Introduction to Internet Protocol (IP) Version 4 and Version 6

OSI Stack & TCP/IP Architecture

Principles of the Internet

- Edge vs. core (end-systems vs. routers)
  - Dumb network
  - Intelligence at the end-systems
- Different communication paradigms
  - Connection oriented vs. connection less
  - Packet vs. circuit switching
- Layered System
- Network of collaborating networks

The network edge

- □ end systems (hosts):
  - ■ run application programs
  - ■ e.g., WWW, email
  - ■ at "edge of network"
- □ client/server model:
  - ■ client host requests, receives service from server
  - ■ e.g., WWW client (browser)/server; email client/server
- □ peer-peer model:
  - ■ host interaction symmetric
    e.g.: teleconferencing
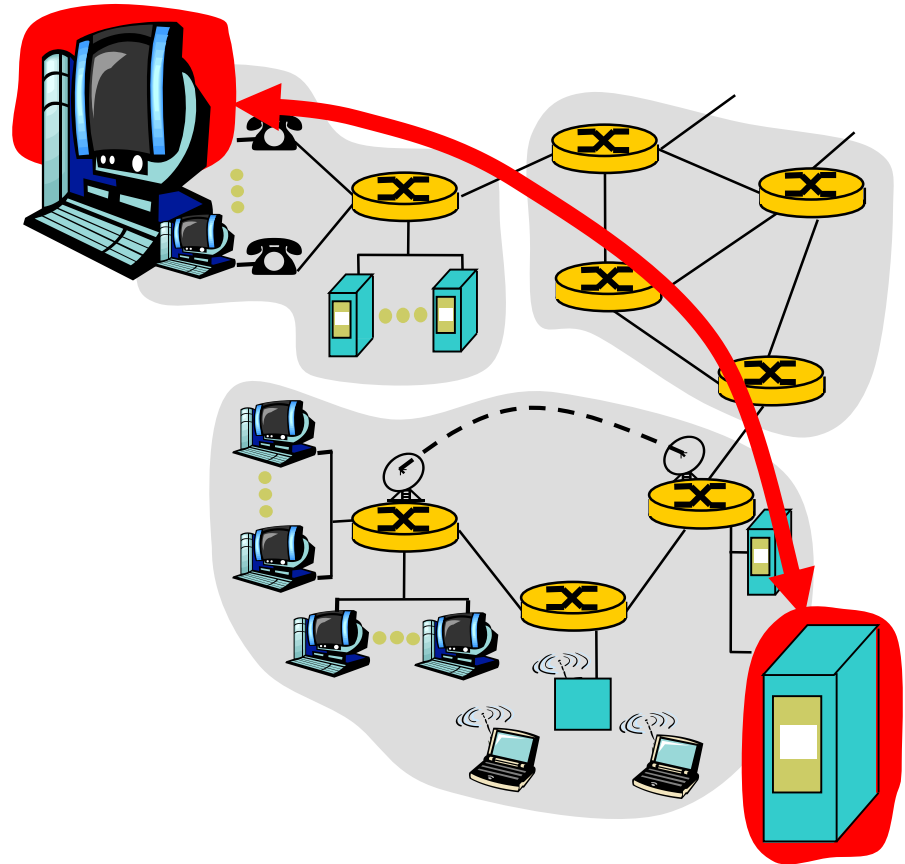
Network edge: connection-oriented service

- Goal: data transfer between end sys.
- handshaking: setup (prepare for) data transfer ahead of time
  - Hello, hello back human protocol
  - set up "state" in two communicating hosts
- TCP - Transmission Control Protocol
  - Internet's connection-oriented service

TCP service [RFC 793]

reliable, in-order byte-stream data transfer

> loss: acknowledgements and retransmissions

flow control:

> sender won't overwhelm receiver

congestion control:

> senders "slow down sending rate" when network congested

Network edge: connectionless service

☐ Goal: data transfer between end systems

☐ UDP - User Datagram Protocol [RFC 768]: Internet's connectionless service
  ■ unreliable data transfer
  ■ no flow control
  ■ no congestion control

Protocol "Layers"

- Networks are complex!
- many "pieces":
    - hosts
    - routers
    - links of various media
    - applications
    - protocols
    - hardware, software

Question:

Is there any hope of organizing structure of network?

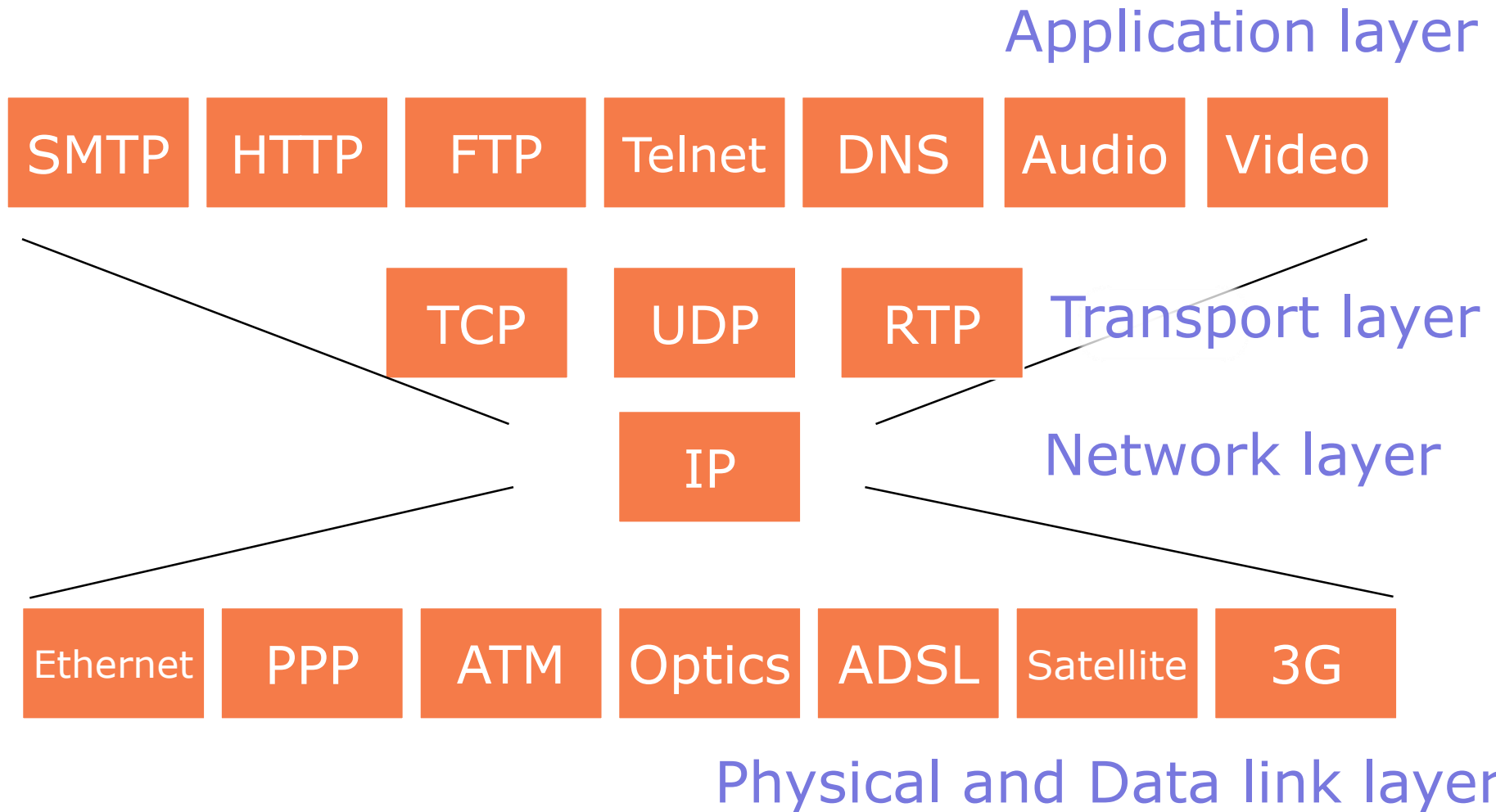Or at least in our discussion of networks?

The unifying effect of the network layer

- ☐ Define a protocol that works in the same way with any underlying network
- ☐ Call it the network layer (e.g. IP)
- ☐ IP routers operate at the network layer
- ☐ IP over anything
- ☐ Anything over IP

Why layering?

□ Dealing with complex systems:

□ explicit structure allows identification, relationship of complex system's pieces

- layered reference model for discussion

□ Modularisation eases maintenance, updating of system

- change of implementation of layer's service transparent to rest of system

- e.g., change in gate procedure does not affect rest of system

The IP Hourglass Model

Application layer

| SMTP | HTTP | FTP | Telnet | DNS | Audio | Video |

| TCP | UDP | RTP |

Transport layer

| IP |

Network layer

| Ethernet | PPP | ATM | Optics | ADSL | Satellite | 3G |

Physical and Data link layer

The OSI Model

|		
7	Application	
6	Presentation	Upper Layers
5	Session	Application oriented
4	Transport	"End-to-End"-Layers
3	Network	Lower Layers
2	Data Link	Network oriented
1	Physical	"Hop-by-hop" layers
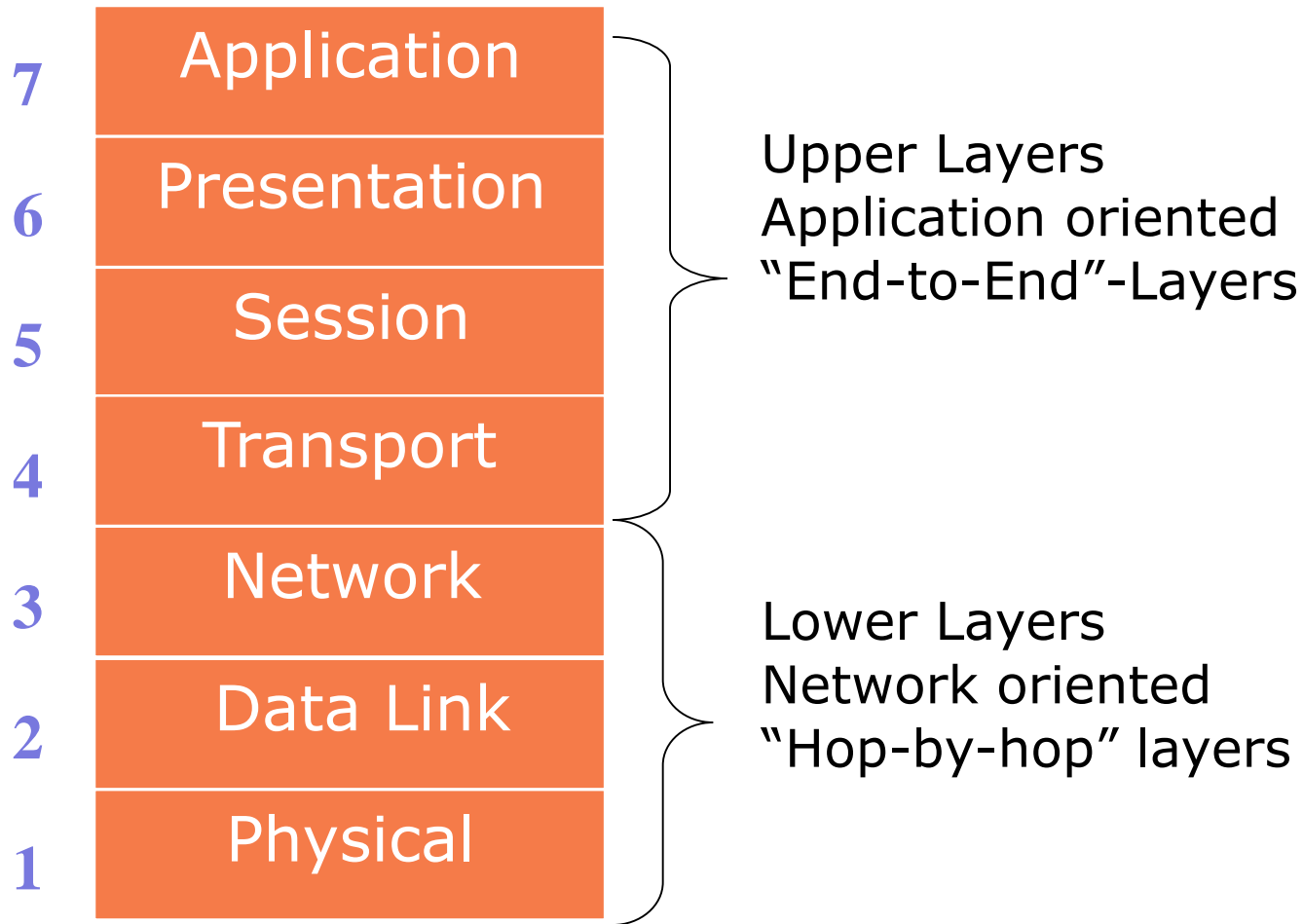
OSI Model and the Internet

- Internet protocols are not directly based on the OSI model

- However, we do often use the OSI numbering system. You should at least remember these:
  - Layer 7: Application
  - Layer 4: Transport (e.g. TCP, UDP)
  - Layer 3: Network (IP)
  - Layer 2: Data link
  - Layer 1: Physical

Layer Interaction: TCP/IP Model
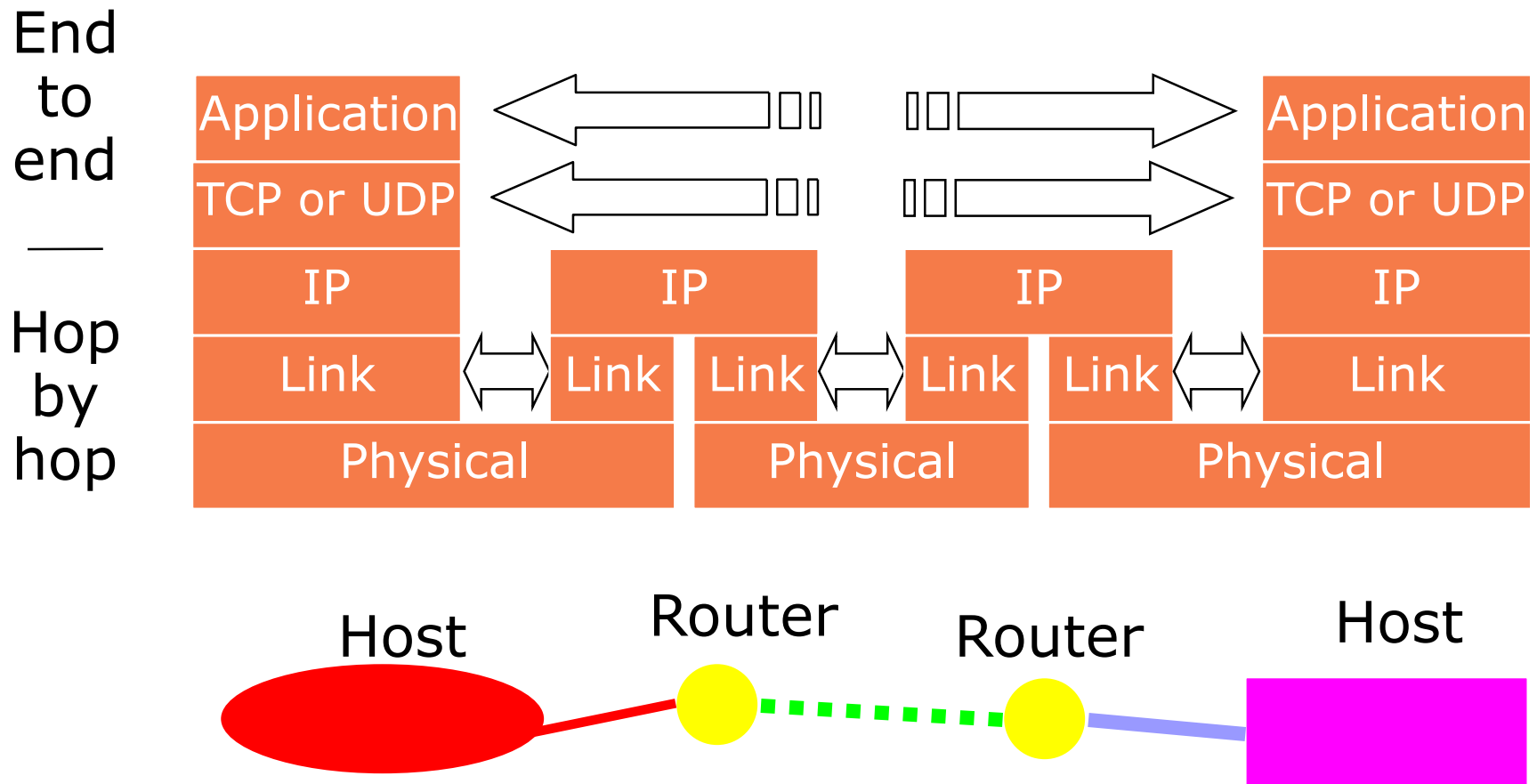
End-to-end layers

- ☐ Upper layers are "end-to-end"
- ☐ Applications at the two ends behave as if they can talk directly to each other
- ☐ They do not concern themselves with the details of what happens in between

Hop-by-hop layers

- At the lower layers, devices share access to the same physical medium

- Devices communicate directly with each other

- The network layer (IP) has some knowledge of how many small networks are interconnected to make a large internet

- Information moves one hop at a time, getting closer to the destination at each hop

Layer Interaction: TCP/IP Model

Application	Application
TCP or UDP	TCP or UDP
IP	IP	IP	IP
Link	Link	Link	Link	Link	Link
Physical	Physical	Physical

Host   Router   Router   Host
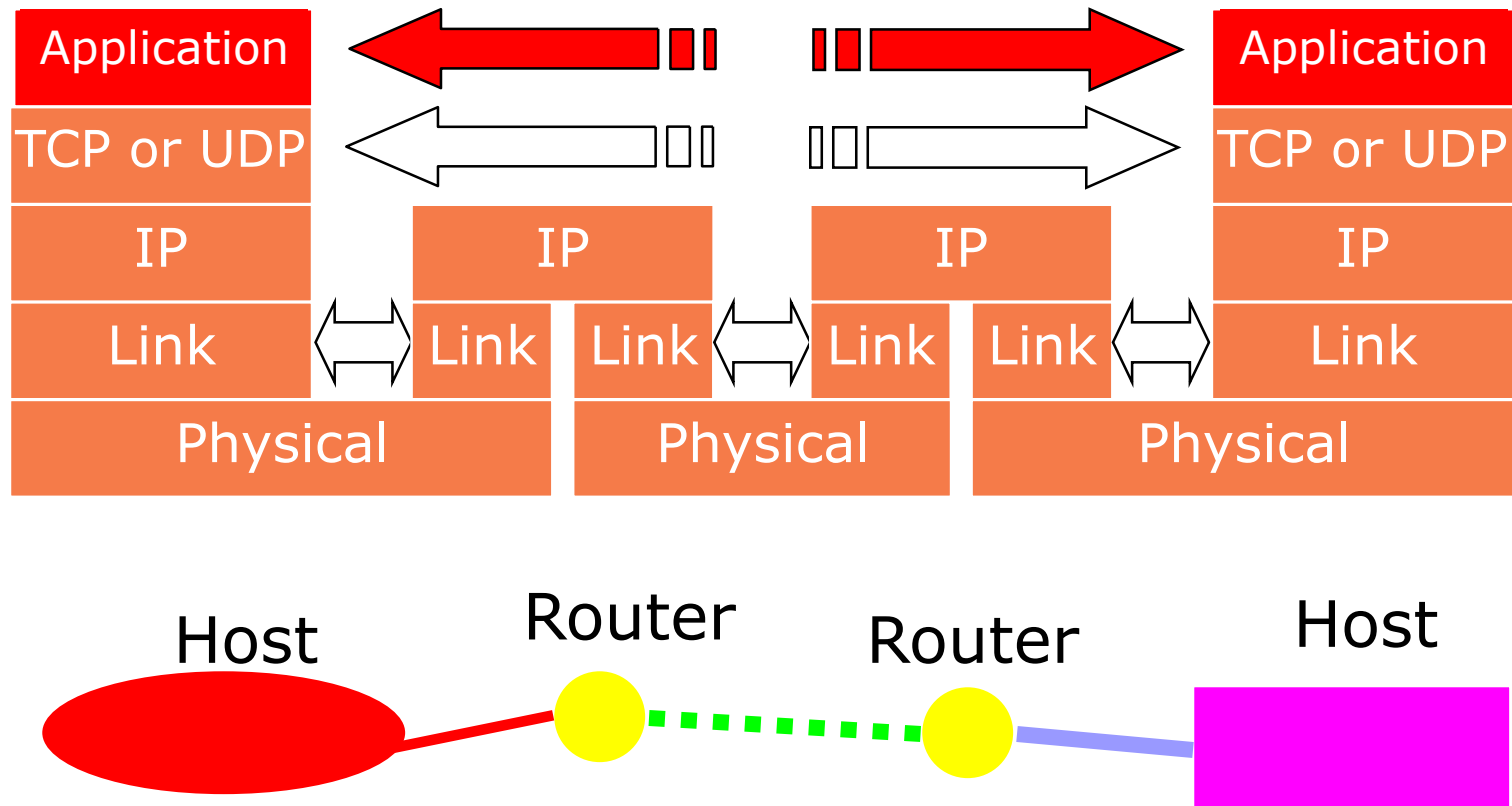
Layer Interaction: The Application Layer

Applications behave as if they can talk to each other, but in reality the application at each side talks to the TCP or UDP service below it.

Application			Application
TCP or UDP			TCP or UDP
IP	IP	IP	IP
Link	Link	Link	Link
Physical	Physical	Physical	

The application layer doesn't care about what happens at the lower layers, provided the transport layer carries the application's data safely from end to end.

Host   Router   Router   Host
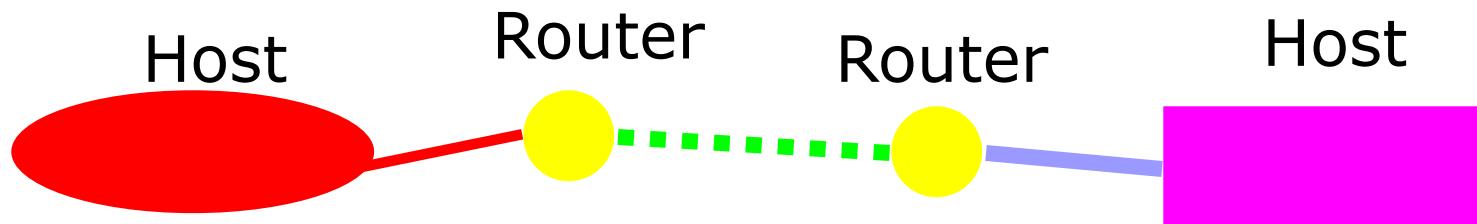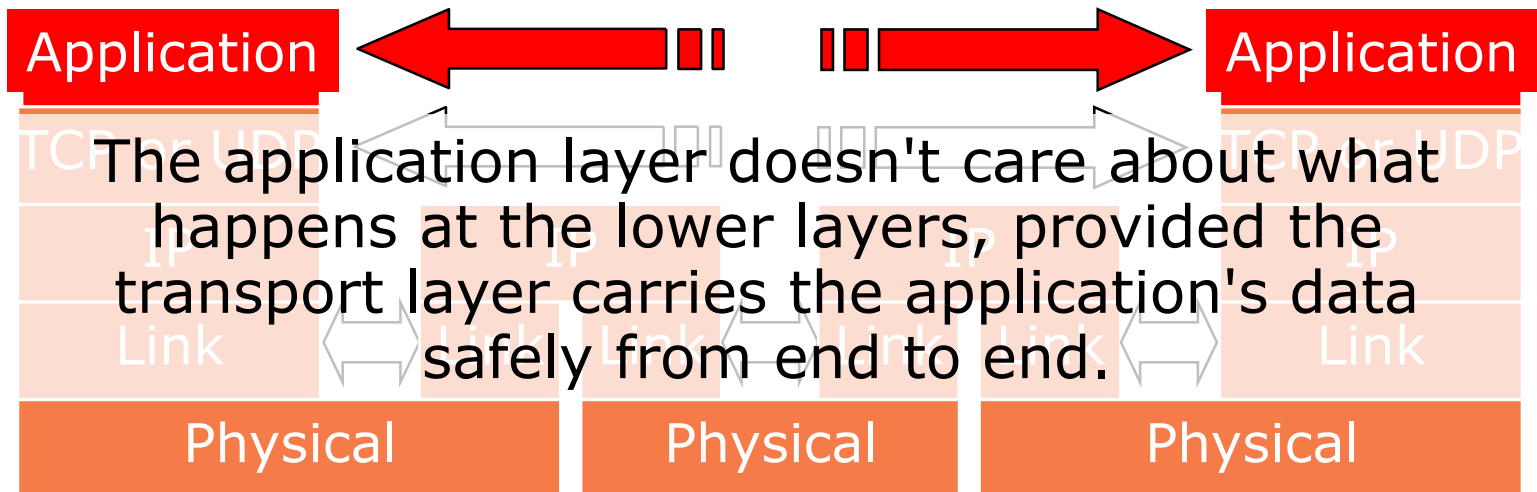
Layer Interaction: The Transport Layer

The transport layer instances at the two ends act as if they are talking to each other, but in reality they are each talking to the IP layer below it. The transport layer doesn't care about what the application layer is doing above it.

Application		Application
TCP or UDP		TCP or UDP

The transport layer doesn't care what happens in the IP layer or below, as long as the IP layer can move datagrams from one side to the other.

IP		IP		IP
Link	Link	Link	Link	Link	Link
Physical	Physical	Physical

Host   Router   Router   Host
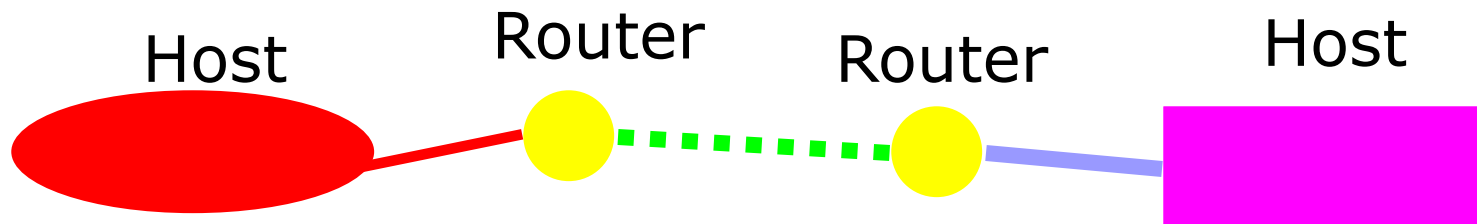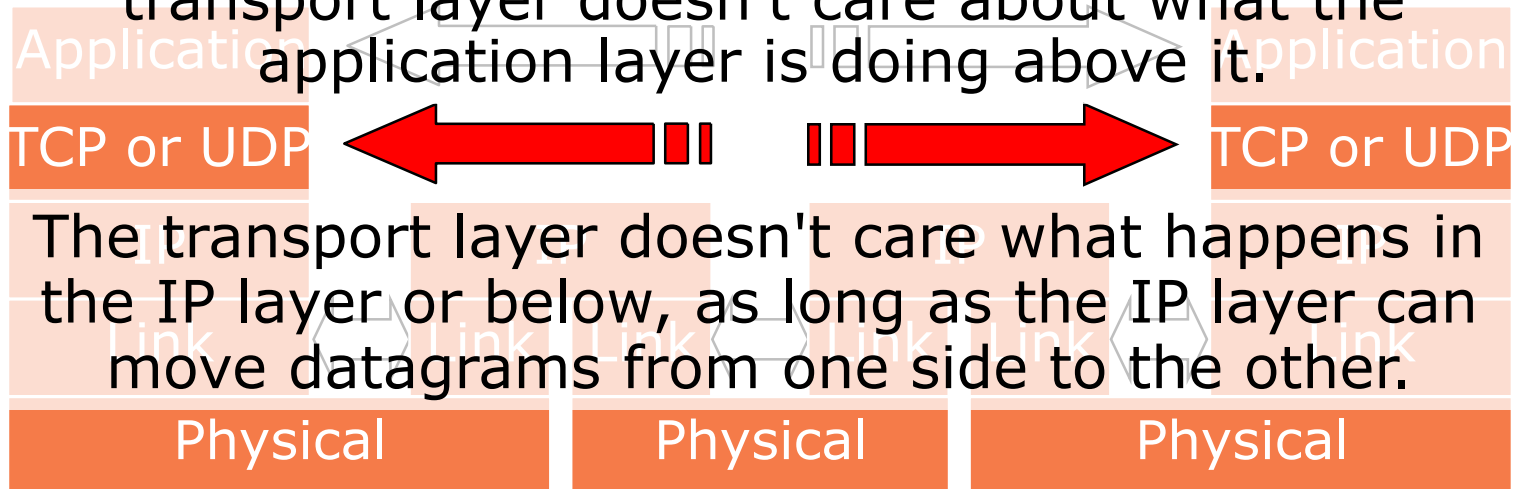
Layer Interaction:
The Network Layer (IP)

The IP layer has to know a lot about the topology of the network (which host is connected to which router, which routers are connected to each other), but it doesn't care about what happens at the upper layers.

Application			Application
TCP or UDP			TCP or UDP
IP	IP	IP	IP
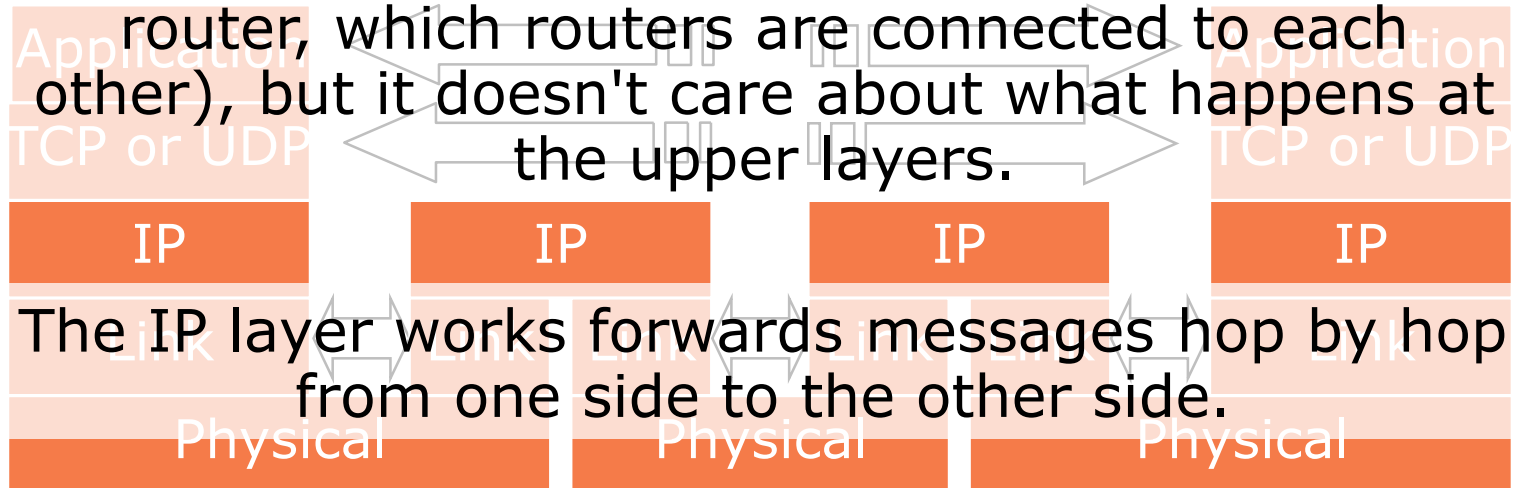
The IP layer works forwards messages hop by hop from one side to the other side.

| Link | Link | Link | Link | Link | Link |
| Physical | Physical | Physical | | |

Host   Router   Router   Host
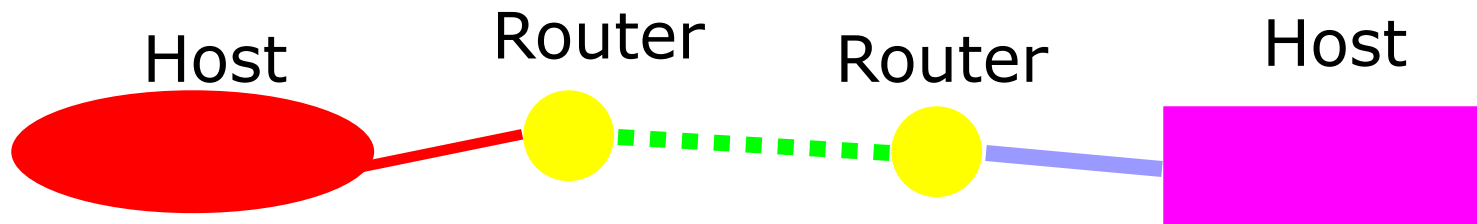
Layer Interaction:
Link and Physical Layers

The link layer doesn't care what happens above it, but it is very closely tied to the physical layer below it.

All links are independent of each other, and have no way of communicating with each other.

Application				Application
TCP or UDP				TCP or UDP
IP	IP	IP	IP	IP
Link	Link	Link	Link	Link	Link
Physical	Physical	Physical

Host   Router   Router   Host
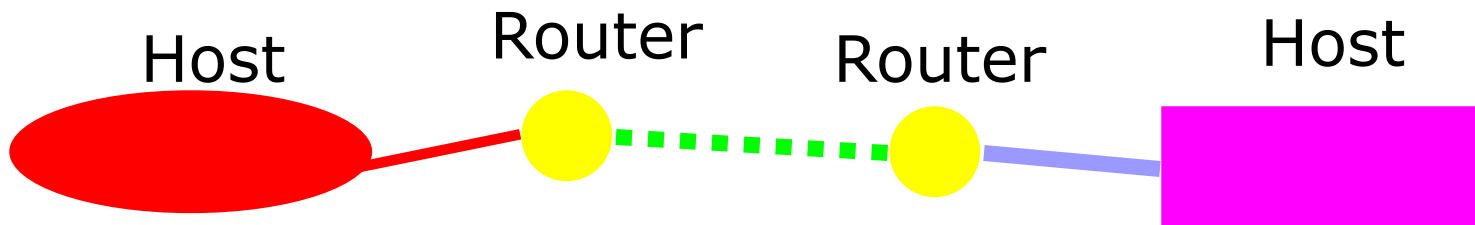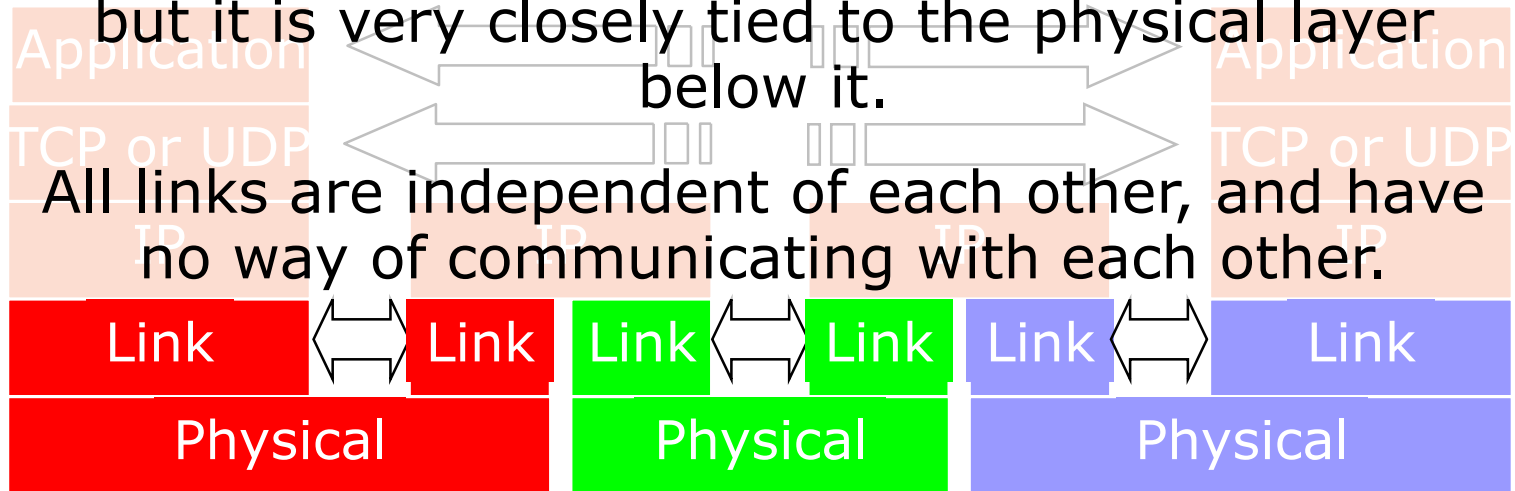
Layering: physical communication
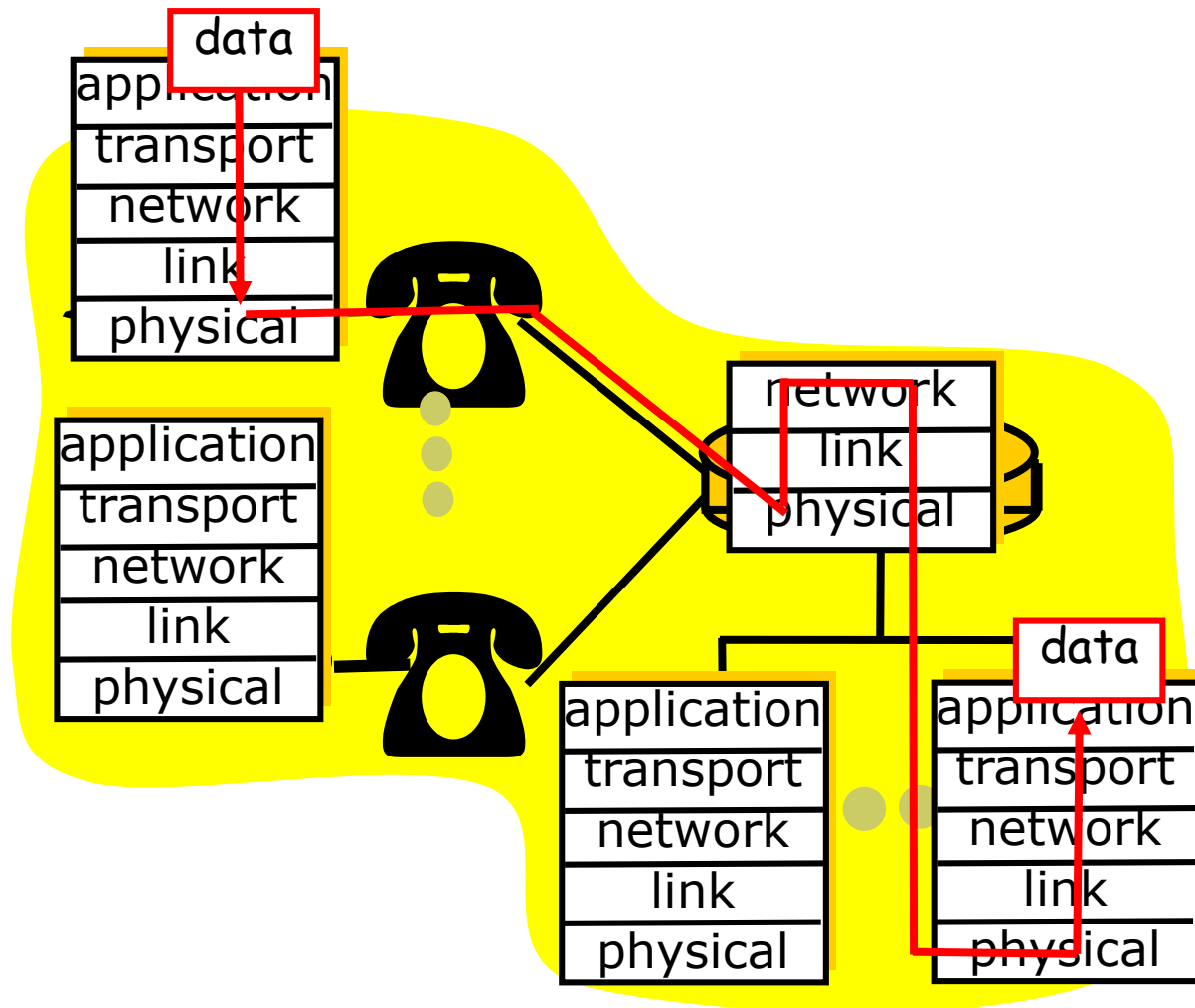
Frame, Datagram, Segment, Packet

- Different names for packets at different layers
  - Ethernet (link layer) frame
  - IP (network layer) datagram
  - TCP (transport layer) segment
- Terminology is not strictly followed
  - we often just use the term "packet" at any layer

Encapsulation & Decapsulation

❑ 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

Layer 2 - Ethernet frame

Preamble	Dest	Source	Type	Data	CRC
	6 bytes	6 bytes	2 bytes	46 to 1500 bytes	4 bytes
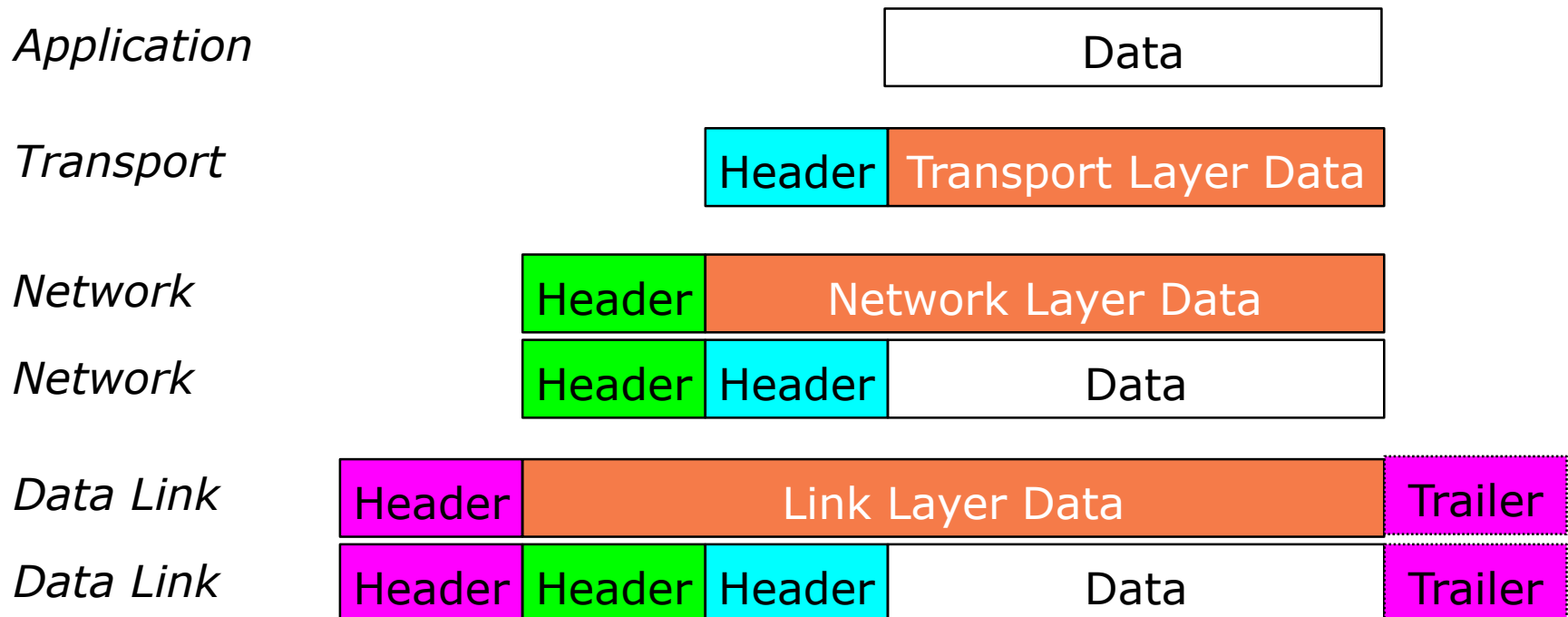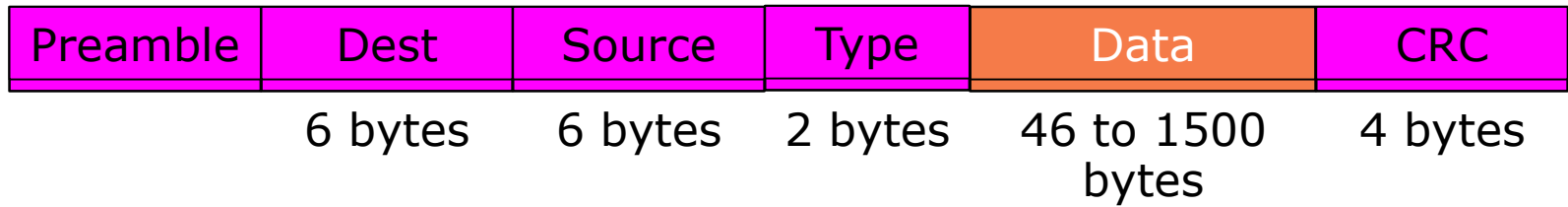
- Destination and source are 48-bit MAC addresses (e.g., 00:26:4a:18:f6:aa)
- Type 0x0800 means that the "data" portion of the Ethernet frame contains an IPv4 datagram. Type 0x0806 for ARP. Type 0x86DD for IPv6.
- "Data" part of layer 2 frame contains a layer 3 datagram.

Layer 3 - IPv4 datagram

Version	IHL	Diff Services	Total Length	
Identification			Flags	Fragment Offset
Time to Live		Protocol	Header Checksum	
Source Address (32-bit IPv4 address)				
Destination Address (32-bit IPv4 address)				
Options				Padding
Data (contains layer 4 segment)				

Version = 4
  If no options, IHL = 5
  Source and Destination are
  32-bit IPv4 addresses

□ Protocol = 6 means data
  portion contains a TCP
  segment. Protocol = 17
  means UDP.

Layer 4 - TCP segment

Source Port								Destination Port	
Sequence Number									
Acknowledgement Number									
Data Offset	Reserved	U R G	A C K	E O L	R S T	S Y N	F I N	Window	
Checksum								Urgent Pointer	
Options									Padding
Data (contains application data)									

- Source and Destination are 16-bit TCP port numbers (IP addresses are implied by the IP header)

- If no options, Data Offset = 5 (which means 20 octets)

IPv4 Addressing

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

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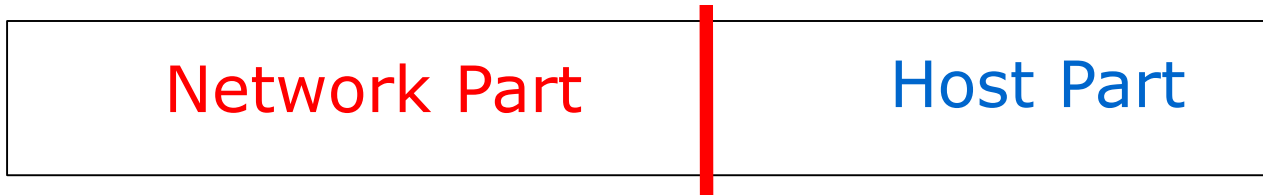
- Boundary can be anywhere
  - Boundaries are chosen according to number of hosts required

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
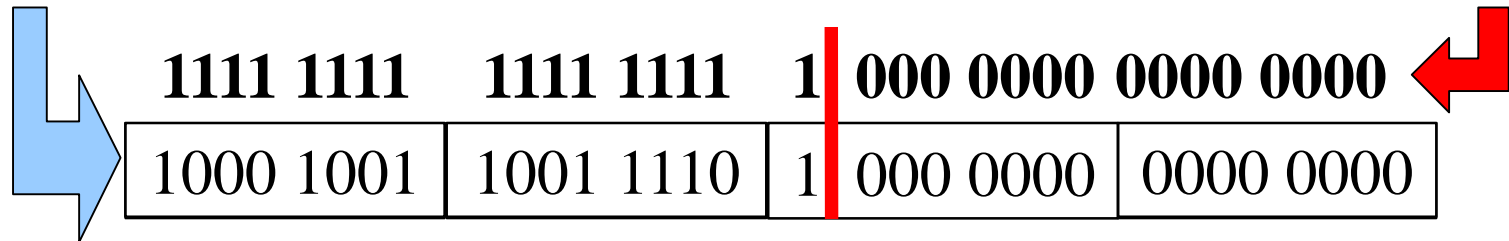
- 198.134.0.0/16   (netmask 255.255.0.0)

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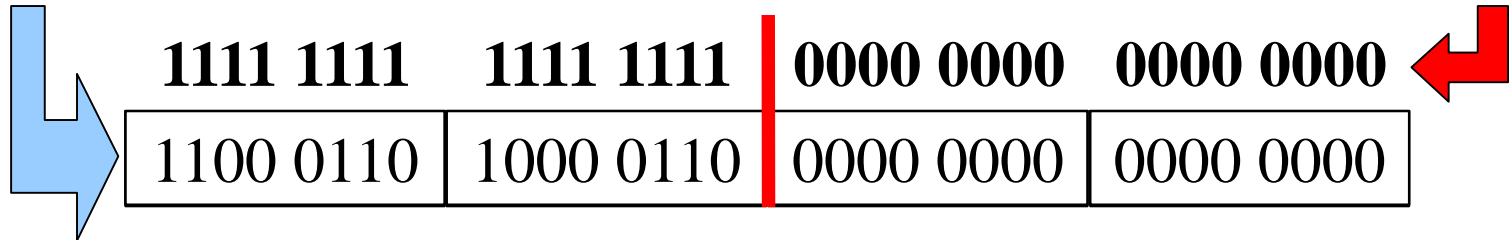
- 205.37.193.128/26   (netmask 255.255.255.192)

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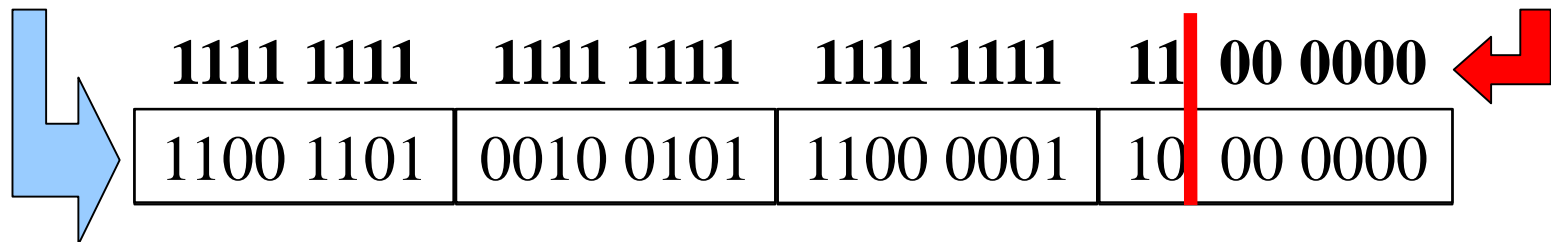
Special Addresses

- 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?

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		
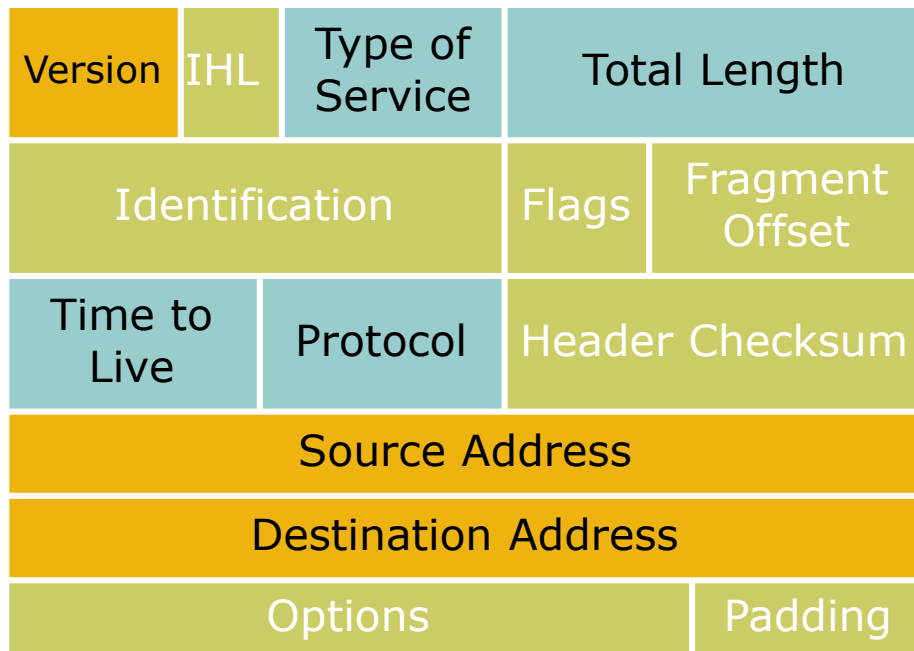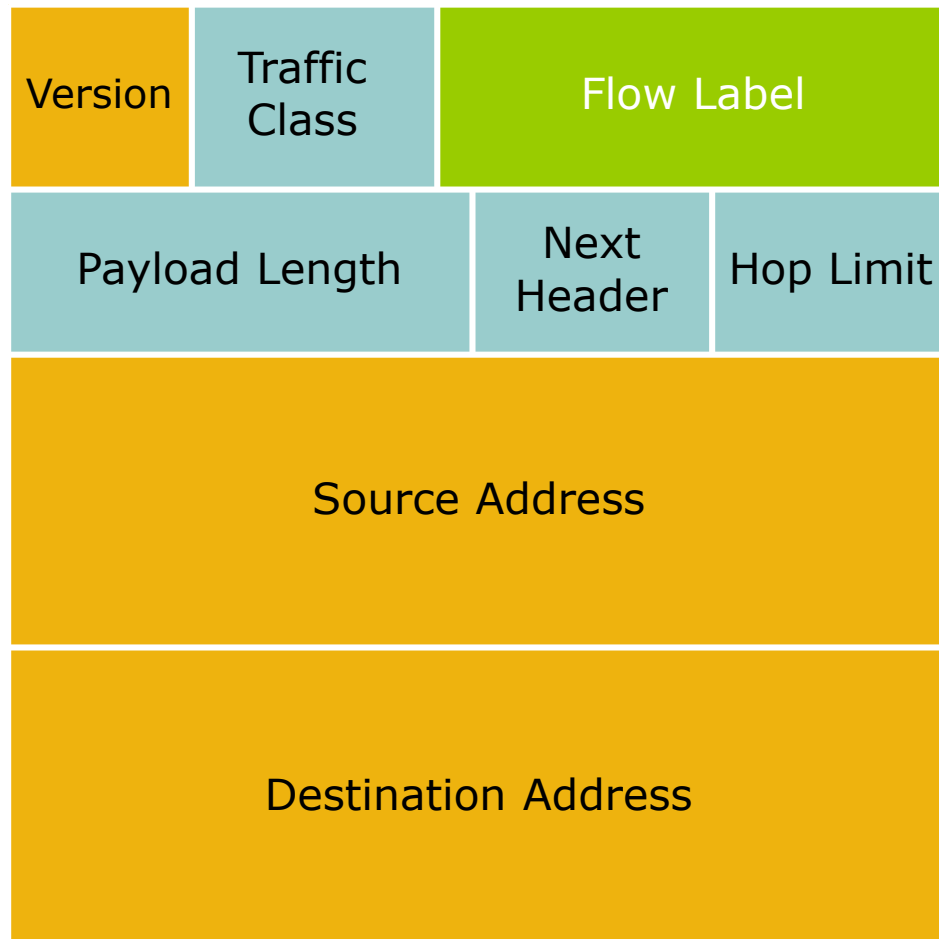
Legend

- 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
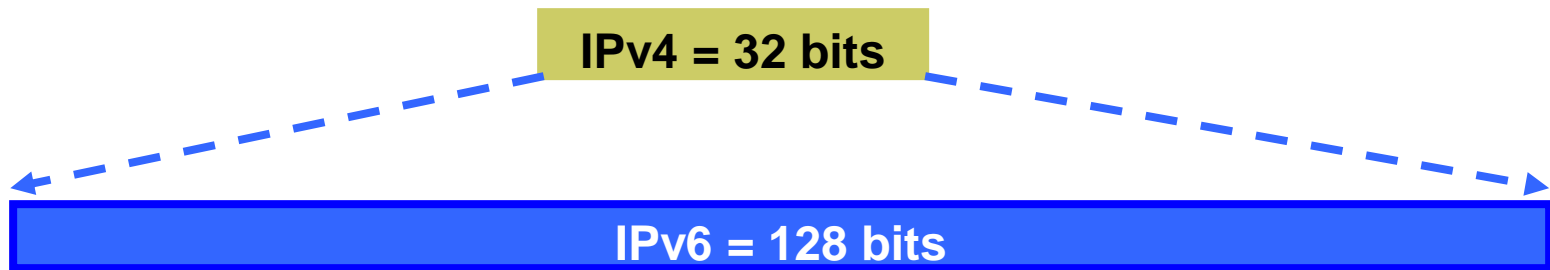
IPv6 = 128 bits

- 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 ok
  - 2031::130F::9C0:876A:130B   is NOT ok (two "::")

  - 0:0:0:0:0:0:0:1 → ::1   (loopback address)
  - 0:0:0:0:0:0:0:0 → ::   (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:db8:12::/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
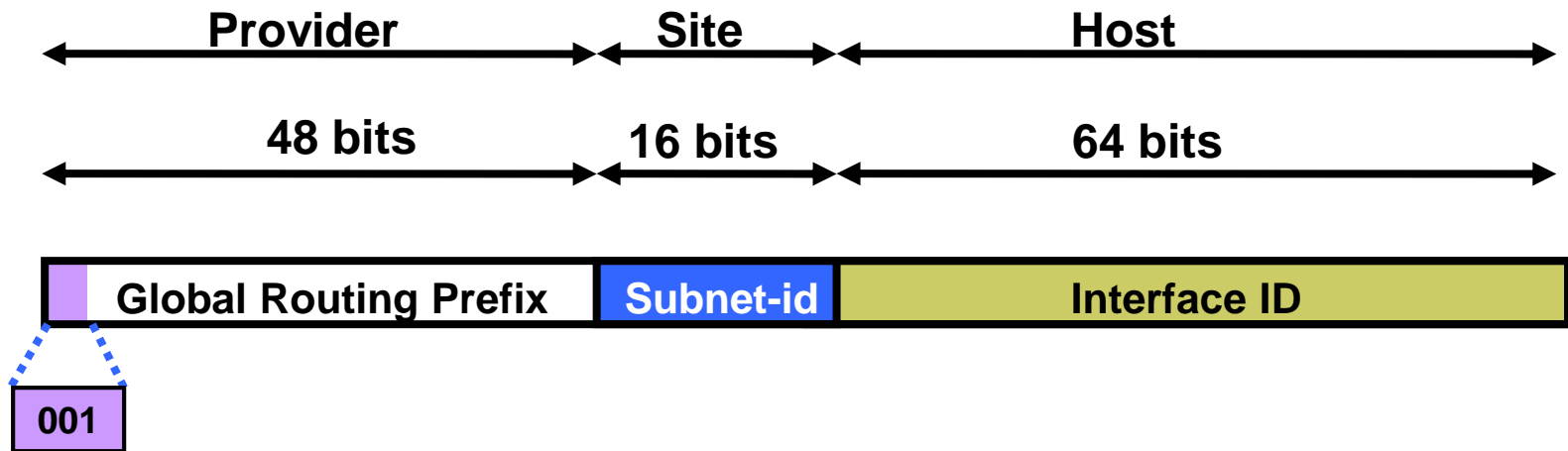
- ☐ IPv6 Global Unicast addresses are:
  - ■ Addresses for generic use of IPv6
  - ■ Hierarchical structure intended to simplify aggregation

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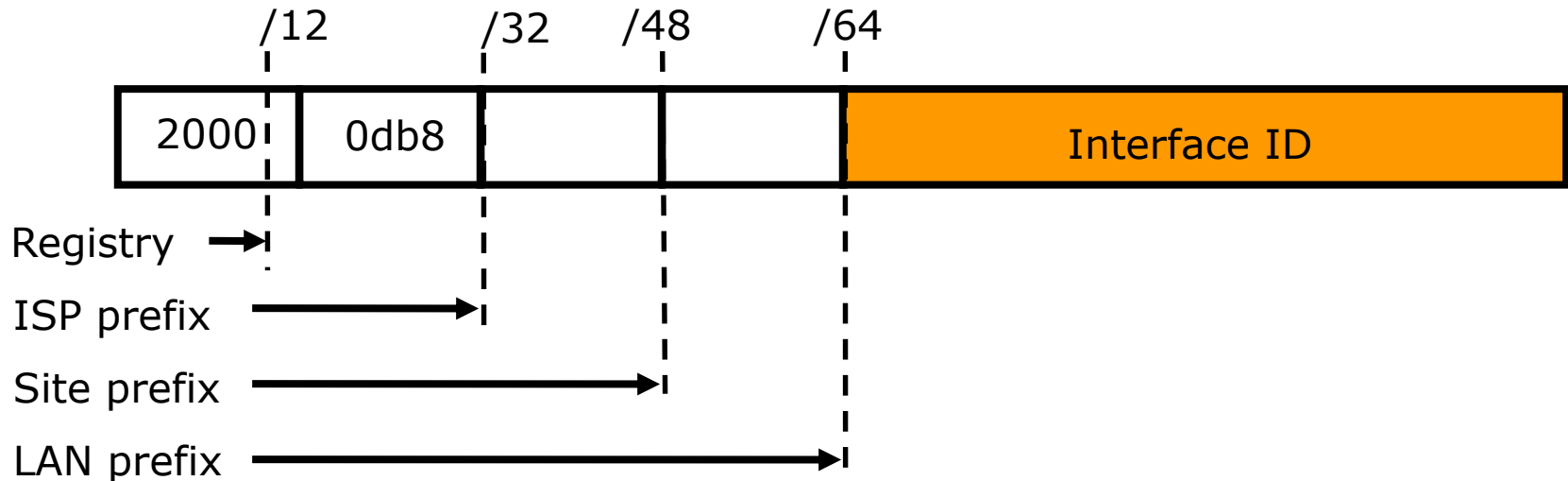
- The allocation process is:
    - The IANA is allocating out of 2000::/3 for initial IPv6 unicast use
    - Each registry gets a /12 prefix from the IANA
    - Registry allocates a /32 prefix (or larger) to an IPv6 ISP
    - ISPs usually allocate a /48 prefix to each end customer

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
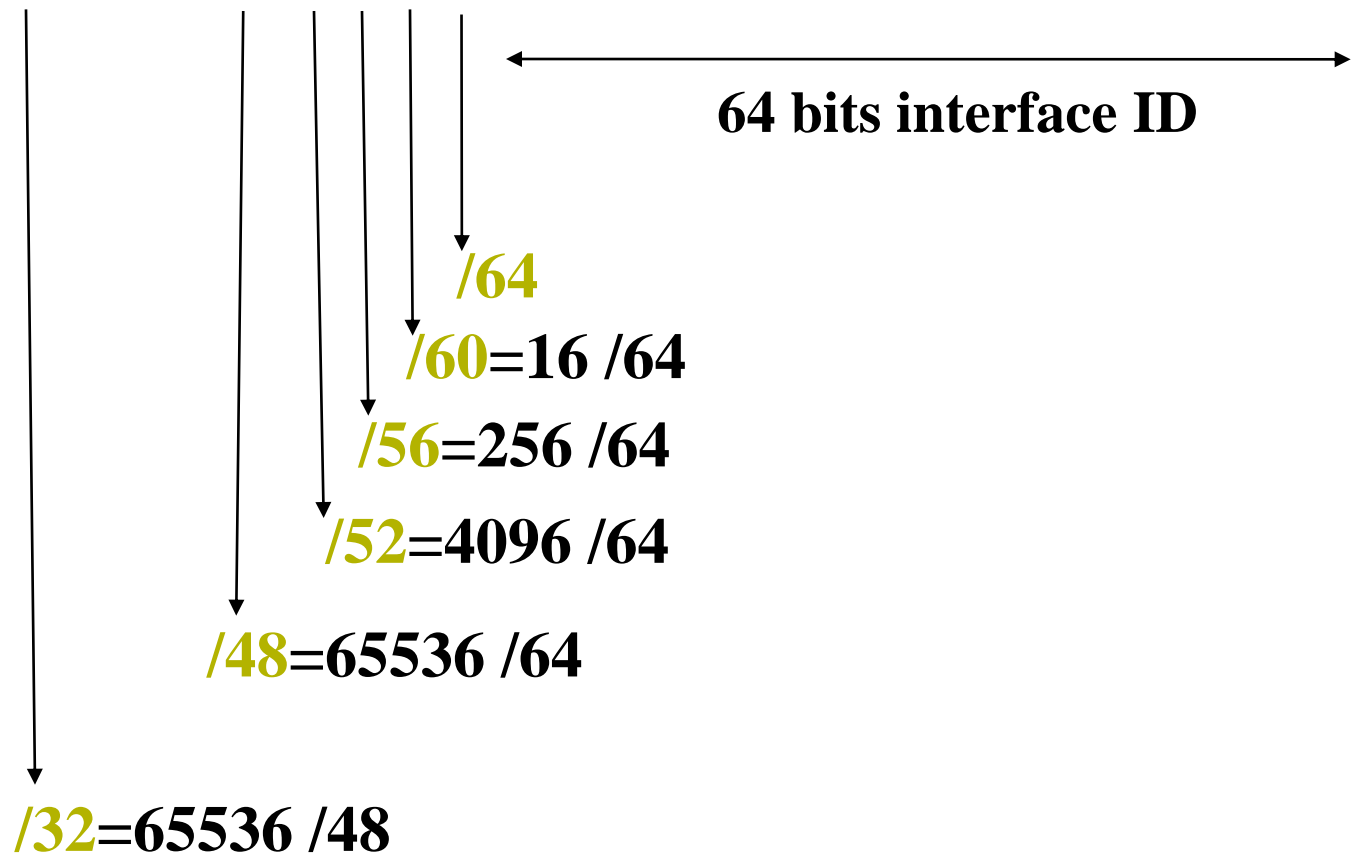
Nibble (4 bits) Concept

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
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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

    - End customers are typically assigned /48s

    - LANs have /64s

- Other IPv6 features discussed later

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