile IPv6

- 1. MN obtains Local IP address using stateless or stateful autoconfiguration – Neighbor Discovery
- 2. MN registers with HA by sending a Binding Update
- 3. HA intercepts traffic for registered MN and tunnels packets from CN to MN
- 4. MN sends packets from CN directly or via HA using Tunnel

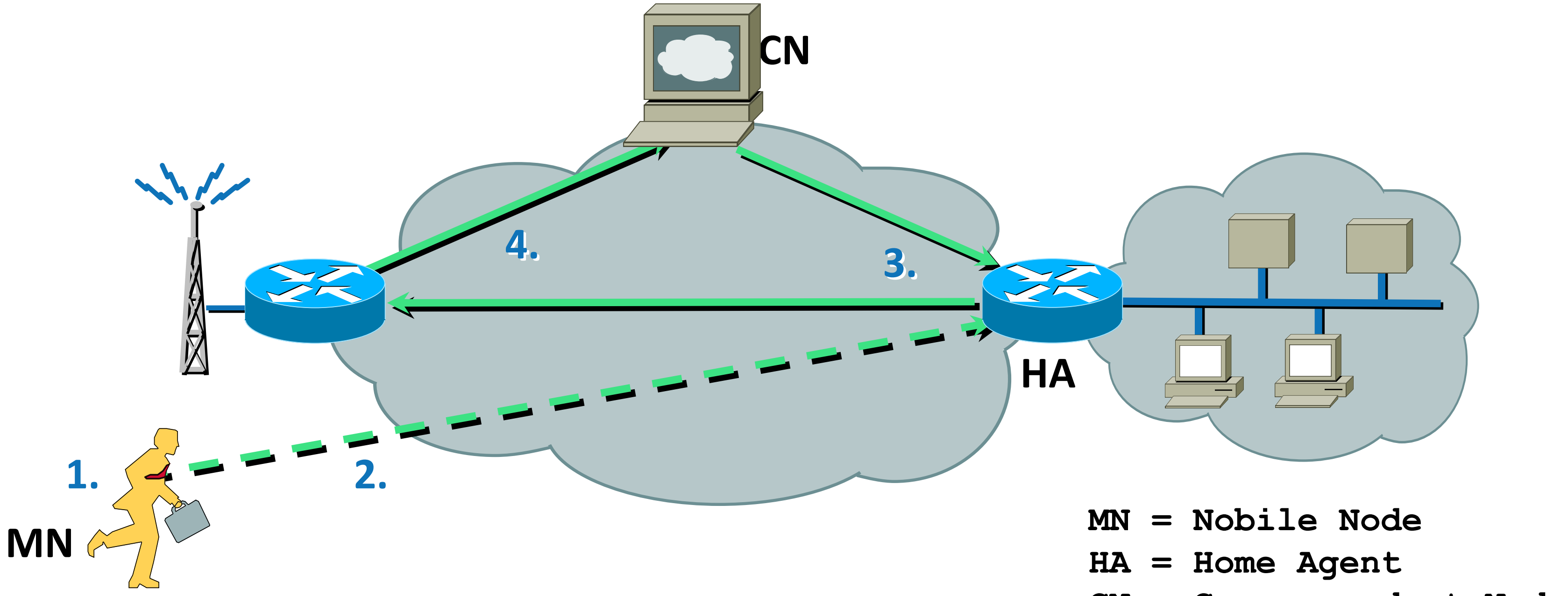
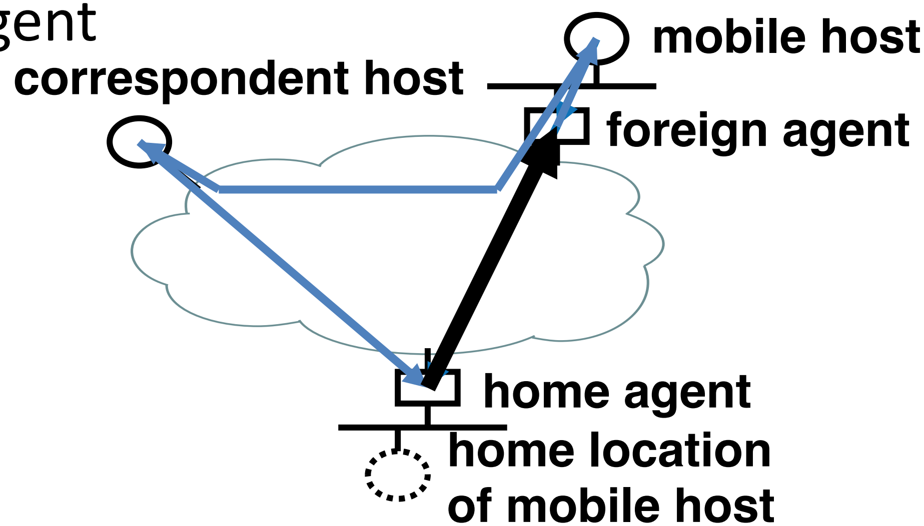


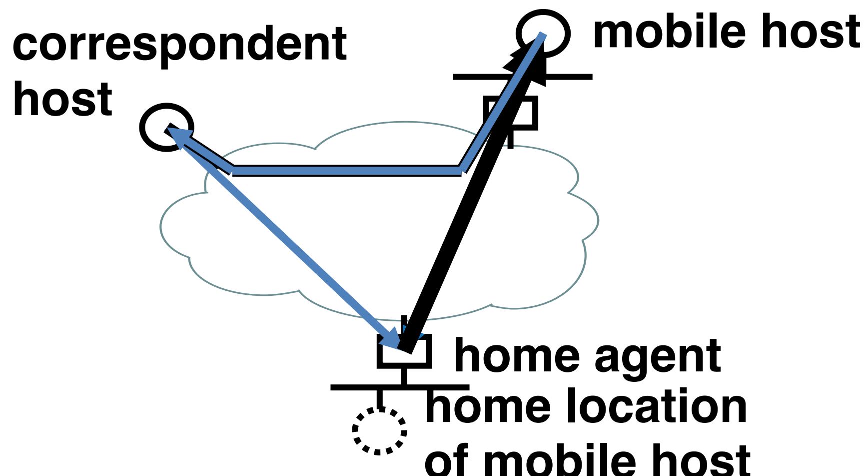
*Figure is courtesy of Cisco

Mobile IP

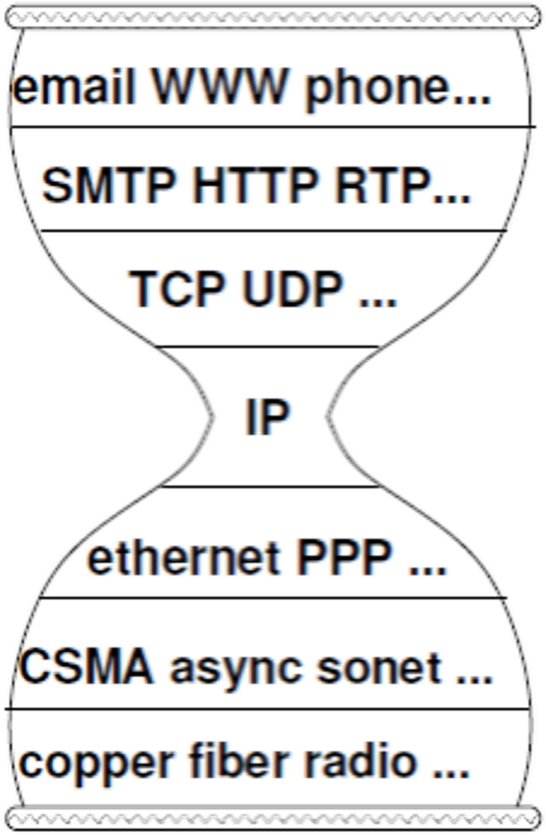
- IPv4 requires foreign agent



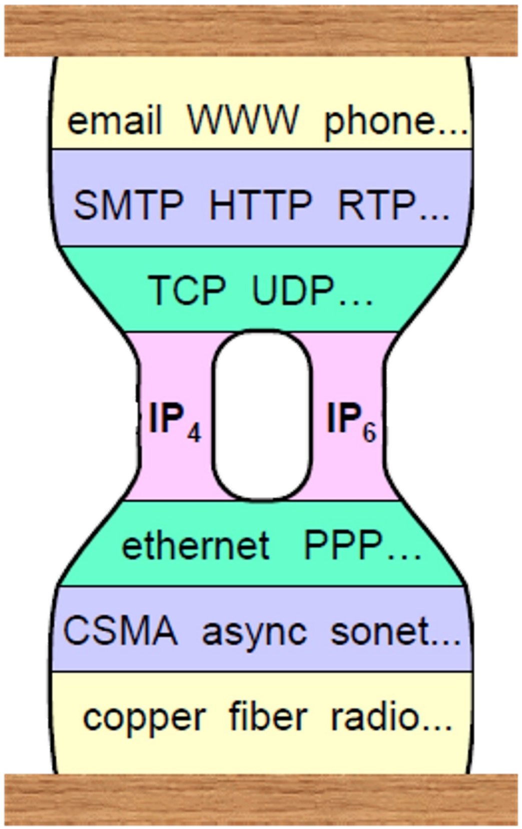
IPv6 does not



Waist of the Hourglass



Traditional

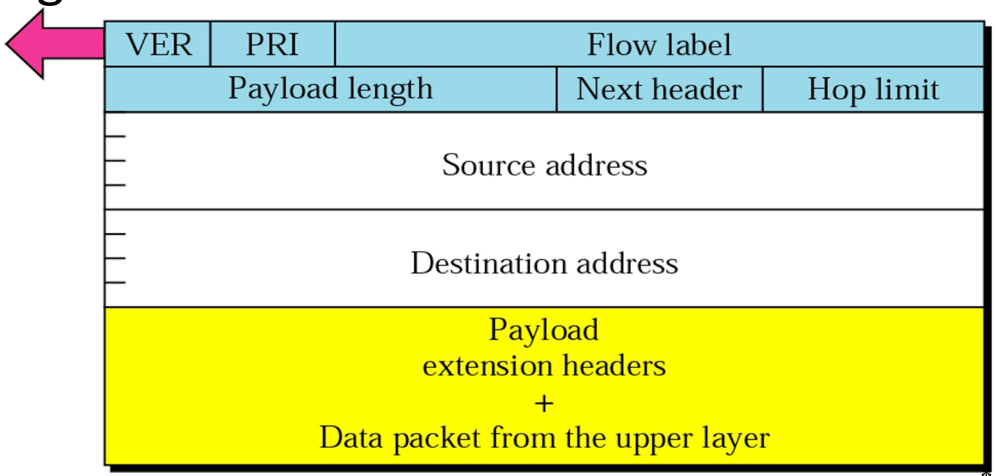


IPv6

•Figure are courtesy of V. Jacobson et al., and S. Deering

IPv6 Header

- Fixed length of all fields, header length irrelevant
- Remove Header Checksum – other layers are responsible
- No hop-by-hop fragmentation – fragment offset irrelevant
  - MTU discovery before sending or minimum MTU=1280
- Extension headers – next header type
- Basic Principle: Routers along the way should do minimal processing



* Figure is courtesy of B. Forouzan

Summary: IPv6

Comparison to IPv4:
Longer Addresses – Avoid Fragmentation

- Longer addresses: 128 bit
- Simpler, fixed-sized header

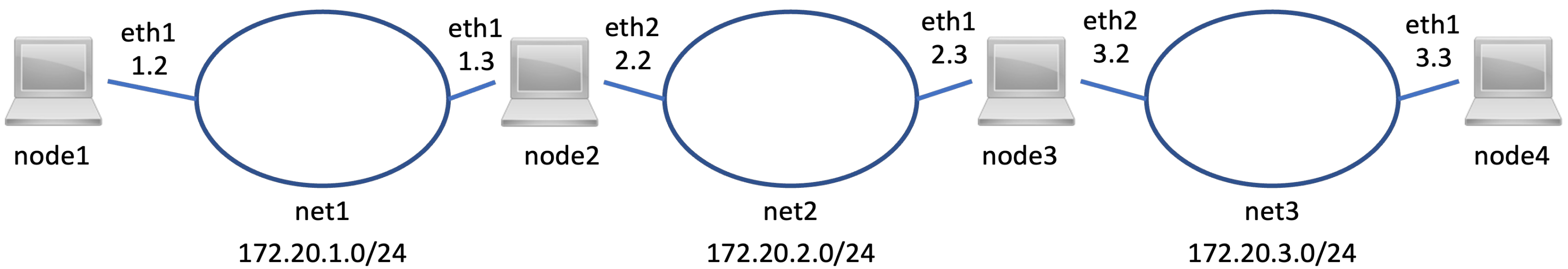
- Types of communication
  - Unicast
  - Multicast
  - Anycast

- Extension headers
  - Hop-by-Hop Options, Routing, Fragmentation, Authentication

- Techniques for transition
  - Dual-Stack
  - Tunneling
  - Translation

Three-Network Example for ARP

(Also: Routing Tables)



Routing table node1

Network	Gateway	Interface
172.20.1.0/24		eth1
172.20.2.0/24	172.20.1.3	eth1
172.20.3.0/24	172.20.1.3	eth1

Routing table node2

Network	Gateway	Interface
172.20.1.0/24		eth1
172.20.2.0/24		eth2
172.20.3.0/24	172.20.2.3	eth2

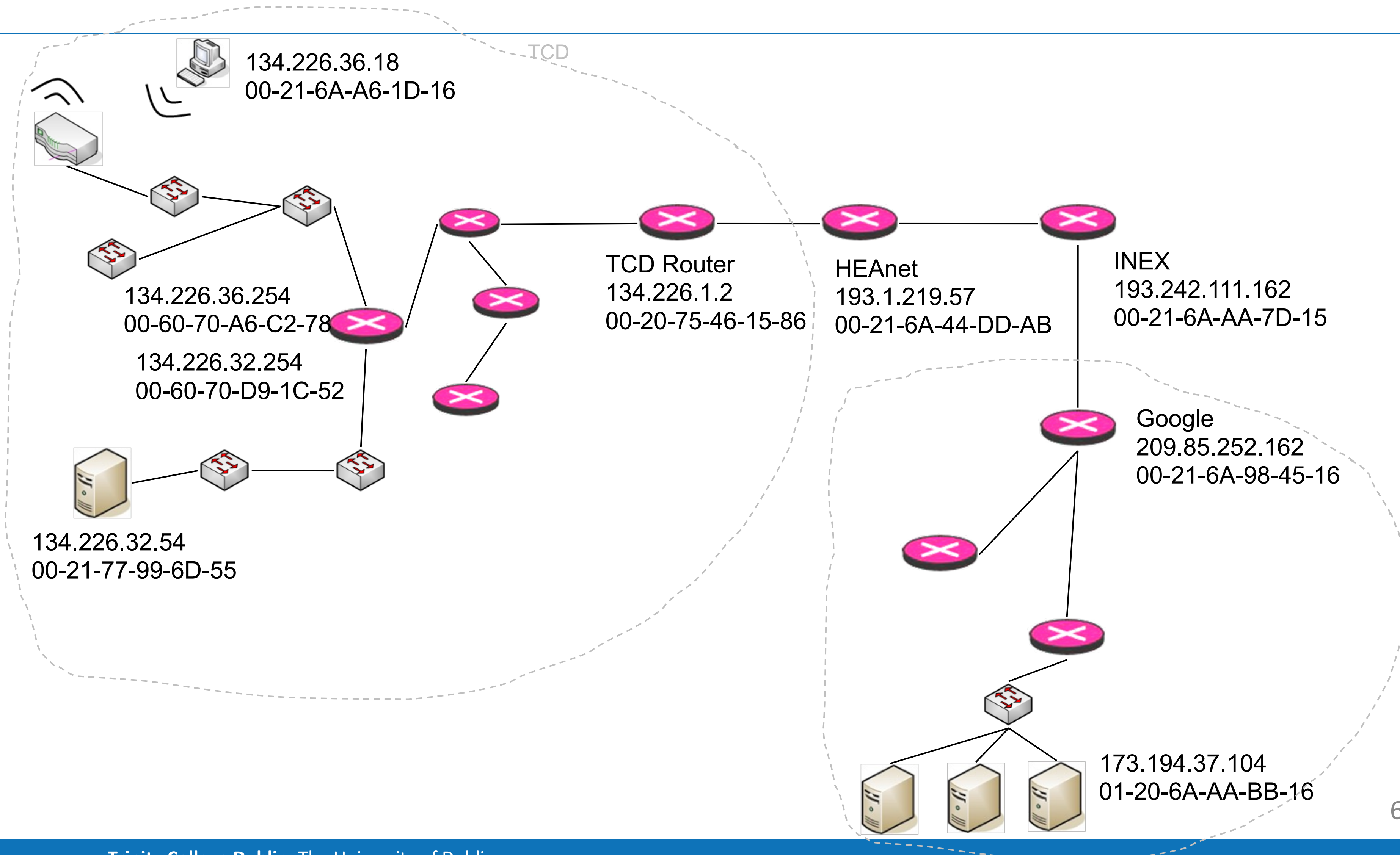
Routing table node3

Network	Gateway	Interface
172.20.1.0/24	172.20.2.2	eth1
172.20.2.0/24		eth1
172.20.3.0/24		eth2

Routing table node4

Network	Gateway	Interface
172.20.1.0/24	172.20.3.2	eth1
172.20.2.0/24	172.20.3.2	eth1
172.20.3.0/24		eth1

Tutorial Scenario for ARP + IPv4



Assignment 1 Part 2

Description of 2nd

The video of part 2 should demonstrate the current state of your solution, the functionality that you have implemented so far, and a capture of network traffic between the components of your solution and the files of your traffic capture in pcap format. In the video, you should explain the basic implementation of your protocol and the information that is being exchanged between the components of your solution.

The submission process for this part consists of two steps: 1) Submitting the PCAP file or files that you captured from your network traffic, and 2) submitting the video for this step.

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin