Computer Network Design

Network Layer I

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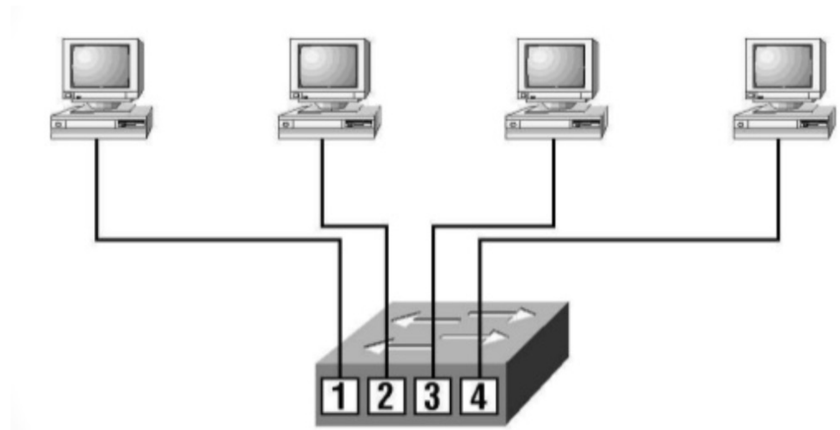
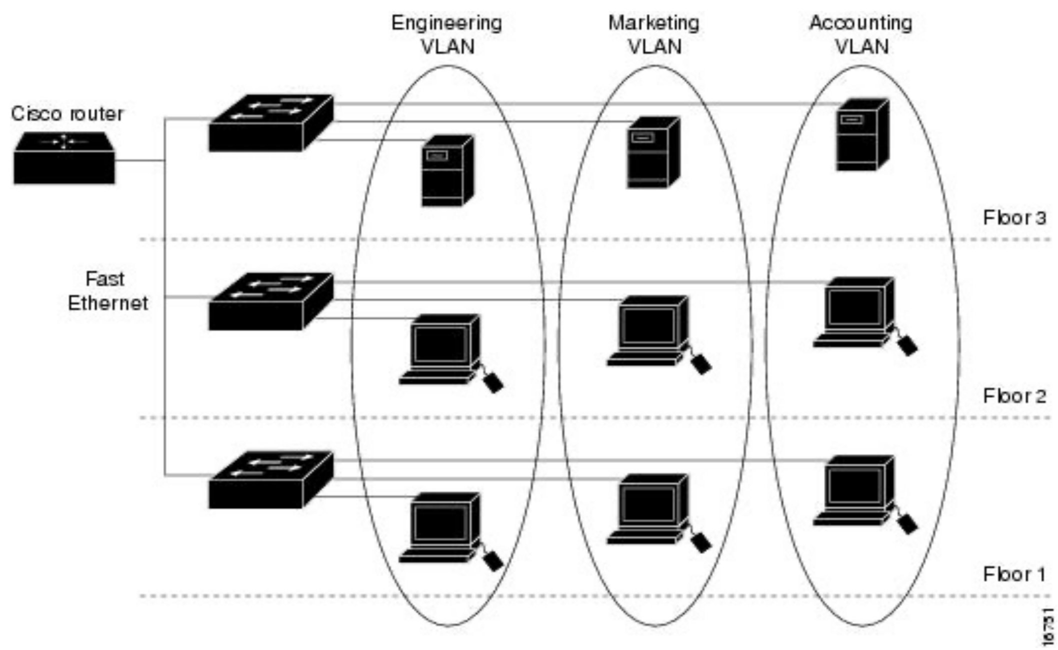
Broadcast Domain

- Normally, routers create broadcast domains
- A switch creates one broadcast domain and individual collision domains
  - Each segment has its own collision domain
  - All segments are in same broadcast domain
- Security problem?



Virtual LAN (VLAN)

- A logical grouping of network users and resources connected to administratively defined ports on a switch
  - Smaller broadcast domains
  - Organized by:
    - Location
    - Function
    - Department
    - …



VLAN Features

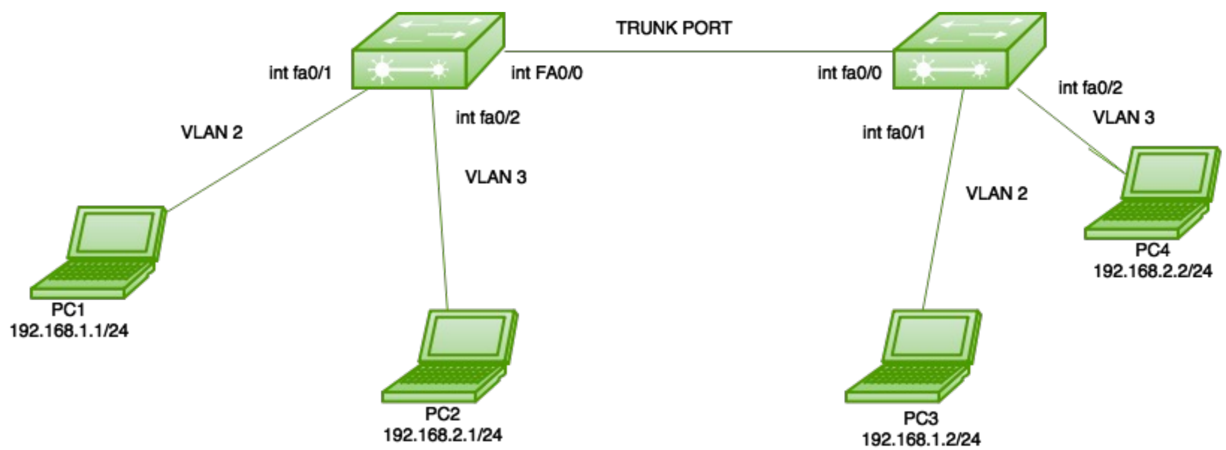
- Layer 2 switches only read frames
  - Can cause a switch to forward all broadcasts
- VLANS
  - Essentially create broadcast domains
    - Greatly reduce broadcast traffic
    - Ability to add wanted users to a VLAN regardless of their physical location
    - Additional VLANs can be created when network growth consumes more bandwidth
    - Simplify network management
    - Provides a level of security over a flat network

How VLANs Work?

- VLANs are identified by a number
  - Valid ranges 1-4094
- On a VLAN-capable switch, you assign ports with the appropriate VLAN number
- The switch then only allows data to be sent between ports with the same VLAN

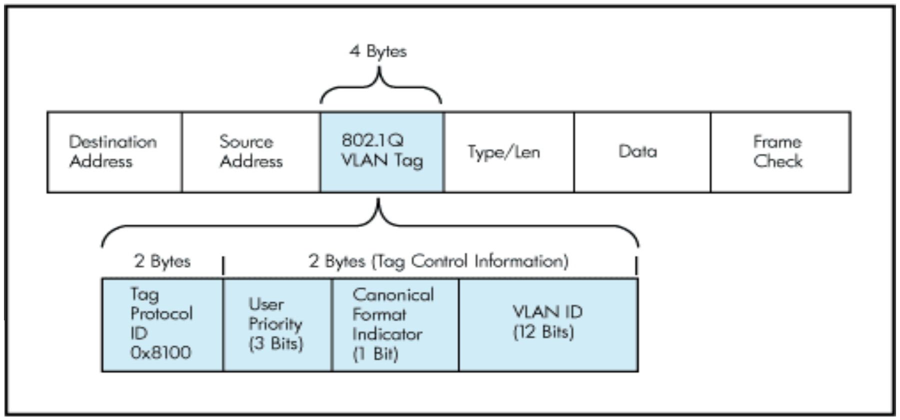
VLAN Links

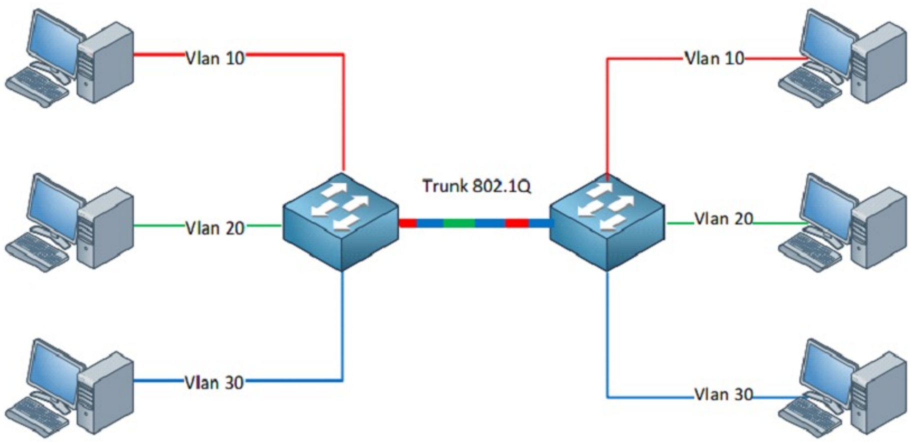
- **Access link**: carry the traffic of only one VLAN. By default, it will carry the traffic of native VLAN (VLAN 1)
- **Trunk link**: carry the traffic of more than one VLAN



VLAN Trunking

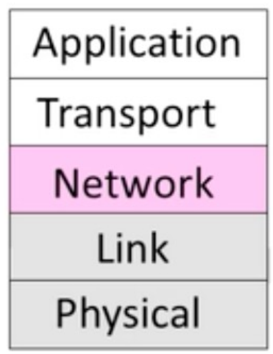
- Need trunking protocols:
  - ISL (Inter-Switch Link)
  - ✓IEEE 802.1Q





Layer 3

- Starting the Network layer
  - Builds on the link layer
  - Routers send packets over multiple networks

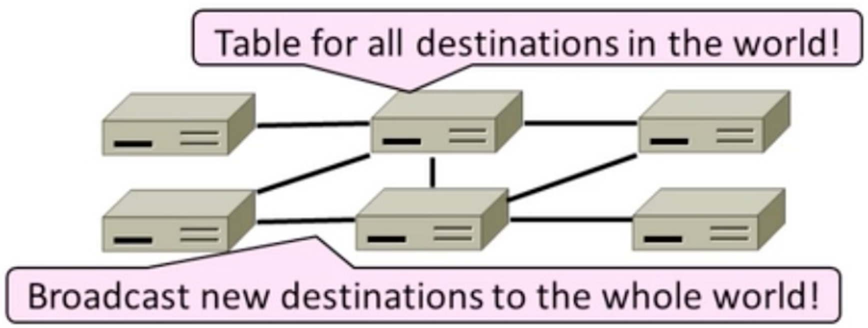


Why Do We Need a Network Layer?

- We can already build networks with links and switches and send frames between hosts …

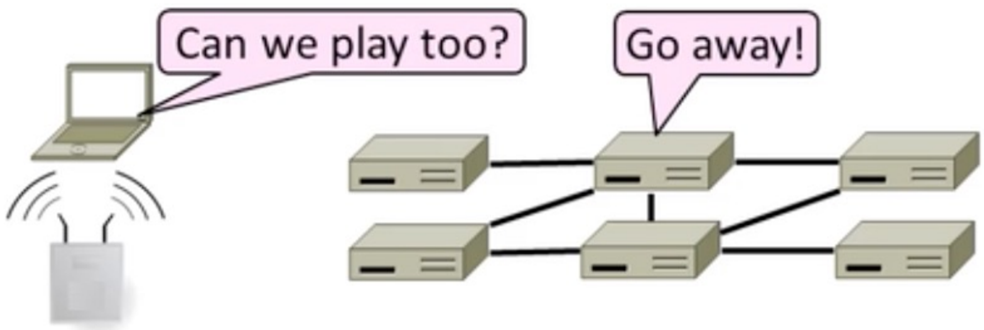
Shortcomings of Switches

1. Don’t scale to large networks
   - Blow up of routing table, broadcast



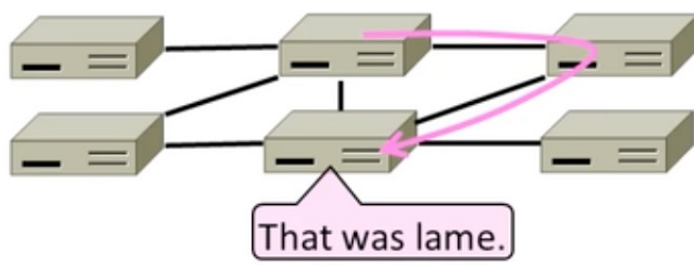
Shortcomings of Switches (2)

2. Don’t work across more than one link layer technology
   - Hosts on Ethernet + 3G + 802.11….



Shortcomings of Switches (3)

3. Don't give much traffic control
   • Want to plan routes / bandwidth

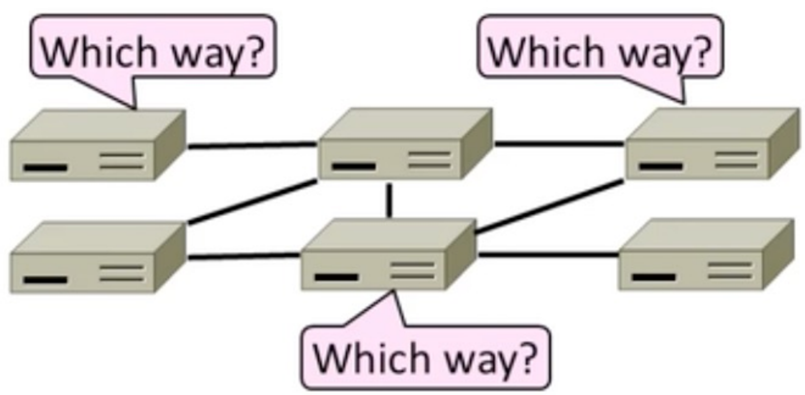


Network Layer Approach

- Scaling:
  - Hierarchy, in the form of prefixes
- Heterogeneity:
  - IP for internetworking
- Bandwidth control:
  - Lowest-cost routing
  - Later QoS (Quality of Service)

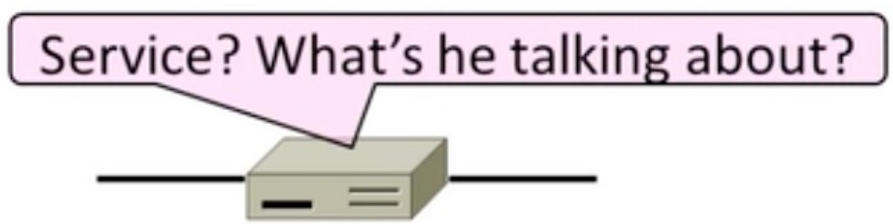
Routing vs. Forwarding

- Routing is the process of deciding in which direction to send traffic
  - Network wide (global) and expensive



Network Layer Services

- What kind of service does the Network layer provide to the Transport layer?
  - How is it implemented at routers?



Two Network Service Models

- Datagrams, or connectionless service
  - Like postal letters
  - (This one is IP)

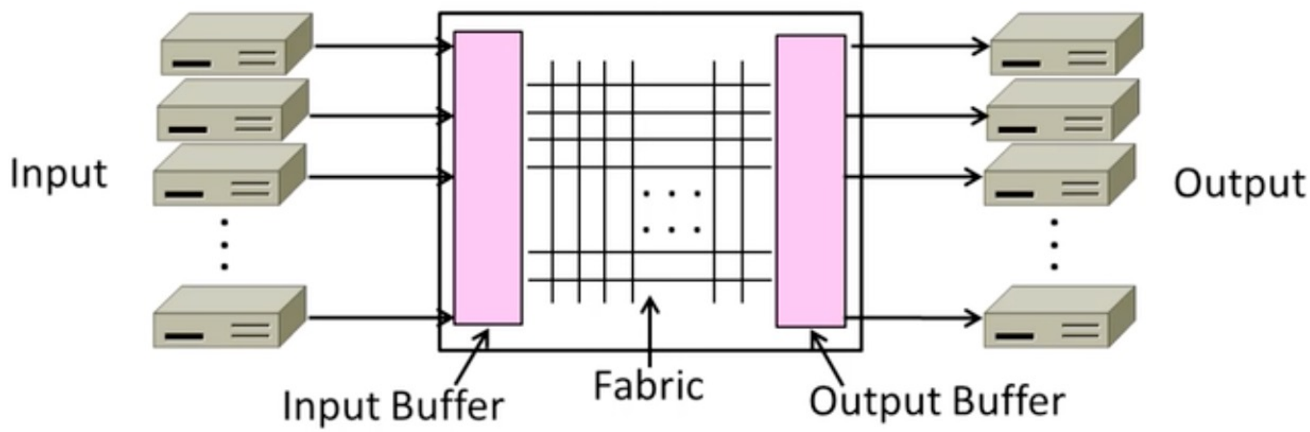
- Virtual circuits, or connection-oriented service
  - Like a telephone call

Store-and-Forward Packet Switching

- Both models are implemented with store-and-forward packet switching
  - Routers receive a complete packet, storing it temporarily if necessary before forwarding it onwards
  - We use statistical multiplexing to share link bandwidth over time

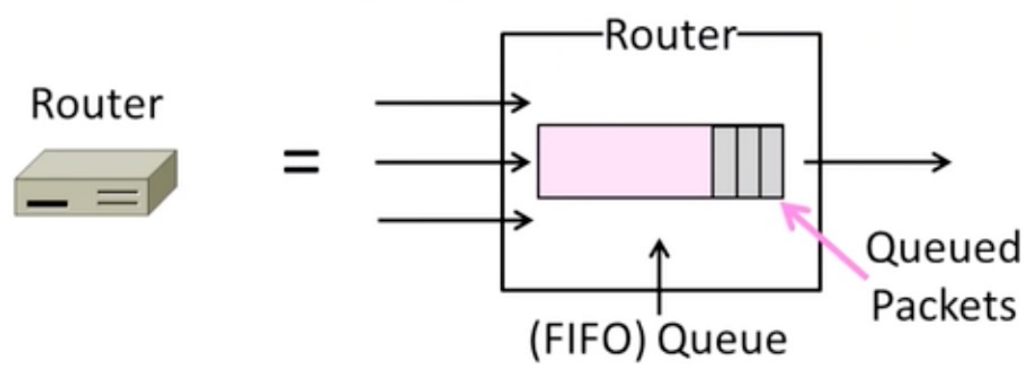
Store-and-Forward (2)

- Switching element has internal buffering for contention



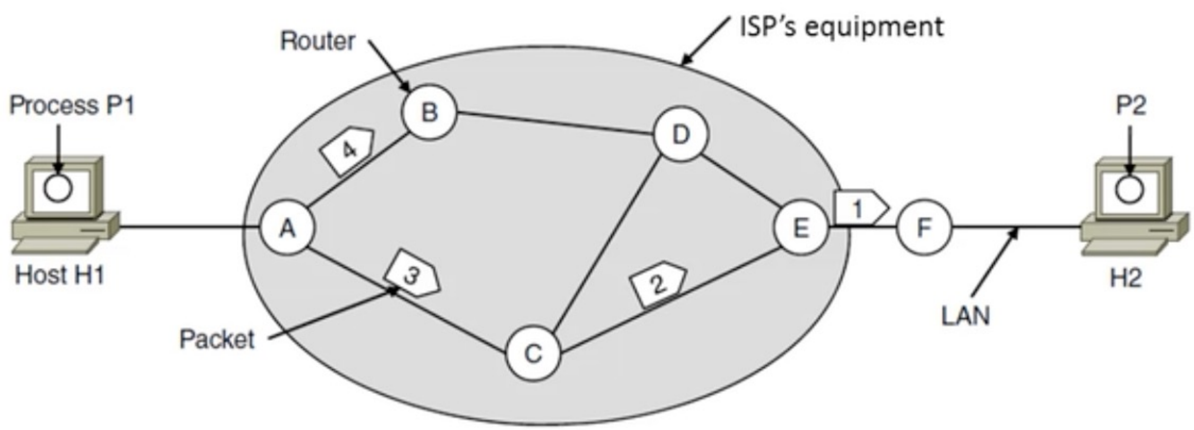
Store-and-Forward (3)

- Simplified view with per port output buffering
  - Buffer is typically a FIFO (First In First Out) queue
  - If full, packets are discarded (congestion)



Datagram Model

- Packets contain a destination address; each router uses it to forward each packet, possible on different paths



Datagram Model (2)

- Each router has a forwarding table keyed by address
  - Given next hop for each destination address; may change

A's table (initially)

Dest.	Line
A	
B	B
C	C
D	B
E	C
F	C

A's table (later)

A	
B	B
C	C
D	B
E	B
F	B

C's Table

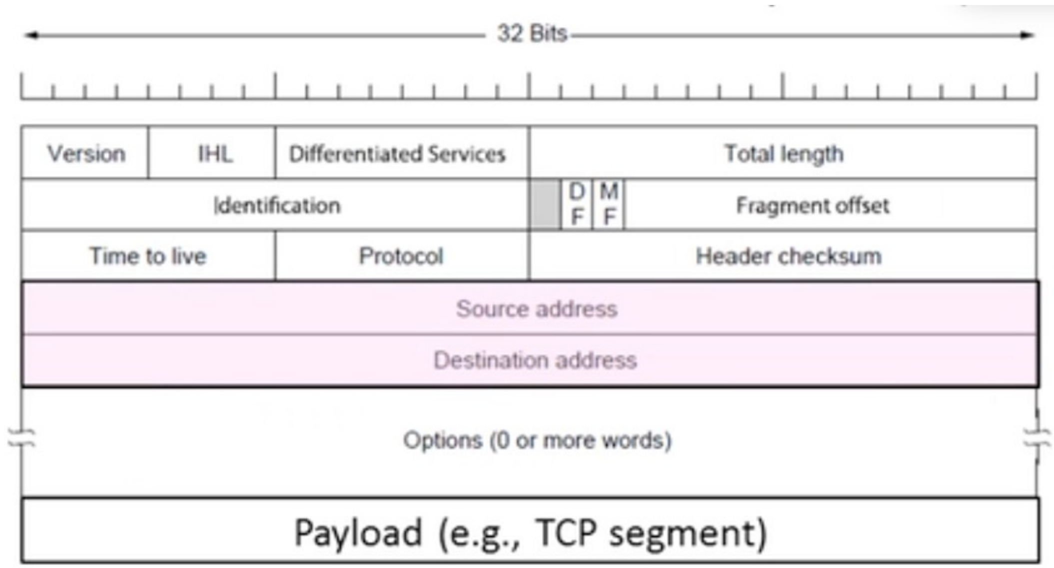
A	A
B	A
C	
D	E
E	E
F	E

E's Table

A	C
B	D
C	C
D	D
E	
F	F

IP (Internet Protocol)

- Network layer of the Internet, uses datagrams
  - IPv4 carries 32 bit addresses on each packet (often 1.5 KB)



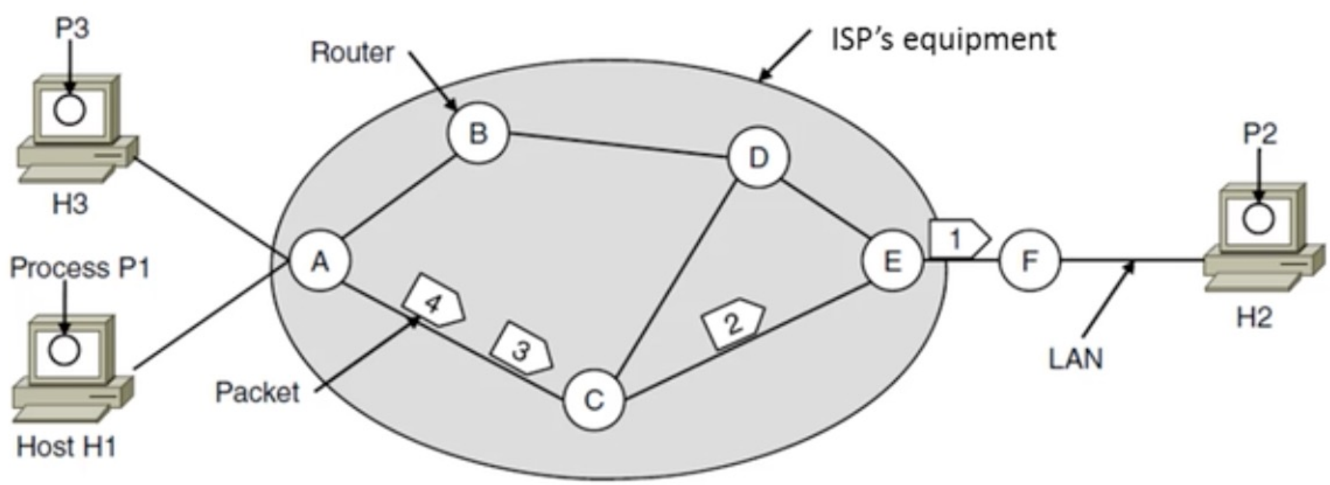
Virtual Circuit Model

- Three phases:
  1. Connection establishment, circuit is set up
     - Path is chosen, circuit information stored in routers
  2. Data transfer, circuit is used
     - Packets are forwarded along the path
  3. Connection teardown, circuit is deleted
     - Circuit information is removed from routers

- Just like a telephone circuit, but virtual in the sense that no bandwidth need be reserved; statistical sharing of links

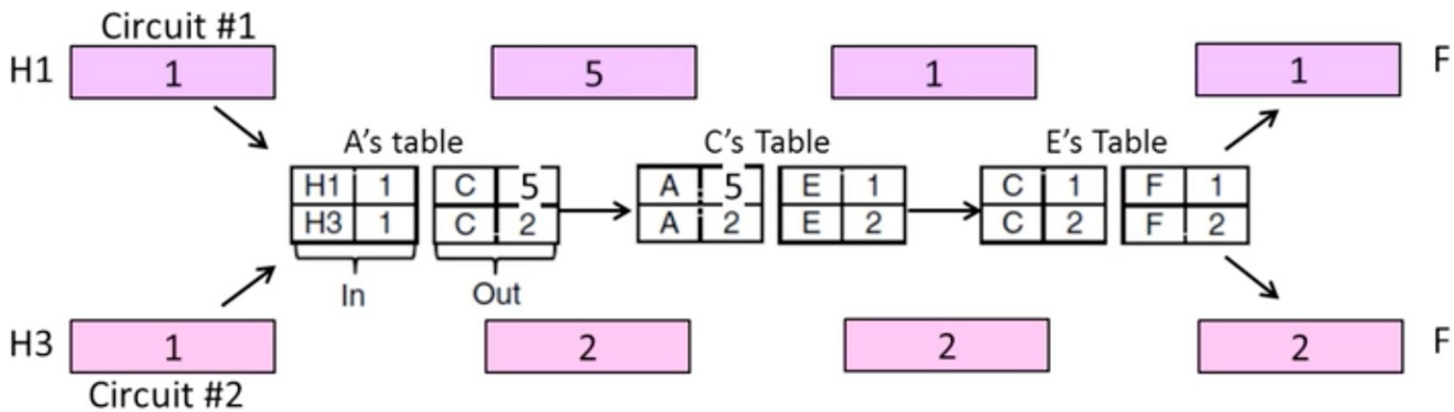
Virtual Circuits (2)

- Packets only contain a short label to identify the circuit
  - Labels don't have any global meaning, only unique for a link



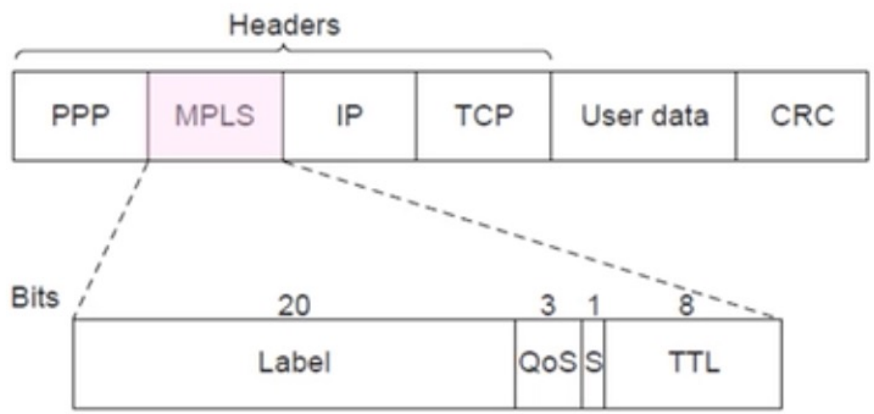
Virtual Circuits (3)

- Each router has a forwarding table keyed by circuit
  - Gives output line and next label to place on packet



MPLS (Multi-Protocol Label Switching)

- A virtual-circuit like technology widely used by ISPs
  - ISP sets up circuit inside their backbone ahead of time
  - ISP adds MPLS label to IP packet at ingress, undoes at egress

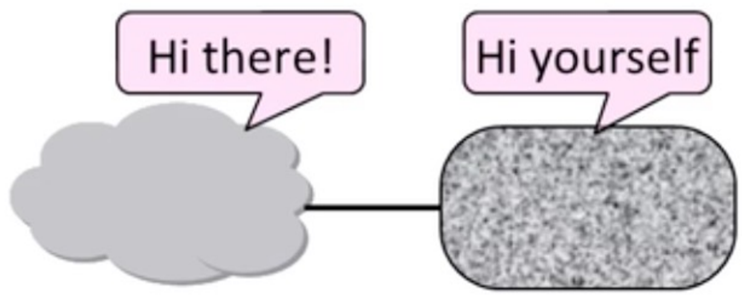


Datagrams vs Virtual Circuits

Issue	Datagrams	Virtual Circuits
Setup phase	Not needed	Required
Router state	Per destination	Per connection
Addresses	Packet carries full address	Packet carries short label
Routing	Per packet	Per circuit
Failures	Easier to mask	Difficult to mask
Quality of service	Difficult to add	Easier to add

Internetworking

- How do we connect different networks together?
  - This is called internetworking
  - We will look at how IP does it



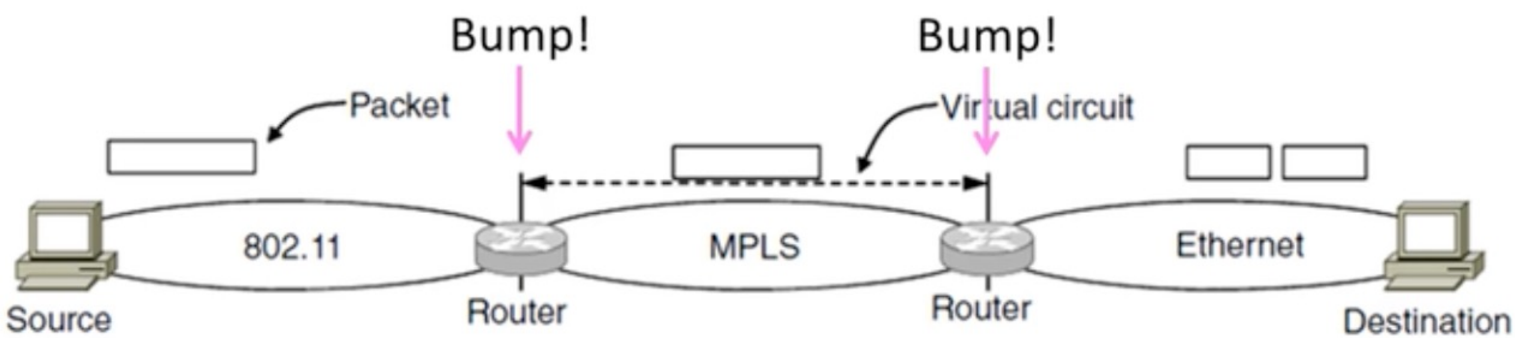
How Networks May Differ

- Basically, in a lot of ways:
  - Service model (datagrams, VCs)
  - Addressing (what kind)
  - QOS (priorities, no priorities)
  - Packet sizes
  - Security (weather encrypted)

- Internetworking hides the differences with a common protocol

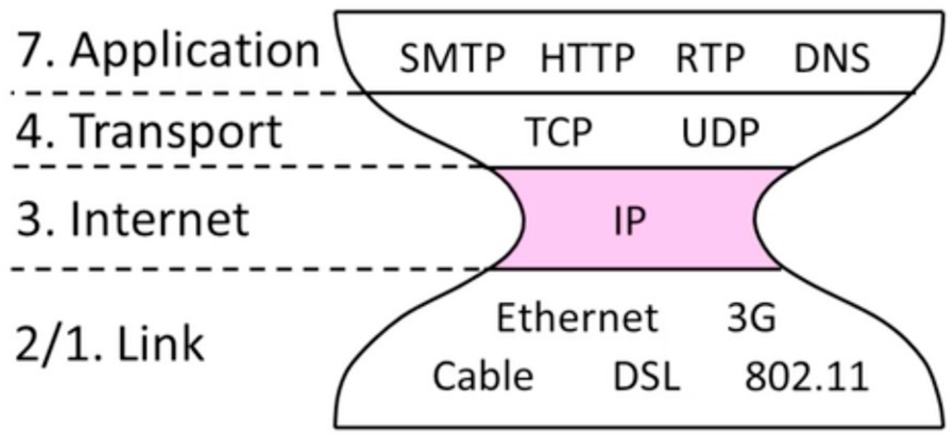
Connecting Datagram and VC networks

- An example to show that it's not so easy
  - Need to map destination address to a VC and vice-versa
  - A bit of a "road bump", e.g., might have to set up a VC



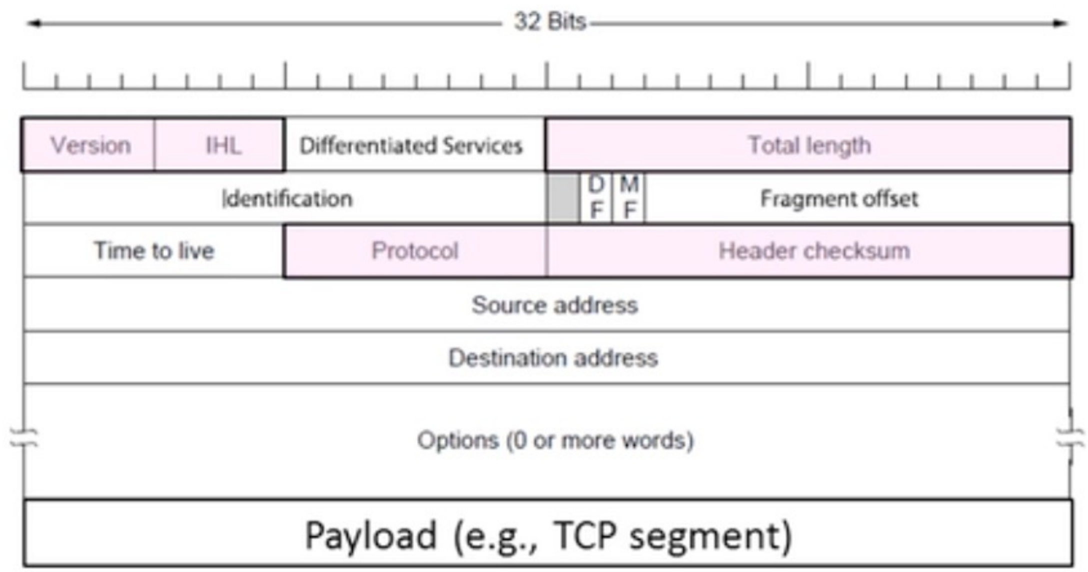
Internet Reference Model

- IP is the “narrow waist” of the Internet
  - Supports many different links below and apps above



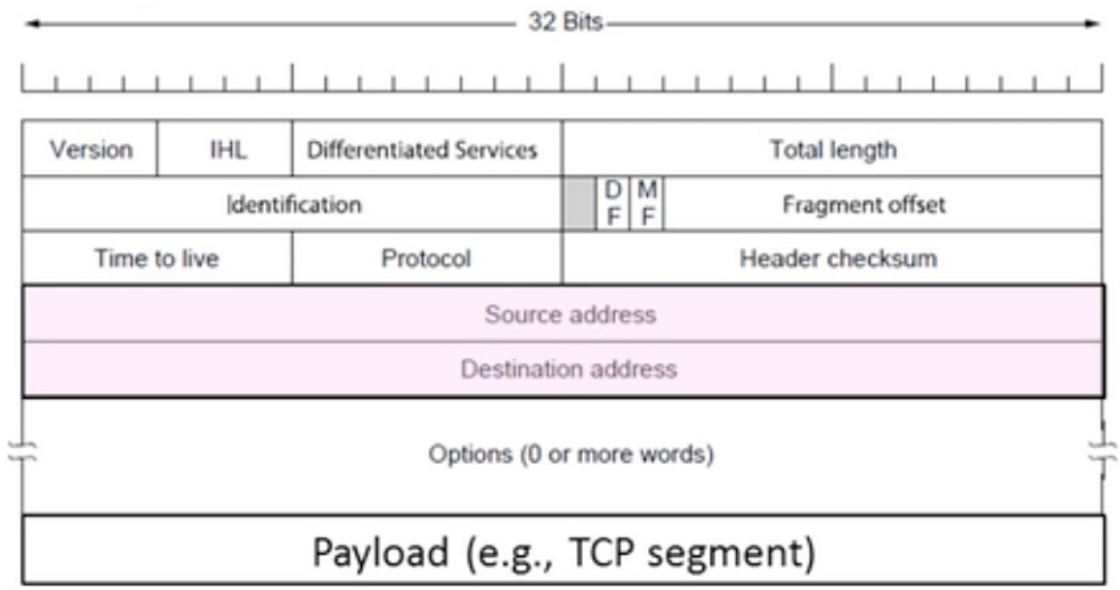
IPv4 (Internet Protocol)

- Various fields to meet straightforward needs
  - Version, header (IHL) and total length, protocol, and header checksum



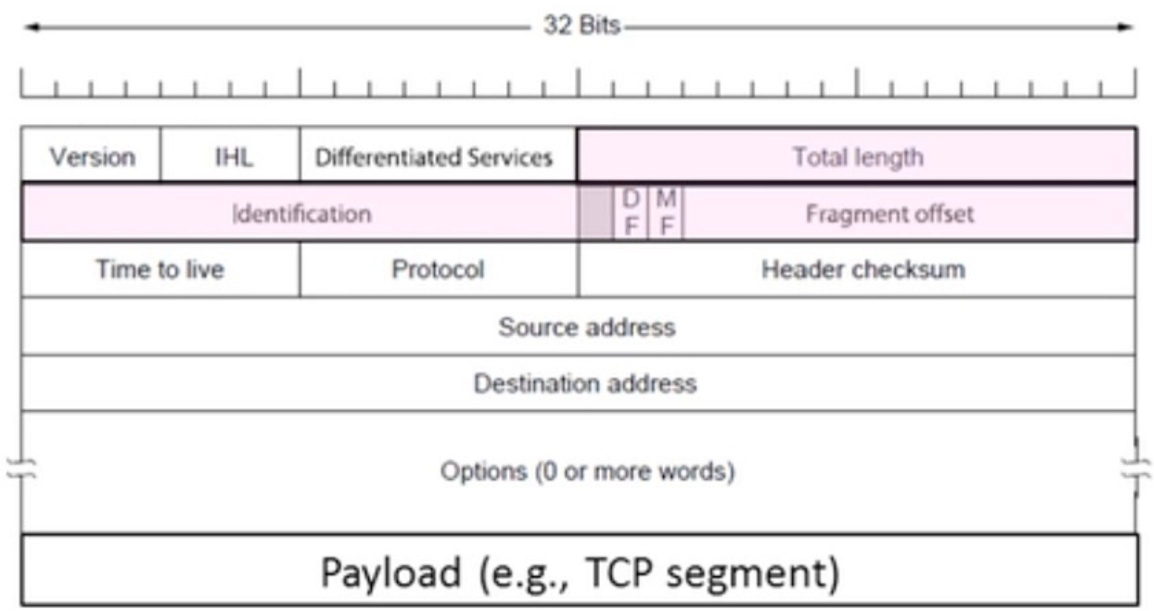
IPv4 (2)

- Network layer of the Internet, uses datagrams
  - Provides a layer of addressing above link addresses



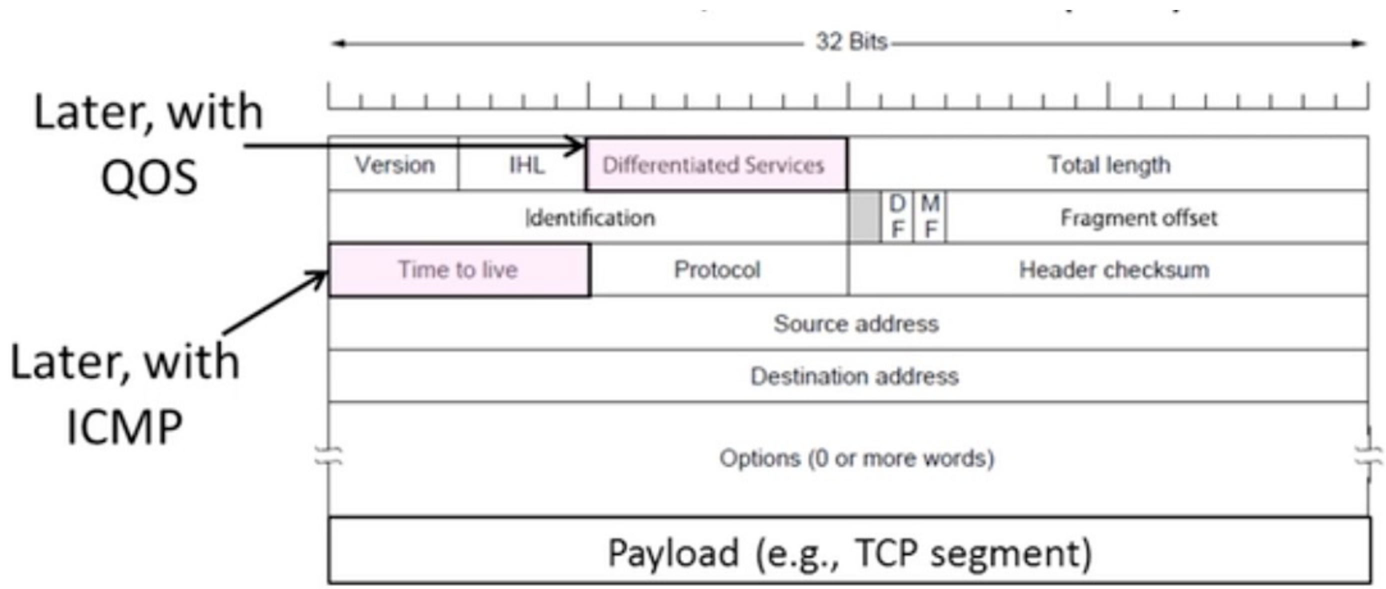
IPv4 (3)

- Some fields to handle packet size differences
  - Identification, fragment offset, fragment control bits



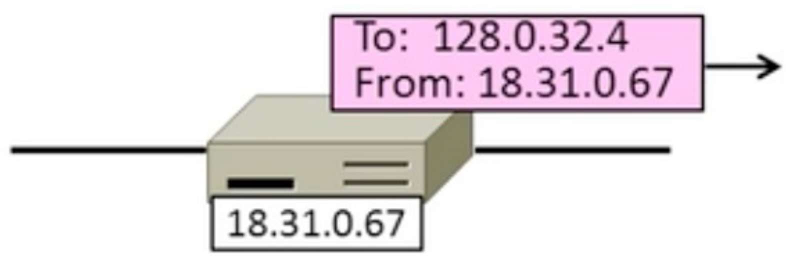
IPv4 (4)

- Other fields to meet other needs
  - Differentiated service, time to live (TTL)



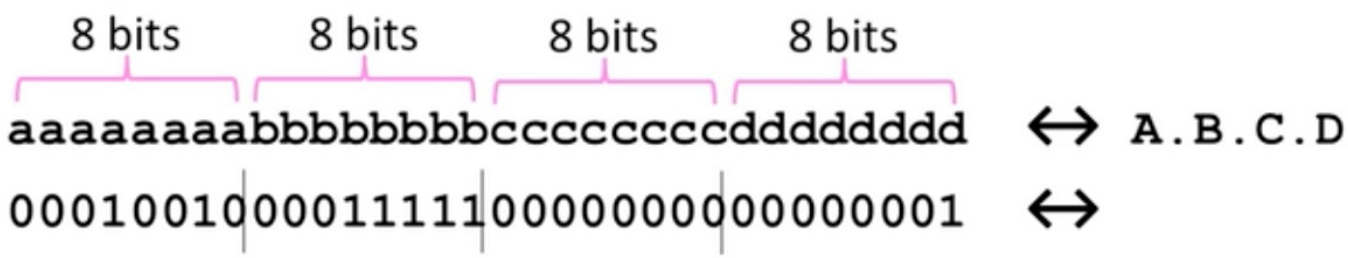
Network Layer Address

- Network layer uses IP addresses to identify each device



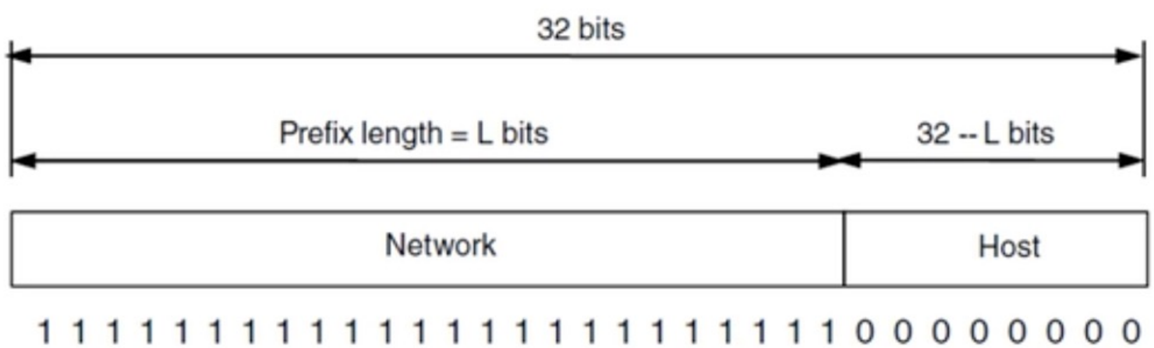
IP Addresses

- IPv4 uses 32-bit addresses
  - (IPv6 uses 128-bit addresses)
- Written in “dotted quad” notation
  - Four 8-bit numbers separated by dots



IP Prefixes

- Addresses are allocated in blocks called prefixes
  - The L bits show the network id
  - The 32-L bits show the host id



IP Prefixes (2)

- Written in ”IP address/length” notation
  - Address is lowest address in the prefix, length is prefix bits
  - E.g., 128.13.0.0/16 is 128.13.0.0 to 128.13.255.255
  - So a /24 (“slash 24”) is 256 addresses, and a /32 is one address

```
00010010|00011111|00000000|xxxxxxxx ↔
        |        |        |
                                      ↔ 128.13.0.0/16
```

IP Prefixes (3)

- All 0s in host part shows the network address
- All 1s in host part shows the broadcast address of that network
- Maximum number of hosts in each network is $2^{32-L} - 2$

- Example:
  - Network address: 176.33.0.0/16
  - First and last available ip address for host , broadcast
    - 10110000.00100001.00000000.00000001->176.33.0.1/16
    - 10110000.00100001.11111111.11111110->176.33.255.254/16
    - 10110000.00100001.11111111.11111111->176.33.255.255/16

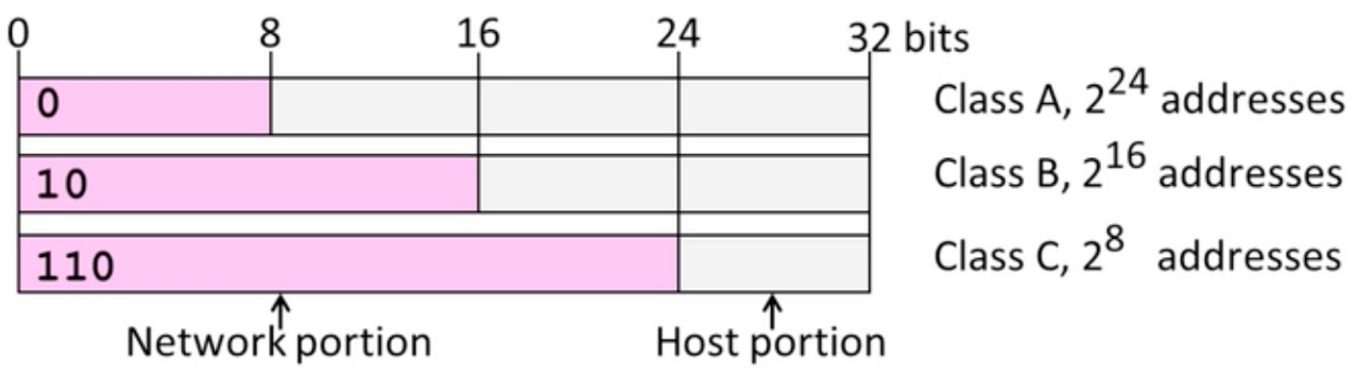
Example

175.15.64.4/22

- Network address?
- Broadcast address?
- First available address?
- Last available address?
- Number of available addresses?

IP Address Class - Historical

- Originally, IP addresses came in fixed size blocks with the class/size encoded in the high-order bits
  - They still do, but the classes are now ignored



Public/Private IP Addresses

- Public IP addresses, e.g., 18.31.0.1
  - Valid destination on the global Internet
  - Must be allocated to you before use
  - Mostly exhausted … time for IPv6!

- Private IP addresses
  - Can be used freely within private networks (home, small company)
  - 10.0.0.0/8, 172.16.0.0/12, 192.168.0.0/16
  - Need public IP address(es) and NAT to connect to global Internet

To do

- Be prepared for a quiz next week
- Lab1 is posted
- Research reference submission deadline is on March 1st