Internet Protocol Addressing

SI-E Workshop

AfNOG 2013 - Zambia

Purpose of an IP address

- Unique Identification of:
  - Source
    - How would the recipient know where the message came from?
    - How would you know who hacked into your network (network/data security)
  - Destination
    - How would you send data to other network
- Network Independent Format
  - IP over anything

Purpose of an IP Address

Identifies a machine's connection to a network

- Uniquely assigned in a hierarchical format
  - IANA (Internet Assigned Number Authority)
  - IANA to RIRs (AfriNIC, ARIN, RIPE, APNIC, LACNIC)
  - RIR to ISPs and large organisations
  - ISP or company IT department to end users
- IPv4 uses unique 32-bit addresses
- IPv6 uses unique 128-bit addresses

Basic Structure of an IPv4 Address

- 32 bit number (4 octet number): (e.g. 133.27.162.125)

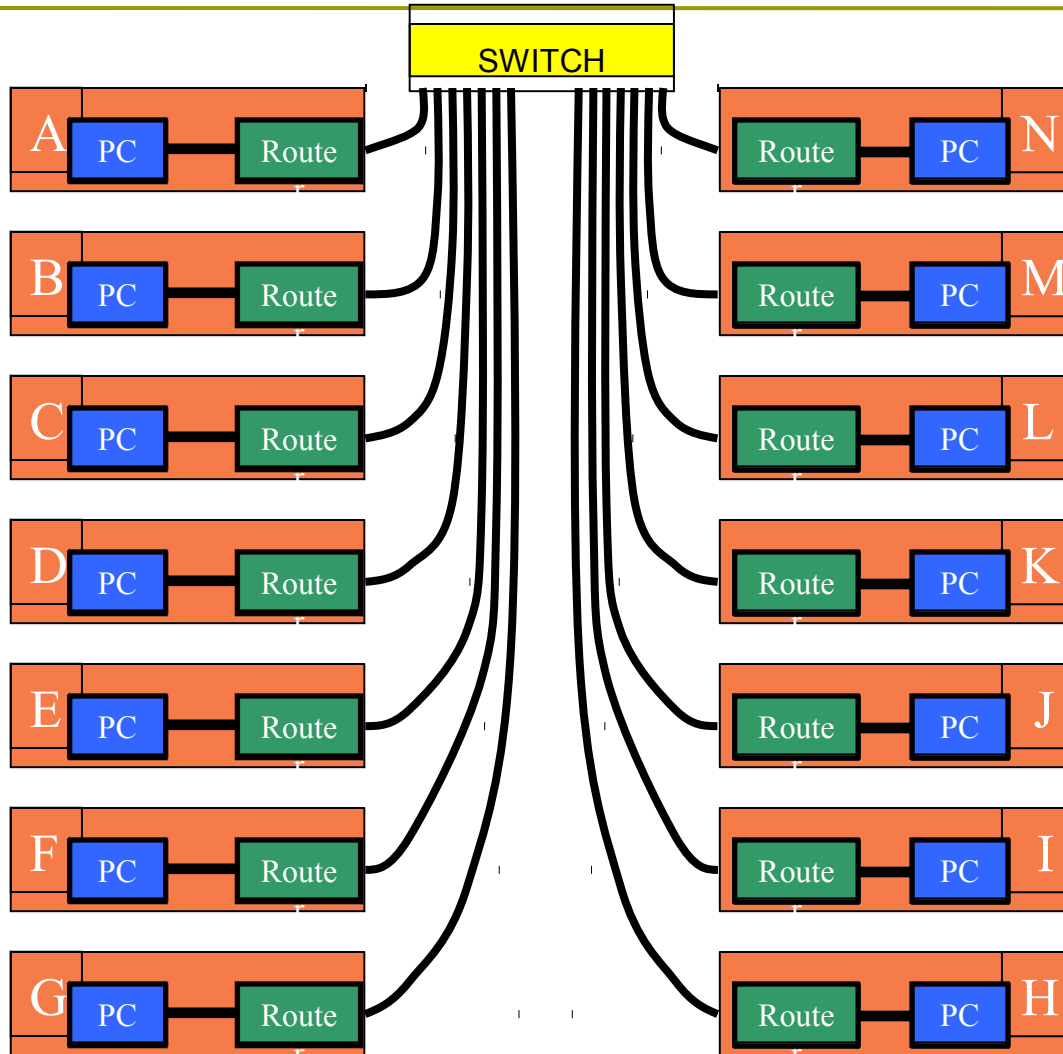- Decimal Representation:

133	27	162	125

- Binary Representation:

10000101	00011011	10100010	01111101

- Hexadecimal Representation:

85	1B	A2	7D

Address Exercise

Address Exercise

- Construct an IP address for your router's connection to the backbone network.
- 196.200.220.x
- x = 1 for row A, 2 for row B, etc.
- Write it in decimal form as well as binary form.

Addressing in Internetworks

- The problem we have
  - More than one physical network
  - Different Locations
  - Larger number of hosts/computer systems
  - Need a way of numbering them all
- We use a structured numbering system
  - Hosts that are connected to the same physical network may have "similar" IP addresses

Network part and Host part

- Remember IPv4 address is 32 bits
- Divide it into a "network part" and "host part"
  - "network part" of the address identifies which network in the internetwork (e.g. the Internet)
  - "host part" identifies host on that network
  - Hosts or routers connected to the same link-layer network will have IP addresses with the same network part, but different host part.
  - Host part contains enough bits to address all hosts on that subnet; e.g. 8 bits allows 256 addresses

Dividing an address

- Hierarchical Division in IP Address:
  - Network Part (or Prefix) – high order bits (left)
    - describes which physical network
  - Host Part – low order bits (right)
    - describes which host on that network

Network Part	Host Part
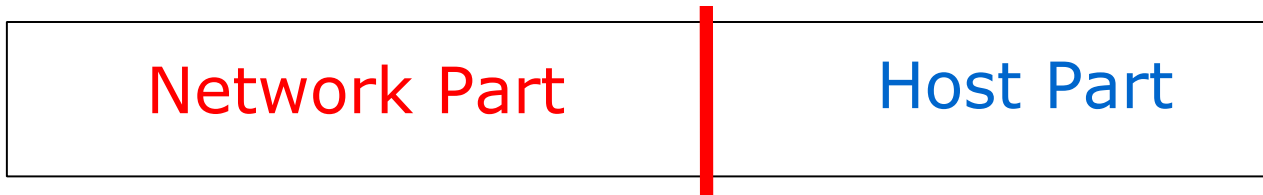
  - Boundary can be anywhere
    - Boundaries are chosen according to number of hosts required

Network Masks

- "Network Masks" help define which bits describe the Network Part and which for the Host Part

- Different Representations:
  - decimal dot notation: 255.255.224.0
  - binary: 11111111 11111111 11100000 00000000
  - hexadecimal: 0xFFFFE000
  - number of network bits: /19
    - count the 1's in the binary representation

- Above examples all mean the same: 19 bits for the Network Part and 13 bits for the Host Part

Example Prefixes

- 137.158.128.0/17   (netmask 255.255.128.0)

1111 1111	**1111 1111**	**1**	**000 0000**	**0000 0000**
1000 1001	1001 1110	1	000 0000	0000 0000
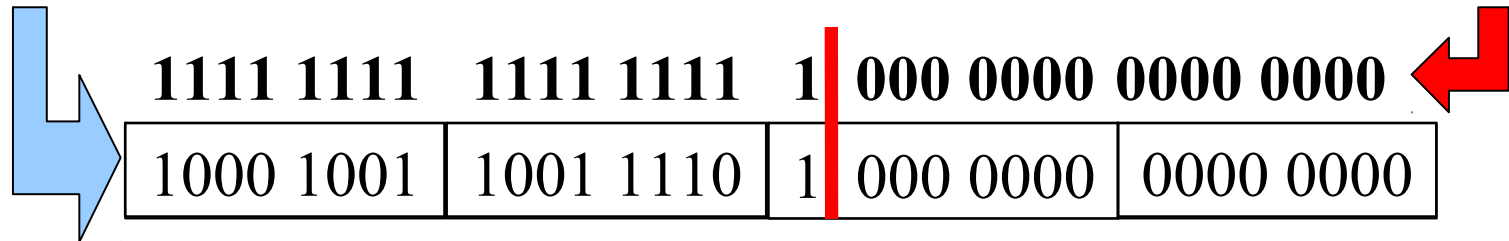
- 198.134.0.0/16   (netmask 255.255.0.0)

1111 1111	**1111 1111**	**0000 0000**	**0000 0000**
1100 0110	1000 0110	0000 0000	0000 0000
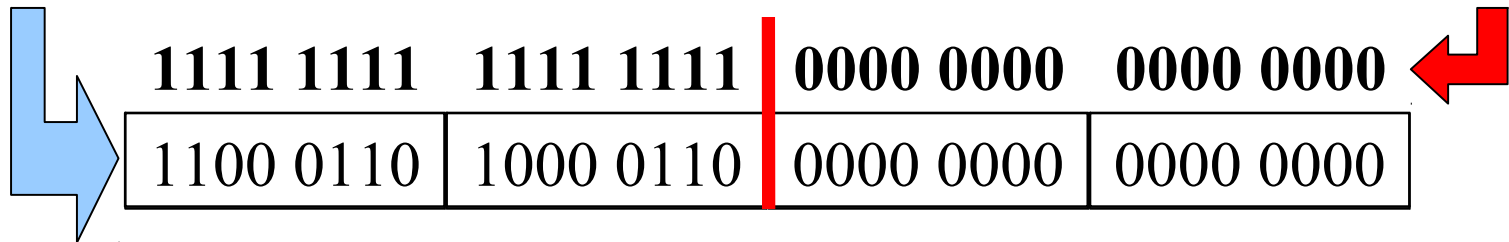
- 205.37.193.128/26   (netmask 255.255.255.192)

1111 1111	**1111 1111**	**1111 1111**	**11**	**00 0000**
1100 1101	0010 0101	1100 0001	10	00 0000
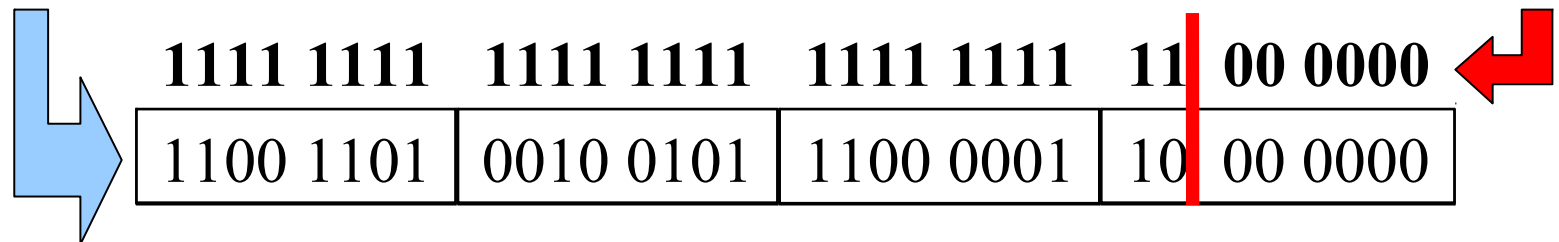
Special Addresses

- All 0's in host part: Represents Network
  - e.g. 193.0.0.0/24
  - e.g. 138.37.64.0/18
- All 1's in host part: Broadcast
  - e.g. 193.0.0.255   (prefix 193.0.0.0/24)
  - e.g. 138.37.127.255 (prefix 138.37.64.0/18)
- 127.0.0.0/8: Loopback address (127.0.0.1)
- 0.0.0.0: For various special purposes

Ancient History:

- A classful network naturally "implied" a prefix-length or netmask:
  - Class A: prefix length /8 (netmask 255.0.0.0)
  - Class B: prefix length /16 (netmask 255.255.0.0)
  - Class C: prefix length /24 (netmask 255.255.255.0)
- Modern (classless) routed networks rather have explicit prefix-lengths or netmasks.
  - So ideally you can't just look at an IP address and tell what its prefix-length or netmask should be.
  - Protocol configurations in this case also need explicit netmask or prefix length.

Post-1994 era of classless addressing

- Class A, Class B, Class C terminology and restrictions are now of historical interest only
  - Obsolete since 1994
- Internet routing and address management today is classless
- CIDR = Classless Inter-Domain Routing
  - Routing does not assume that former class A, B, C addresses imply prefix lengths of /8, /16, /24
- VLSM = Variable-Length Subnet Masks
  - Routing does not assume that all subnets are the same size

Classless addressing example

- An ISP gets a large block of addresses
  - e.g., a /16 prefix, or 65536 separate addresses
- Assign smaller blocks to customers
  - e.g., a /24 prefix (256 addresses) to one customer, and a /28 prefix (16 addresses) to another customer (and some space left over for other customers)
- An organisation that gets a /24 prefix from their ISP divides it into smaller blocks
  - e.g. a /27 prefix (32 addresses) for one department, and a /28 prefix (16 addresses) for another department (and some space left over for other internal networks)

Classless addressing exercise

- Consider the address block 133.27.162.0/24
- Allocate 5 separate /28 blocks, one /27 block, and one /30 block
- What are the IP addresses of each block allocated above?
  - In prefix length notation
  - Netmasks in decimal
  - IP address ranges
- What blocks are still available (not yet allocated)?
- How big is the largest available block?

Configuring interfaces – *ifconfig*

- ifconfig interface [address_family] address [params]
  - interface: network interface, e.g., eth0 or bge0
  - options: up, down, netmask mask
  - address: IP address

- Examples:
  - ifconfig bge0 inet 192.168.2.2; ifconfig bge1 192.168.3.1
  - ifconfig eth0 inet 172.16.1.1/24
  - ifconfig bge0 192.168.2.2 netmask 255.255.255.0
  - ifconfig bge0 inet6 2001:db8:bdbd::123 prefixlen 48 alias

IPv6 Addressing

IP Addresses Continues

IP version 6

- IPv6 designed as successor to IPv4
  - Expanded address space
    - Address length quadrupled to 16 bytes (128 bits)
  - Header Format Simplification
    - Fixed length, optional headers are daisy-chained
  - No checksum at the IP network layer
  - No hop-by-hop fragmentation
    - Path MTU discovery
  - 64 bits aligned fields in the header
  - Authentication and Privacy Capabilities
    - IPsec is mandated
  - No more broadcast

IPv4 and IPv6 Header Comparison

IPv4 Header

Version	IHL	Type of Service	Total Length	
Identification			Flags	Fragment Offset
Time to Live		Protocol	Header Checksum	
Source Address				
Destination Address				
Options			Padding	

IPv6 Header

Version	Traffic Class	Flow Label	
Payload Length		Next Header	Hop Limit
Source Address			
Destination Address			
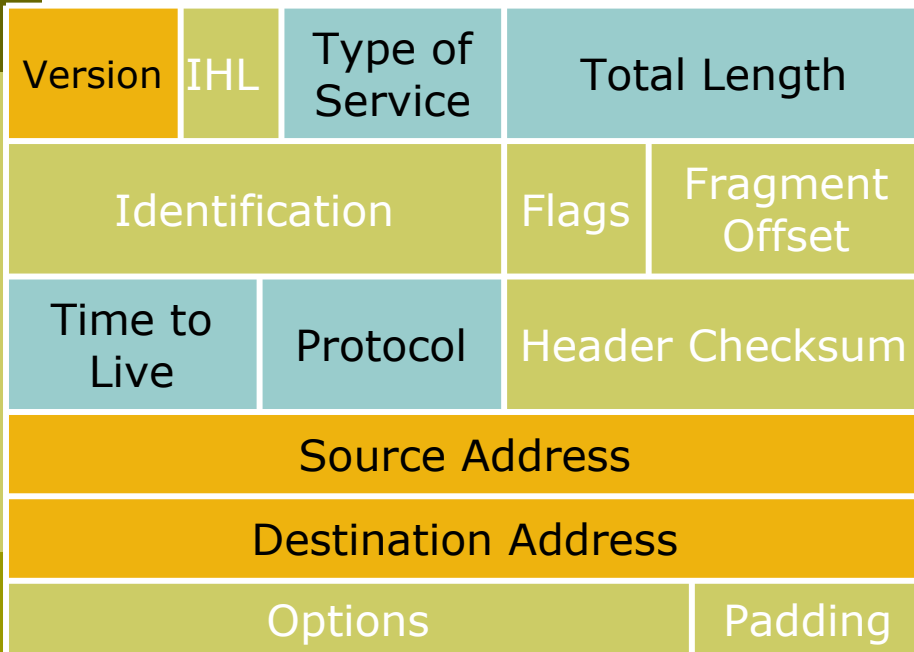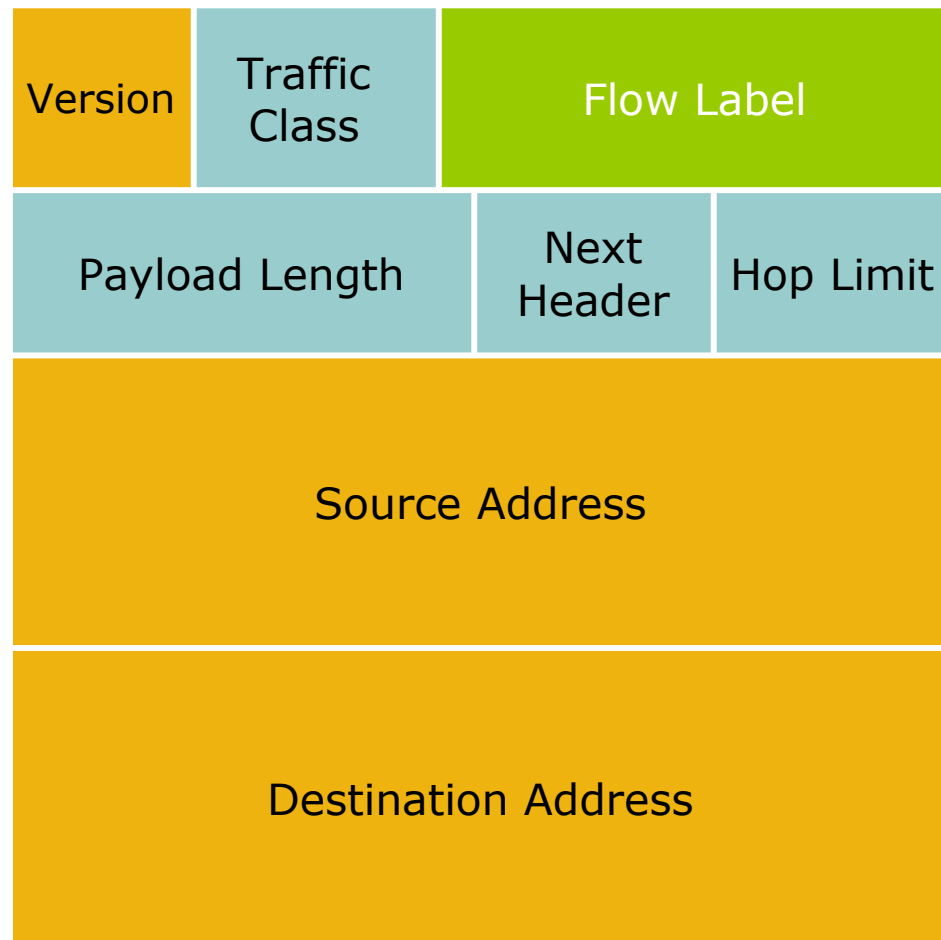
Legend

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

Larger Address Space

IPv4 = 32 bits
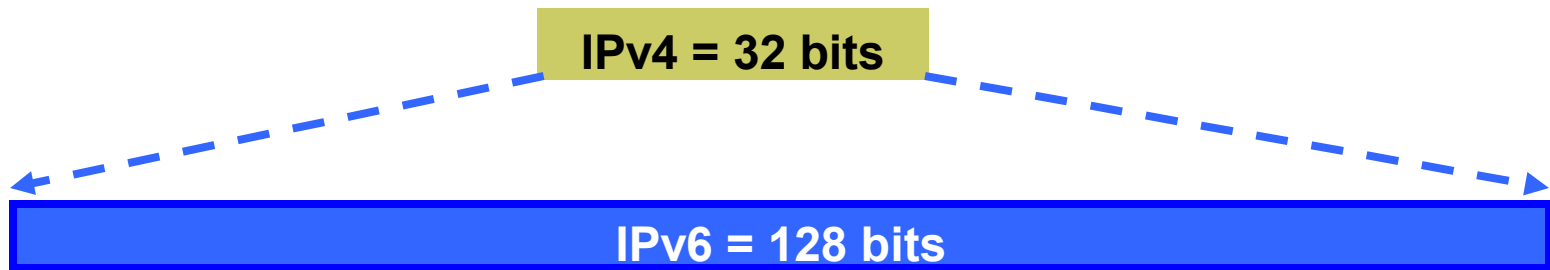
IPv6 = 128 bits

- IPv4
  - 32 bits
  - = 4,294,967,296 possible addressable devices
- IPv6
  - 128 bits: 4 times the size in bits
  - = 3.4×10^{38} possible addressable devices
  - = 340,282,366,920,938,463,463,374,607,431,768,211,456
  - ~ 5×10^{28} addresses per person on the planet

IPv6 Address Representation

- 16 bit fields in case insensitive colon hexadecimal representation
  - 2031:0000:130F:0000:0000:09C0:876A:130B
- Leading zeros in a field are optional:
  - 2031:0:130F:0:0:9C0:876A:130B
- Successive fields of 0 represented as ::, but only once in an address:
  - 2031:0:130F::9C0:876A:130B   ~~is o~~k
  - 2031::130F::9C0:876A:130B   is NOT ok (two "::")

  - 0:0:0:0:0:0:0:1 $\rightarrow$ ::1   (loopback address)
  - 0:0:0:0:0:0:0:0 $\rightarrow$ ::   (unspecified address)

IPv6 Address Representation

- In a URL, it is enclosed in brackets (RFC3986)
  - http://[2001:db8:4f3a::206:ae14]:8080/index.html
  - Complicated for typical users
  - This is done mostly for diagnostic purposes
  - Use fully qualified domain names (FQDN) instead of this
- Prefix Representation
  - Representation of prefix is same as for IPv4 CIDR
    - Address and then prefix length, with slash separator
  - IPv4 address:
    - 198.10.0.0/16
  - IPv6 address:
    - 2001:db8:1200::/40

IPv6 Addressing

Type	Binary	Hex
Unspecified	0000…0000	::/128
Loopback	0000…0001	::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

IPv6 Global Unicast Addresses

Provider	Site	Host
48 bits	16 bits	64 bits

	Global Routing Prefix	Subnet-id	Interface ID

001
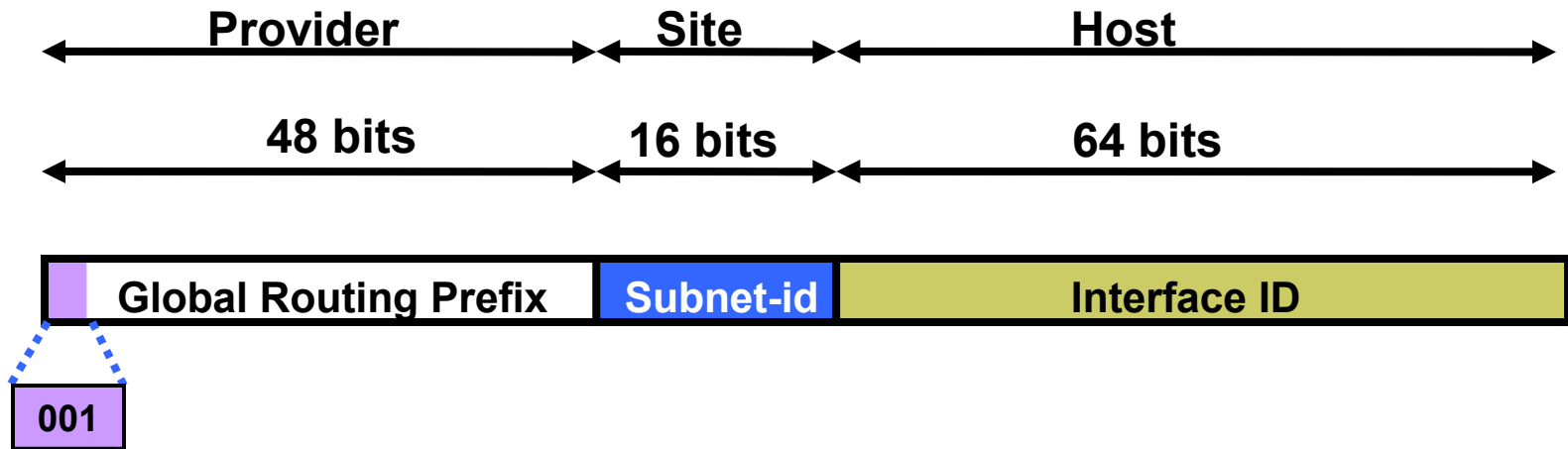
□ IPv6 Global Unicast addresses are:

- ■ Addresses for generic use of IPv6
- ■ Hierarchical structure intended to simplify aggregation

IPv6 Address Allocation

/12	/32	/48	/64	
2000	0db8			Interface ID

Registry →

ISP prefix →

Site prefix →

LAN prefix →
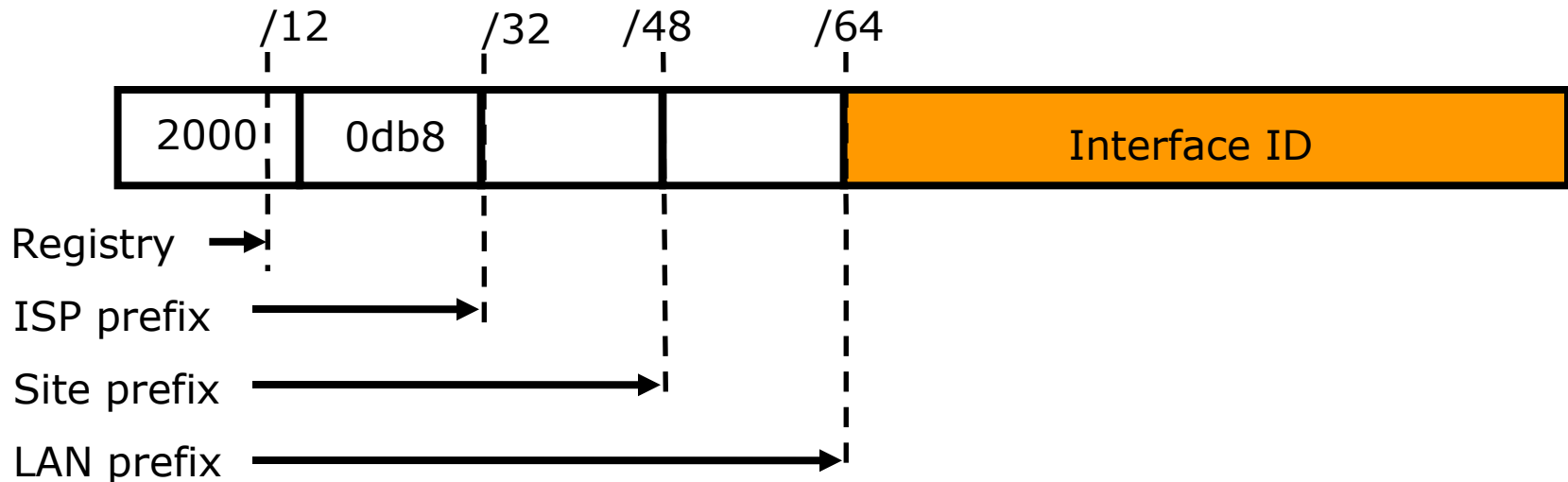
- □ The allocation process is:
  - ▪ The IANA is allocating out of 2000::/3 for initial IPv6 unicast use
  - ▪ Each registry gets a /12 prefix from the IANA
  - ▪ Registry allocates a /32 prefix (or larger) to an IPv6 ISP
  - ▪ ISPs usually allocate a /48 prefix to each end customer

IPv6 Addressing Scope

- 64 bits used for the interface ID
  - Possibility of 2^{64} hosts on one network LAN
  - Arrangement to accommodate MAC addresses within the IPv6 address
- 16 bits used for the end site
  - Possibility of 2^{16} networks at each end-site
  - 65536 subnets

IPV6 Subnetting

2001:0db8:0000:0000:0000:0000:0000:0000

64 bits interface ID

/64

/60=16 /64

/56=256 /64

/52=4096 /64

/48=65536 /64

/32=65536 /48
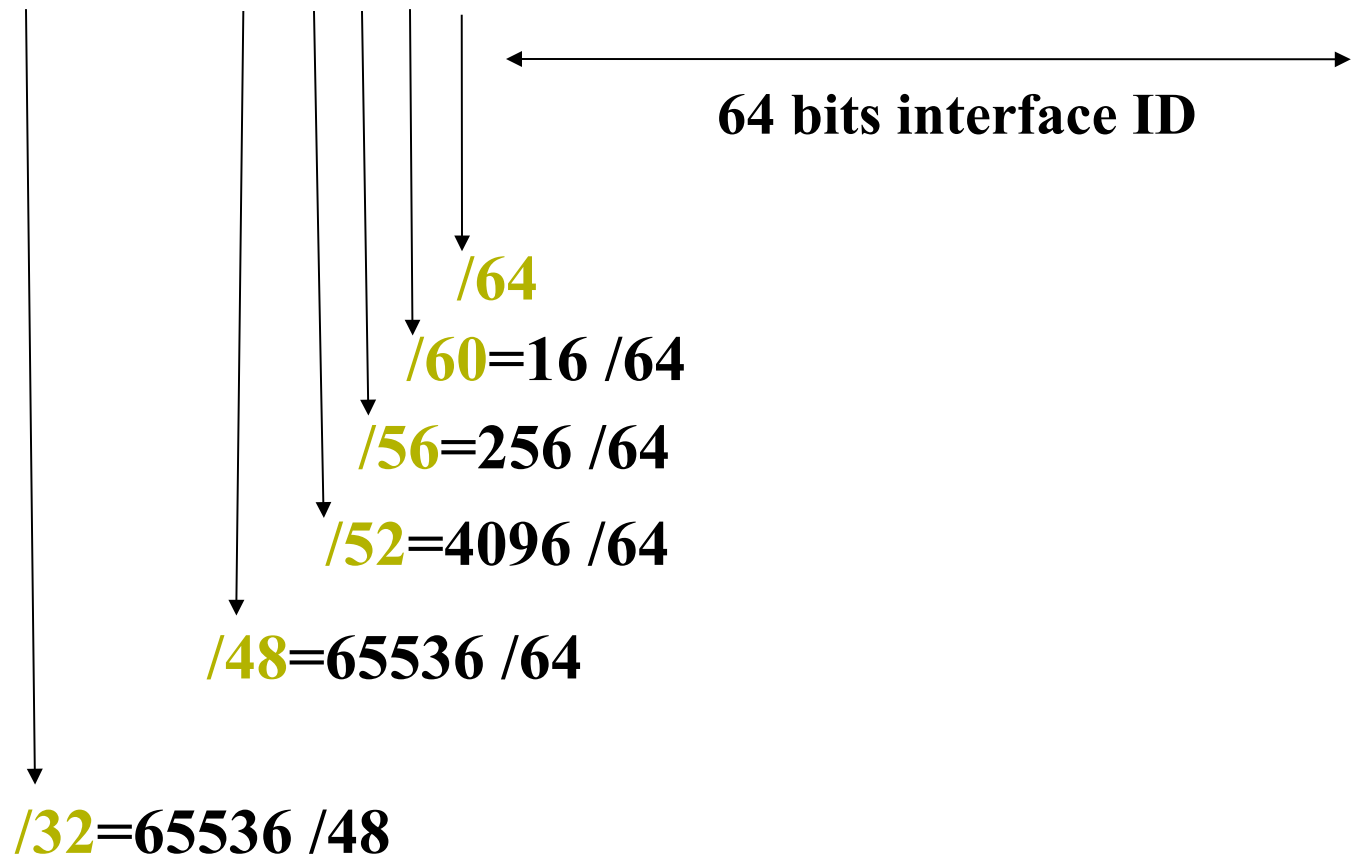
Nibble (4 bits) Concept

Decimal	Binary	Hexadecimal
0	0000	0
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
10	1010	a
11	1011	b
12	1100	c
13	1101	d
14	1110	e
15	1111	f

2001:0db8::/32

2001:0db8:0000::/48	2001:0db8:0100::/48	2001:0db8:0200::/48	2001:0db8:0300::/48
2001:0db8:0001::/48	2001:0db8:0101::/48	2001:0db8:0201::/48	2001:0db8:0301::/48
2001:0db8:0002::/48	2001:0db8:0102::/48	2001:0db8:0202::/48	2001:0db8:0302::/48
2001:0db8:0003::/48	2001:0db8:0103::/48	2001:0db8:0203::/48	2001:0db8:0303::/48
2001:0db8:0004::/48	2001:0db8:0104::/48	2001:0db8:0204::/48	2001:0db8:0304::/48
2001:0db8:0005::/48	2001:0db8:0105::/48	2001:0db8:0205::/48	2001:0db8:0305::/48
2001:0db8:0006::/48	2001:0db8:0106::/48	2001:0db8:0206::/48	2001:0db8:0306::/48
2001:0db8:0007::/48	2001:0db8:0107::/48	2001:0db8:0207::/48	2001:0db8:0307::/48
2001:0db8:0008::/48	2001:0db8:0108::/48	2001:0db8:0208::/48	2001:0db8:0308::/48
2001:0db8:0009::/48	2001:0db8:0109::/48	2001:0db8:0209::/48	2001:0db8:0309::/48
2001:0db8:000a::/48	2001:0db8:010a::/48	2001:0db8:020a::/48	2001:0db8:030a::/48
2001:0db8:000b::/48	2001:0db8:010b::/48	2001:0db8:020b::/48	2001:0db8:030b::/48
2001:0db8:000c::/48	2001:0db8:010c::/48	2001:0db8:020c::/48	2001:0db8:030c::/48
2001:0db8:000d::/48	2001:0db8:010d::/48	2001:0db8:020d::/48	2001:0db8:030d::/48
2001:0db8:000e::/48	2001:0db8:010e::/48	2001:0db8:020e::/48	2001:0db8:030e::/48
2001:0db8:000f::/48	2001:0db8:010f::/48	2001:0db8:020f::/48	2001:0db8:030f::/48
2001:0db8:0010::/48	2001:0db8:0110::/48	2001:0db8:0210::/48	2001:0db8:0310::/48
2001:0db8:0011::/48	2001:0db8:0111::/48	2001:0db8:0211::/48	2001:0db8:0311::/48
2001:0db8:0012::/48	2001:0db8:0112::/48	2001:0db8:0212::/48	2001:0db8:0312::/48
2001:0db8:0013::/48	2001:0db8:0113::/48	2001:0db8:0213::/48	2001:0db8:0313::/48
2001:0db8:0014::/48	2001:0db8:0114::/48	2001:0db8:0214::/48	2001:0db8:0314::/48
2001:0db8:0015::/48	2001:0db8:0115::/48	2001:0db8:0215::/48	2001:0db8:0315::/48
2001:0db8:0016::/48	2001:0db8:0116::/48	2001:0db8:0216::/48	2001:0db8:0316::/48
2001:0db8:0017::/48	2001:0db8:0117::/48	2001:0db8:0217::/48	2001:0db8:0317::/48
2001:0db8:0018::/48	2001:0db8:0118::/48	2001:0db8:0218::/48	2001:0db8:0318::/48
2001:0db8:0019::/48	2001:0db8:0119::/48	2001:0db8:0219::/48	2001:0db8:0319::/48
2001:0db8:001a::/48	2001:0db8:011a::/48	2001:0db8:021a::/48	2001:0db8:031a::/48
2001:0db8:001b::/48	2001:0db8:011b::/48	2001:0db8:021b::/48	2001:0db8:031b::/48
2001:0db8:001c::/48	2001:0db8:011c::/48	2001:0db8:021c::/48	2001:0db8:031c::/48
2001:0db8:001d::/48	2001:0db8:011d::/48	2001:0db8:021d::/48	2001:0db8:031d::/48
2001:0db8:001e::/48	2001:0db8:011e::/48	2001:0db8:021e::/48	2001:0db8:031e::/48
2001:0db8:001f::/48	2001:0db8:011f::/48	2001:0db8:021f::/48	2001:0db8:031f::/48
2001:0db8:0020::/48	2001:0db8:0120::/48	2001:0db8:0220::/48	2001:0db8:0320::/48
2001:0db8:0021::/48	2001:0db8:0121::/48	2001:0db8:0221::/48	2001:0db8:0321::/48
2001:0db8:0022::/48	2001:0db8:0122::/48	2001:0db8:0222::/48	2001:0db8:0322::/48
2001:0db8:0023::/48	2001:0db8:0123::/48	2001:0db8:0223::/48	2001:0db8:0323::/48
2001:0db8:0024::/48	2001:0db8:0124::/48	2001:0db8:0224::/48	2001:0db8:0324::/48
2001:0db8:0025::/48	2001:0db8:0125::/48	2001:0db8:0225::/48	2001:0db8:0325::/48
2001:0db8:0026::/48	2001:0db8:0126::/48	2001:0db8:0226::/48	2001:0db8:0326::/48
2001:0db8:0027::/48	2001:0db8:0127::/48	2001:0db8:0227::/48	2001:0db8:0327::/48
2001:0db8:0028::/48	2001:0db8:0128::/48	2001:0db8:0228::/48	2001:0db8:0328::/48
2001:0db8:0029::/48	2001:0db8:0129::/48	2001:0db8:0229::/48	2001:0db8:0329::/48
2001:0db8:002a::/48	2001:0db8:012a::/48	2001:0db8:022a::/48	2001:0db8:032a::/48
2001:0db8:002b::/48	2001:0db8:012b::/48	2001:0db8:022b::/48	2001:0db8:032b::/48
2001:0db8:002c::/48	2001:0db8:012c::/48	2001:0db8:022c::/48	2001:0db8:032c::/48
2001:0db8:002d::/48	2001:0db8:012d::/48	2001:0db8:022d::/48	2001:0db8:032d::/48
2001:0db8:002e::/48	2001:0db8:012e::/48	2001:0db8:022e::/48	2001:0db8:032e::/48
2001:0db8:002f::/48	2001:0db8:012f::/48	2001:0db8:022f::/48	2001:0db8:032f::/48
2001:0db8:0030::/48	2001:0db8:0130::/48	2001:0db8:0230::/48	2001:0db8:0330::/48
2001:0db8:0031::/48	2001:0db8:0131::/48	2001:0db8:0231::/48	2001:0db8:0331::/48

Summary

- Vast address space
- Hexadecimal addressing
- Distinct addressing hierarchy between ISPs, end-sites, and LANs
  - ISPs are typically allocated /32s or bigger
  - End customers are typically assigned /48s
  - LANs have /64s
- Other IPv6 features discussed later

The need for Packet Forwarding

- Many small networks can be interconnected to make a larger internetwork
- A device on one network cannot send a packet directly to a device on another network
- The packet has to be forwarded from one network to another, through intermediate nodes, until it reaches its destination
- The intermediate nodes are called "routers"

An IP Router

- A device with more than one link-layer interface (breaks broadcast domains)
- Different IP addresses (from different subnets) on different interfaces
- Receives packets on one interface, and forwards them (usually out of another interface) to get them one hop closer to their destination
- Maintains forwarding tables and routing information base

IP router - action for each packet

- Packet is received on one interface (ingress)
- Checks whether the destination address is the router itself – if so, pass it to higher TCP/IP stack layers
- Decrement TTL (time to live) and discard packet if it reaches zero (0). TTL value is a single octet and maximum is 255.
- Look up the destination IP address in the forwarding table.
- Destination could be on a directly attached link, or through another directly connected or remote router.

Forwarding vs. Routing

- Forwarding: moving packets between ingress and egress interfaces
  - Depends on the forwarding table
  - Information is in the packet
- Routing: process of building routing maps and giving directions
  - One or more routing protocols
  - Procedures (algorithms) to convert routing info to forwarding table.
- (Much more later …)

Forwarding is hop by hop

- Each router makes an independent decision, based on its own forwarding table
- Different routers have different forwarding tables and make different decisions
- Routers talk routing protocols to each other, to help update routing information and forwarding tables

Hop by Hop Forwarding
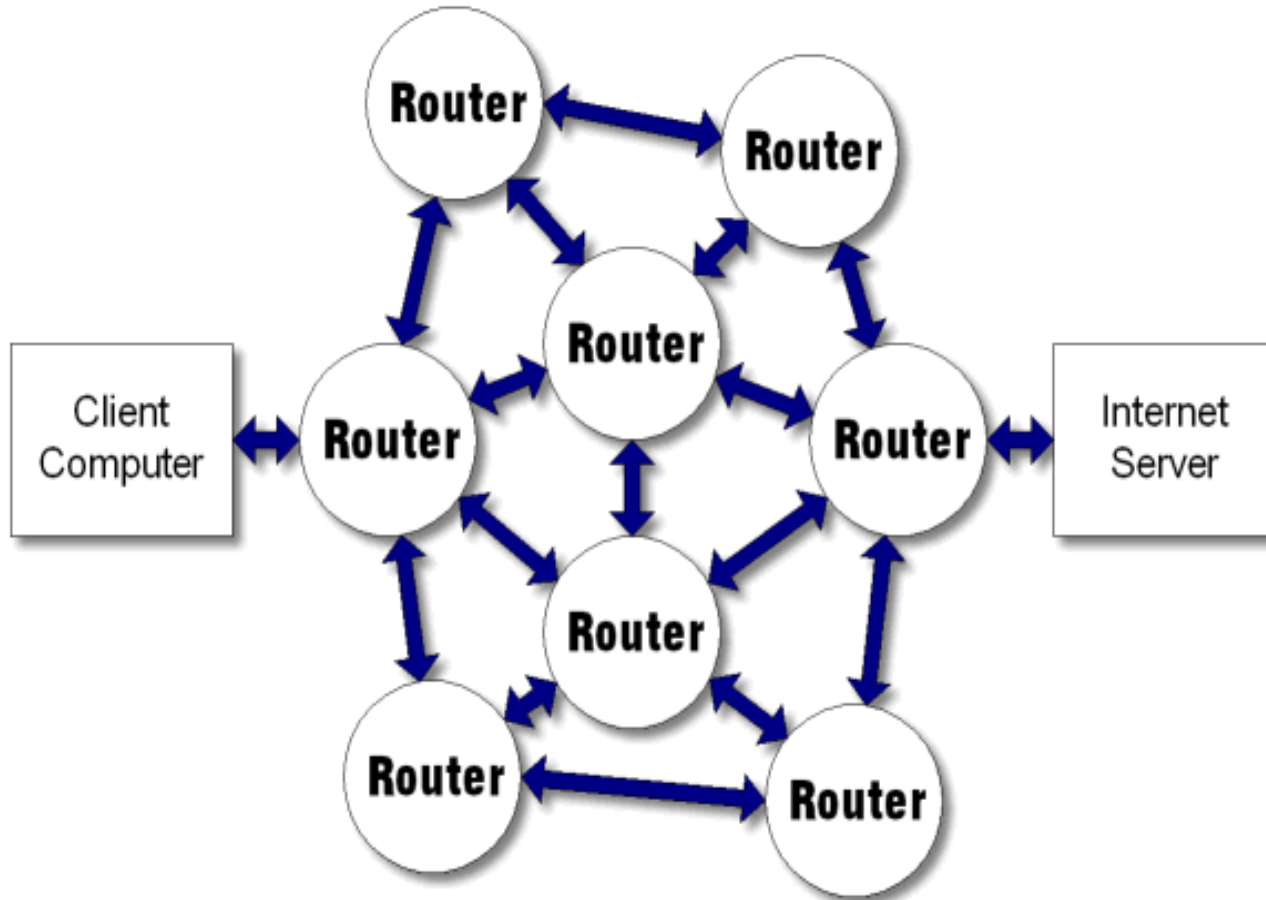
Router Functions

- Determine optimum routing paths through a network
  - Lowest delay means shortest path
  - Highest reliability
- Move packets through the network
  - Determine and extermine destination address in packet
  - Makes a decision on which port to forward the packet through
  - Decision is based on the Routing Table
- Interconnected Routers exchange routing tables in order to maintain a clear picture/map of the network
- In a large network, the routing table updates can consume a lot of resource (cpu, memory, bandwidth)
  - a protocol for route updates is required

Forwarding table structure

- Not every IP address on the Internet is listed otherwise the routing/forwarding table would be huge.
- Instead, the forwarding table contains ip prefixes (networks or subnetwork)
  - "If the first /n bits in the routing table matches this entry, send the datagram that way"
  - If more than one prefix matches, the longest prefix wins (more specific routes)
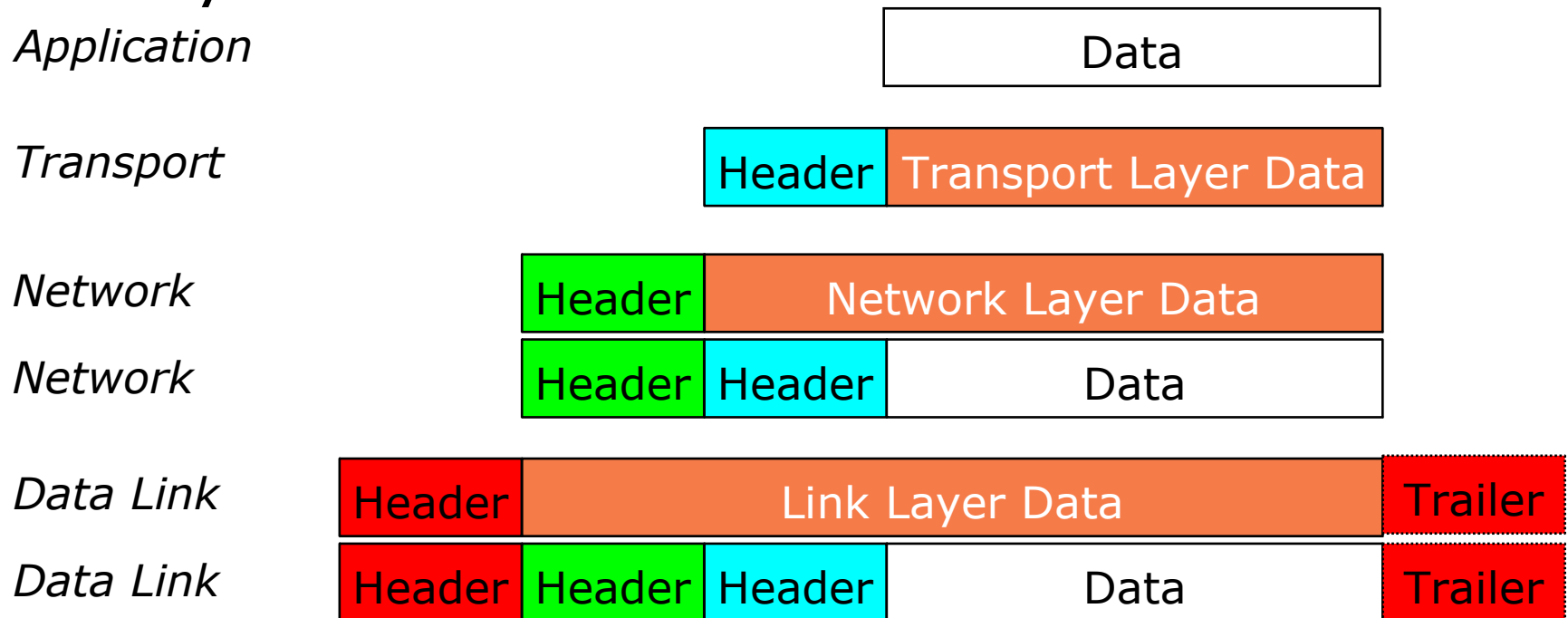- 0.0.0.0/0 is "default route" - matches anything, but only if no other prefix matches.

ARP

Continuation

Encapsulation Reminder

□ Lower layers add headers (and sometimes trailers) to data from higher layers

Application	Data

Transport	Header	Transport Layer Data

Network	Header	Network Layer Data

Network	Header	Header	Data

Data Link	Header	Link Layer Data	Trailer

Data Link	Header	Header	Header	Data	Trailer

Ethernet Essentials

- Ethernet is a broadcast medium
- Structure of Ethernet frame:

Preamble	Dest	Source	Length	Type	Data	CRC

- Entire IP packet makes data part of Ethernet frame
- Delivery mechanism (CSMA/CD)
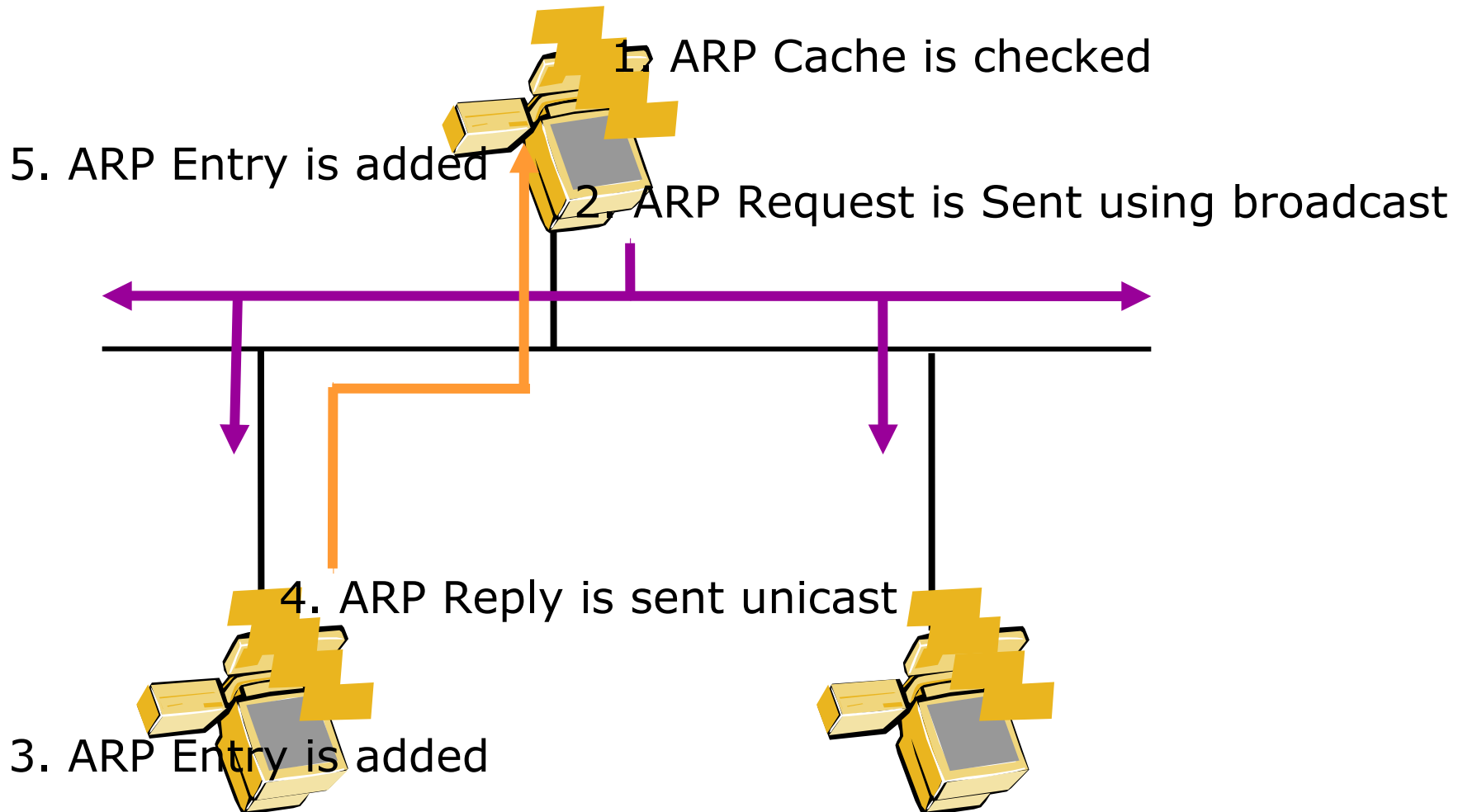 - back off and try again when collision is detected

Ethernet/IP Address Resolution

- Internet Address
  - Unique worldwide (excepting private nets)
  - Independent of Physical Network technology
- Ethernet Address
  - Unique worldwide (excepting errors)
  - Ethernet Only
- Need to map from higher layer to lower (i.e. IP to Ethernet, using ARP)

Address Resolution Protocol

- ARP is only used in IPv4
  - ND (Neighbor Discovery) replaces ARP in IPv6
- Check ARP cache for matching IP address
- If not found, broadcast packet with IP address to every host on Ethernet
- "Owner" of the IP address responds
- Response cached in ARP table for future use
- Old cache entries removed by timeout

ARP Procedure

1. ARP Cache is checked

5. ARP Entry is added

2. ARP Request is Sent using broadcast

4. ARP Reply is sent unicast

3. ARP Entry is added

ARP Table

IP Address	Hardware Address	Age (Sec)
192.168.0.2	08-00-20-08-70-54	3
192.168.0.65	05-02-20-08-88-33	120
192.168.0.34	07-01-20-08-73-22	43

Types of ARP Messages

- ARP request
  - Who is IP addr X.X.X.X tell IP addr Y.Y.Y.Y
- ARP reply
  - IP addr X.X.X.X is Ethernet Address hh:hh:hh:hh:hh:hh
  - An ARP announcement is not intended to solicit a reply; instead it updates any cached entries in the ARP tables of other hosts that receive the packet.

Asante Sana

Any ????