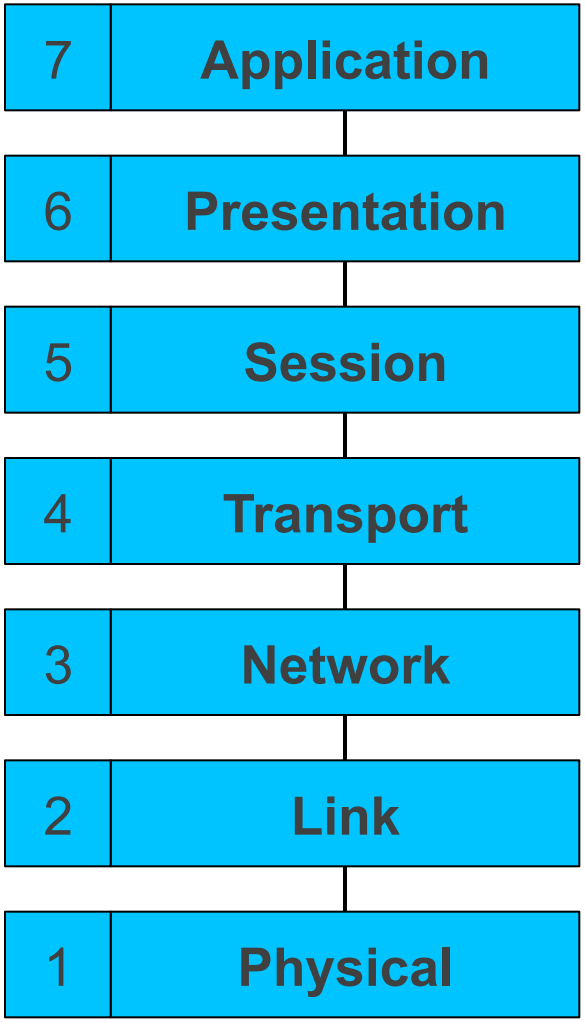
Campus Networking Workshop

Networking Fundamentals Refresher

Objectives

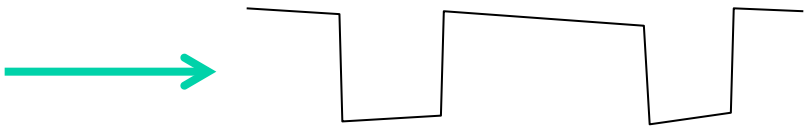
- To revise the core concepts
- To ensure we are using the same terminology

What is this?


7
Application
6
Presentation
5
Session
4
Transport
3
Network
2
Link
1
Physical

Layer 1: Physical Layer

- Transfers a stream of *bits*
- Defines physical characteristics
  - Connectors, pinouts
  - Cable types, voltages, modulation
  - Fibre types, lambdas
  - Transmission rate (bps)
- No knowledge of bytes or frames

`101101` 

Examples of Layer 1 technologies and standards?

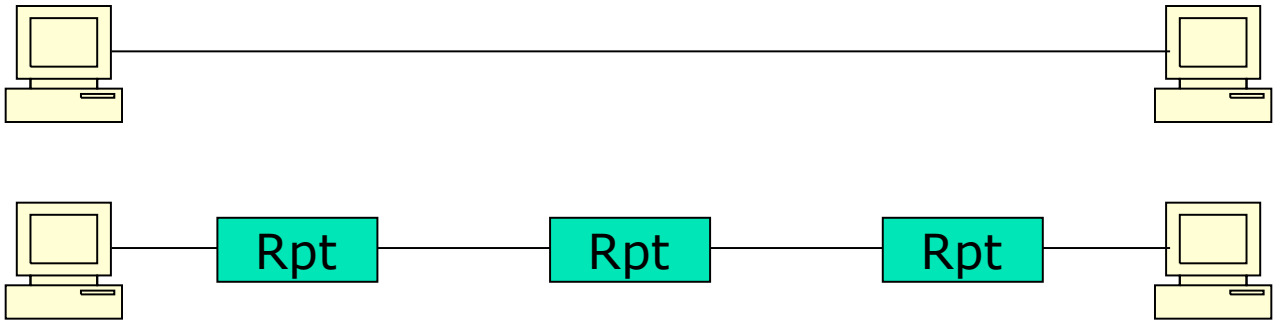
Types of equipment

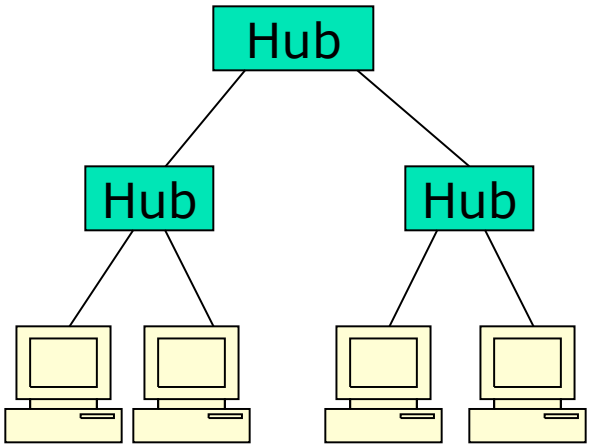
- Layer 1: **Hub, Repeater, Media Convertor**
- Works at the level of individual bits

- All data sent out of all ports
- Hence data may end up where it is not needed

Building networks at Layer 1

What limits do we hit?

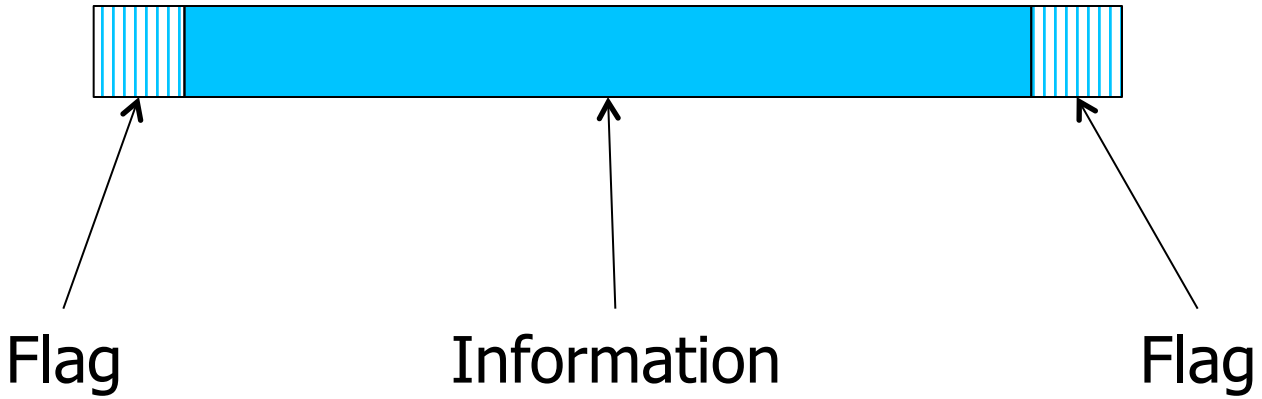




Layer 2: (Data)Link Layer

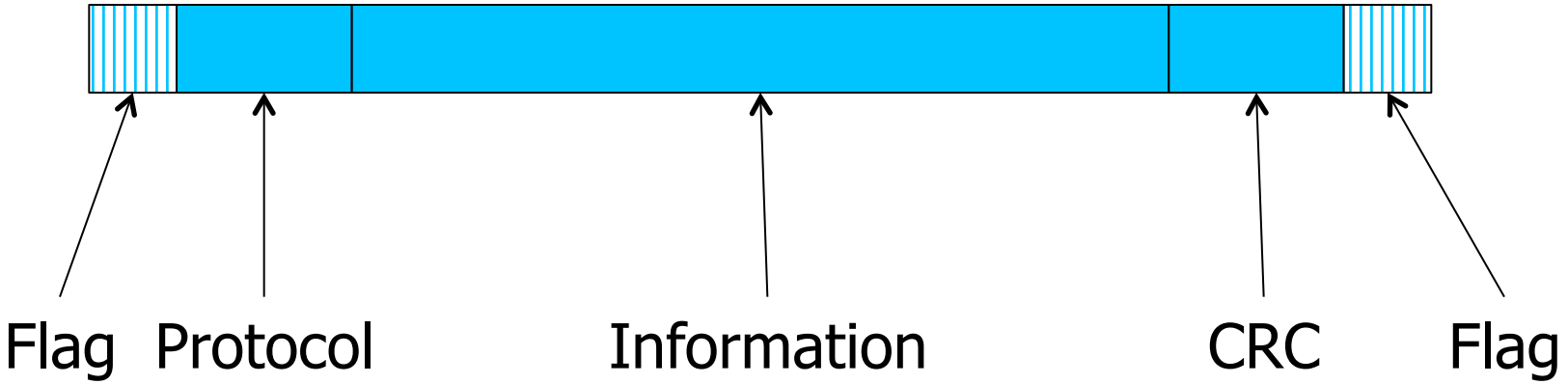
- Organises data into *frames*
- May detect transmission errors (corrupt frames)
- May support shared media
  - Addressing (unicast, multicast) – who should receive this frame
  - Access control, collision detection
- Usually identifies the layer 3 protocol being carried

Example Layer 2: SLIP



That's it!

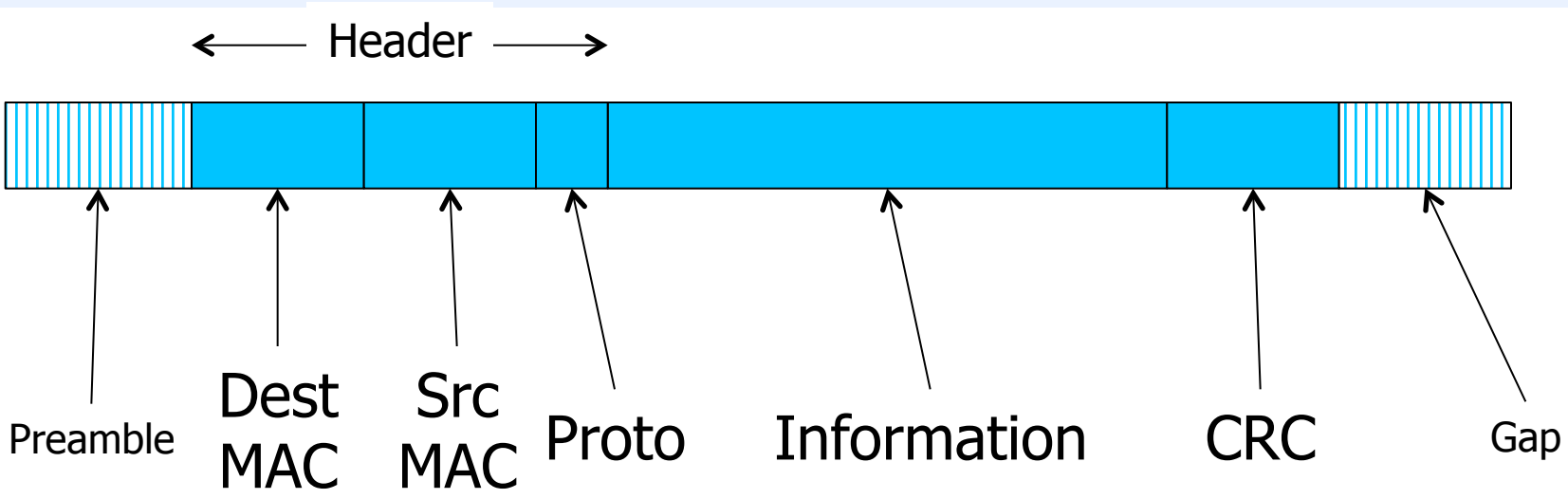
Example Layer 2: PPP



Also includes link setup and negotiation

- Agree link parameters (LCP)
- Authentication (PAP/CHAP)
- Layer 3 settings (IPCP)

Example Layer 2: Ethernet



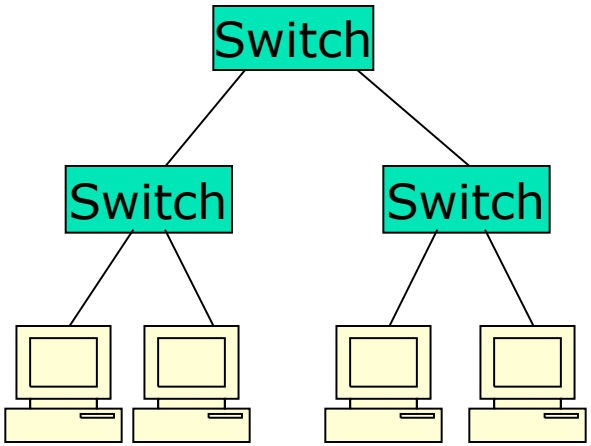
- MAC addresses
- Protocol: 2 bytes
  - e.g. 0800 = IPv4, 0806 = ARP, 86DD = IPv6
- Preamble: carrier sense, collision detection

Types of equipment (contd)

- Layer 2: **Switch, Bridge**
- Receives whole layer 2 frames and selectively retransmits them
- Learns which MAC addr is on which port
- If it knows the destination MAC address, will send it out only on that port
- Broadcast frames must be sent out of all ports, just like a hub
- Doesn’t look any further than L2 header

Building networks at Layer 2

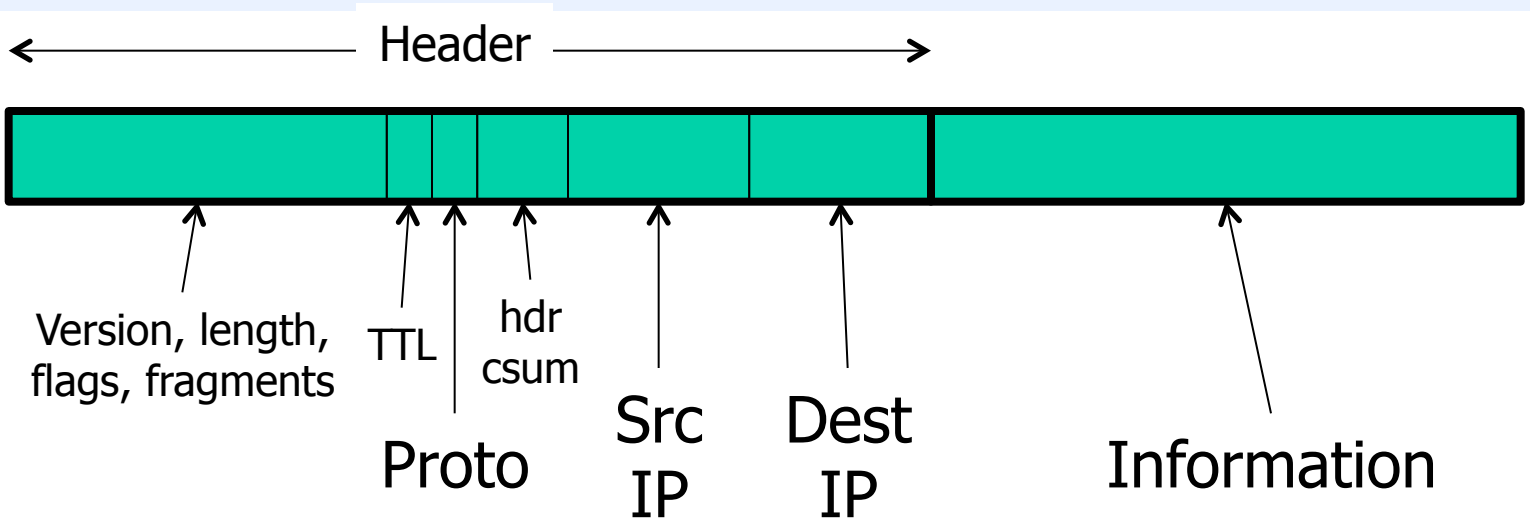
- What limits do we hit?



Layer 3: (Inter)Network Layer

- Connects Layer 2 networks together
  - Forwarding data from one network to another
- Universal frame format (datagram)
- Unified addressing scheme
  - Independent of the underlying L2 network(s)
  - Addresses organised so that it can scale globally (aggregation)
- Identifies the layer 4 protocol being carried
- Fragmentation and reassembly

Example Layer 3: IPv4 Datagram

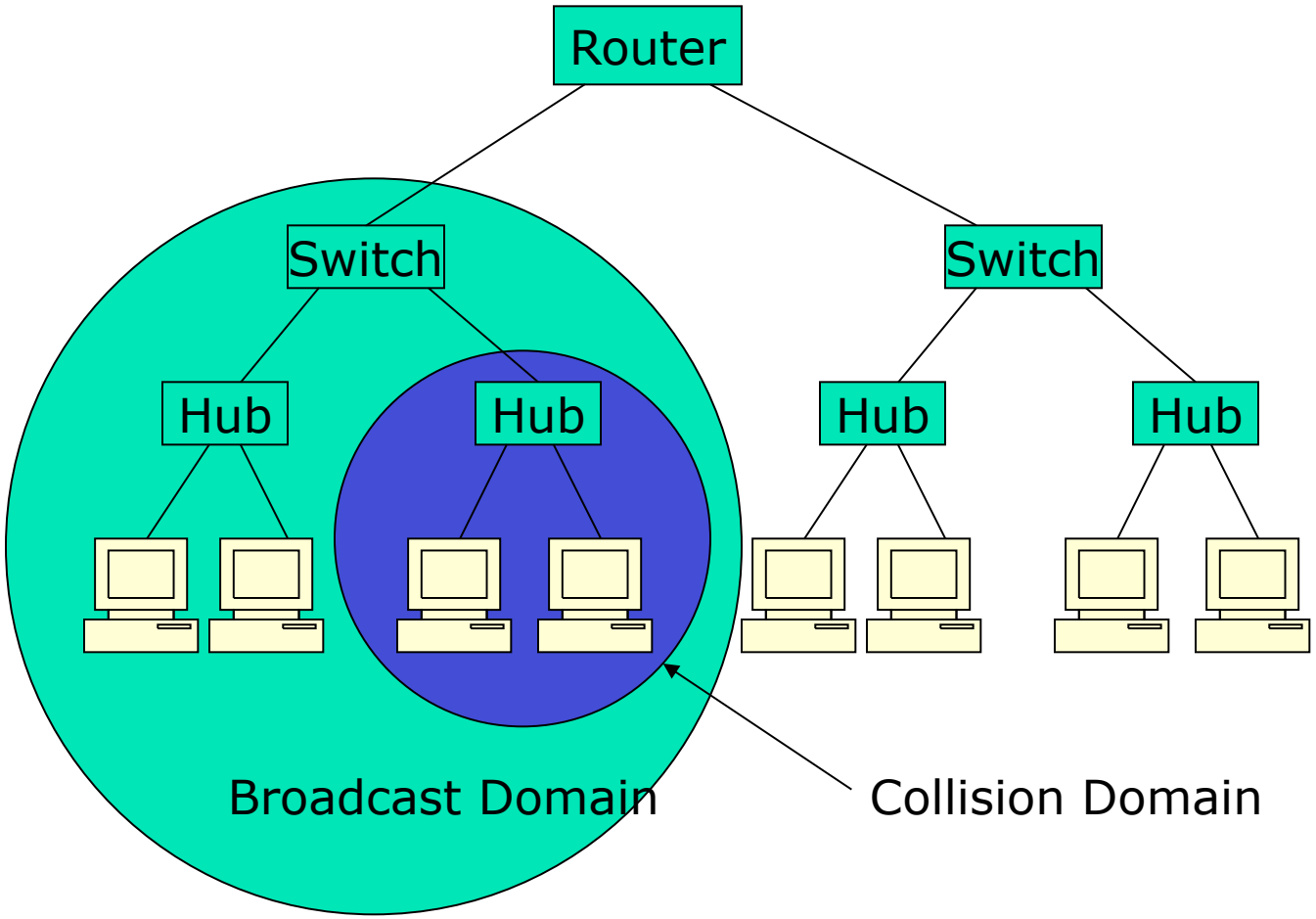


- Src, Dest: IPv4 addresses
- Protocol: 1 byte
  - e.g. 6 = TCP, 17 = UDP (see /etc/protocols)

Types of equipment (contd)

- Layer 3: **Router**
- Looks at the dest IP in its Forwarding Table to decide where to send next
- Collection of routers managed together is called an “Autonomous System”
- The forwarding table can be built by hand (static routes) or dynamically
  - Within an AS: IGP (e.g. OSPF, IS-IS)
  - Between ASes: EGP (e.g. BGP)

Traffic Domains



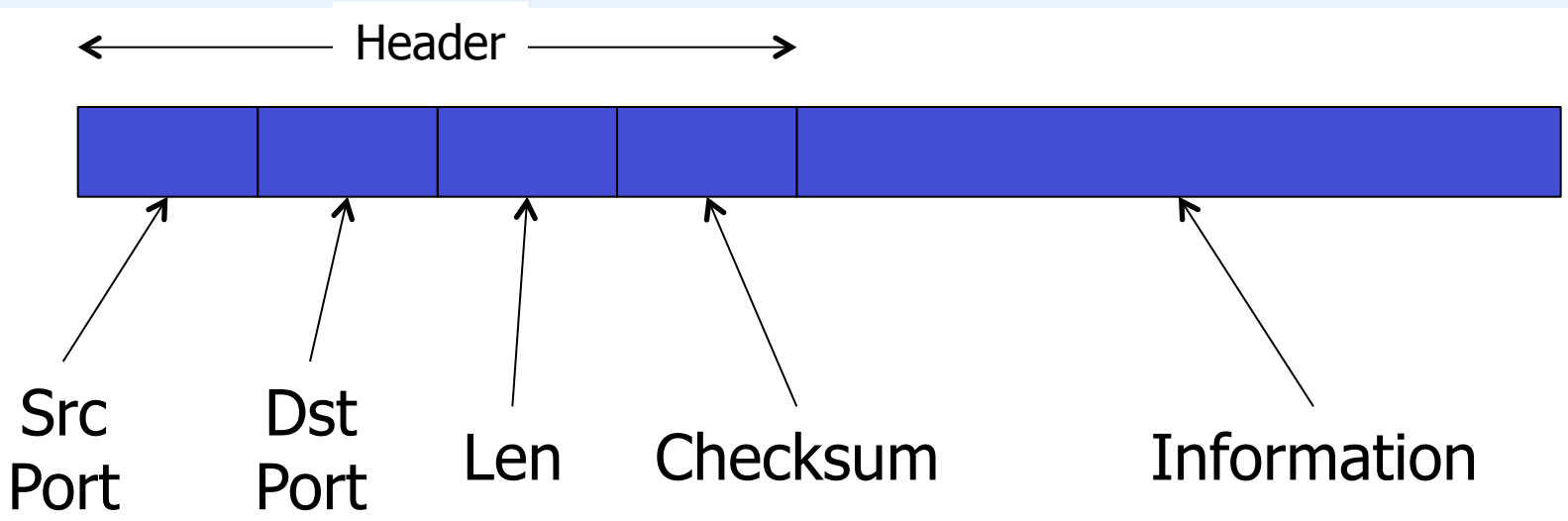
Network design guidelines

- No more than ~250 hosts on one subnet
  - Implies: subnets no larger than /24
- Campus guideline: one subnet per building
  - More than one may be required for large buildings

Layer 4: Transport Layer

- Identifies the *endpoint process*
  - Another level of addressing (port number)
- May provide reliable delivery
  - Streams of unlimited size
  - Error correction and retransmission
  - In-sequence delivery
  - Flow control
- Or might just be unreliable datagram transport

Example Layer 4: UDP



- Port numbers: 2 bytes
  - Well-known ports: e.g. 53 = DNS
  - Ephemeral ports: ≥1024, chosen dynamically by client

Layers 5 and 6

- Session Layer: long-lived sessions
  - Re-establish transport connection if it fails
  - Multiplex data across multiple transport connections
- Presentation Layer: data reformatting
  - Character set translation
- Neither exist in the TCP/IP suite: the application is responsible for these functions

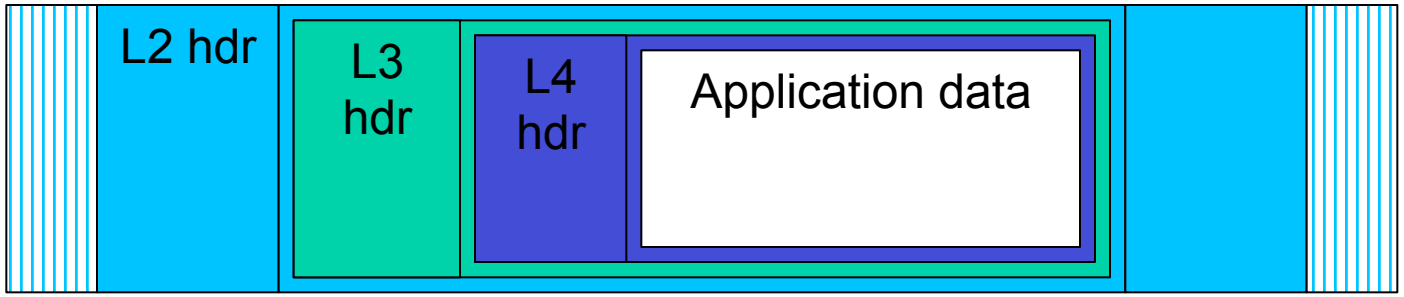
Layer 7: Application layer

- The actual work you want to do
- Protocols specific to each application
- *Examples?*

Encapsulation

- Each layer provides services to the layer above
- Each layer makes use of the layer below
- Data from one layer is *encapsulated* in frames of the layer below

Encapsulation in action



- L4 segment contains part of stream of application protocol
- L3 datagram contains L4 segment
- L2 frame contains L3 datagram in its data portion

For discussion

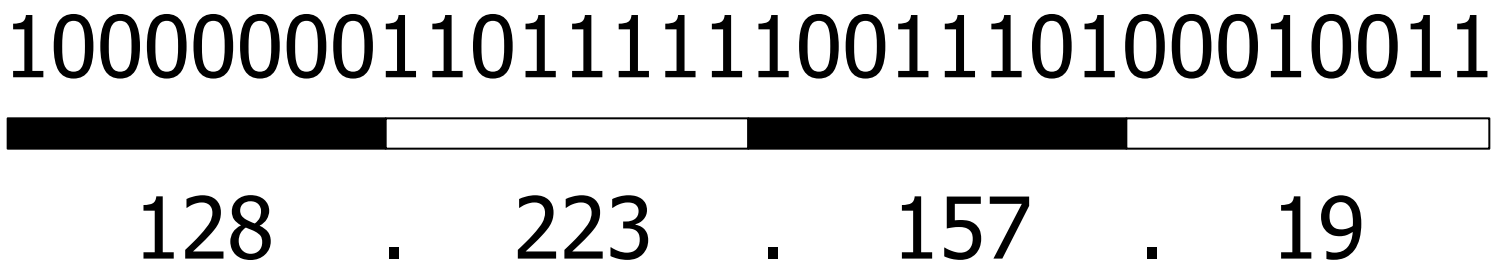
- Can you give examples of equipment which operates at layer 4? At layer 7?
- At what layer does a wireless access point work?
- What is a “Layer 3 switch”?
- How does traceroute find out the routers which a packet traverses?

Addressing at each layer

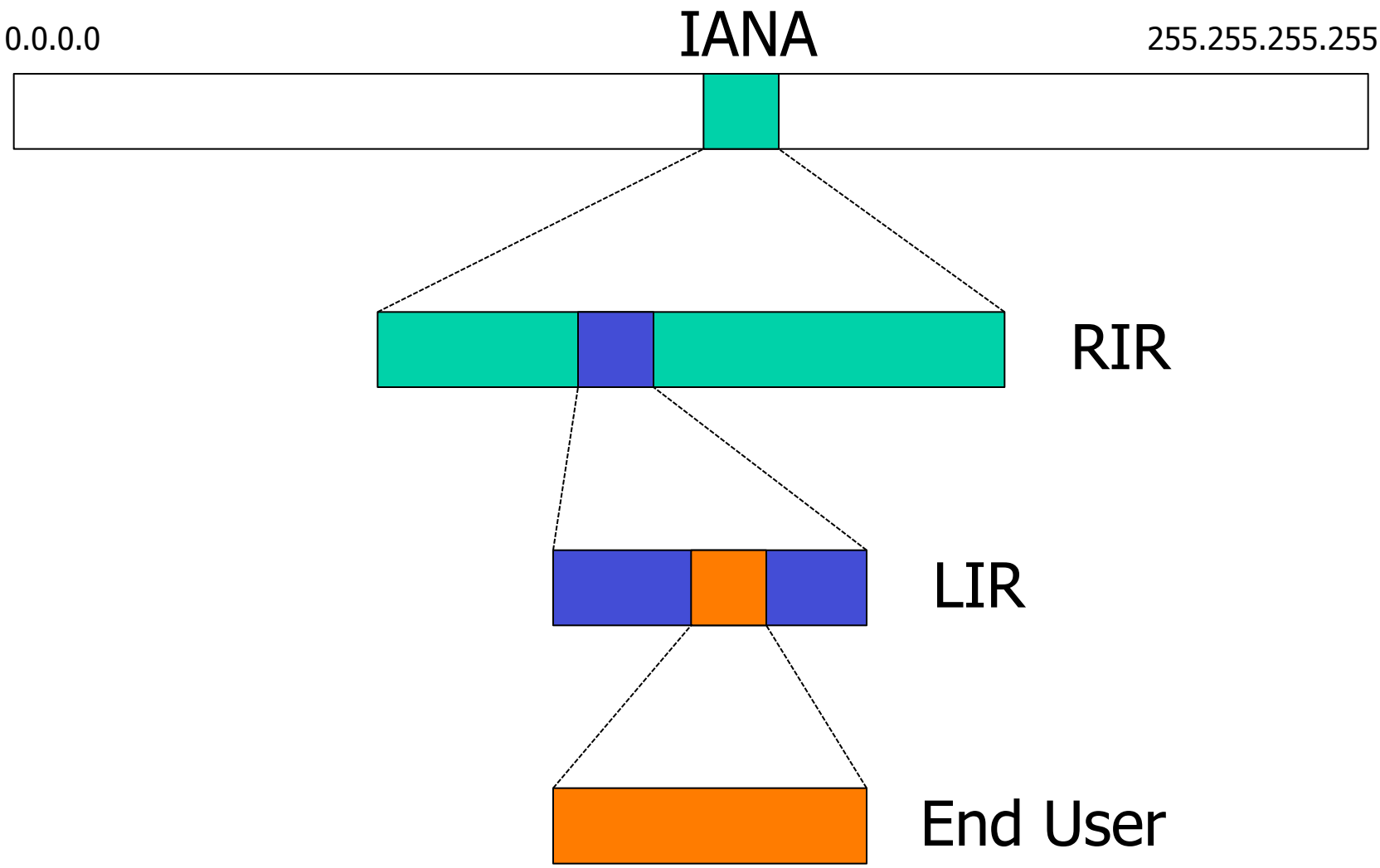
- What do the addresses look like?
- How do they get allocated, to avoid conflicts?
- Examples to consider:
  - L2: Ethernet MAC addresses
  - L3: IPv4, IPv6 addresses
  - L4: TCP and UDP port numbers

IPv4 addresses

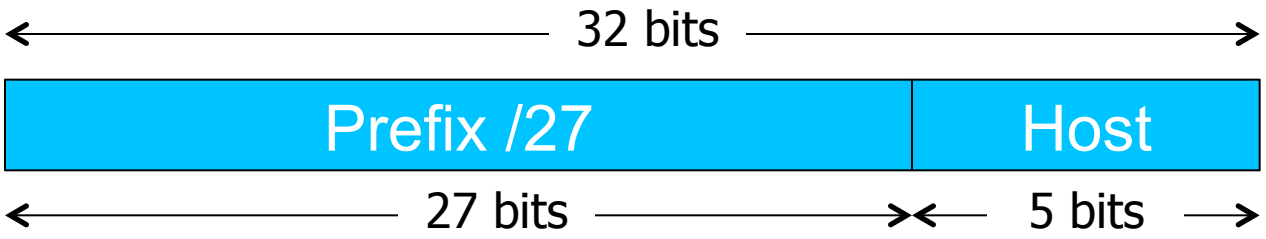
- 32-bit binary number
  - How many unique addresses in total?
- Conventionally represented as four dotted decimal octets



Hierarchical address allocation

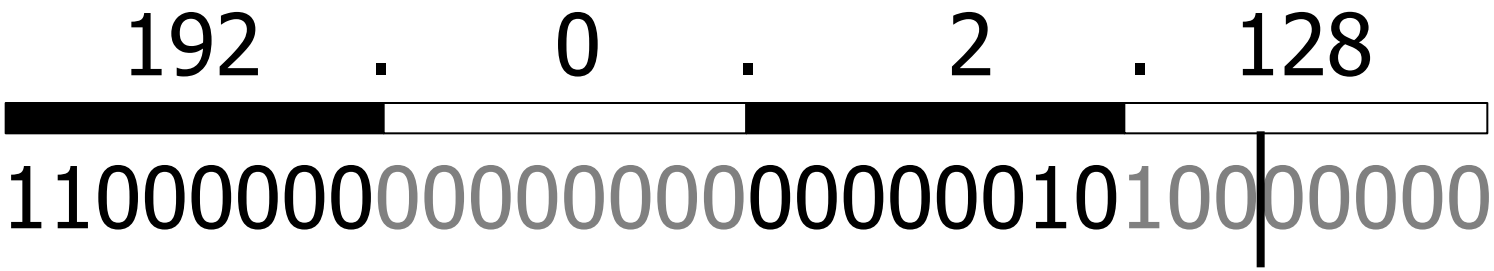


Prefixes



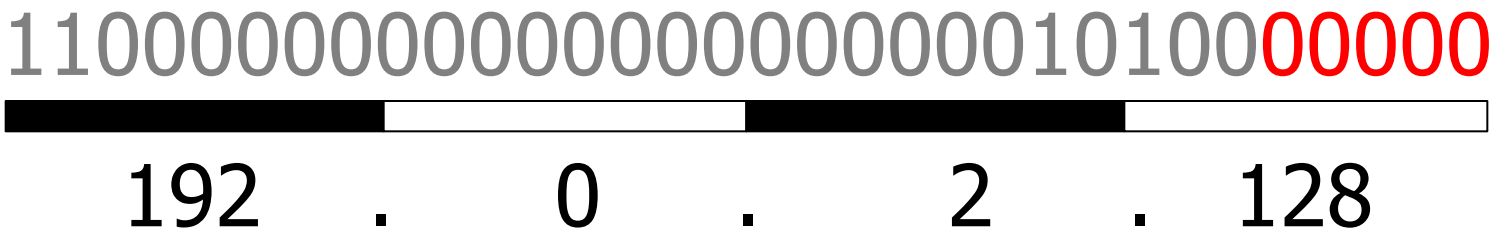
- A range of IP addresses is given as a *prefix*, e.g. 192.0.2.128/27
- In this example:
  - How many addresses are available?
  - What are the lowest and highest addresses?

Prefix calculation

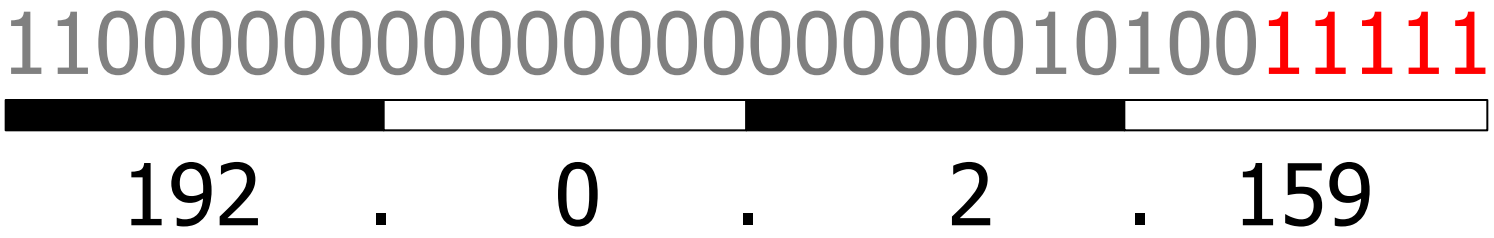


Prefix length /27 ➔ First 27 bits are fixed

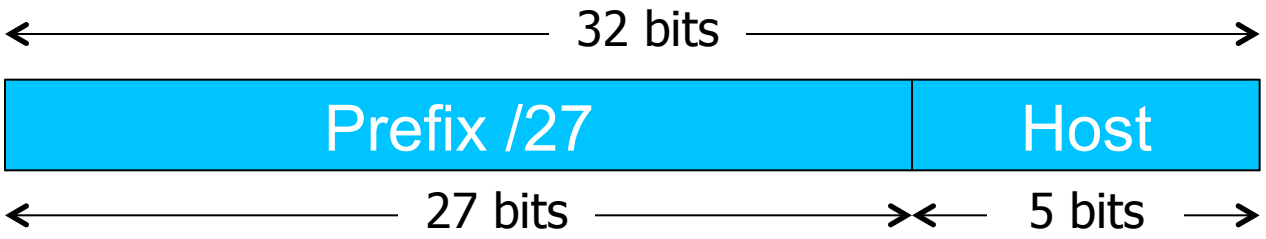
Lowest address:



Highest address:



IPv4 “Golden Rules”



1. All hosts on the same L2 network must share the *same* prefix
2. All hosts on the same subnet have *different* host part
3. Host part of all-zeros and all-ones are reserved

Golden Rules for 192.0.2.128/27

- Lowest 192.0.2.128 = network address
- Highest 192.0.2.159 = broadcast address
- Usable: 192.0.2.129 to 192.0.2.158
- Number of usable addresses: 32 - 2 = 30

Exercises

- Network 10.10.10.0/25
  - How many addresses in total?
  - How many usable addresses?
  - What are the lowest and highest usable addresses?
- Network 10.10.20.0/22
  - How many addresses in total?
  - How many usable addresses?
  - What the the lowest and highest usable addresses?

An edge case

- How many usable addresses in a /30 prefix?
- What is this used for?
  - (Note: modern routers support /31 for this purpose to reduce IP address wastage)

Netmask

- Netmask is just an alternative (old) way of writing the prefix length
- A '1' for a prefix bit and '0' for a host bit
- Hence N x 1's followed by (32-N) x 0's

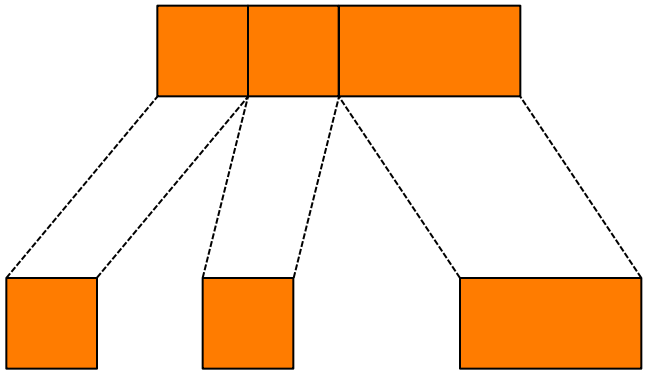
/27 =

11111111111111111111111111100000

255 . 255 . 255 . 224

Subnetting

- Since each L2 network needs its own prefix, then if you route more than one network you need to divide your allocation
- Ensure each prefix has enough IPs for the number of hosts on that network



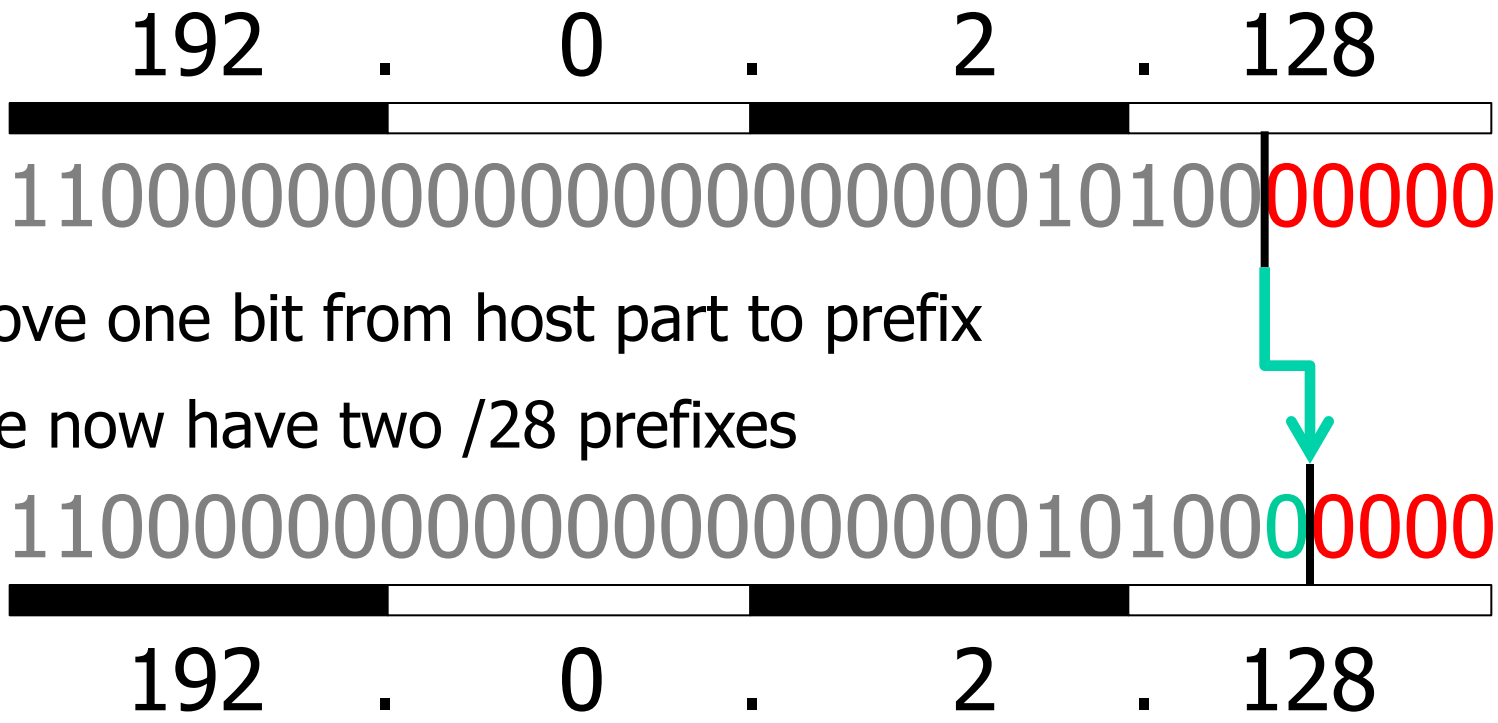
End User Allocation

Subnets

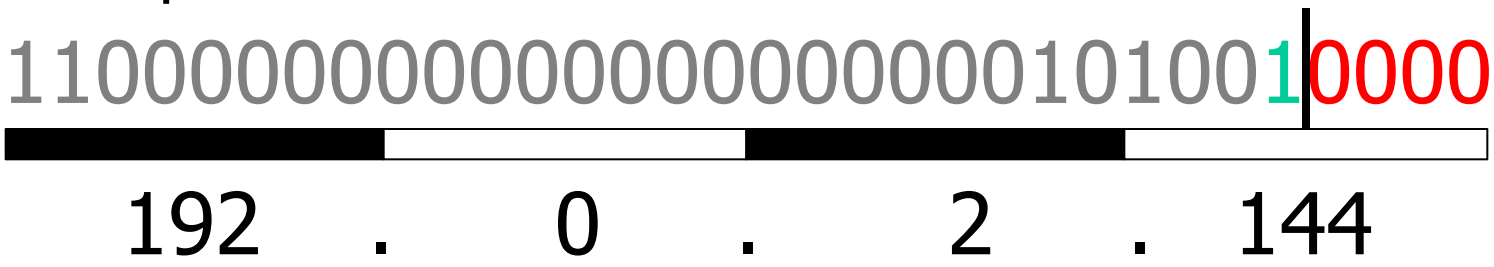
Subnetting Example

- You have been given 192.0.2.128/27
- However you want to build two Layer 2 networks and route between them
- The Golden Rules demand a different prefix for each network
- Split this address space into two equal-sized pieces
  - What are they?

Subnetting /27



Second prefix:

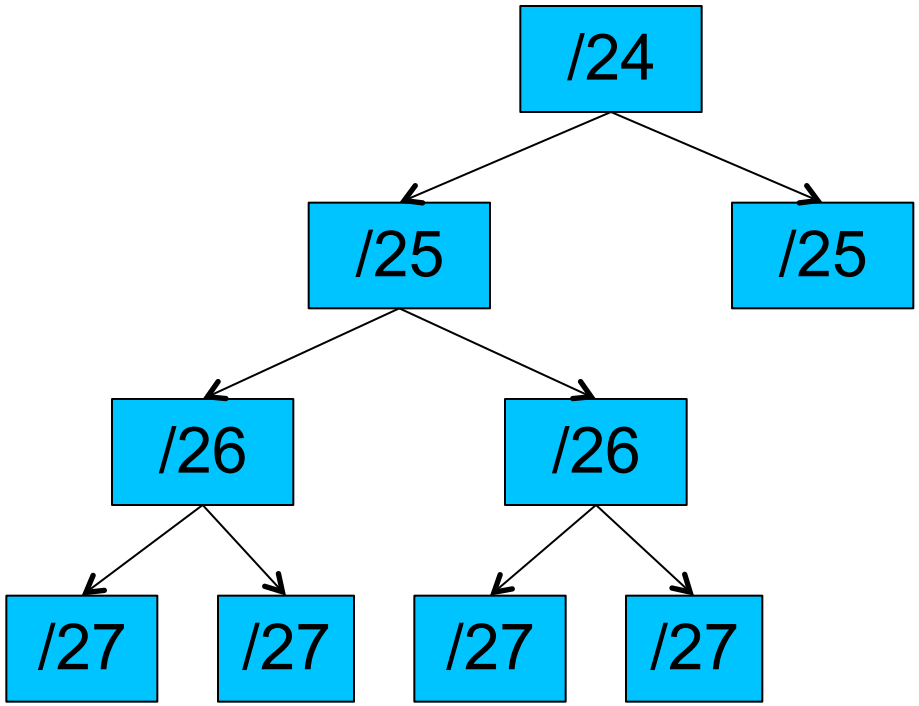


Check correctness

- Expand each new prefix into lowest and highest
- Ranges should not overlap
  - 192.0.2.128/28
    - Lowest (network) = 192.0.2.128
    - Highest (broadcast) = 192.0.2.143
  - 192.0.2.144/28
    - Lowest (network) = 192.0.2.144
    - Highest (broadcast) = 192.0.2.159
  - How many usable addresses now?

Aggregation tree

- Continue to divide prefixes as required
- Can visualize this as a tree



Questions on IPv4?

IPv6 addresses

- 128-bit binary number
- Conventionally represented in hexadecimal – 8 words of 16 bits, separated by colons

2001:0468:0d01:0103:0000:0000:80df:9d13

- Leading zeros can be dropped
- One contiguous run of zeros can be replaced by ::

2001:468:d01:103::80df:9d13

Hexadecimal

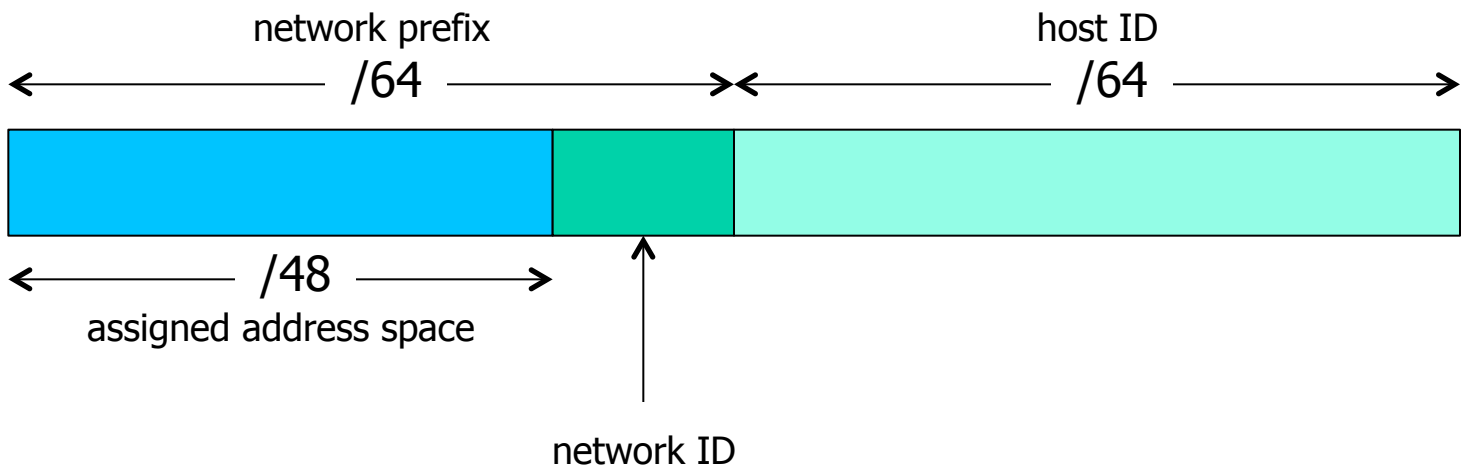
0000 **0**	1000 **8**
0001 **1**	1001 **9**
0010 **2**	1010 **a**
0011 **3**	1011 **b**
0100 **4**	1100 **c**
0101 **5**	1101 **d**
0110 **6**	1110 **e**
0111 **7**	1111 **f**

```
0000 = 0000000000000000
ffff = 1111111111111111
```

IPv6 rules

- With IPv6, every network prefix is /64
  - (OK, some people use /127 for P2P links)
- The remaining 64 bits can be assigned by hand, or picked automatically
  - e.g. derived from NIC MAC address
- There are special prefixes
  - e.g. link-local addresses start fe80::
- Total available IPv6 space is ≈ 2^{61} subnets
- Typical end-user allocation is /48 (or /56)

IPv6 addressing



- How many /64 networks can you build given a /48 allocation?

IPv6 addressing

- You are assigned 2001:db8:123::/48
  - 2001:0db8:0123:0000:0000:0000:0000:0000
- Lowest /64 network?
  - 2001:db8:123:0000::/64
  - written simply 2001:db8:123::/64
- Highest /64 network?
  - 2001:db8:123:ffff::/64

Ways to allocate the host part

- Do it automatically from MAC address – "stateless autoconfiguration"
  - Not recommended for servers: if you change the NIC then the IPv6 address changes!
- Can number sequentially from 1, or use the last octet of the IPv4 address
- Or embed the whole IPv4 address
  - e.g. 2607:8400:2880:4::80df:9d13
  - 80df9d13 hex = 128.223.157.19 in decimal
  - Can write 2607:8400:2880:4::128.223.157.19

Questions on IPv6?

Notes on IPv6

- Broadly similar to IPv4
- "ARP" is replaced by "NDP"
- IPv6 client configuration options
  - Stateless autoconf (router advertisements)
  - Stateless autoconf + stateless DHCPv6
  - Stateful DHCPv6
- Interfaces typically get both a link-local address and one or more routable prefixes
- "Dual stack" = v4 and v6 side-by-side

Debugging Tools

What tools can you use to debug your network:

- At layer 1?
- At layer 2?
- At layer 3?
- Higher layers?

Other pieces

- What is MTU? What limits it?
- What is ARP?
  - Where does it fit in the model?
- What is ICMP?
  - Where does it fit in the model?
- What is NAT? PAT?
  - Where do they fit in the model?
- What is DNS?
  - Where does it fit in the model?