ECE 671
Introduction to Computer Networks

Lesson 6
Network Layer

Rationale

- Network layer is used by the transport layer to send packets from one end-system interface to another
- Network layer illustrates how global connectivity is achieved
- Internet Protocol in the network layer is common to all data exchanges on the Internet

Objectives

- Analyze the importance of interaction between Internet Protocol (IP) and other protocol stack components
- Describe components necessary to provide interface-to-interface connectivity
- Describe the purpose of subnets for allocating IP addresses
- Explain the role of the data plane within IP

Prior Knowledge

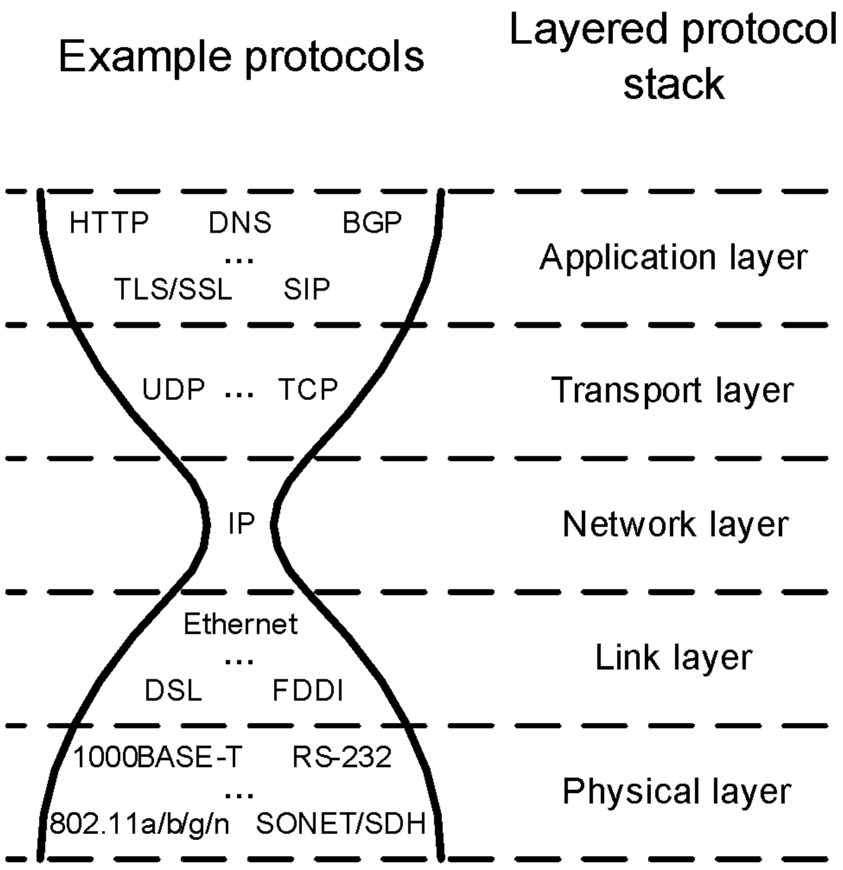
- Network layer carries packets between network interfaces
  - Packet-switched network connectivity
  - Hourglass architecture has Internet Protocol in network layer at the center

Orchestrated Discussion (Hand Raise): Lesson Reflection Feedback

- Discuss questions and comments on Lesson Reflection from prior lesson

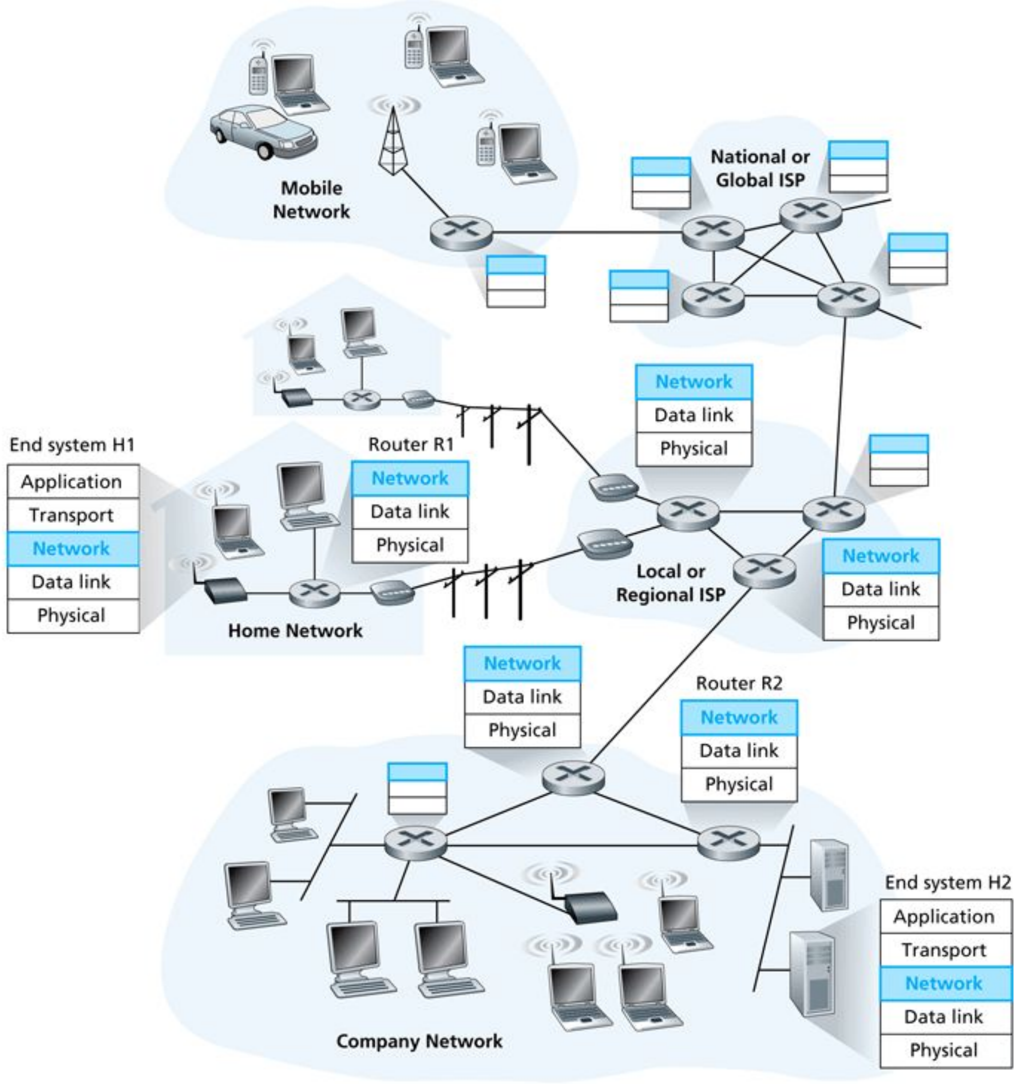
Recap: Internet Architecture

- “Hourglass architecture”
- Achieves interoperability
  - Single, common network layer protocol: Internet Protocol (IP)
  - All network nodes need to support this protocol
- Supports diversity
  - Different link/physical layer protocols below
  - Different transport/application layer protocols above



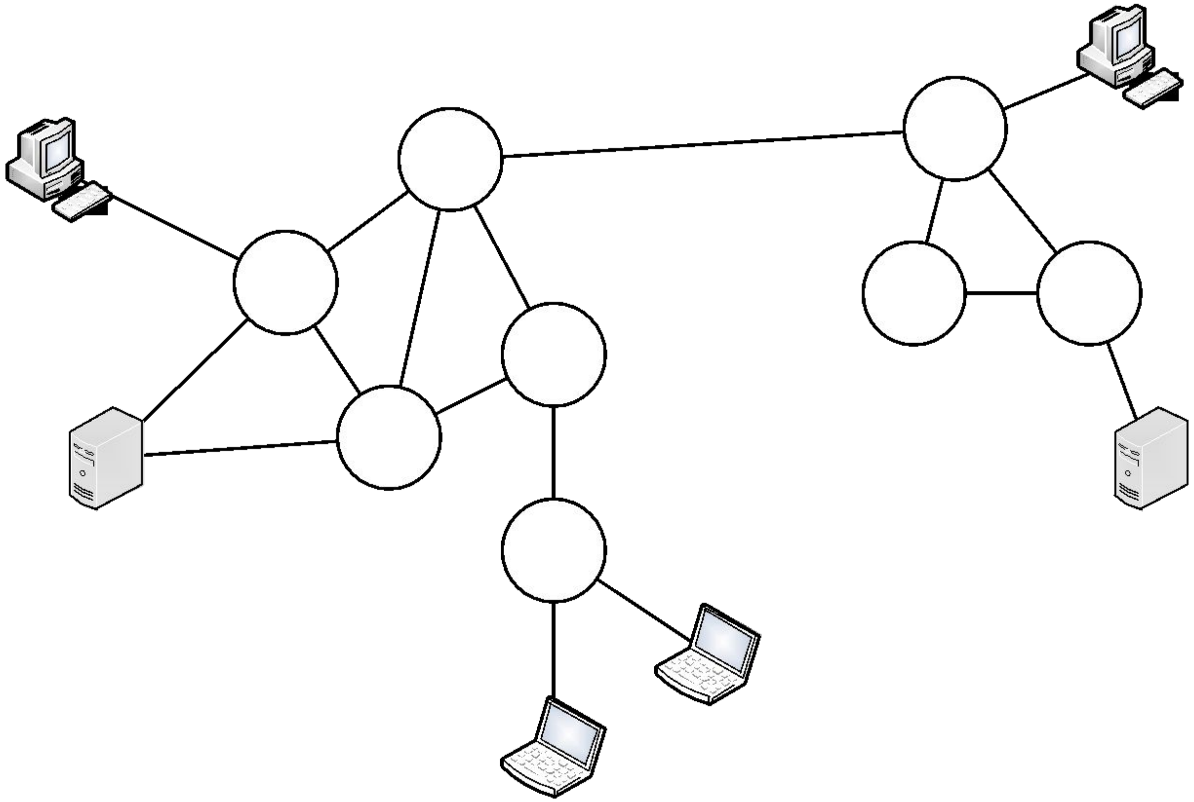
Network Layer

- Network layer provides end-to-end connectivity
  - Service to layer above
    - Unreliable channel
  - Uses link layer
    - Point-to-point links
- Connectivity is between end-system interfaces
  - Computers may have multiple interfaces



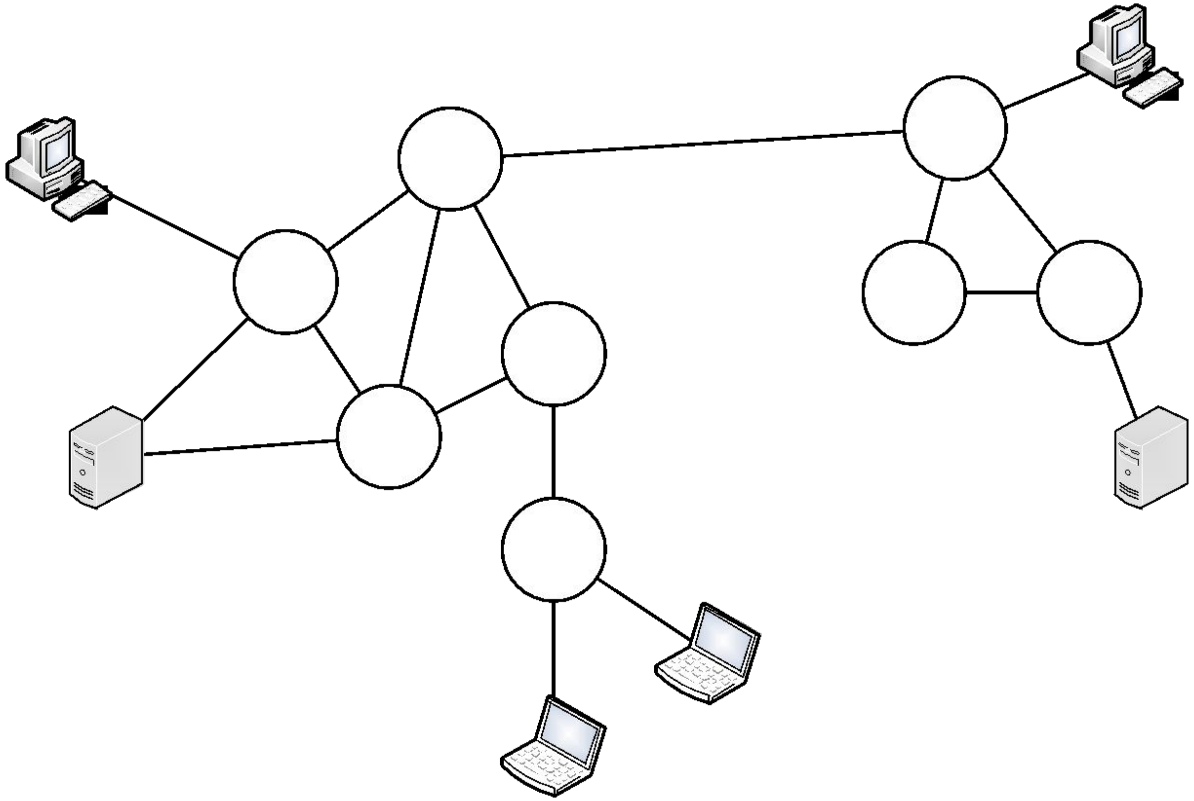
Orchestrated Discussion (Short Answer): Interface-to-Interface Connectivity

- How can we provide end-to-end connectivity if we can only send link by link?



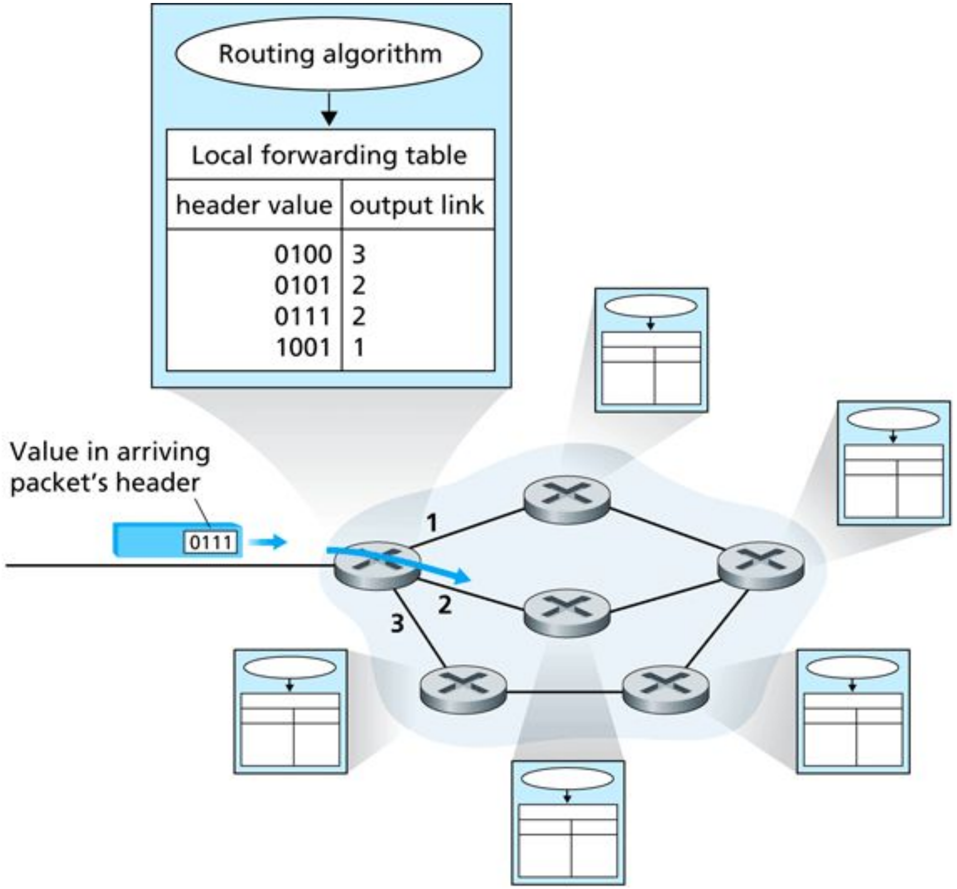
Interface-to-Interface Connectivity

- How can we provide end-to-end connectivity if we can only send link by link?
  - Need to have addresses to identify end-systems
  - Need to know which path to take



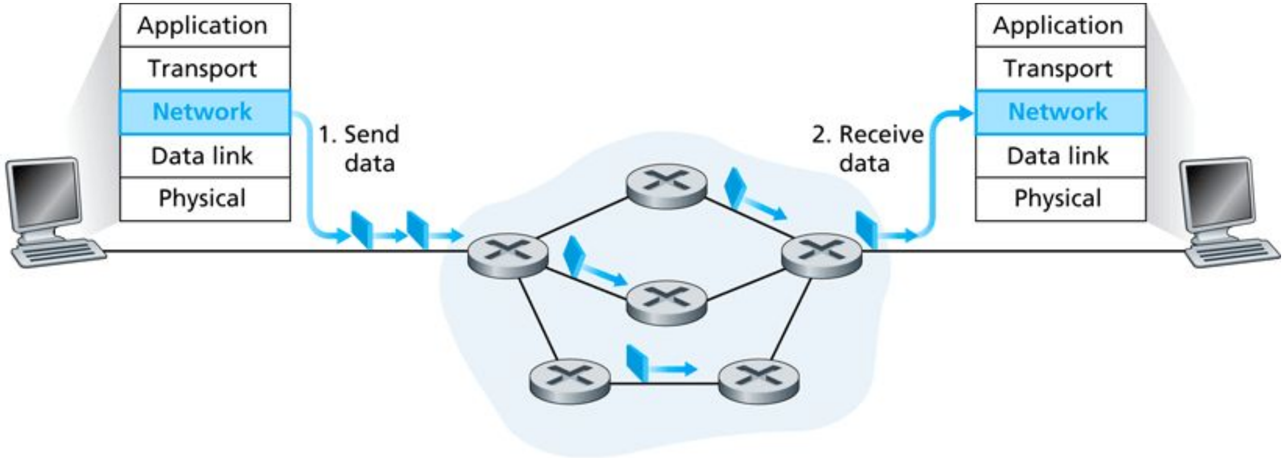
Connectivity

- Connectivity requires
  - Addressing
  - Routing and forwarding
- Internet is packet-switched network
- Two different approaches for connectivity
  - Datagram network
  - Virtual circuit network



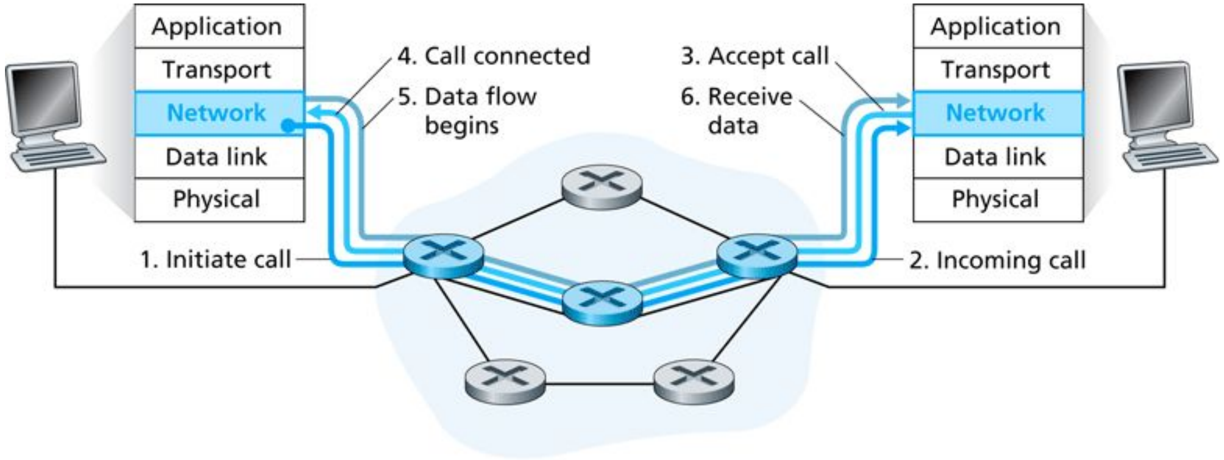
Datagram Networks

- Packets are sent independently of each other
  - Each packet has full set of control information
- Every switch needs to be able to handle any packet
  - No need for per-connection state



Virtual Circuit Networks

- End-to-end connectivity through virtual circuits
- Connection process
  - Connection setup
  - Data transfer
  - Connection teardown
- Router maintains state for every connection
- We will see that again later in context of software-defined networks

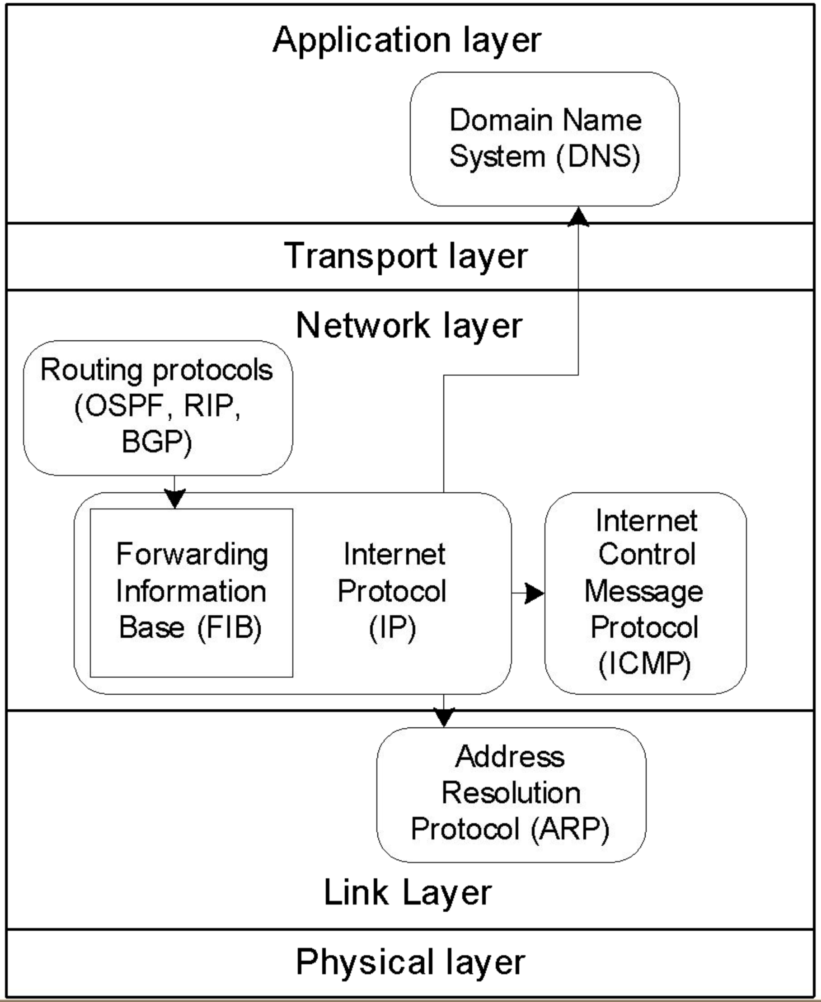


Internet Protocol

- Internet Protocol (IP)
  - Network layer of the Internet
- Data plane
  - Forwarding of IP packets on node
  - Local per-node functions
- Control plane
  - Routing from source to destination along end-to-end path
  - Network-wide functions

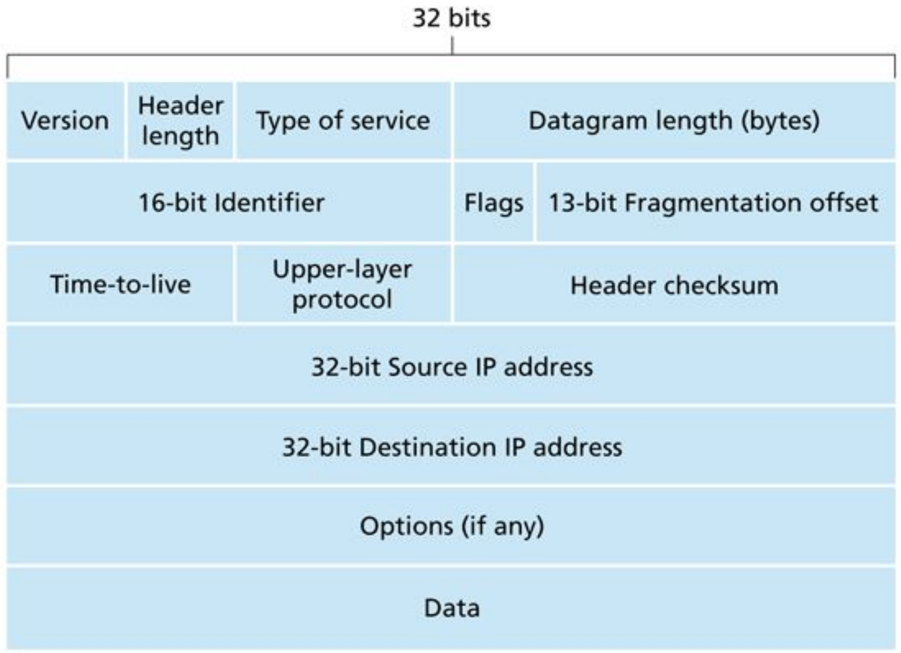
Other IP Aspects

- IP needs to interact with other components in protocol stack
- ICMP
  - Error handling
- Link layer
  - Address resolution (ARP)
- Application layer
  - Domain names (DNS)
  - Dynamic IP addresses (DHCP)
- Transport layer
  - Network address translation (NAT)



Internet Protocol

- IP (version 4) header format:
  - Source and destination address
  - Datagram length
  - Upper layer protocol
    - Identifies TCP, UDP, etc.
  - Time to live
    - Protection against accidental loops
  - Header checksum
    - Protection against bit errors
  - Fragmentation possible
    - Link layer limited to some datagram size (min. MTU is 576 bytes)



Whiteboard: IP Addressing

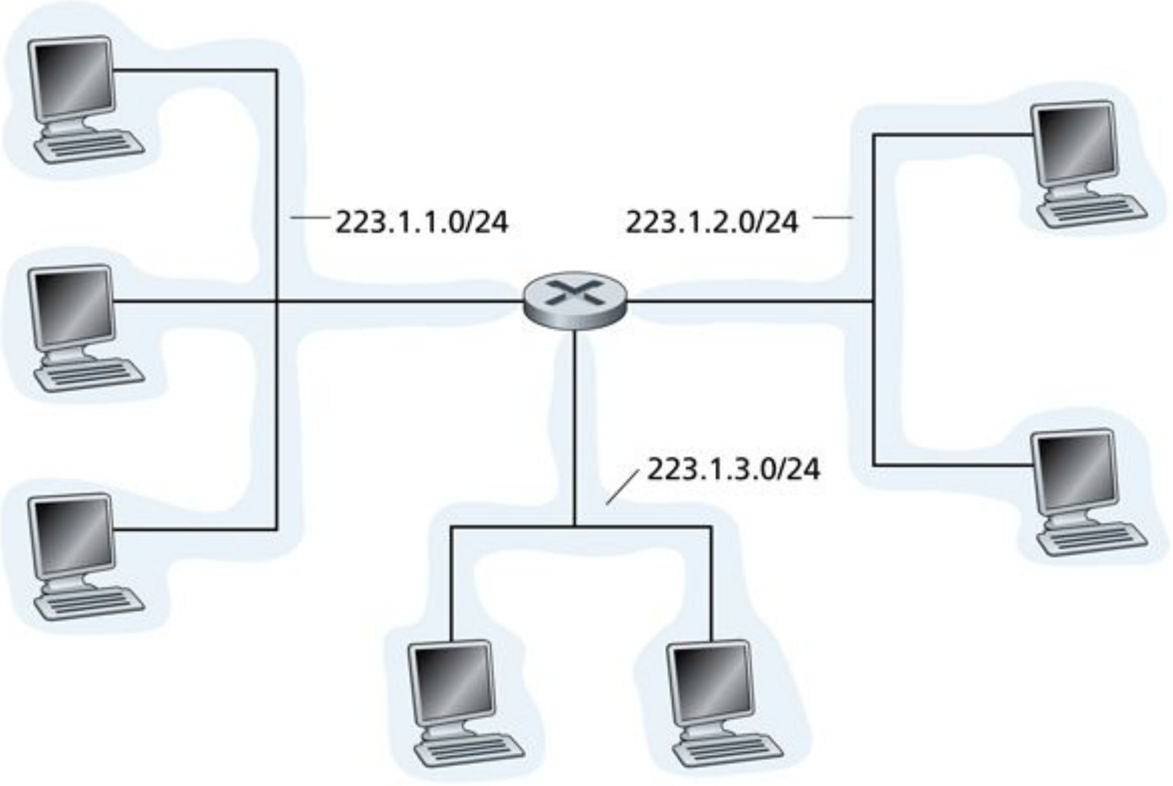
- A 32-bit globally unique identifier for an interface
  - Typically written in dotted-decimal notation: 192.168.0.1
- IP address assignment
  - In blocks of neighboring IP addresses: “subnets”
  - Notation: lowest address / prefix: 192.168.0.128/25
- Note: the address classes are dead!
  - Classless Interdomain Routing (CIDR)
- Allocation of addresses is crucial for routing
- Addresses assigned by Internet Assigned Numbers Authority (IANA)

Video: IANA


WHAT YOU NEED TO KNOW ABOUT IANA
iana
Internet Assigned Numbers Authority
0:01 / 5:04

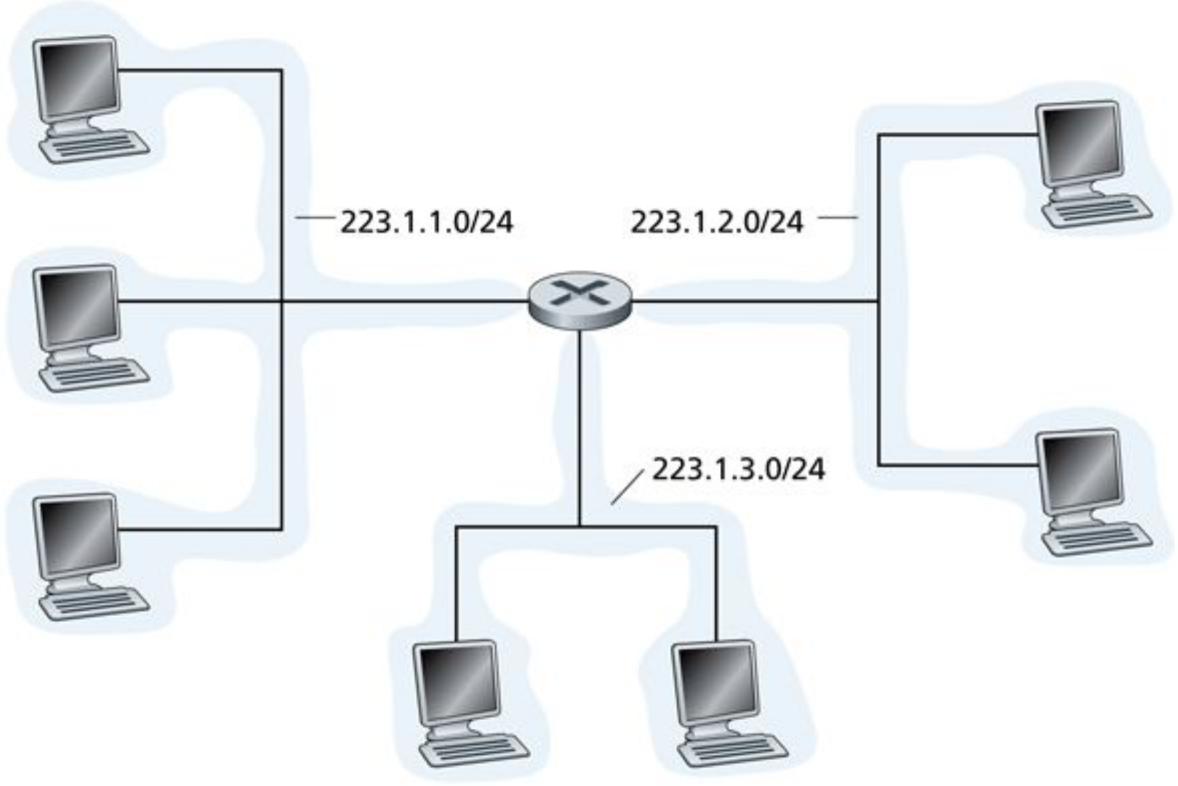
IP Address Allocation

- Address space is allocated to subnetwork
  - Each subnet represented by "prefix"
  - Notation indicates length of prefix
  - Example: 223.1.1.0/24



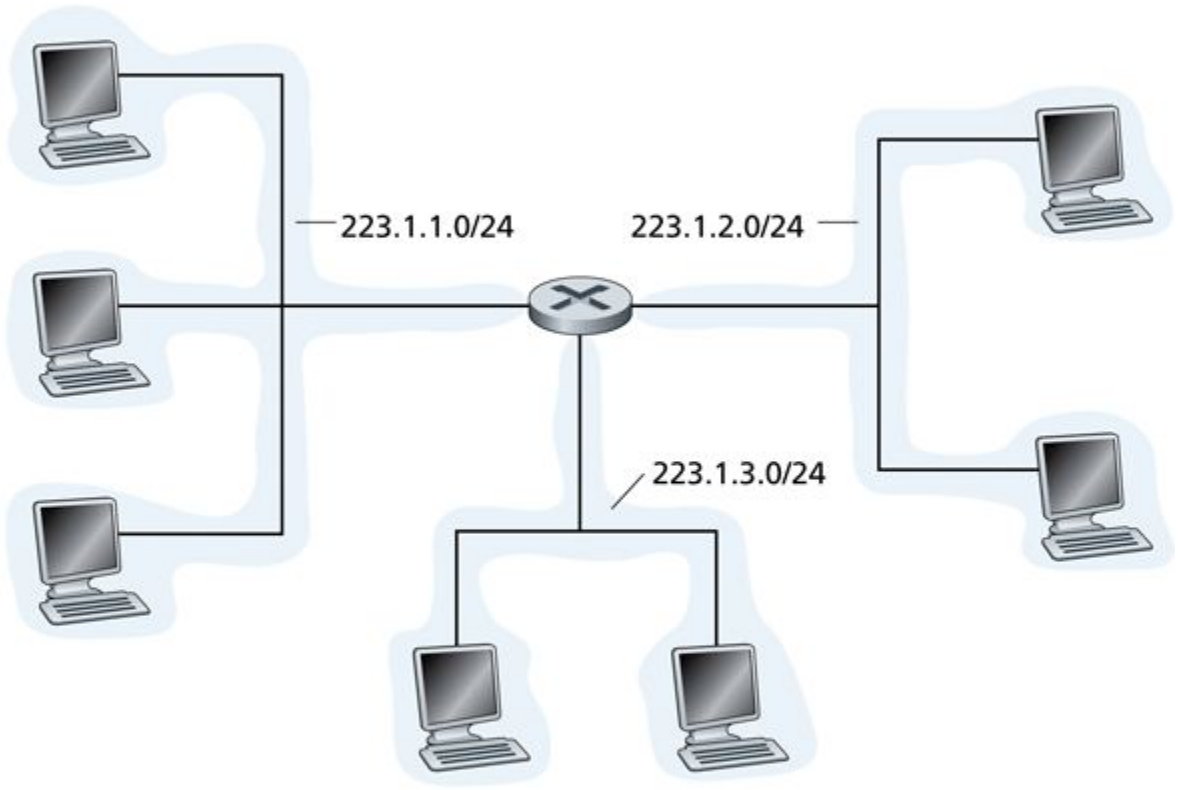
Poll: IP Address Allocation

- How many possible addresses are in 223.1.1.0/24?
  - 256
  - 16.7 million
  - 24
  - 223



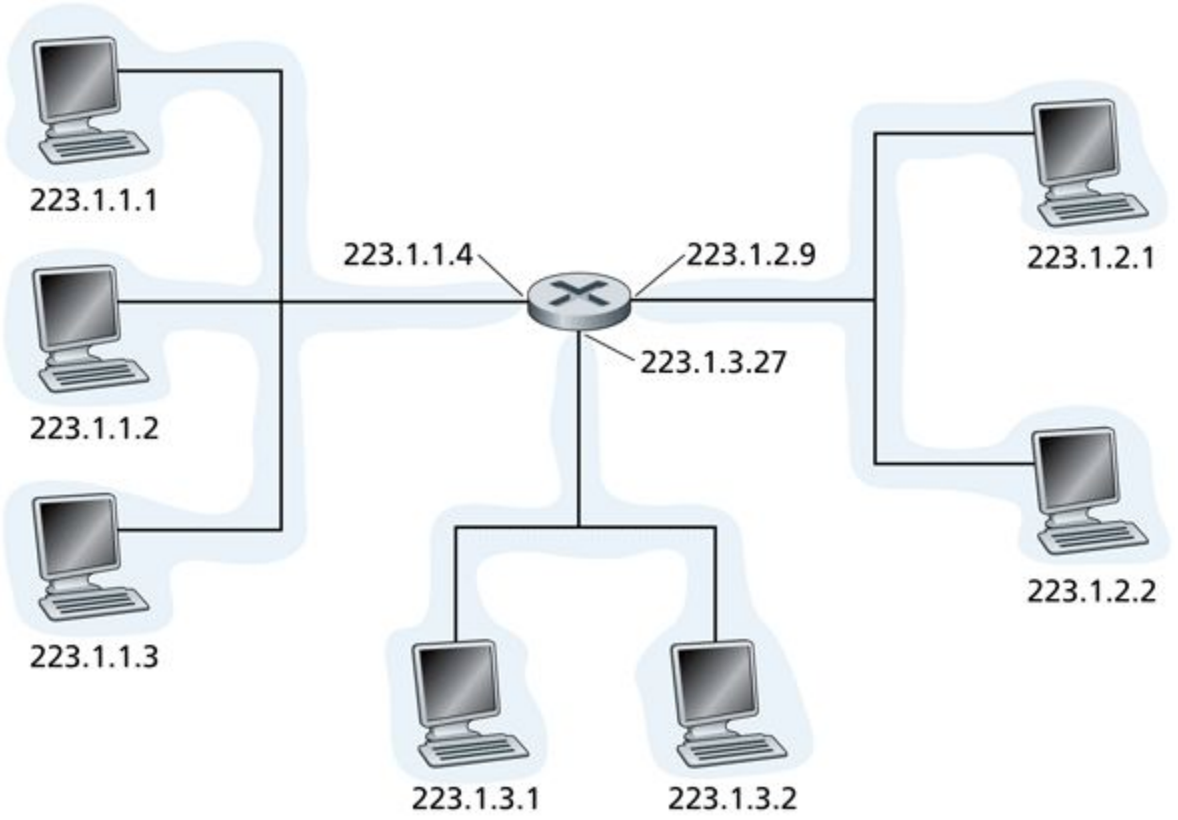
Poll: IP Address Allocation

- What is a valid addresses for router interface in that subnet? There are multiple correct answers.
  - 223.1.1.1
  - 223.1.1.24
  - 223.1.1.42
  - 223.1.1.500
  - 223.1.24.1



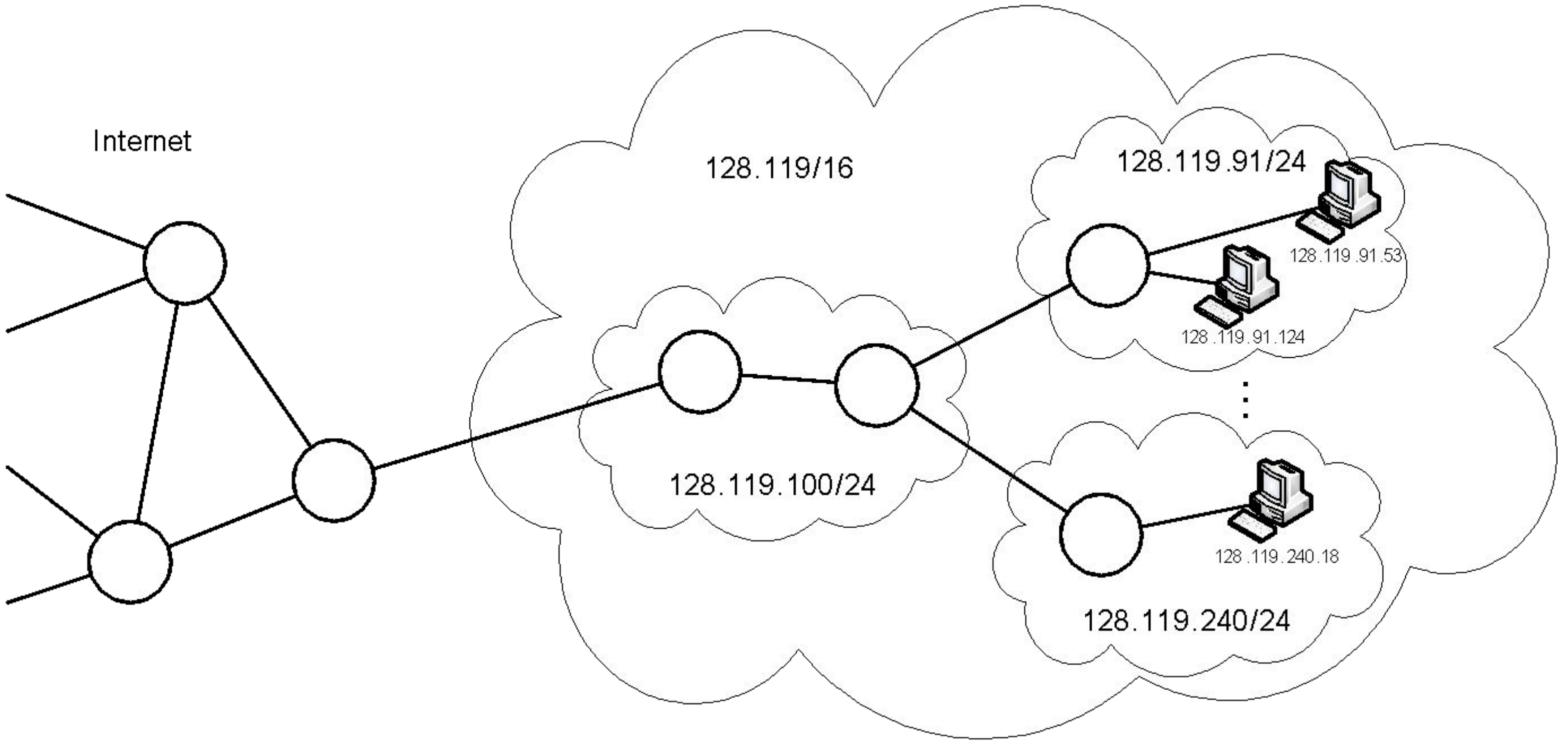
IP Address Allocation

- Example address allocation:
  - Address allocation determined by network administrator
  - Even point-to-point links require addresses for interfaces



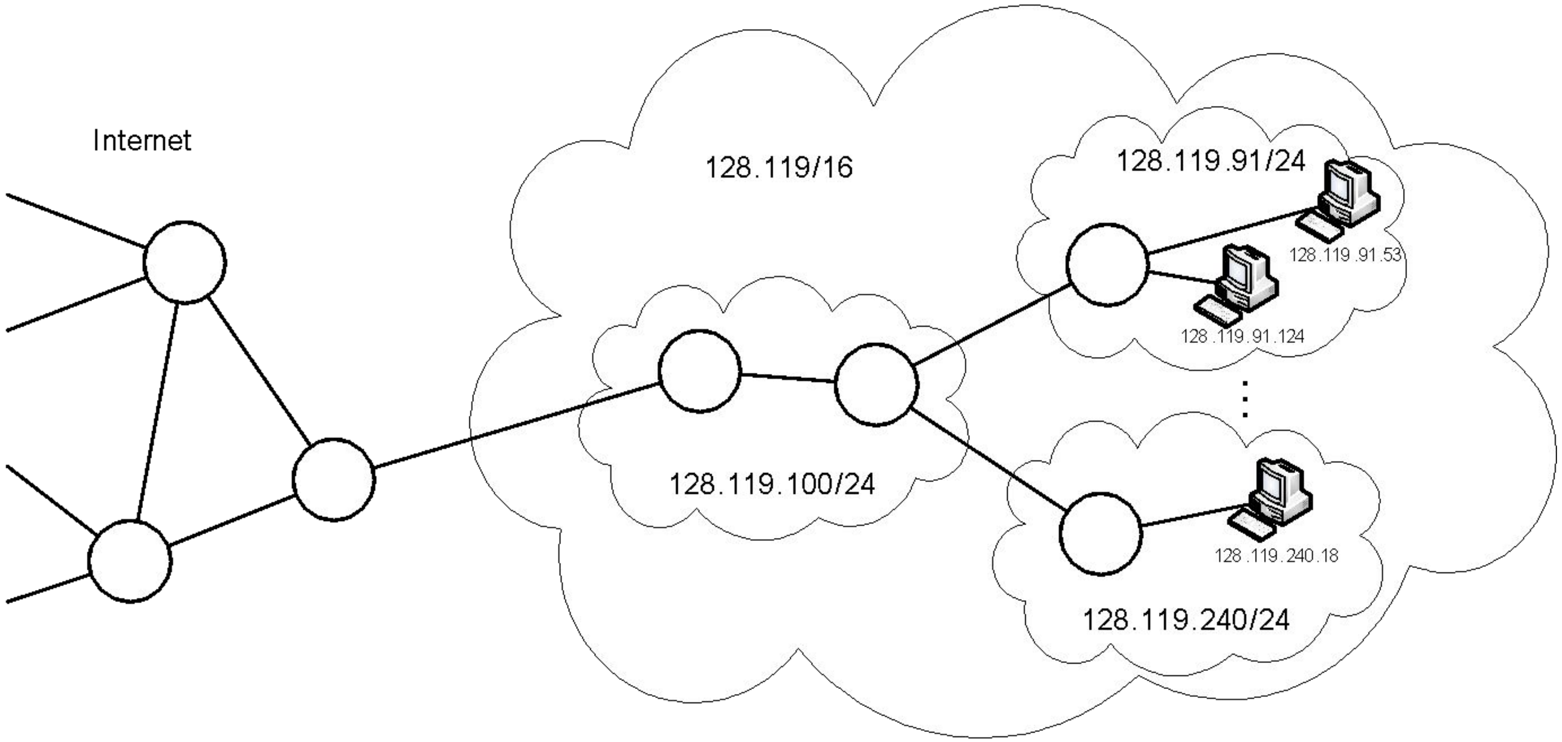
Hierarchical Address Allocation

- IP address allocation is hierarchical
  - Subnets within subnets have longer prefixes
- Rest of Internet only needs to know of highest layer in hierarchy for routing ("address aggregation")
- Example:



Orchestrated Discussion (Short Answer): Address Aggregation

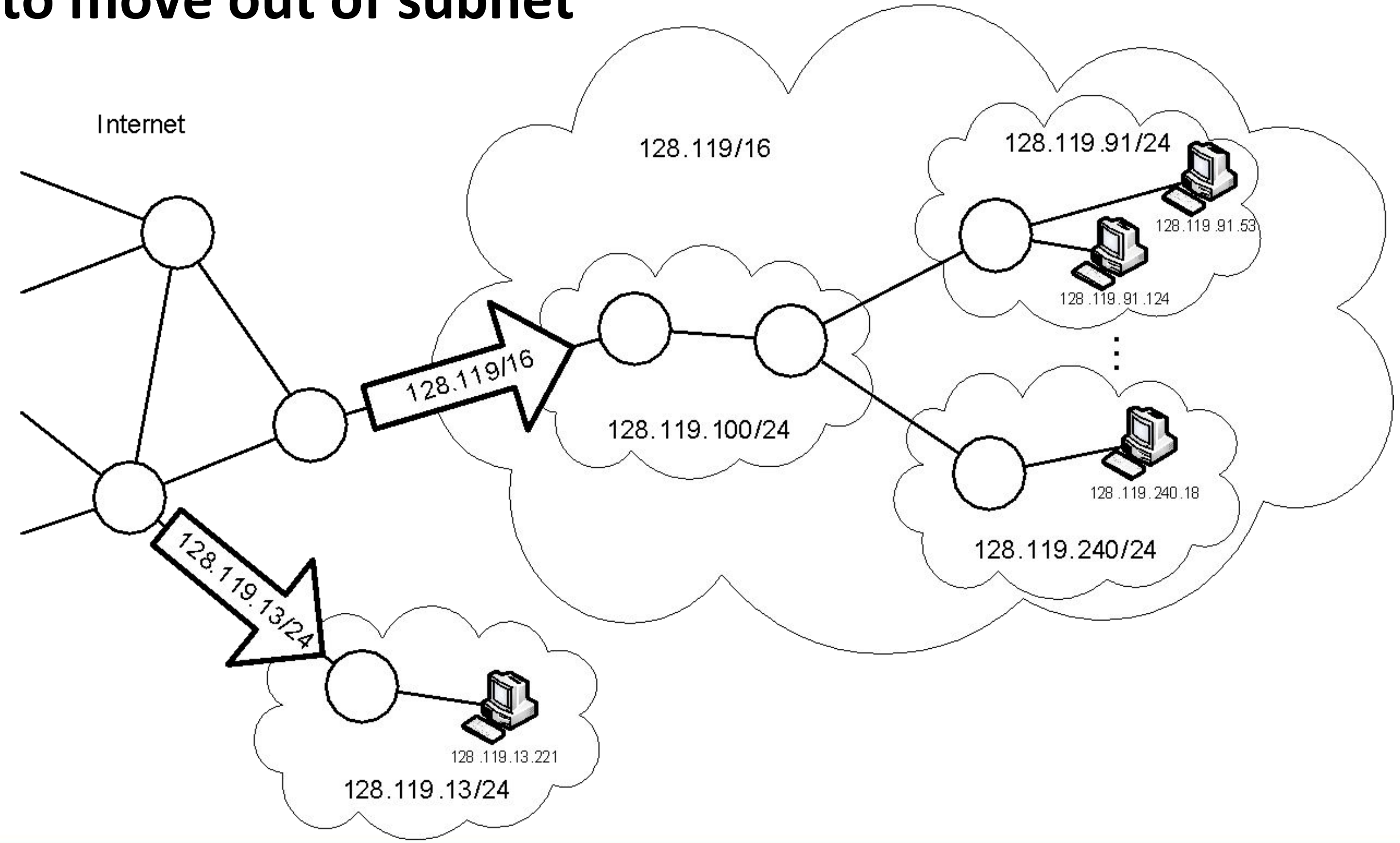
- **What are challenges with hierarchical address allocation in practice?**



Address Aggregation

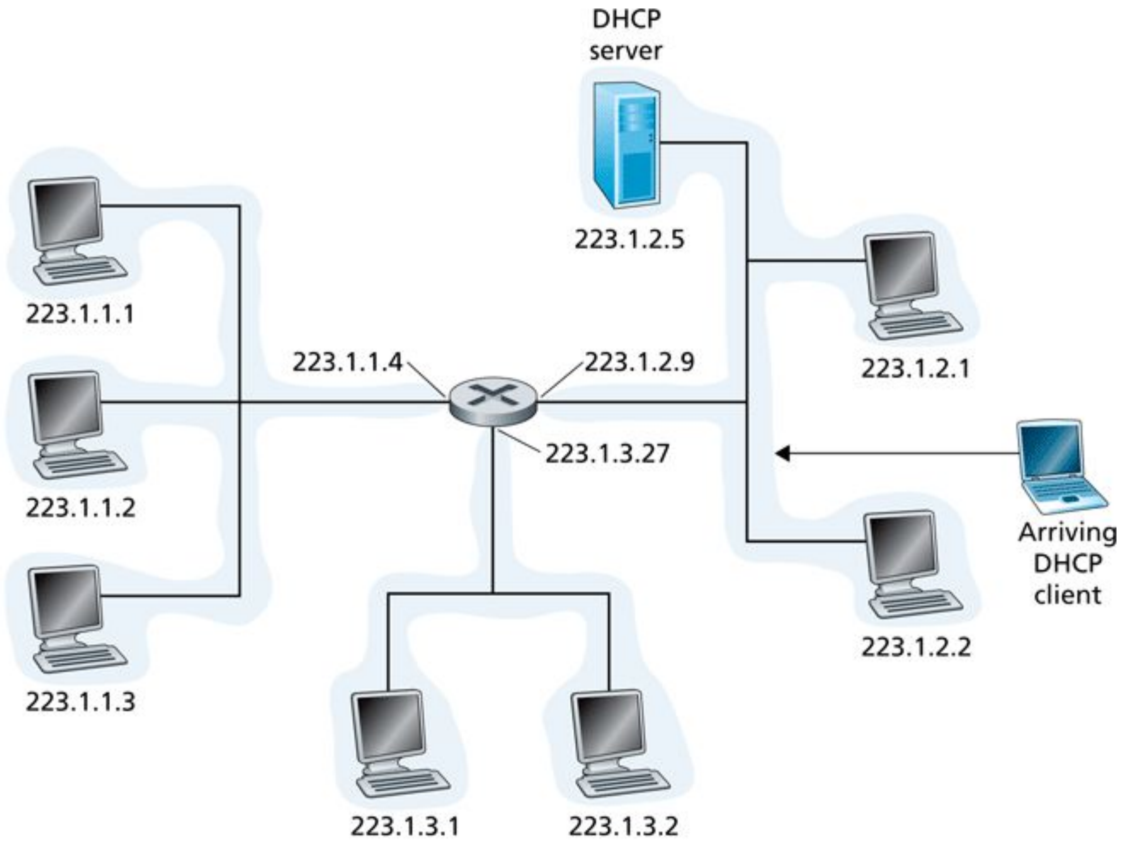
- Internet does allow addresses to move out of subnet
- Work-around to handle disaggregation:

- Both aggregates are known to routers
- Routers perform "longest prefix match"
  - Most specific route used for forwarding



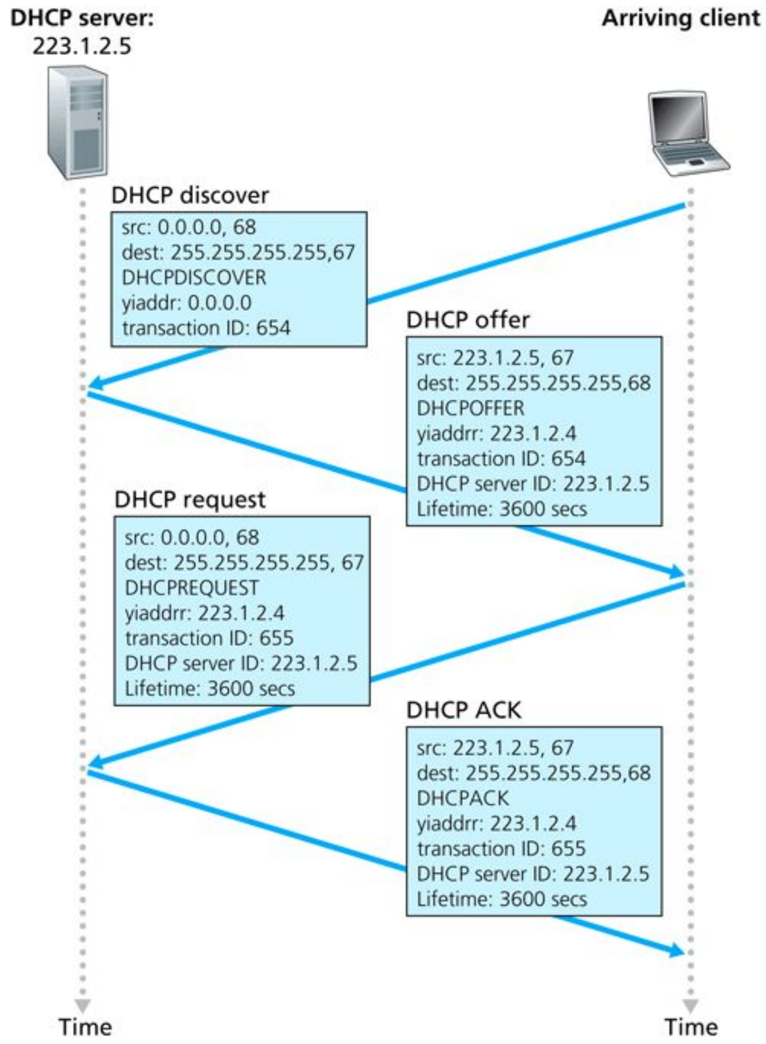
Dynamic Host Configuration Protocol

- DHCP provides IP addresses to end
  - Example: using a laptop in a coffee shop
  - Manual configuration may be too complex



Dynamic Host Configuration Protocol

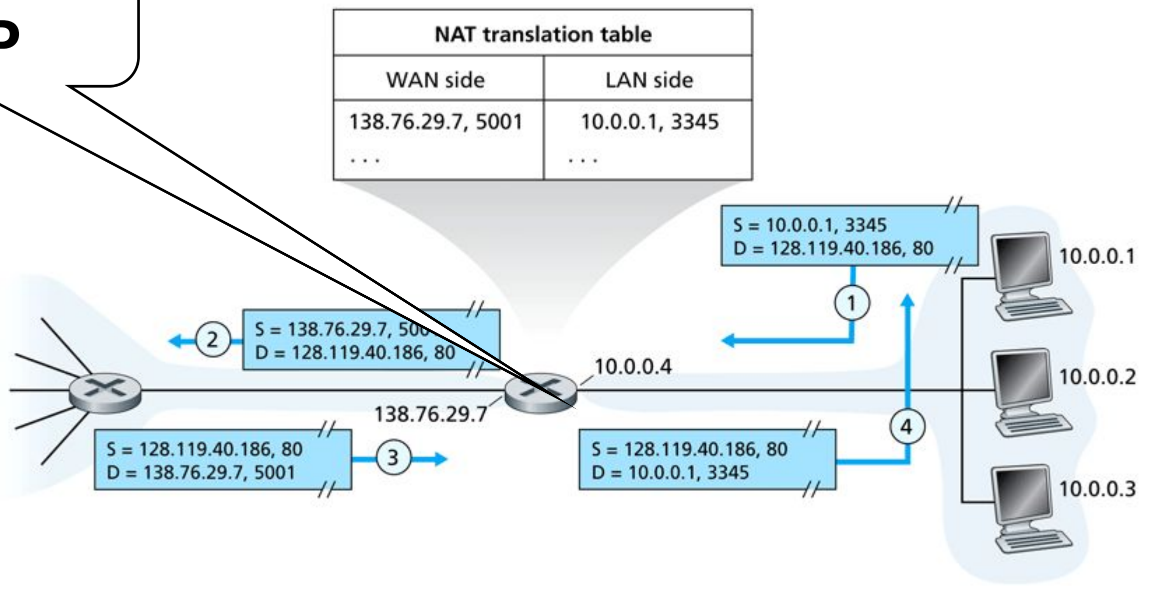
- DHCP protocol exchange
  - DHCP client tries to discover DHCP server
    - Communication possible without IP address
  - DHCP server offers IP address to client
  - DHCP client requests use of IP address
  - DHCP server assigns IP address to client
- Address lease for limited time



Network Address Translation (NAT)

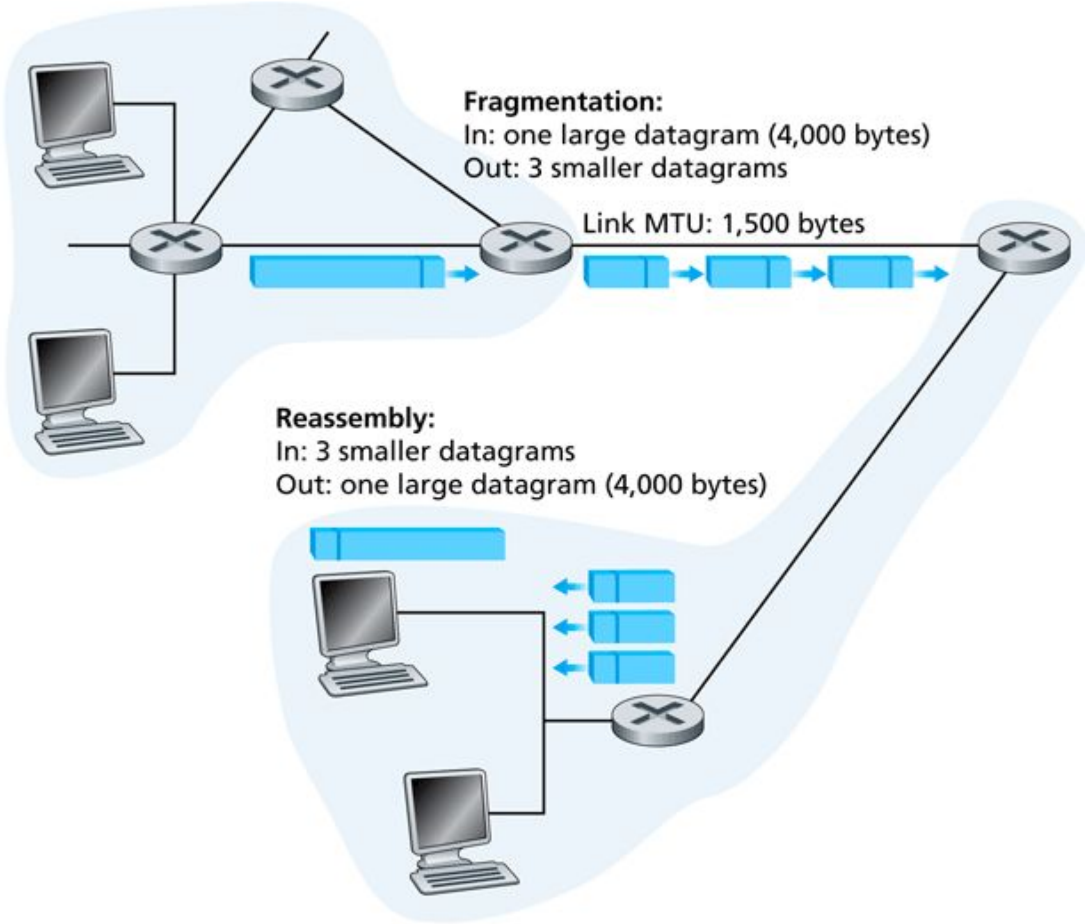
- Limited number of IP addresses
  - Block of addresses reserved for “local” use
    - 10.*.*.* and 192.168.*.*
- Network address translator
  - Connects local net through single outside IP address

often with DHCP



IP Fragmentation

- Data link layer determines Maximum Transfer Unit
  - E.g., 1500 bytes on Ethernet
- If packet encounters smaller MTU than size, then router fragments packet
- Reassembly on end-system
  - Not on router!
- Internet minimum MTU is 576 bytes



Internet Control Message Protocol

- ICMP provides control and error messages:
  - Echo request / reply
  - Destination unreachable (network, host, protocol, port)
  - Destination unknown (network, host)
  - Congestion control
  - Router advertisement
  - Router discovery
  - TTL expired
  - IP header bad
- Can be used (and abused) for many purposes
  - Intentional TTL expiration for route discovery

Group Discussion and Report Back (Short Answer): IPv4 vs. IPv6

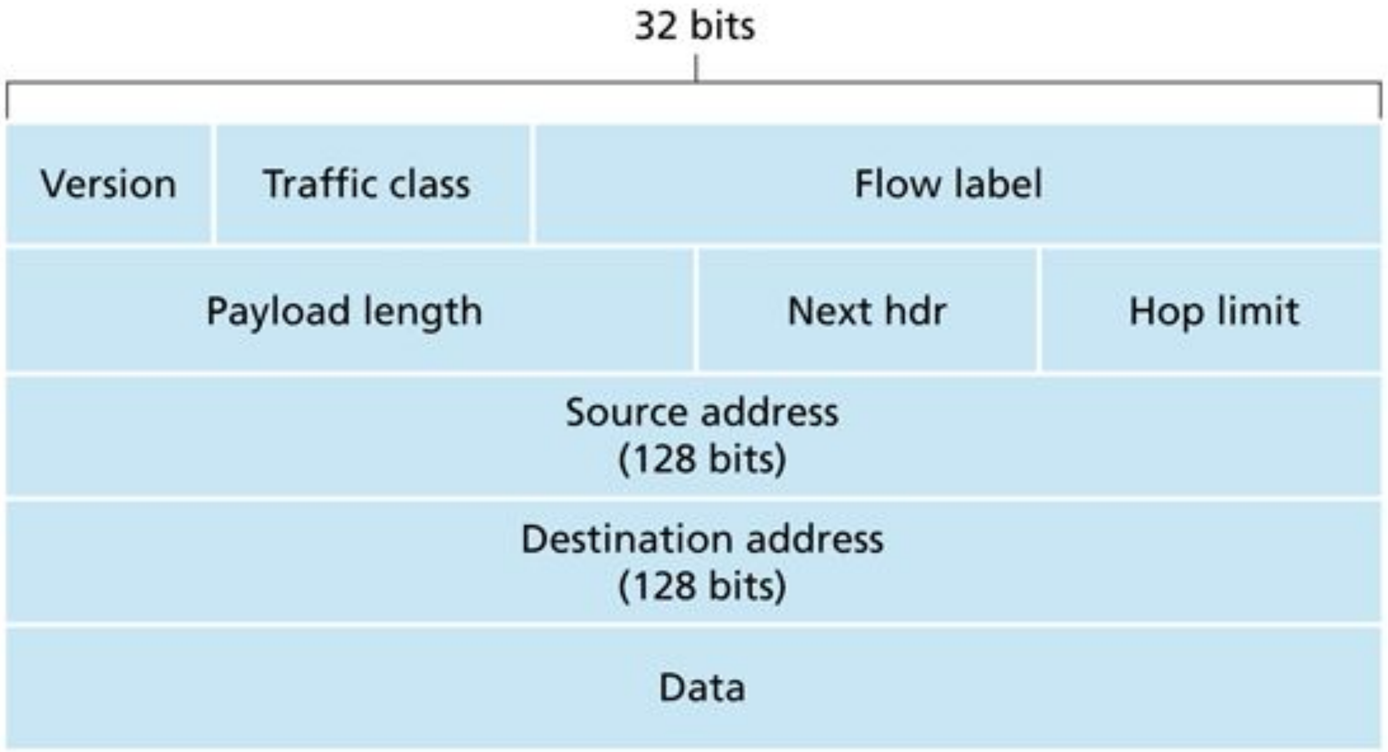
- **Get into small groups and discuss the following topics in detail:**
  - **What drove the development of IPv6?**
  - **What are some of the most important changes in IPv6 compared to IPv4?**
  - **Which fields have been defined in IPv6 and which are no longer present?**
  - **What are possible options for transitioning from IPv4 to IPv6?**

IP Version 6

- 32-bit address space of IPv4 almost completely allocated
  - Difficult to get IP addresses
  - More fragmentation of IP address space
  - Network address translation “obscures” network
- Version 6 of IP
  - 128-bit addresses
  - Improved header format for faster processing on routers

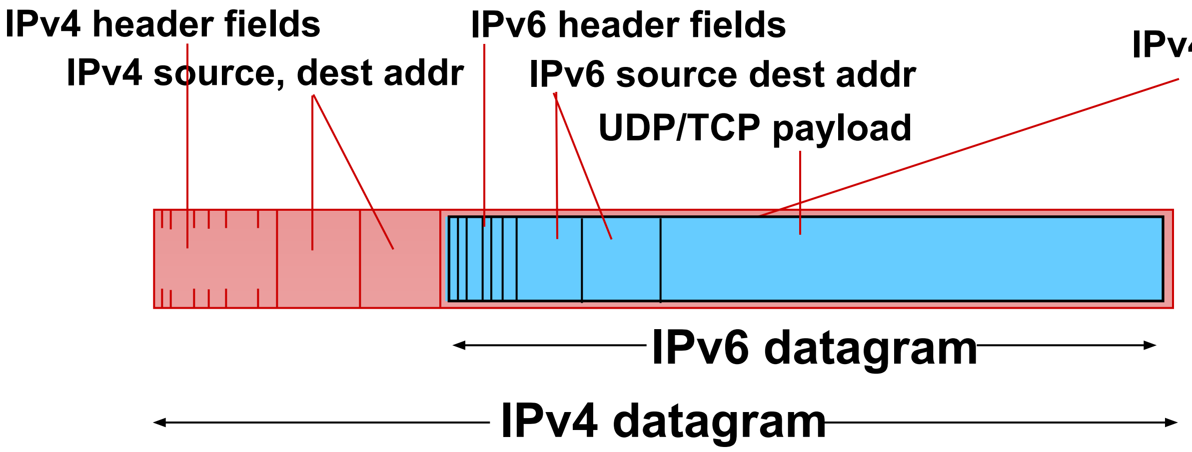
IP Version 6

- IP (version 6) header format:
  - 128-bit addresses (unicast, multicast, anycast)
  - Flow labeling and priority
  - No fragmentation
  - No header checksum
  - Option in next header

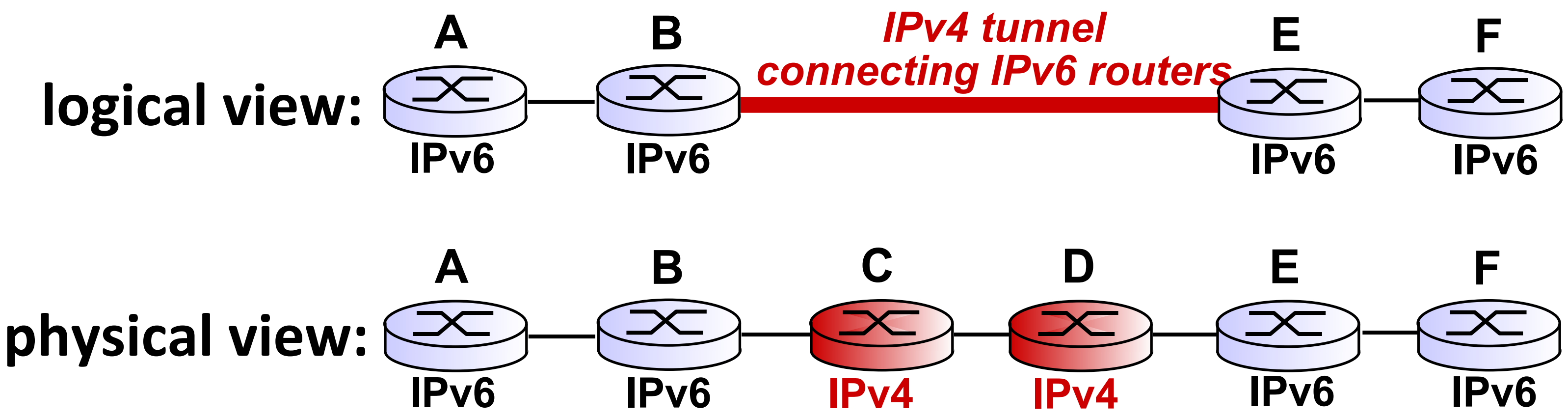


Transition to IPv6

- Not all routers can be upgraded simultaneously
  - No “flag day”
  - How will network operate with mixed IPv4 and IPv6 routers?
- Tunneling: IPv6 datagram carried as payload in IPv4 datagram among IPv4 routers

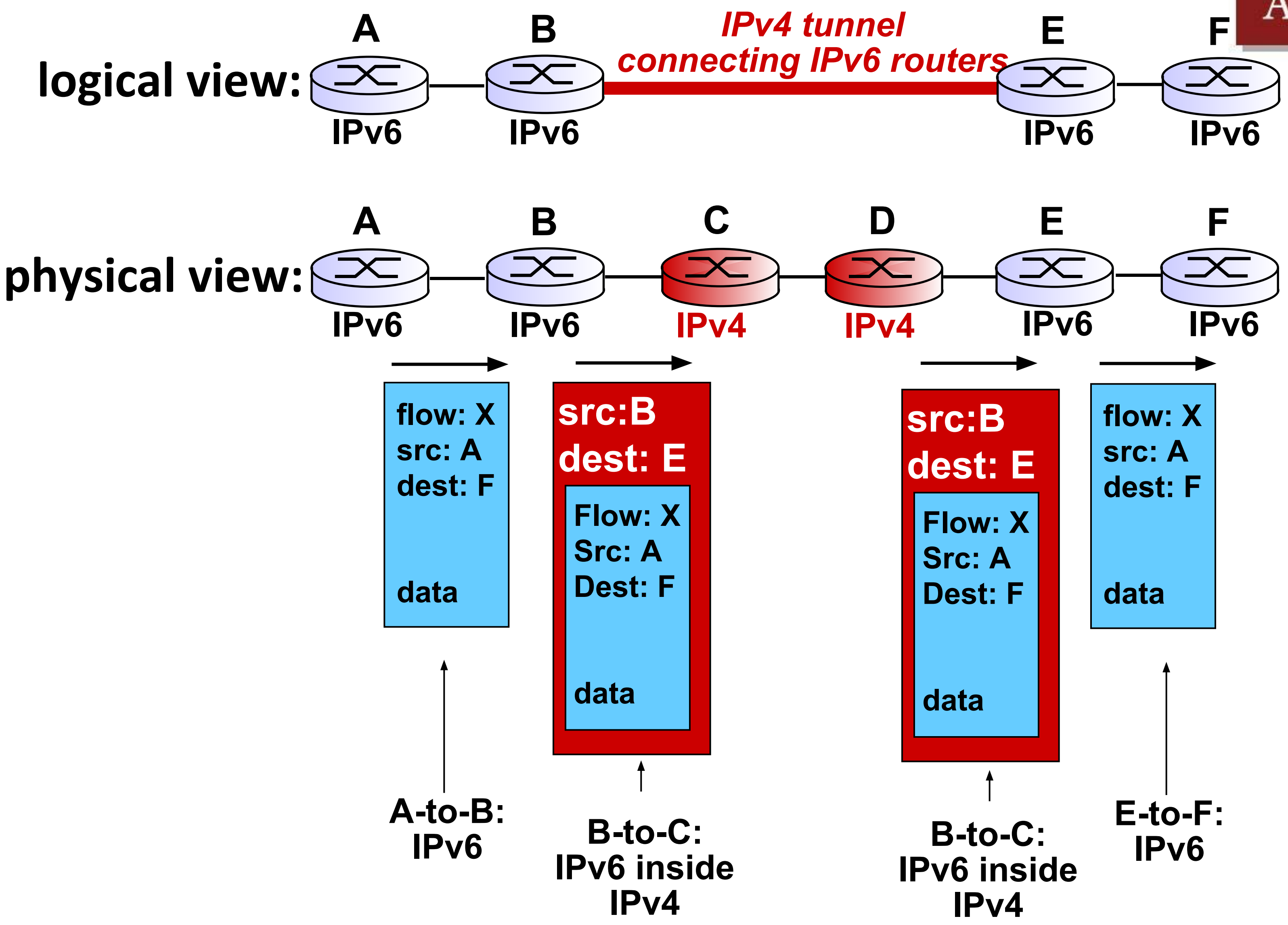


Tunneling



logical view:
A
B
IPv4 tunnel
connecting IPv6 routers
E
F
IPv6
IPv6
IPv6
IPv6
physical view:
A
B
C
D
E
F
IPv6
IPv6
IPv4
IPv4
IPv6
IPv6

Tunneling



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A
B
C
D
E
F
IPv6
IPv6
IPv4
IPv4
IPv6
IPv6
flow: X
src: A
dest: F
data
src:B
dest: E
Flow: X
Src: A
Dest: F
data
src:B
dest: E
Flow: X
Src: A
Dest: F
data
flow: X
src: A
dest: F
data
A-to-B:
IPv6
B-to-C:
IPv6 inside
IPv4
B-to-C:
IPv6 inside
IPv4
E-to-F:
IPv6

IPv6 Deployment

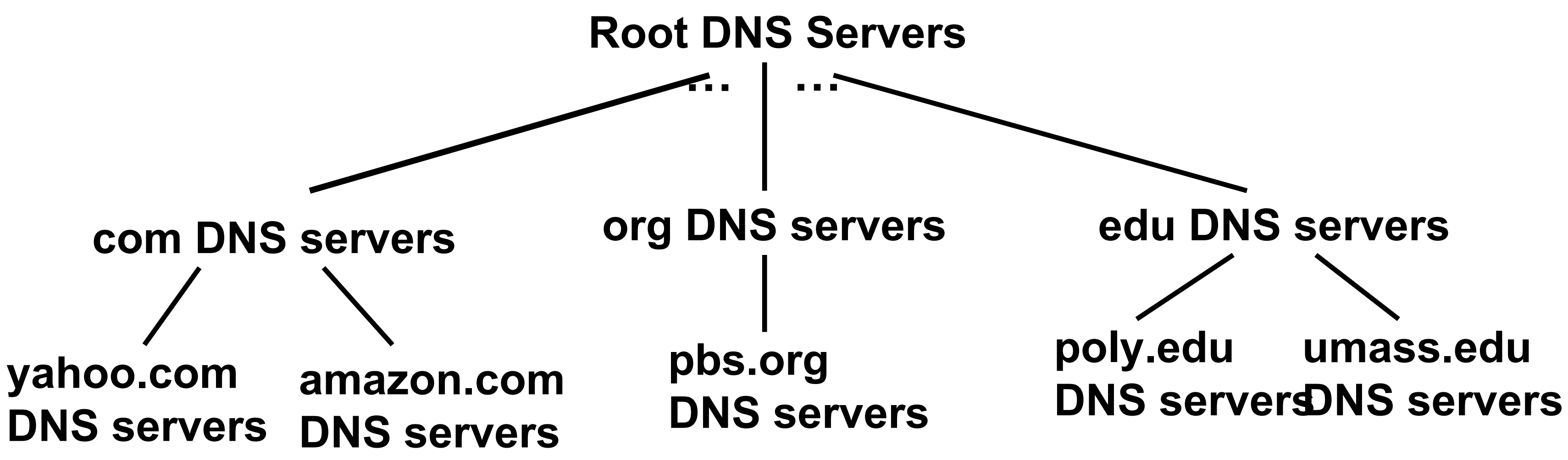
- IPv6 has existed for almost 20 years
- Deployment status
  - Operating systems support IPv6
  - Dec 2016: 12% of Google users
- Deployment challenges illustrate importance of network layer and Internet Protocol
  - Network layer protocol used by all systems in the Internet
  - Change is difficult if all systems need to change

Domain Name System (DNS)

- Internet hosts and routers use IP addresses
    - Difficult for humans to remember and use
- "Names" are easier to use
    - Example: www.umass.edu, www.amazon.com, etc.
- Domain Name System maps from IP to name
    - Distributed database
    - Application layer protocol (used to find network layer IP)
    - Additional features: mail server info, load balancing, etc.

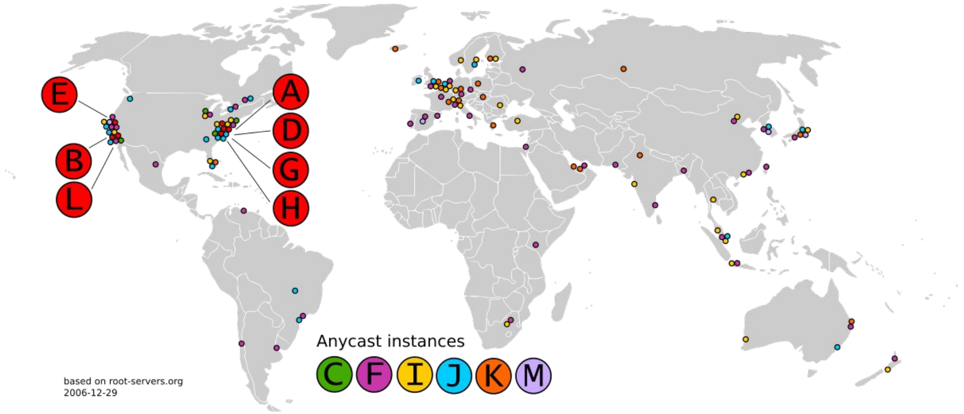
DNS Structure

- Hierarchical structure of names
    - Later parts of names are higher in hierarchy



DSN Root Name Servers

- Root name servers
  - Responsible for regions
  - Provide top-level domain (TLD) server
- TLD name server
  - Responsible for TLD
  - Provide authoritative name server
- Authoritative name server
  - Responsible for domain
  - Respond mapping between host name and IP



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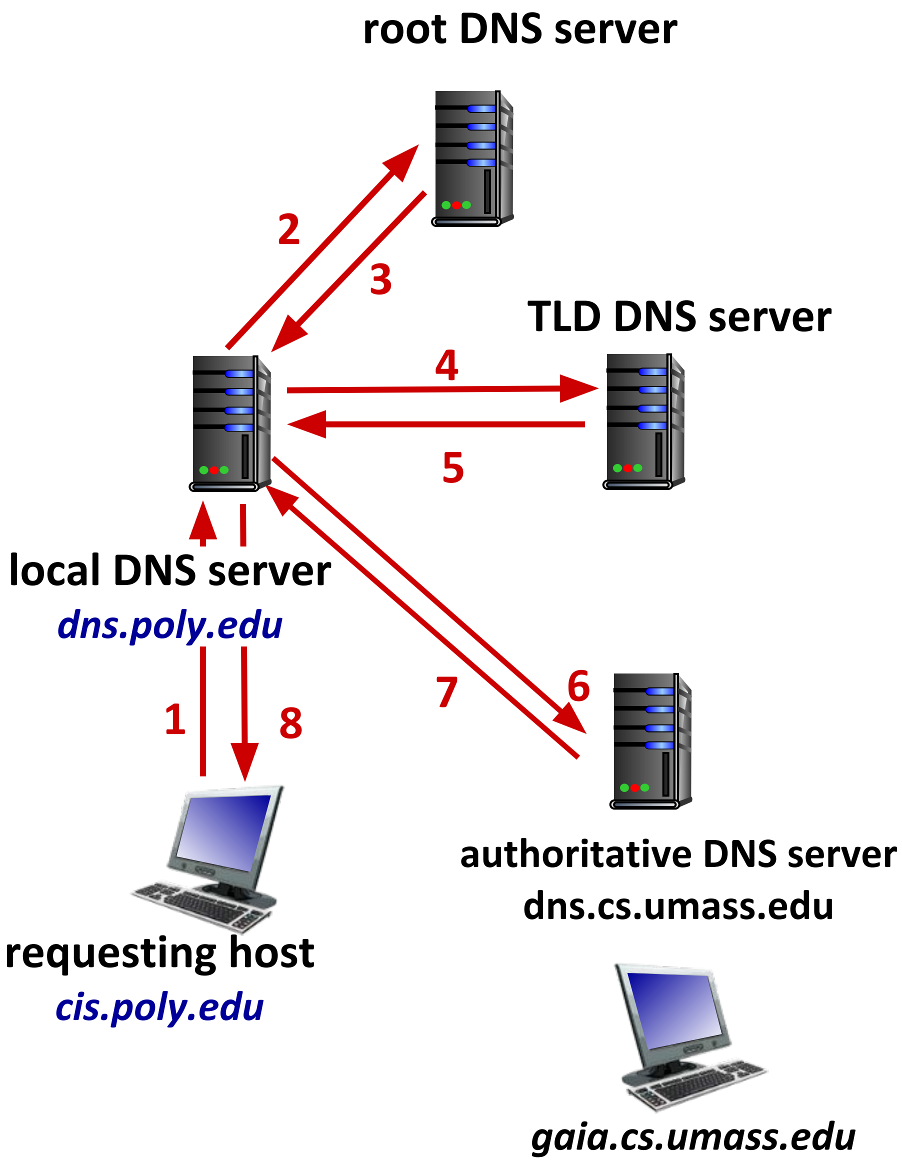
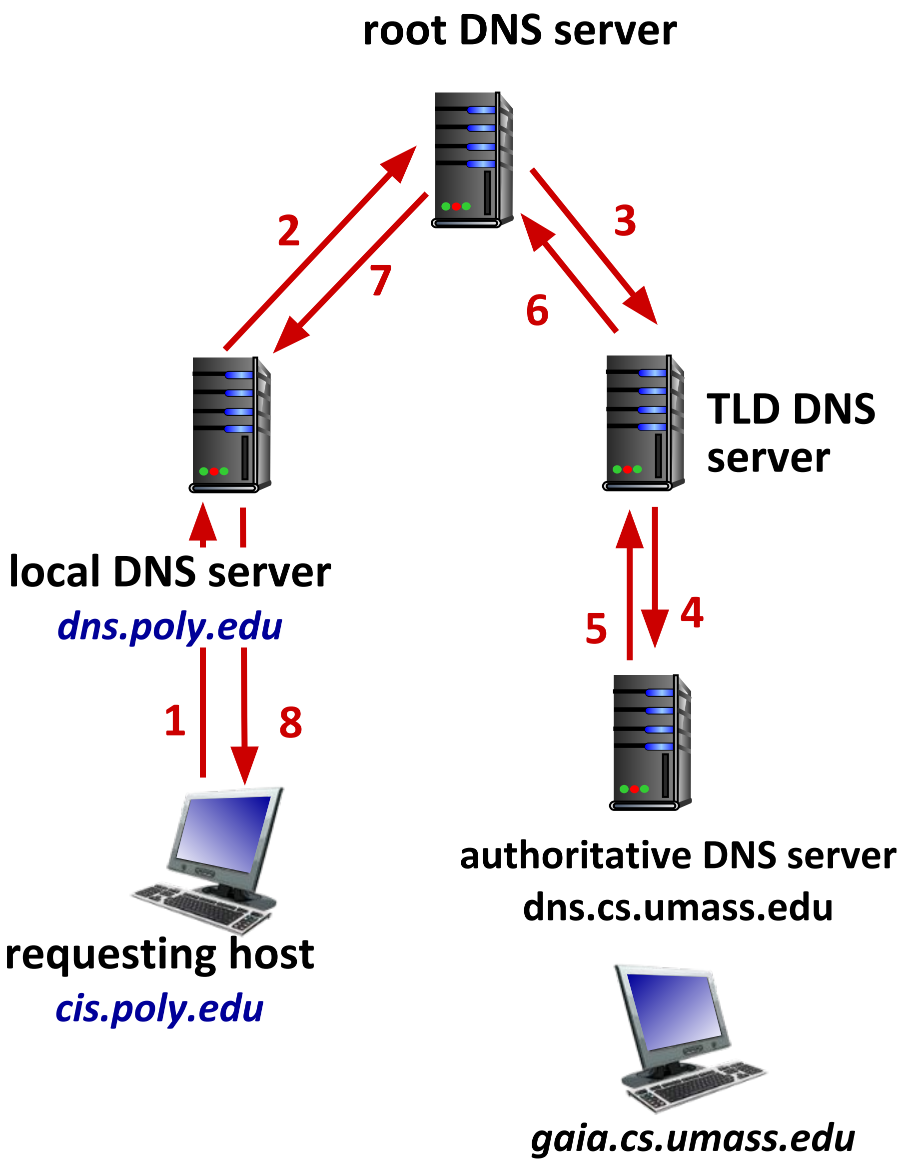
DNS Example

- DNS example: iterative query
  - Server responds: “I don’t know, ask this server.”
  - Assumes only authoritative name server knows answer
  - In practice, results may be cached



DNS Example

- DNS example: recursive query
  - Server relays query and responds when result available
  - Assumes only authoritative name server knows answer
  - In practice, results may be cached



Connected Device: DNS Example

- Command line tool “nslookup”
    - Can perform DNS query

wolf — -bash — 64×10

```
Finrod:~ wolf$ nslookup www.tsinghua.edu.cn
Server:         192.168.42.1
Address:        192.168.42.1#53

Non-authoritative answer:
www.tsinghua.edu.cn     canonical name = www.d.tsinghua.edu.cn.
Name:   www.d.tsinghua.edu.cn
Address: 166.111.4.100

Finrod:~ wolf$
```

Summary of Lesson

- Performance requirements
- Shared memory
- Shared bus
- Crossbar
- Multi-stage switching fabrics
- Buffering

Post-work for Lesson 6

Homework #4

- **After the Live Lecture, you will complete and submit a homework assignment. Go to the online classroom to view and submit the assignment.**

Mid-Course Reflection

- **After the Live Lecture, you will reflect on what you learned. Then, you will answer questions and share your observations. Go to the online classroom to view the questions and submit your responses.**

To Prepare for the Next Lesson

- Complete and submit the Post-work for Lesson 6.
- Read the Required Readings for Lesson 7.
- Complete the Pre-work for Lesson 7.

Go to the online classroom for details.