Light at the end of the tunnel

Course Overview

Lecture 23

COS 461: Computer Networks

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Key Concepts in Networking

Some Key Concepts

- Course was organized around protocols
  - But a small set of concepts recur in many protocols
- General CS concepts
  - Hierarchy, indirection, caching, randomization
- Networking-specific concepts
  - Soft state, layering, (de)multiplexing
  - End-to-end argument

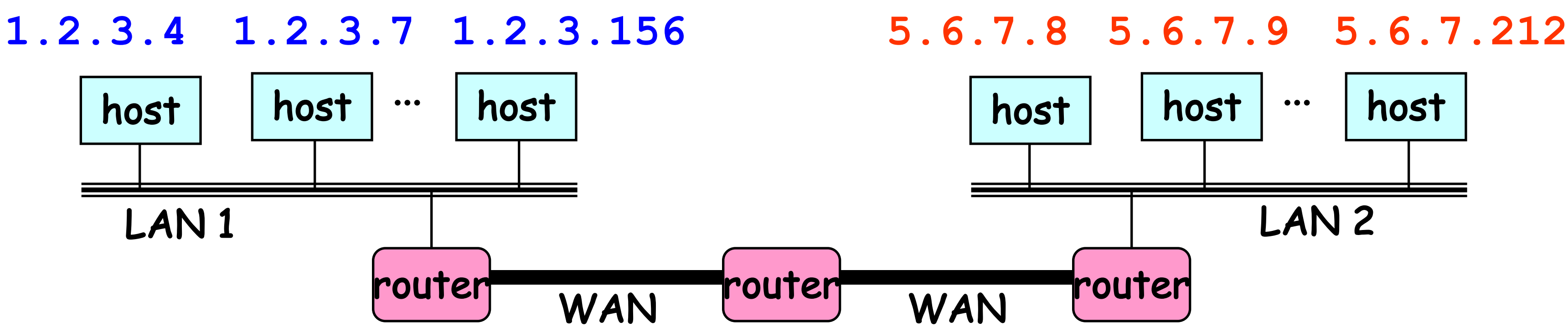
Hierarchy

- Scalability of large systems
  - Cannot store all information everywhere
  - Cannot centrally coordinate everything
- Hierarchy to manage scale
  - Divide system into smaller pieces

- Hierarchy to divide control
  - Decentralized management
- Examples in the Internet
  - IP addresses, routing protocols, DNS, P2P

Hierarchy: IP Address Blocks

- Number related hosts from a common subnet
  - 1.2.3.0/24 on the left LAN
  - 5.6.7.0/24 on the right LAN



1.2.3.0/24	←
5.6.7.0/24	→

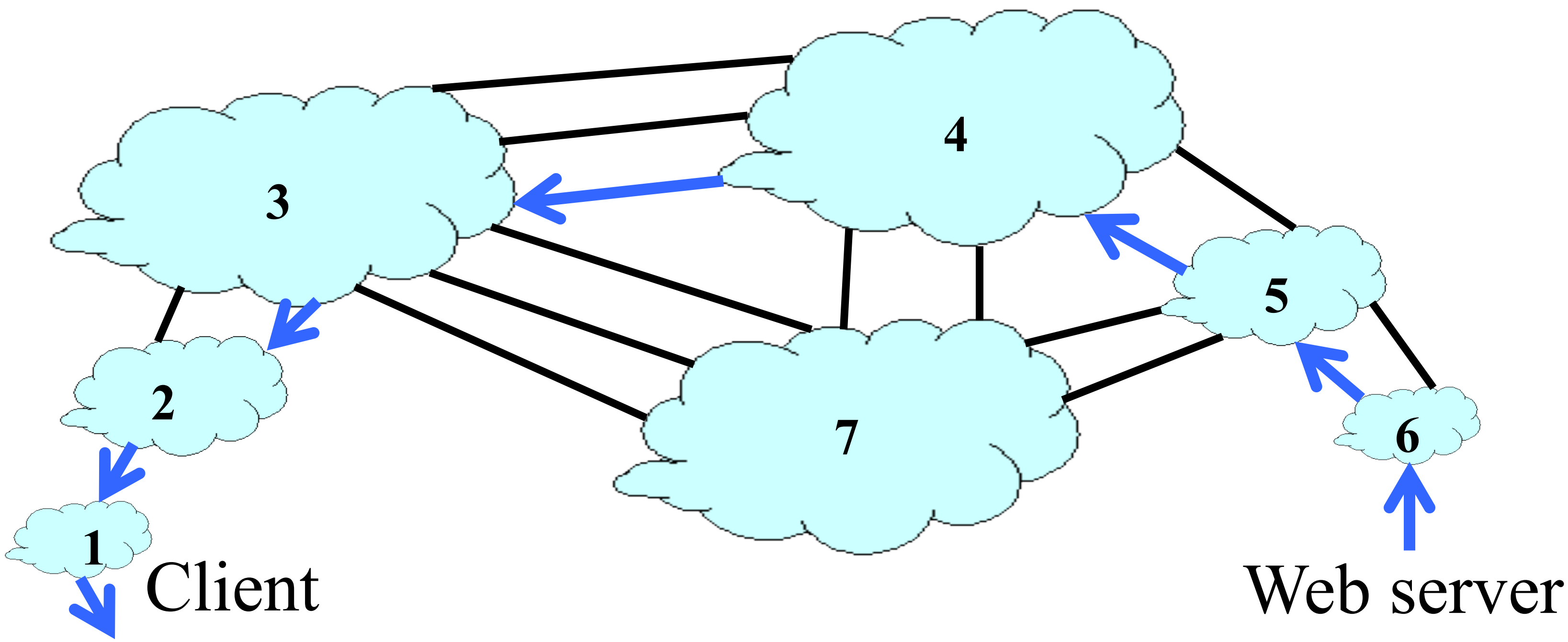
forwarding table

Hierarchy: IP Address Blocks

- Separation of control
  - Prefix: assigned to an institution
  - Addresses: assigned by institution to its nodes
- Who assigns prefixes?
  - Internet Corporation for Assigned Names & Numbers
  - Regional Internet Registries (RIRs)
  - Internet Service Providers (ISPs)
  - Stub networks
  - Regions within an enterprise

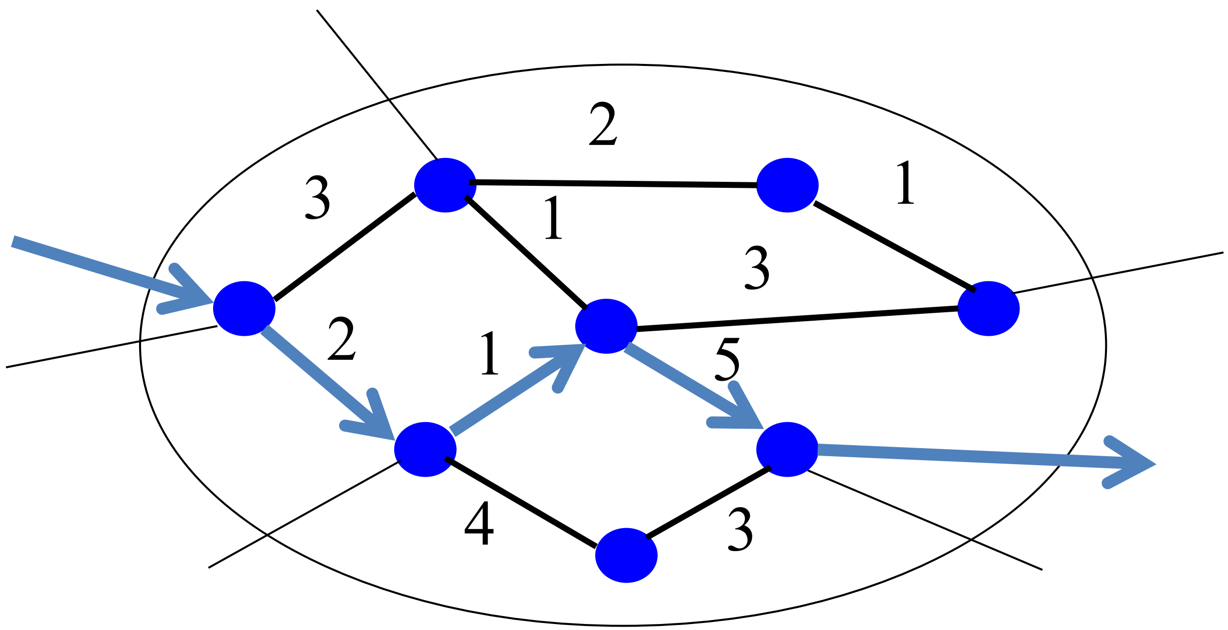
Hierarchy: Routing Protocols

- AS-level topology
  - Nodes are Autonomous Systems (ASes)
  - Edges are links and business relationships
  - Hides the detail within each AS's network



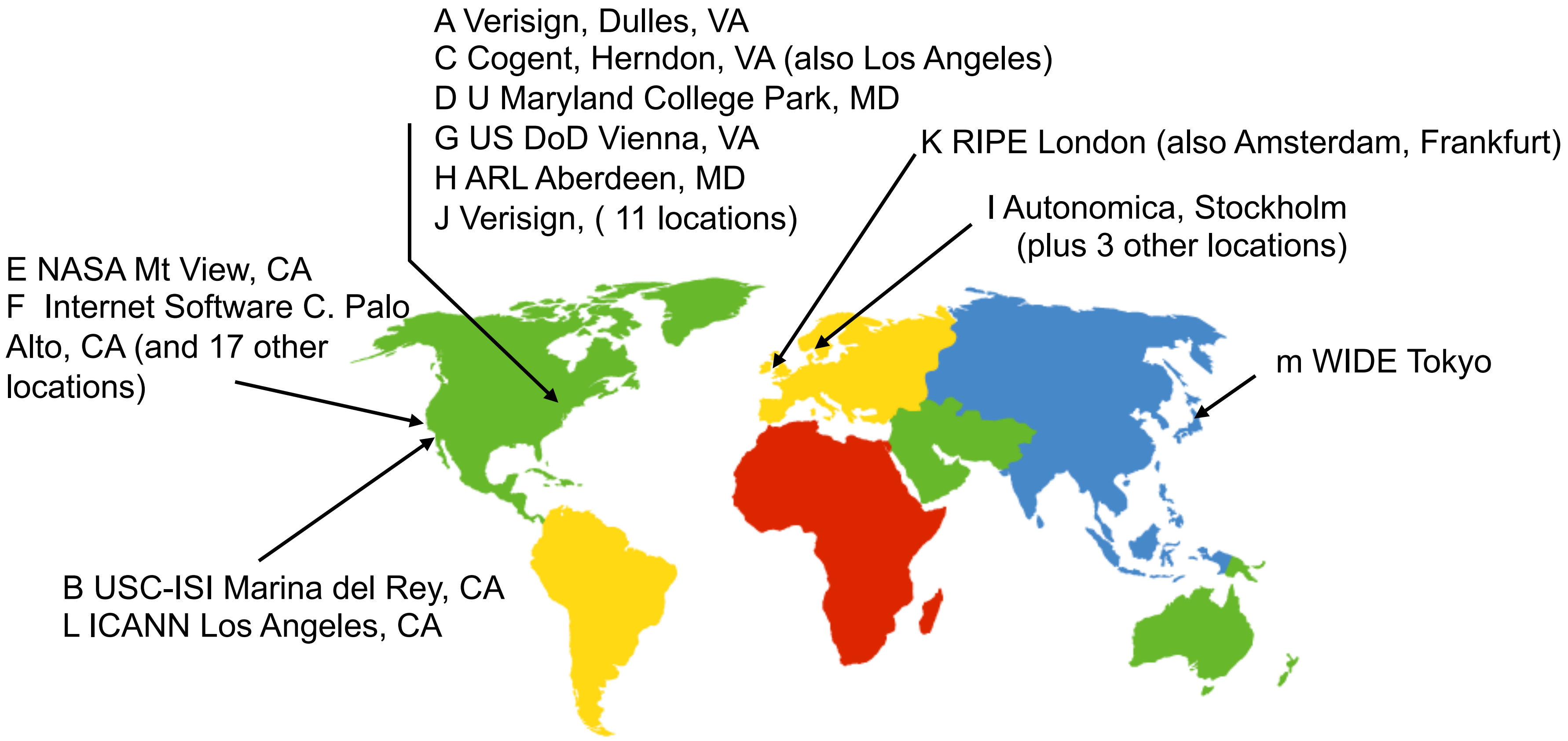
Hierarchy: Routing Protocols

- Interdomain routing ignores details in an AS
  - Routers flood information to learn the topology
  - Routers determine "next hop" to other routers…
  - By computing shortest paths based on link weights

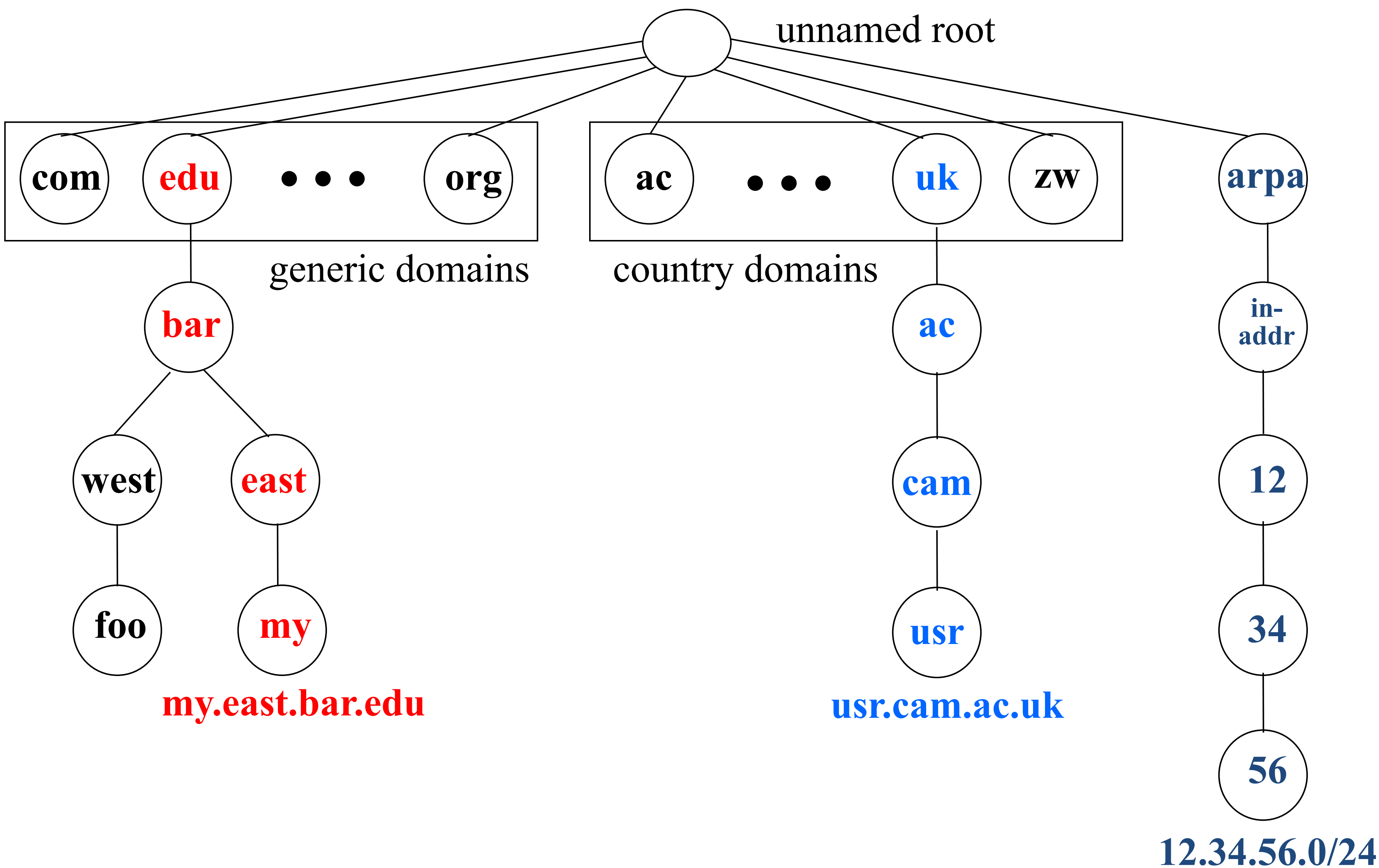


Hierarchy: Domain Name System

- 13 root servers (see http://www.root-servers.org/)
- Labeled A through M

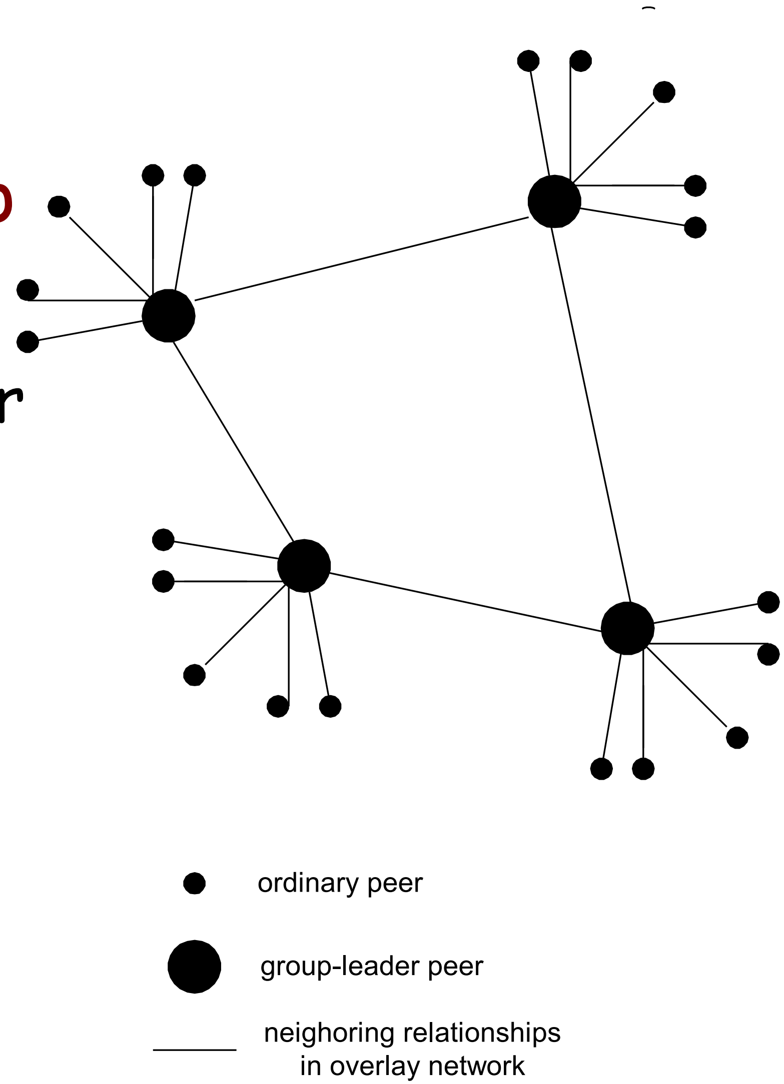


Hierarchy: Domain Name System



Hierarchy: Super Peers in P2P (KaZaA)

- Each peer is either group leader or assigned to group leader
  - TCP connection between peer and its group leader
  - TCP connections between some pairs of group leaders
- Group leader tracks the content in all its children



Indirection

- Referencing by name
  - Rather than the value itself
  - E.g., manipulating a variable through a pointer
- Benefits of indirection
  - Human convenience
  - Reducing overhead when things change
- Examples of indirection in the Internet
  - Names vs. addresses
  - Mobile IP

Indirection: Names vs. Addresses

- Host name to IP address
  - Mnemonic names to location-dependent addresses
  - E.g., from www.cnn.com to 64.236.16.20
  - Using the Domain Name System (DNS)
- From IP address to MAC address
  - From hierarchical global address to interface card
  - E.g., from 64.236.16.20 to 00-15-C5-49-04-A9
  - Using the Address Resolution Protocol (ARP)

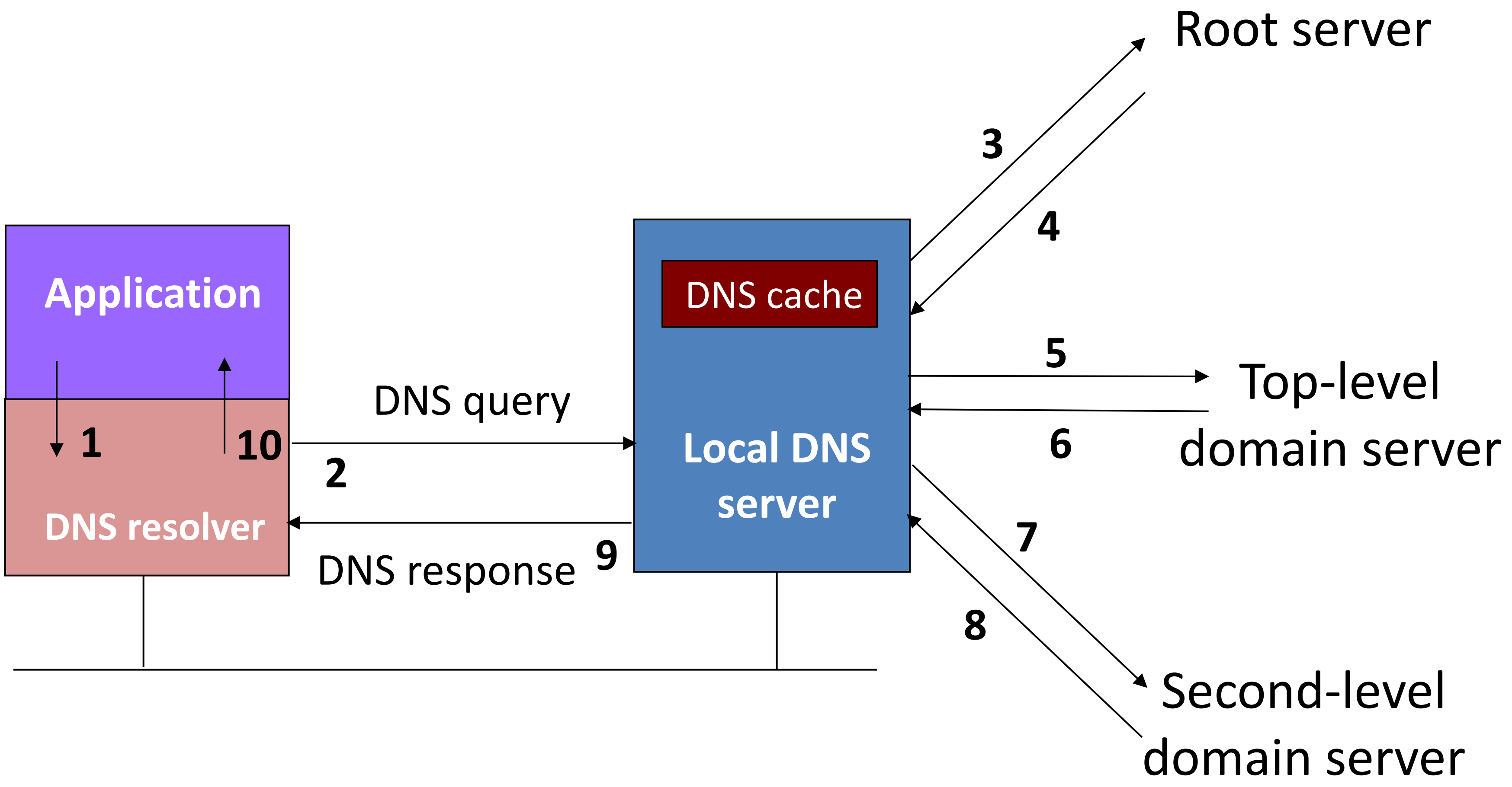
Indirection: Load Balancers & Switches

- Not fixed binding of IPs or MAC address to physical machine
  - NAT allows multiple machines to share single public IP address
  - Load balancers: Machines share IP address, LB maps to physical machine by network flow
  - VM can migrate across L2 network through gratuitous ARP

Caching

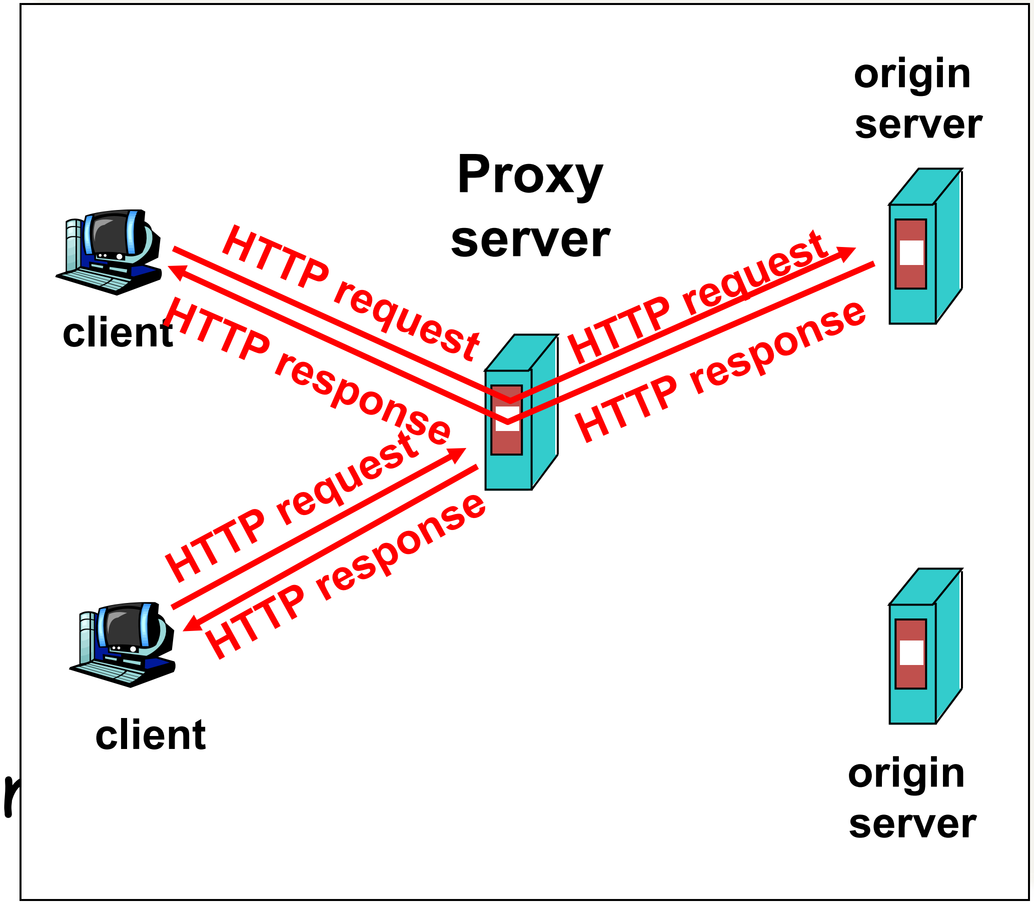
- Duplicating data stored elsewhere
  - To reduce latency for accessing the data
  - To reduce resources consumed
- Caching is often quite effective
  - Speed difference between cache and primary copy
  - Locality of reference, and small set of popular data
- Examples from the Internet
  - DNS caching, Web caching

Caching: DNS Caching



Caching: Web Caching

- Caching location
  - Proxy cache
  - Browser cache
- Better performance
  - Lower RTT
  - Existing connection
  - Less network load

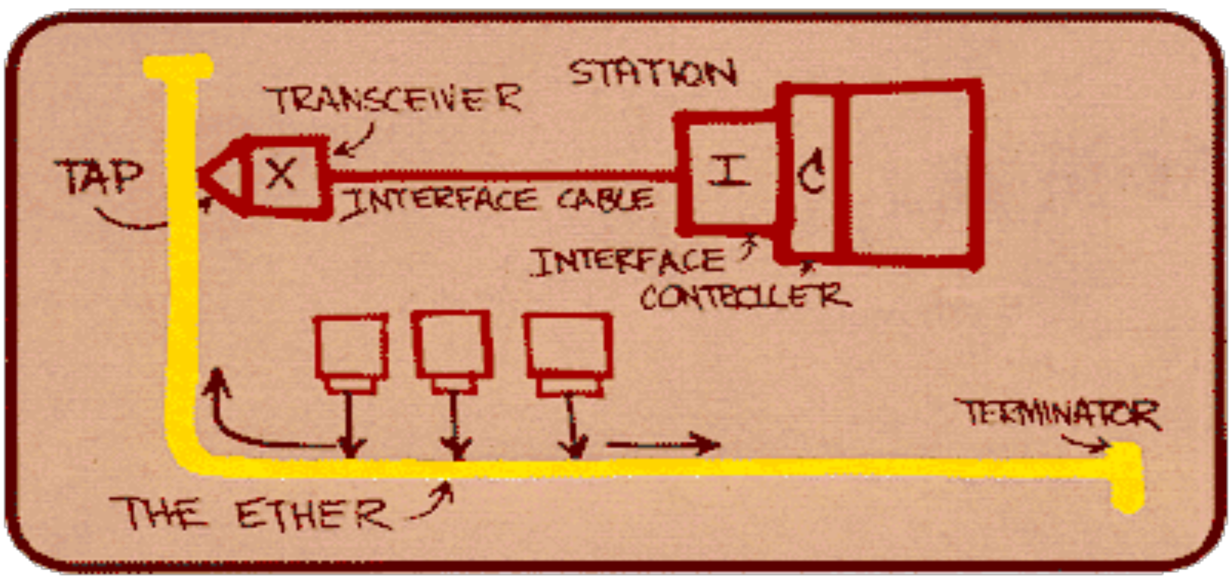


Randomization

- Distributed adaptive algorithms
  - Multiple distributed parties
  - Adapting independently
- Risk of synchronization
  - Many parties reacting at the same time
  - Leading to bad aggregate behavior
- Randomization can desynchronize
  - Ethernet back-off, Random Early Detection
- Rather than imposing centralized control

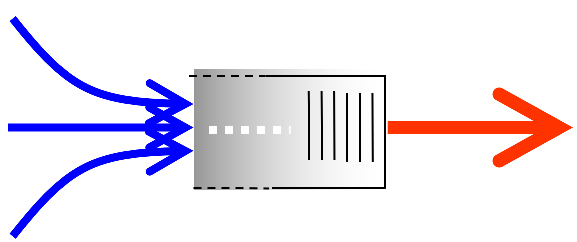
Randomization: Ethernet Back-off

- Random access: exponential back-off
  - After collision, wait random time before retrying
  - After m^{th}, choose K randomly from $\{0, \ldots, 2^m-1\}$
  - Wait for K*512 bit times before trying again



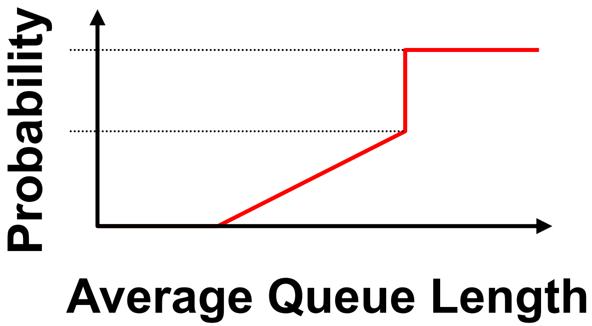
Randomization: Dropping Packets Early

- Congestion on a link
  - Eventually the queue becomes full
  - And new packets must be dropped
- Drop-tail queuing leads to bursty loss
  - Many packets encounter a full queue
  - Many TCP senders reduce their sending rates



Randomization: Dropping Packets Early

- Better to give early feedback
  - Get a few connections to slow down
  - … before it is too late
- Random Early Detection (RED)
  - Randomly drop packets when queue (near) full
  - Drop rate increases as function of queue length



Soft State

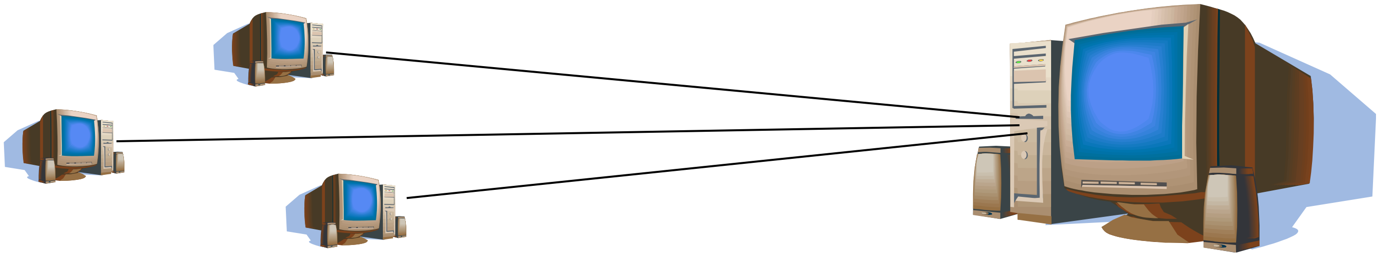
- State: stored in nodes by network protocols
  - Installed by receiver of a set-up message
  - Updated when conditions change

- Hard state: valid unless told otherwise
  - Removed by receiver of tear-down message
  - Requires error handling to deal with sender failure
- Soft state: invalid if not told to refresh
  - Periodically refreshed, removed by timeout

- Soft state reduces complexity
  - DNS caching, DHCP leases

Soft State: DNS Caching

- Cache consistency is a hard problem
  - Ensuring the cached copy is not out of date
- Strawman: explicit revocation or updates
  - Keep track of everyone who has cached information
  - If name-to-host mapping changes, update caches
- Soft state solution
  - DNS responses include a "time to live" (TTL) field
  - Cached entry is deleted after TTL expires

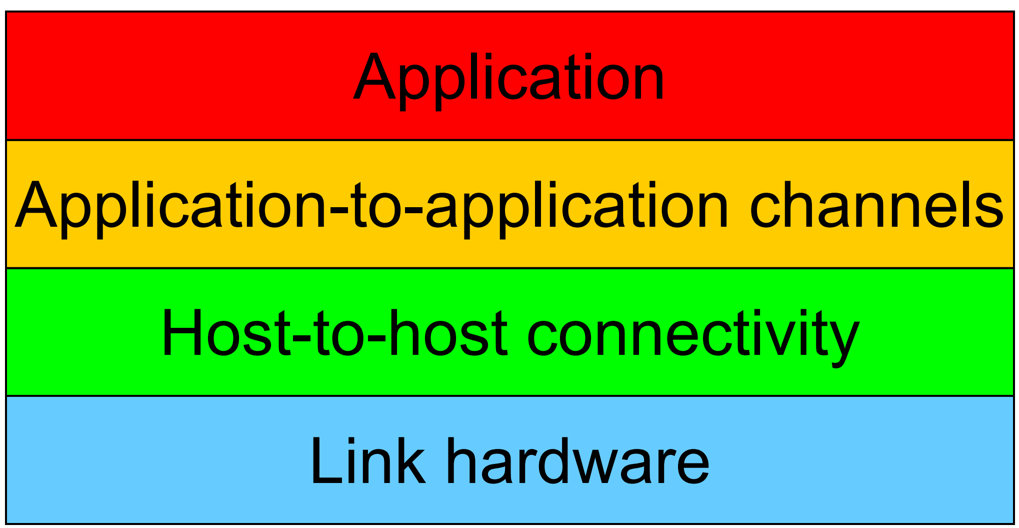


Soft State: DHCP Leases

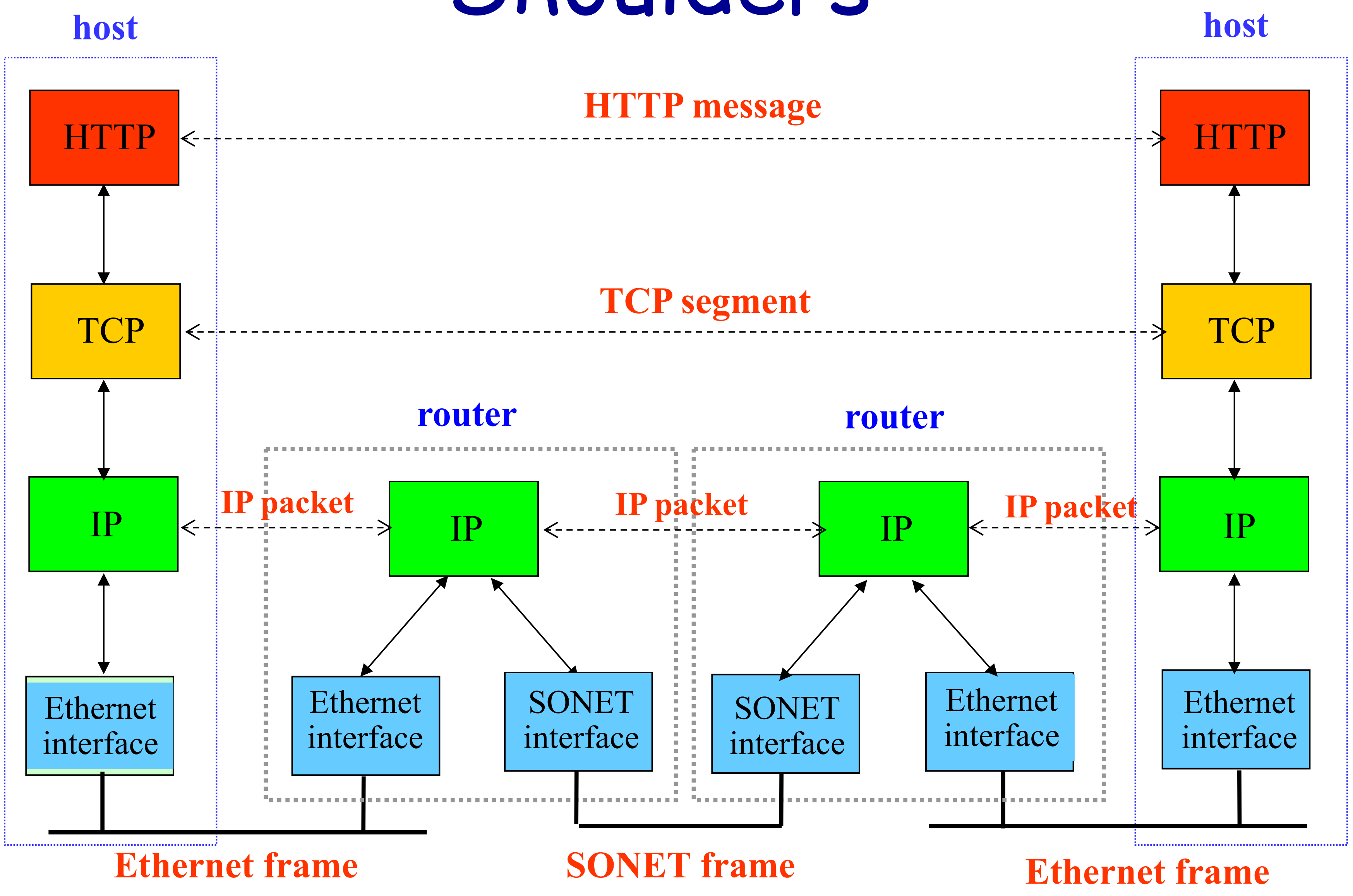
- DHCP "offer message" from the server
  - Configuration parameters (proposed IP address, mask, gateway router, DNS server, ...)
  - Lease time (the time information remains valid)
- Why is a lease time necessary?
  - Client can release address (DHCP RELEASE)
    - E.g., "ipconfig /release" or clean shutdown of computer
  - But, the host might not release the address
    - E.g., the host crashes or buggy client software
  - You don't want address to be allocated forever

Layering: A Modular Approach

- Sub-divide the problem
  - Each layer relies on services from layer below
  - Each layer exports services to layer above
- Interface between layers defines interaction
  - Hides implementation details
  - Layers can change without disturbing other layers

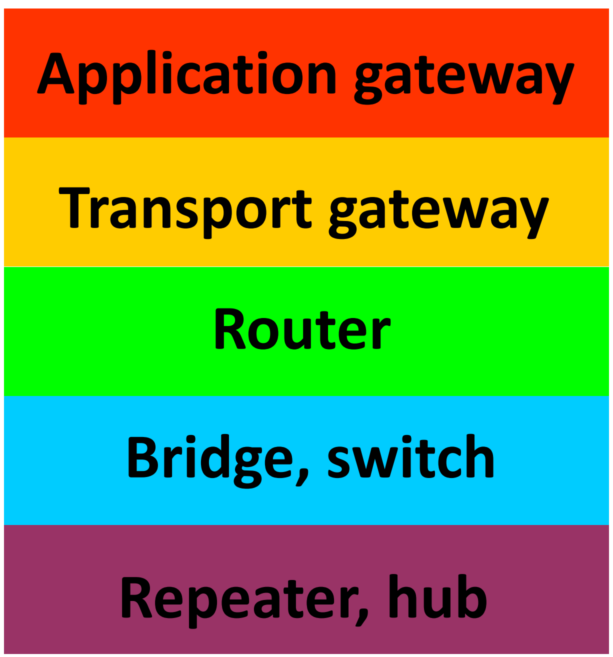


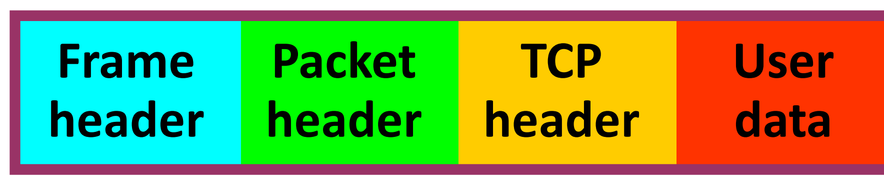
Layering: Standing on Shoulders



Layering: Encapsulation of Data

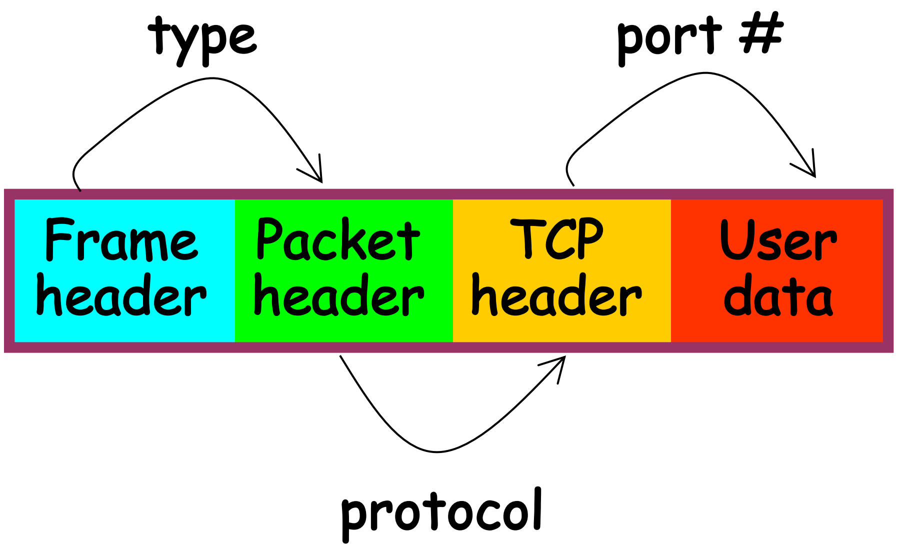
- Different devices switch different things
  - Physical layer: electrical signals (repeaters and hubs)
  - Link layer: frames (bridges and switches)
  - Network layer: packets (routers)



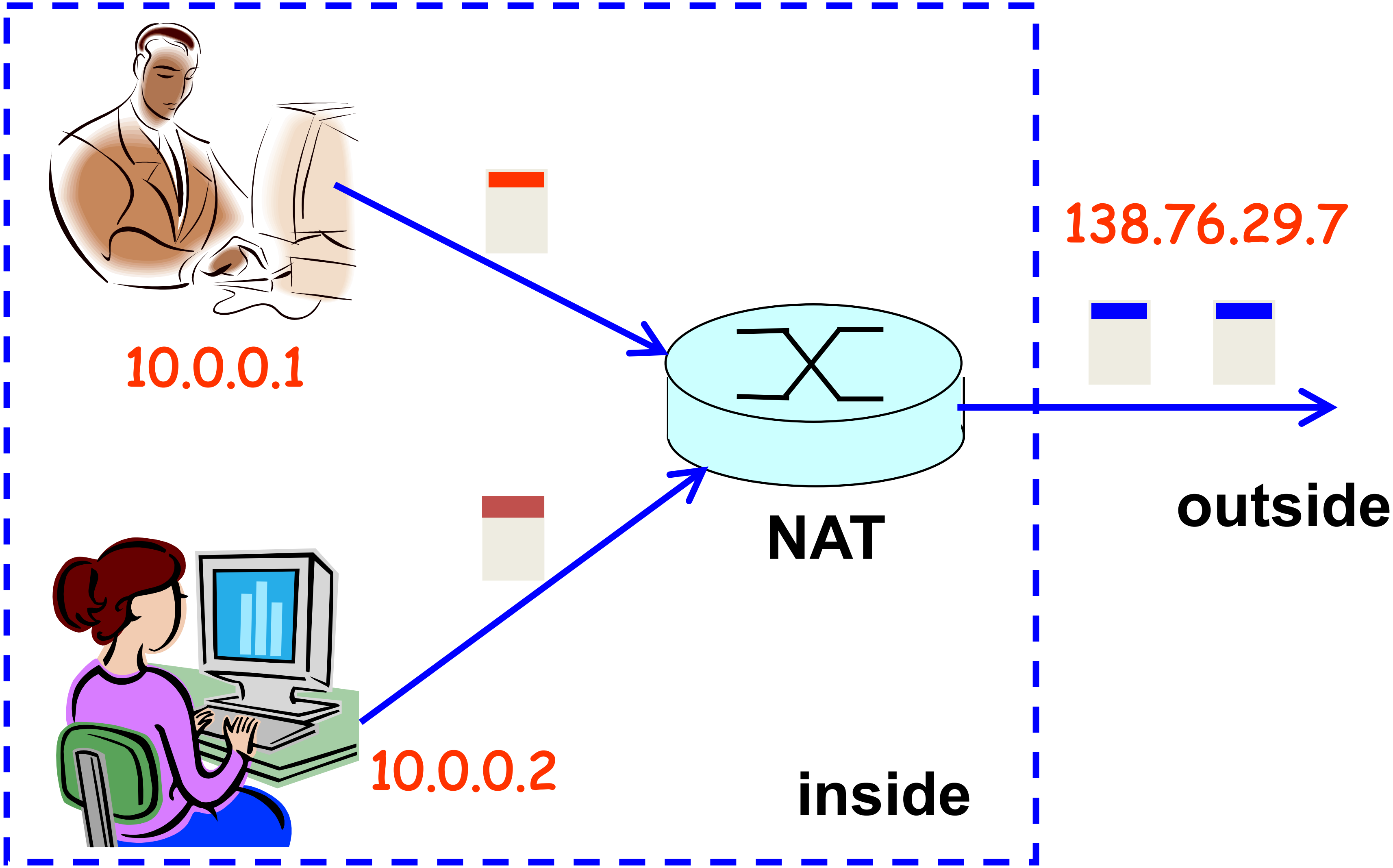


Demultiplexing

- Separating multiple streams out of one
  - Recognizing the separate streams
  - Treating the separate streams accordingly
- Examples in the Internet



(De)multiplexing: With a NAT



Power at the End Host

End-to-End Principle

Whenever possible, communications protocol operations should be defined to occur at the end-points of a communications system.

Programmability

With programmable end hosts, new network services can be added at any time, by anyone.

What Will Happen to the Internet

No Strict Notions of Identity

"On the Internet, nobody knows you're a dog."

- Leads to
  - Spam
  - Spoofing
  - Denial-of-service
  - Route hijacking

Protocols Designed Based on Trust

- That you don't spoof your addresses
  - MAC spoofing, IP address spoofing, spam, …
- That port numbers correspond to applications
  - Rather than being arbitrary, meaningless numbers
- That you adhere to the protocol
  - Ethernet exponential back-off after a collision
  - TCP additive increase, multiplicative decrease
- That protocol specifications are public
  - So others can build interoperable implementations

Nobody in Charge

- Traffic traverses many Autonomous Systems
  - Who's fault is it when things go wrong?
  - How do you upgrade functionality?
- Implicit trust in the end host
  - What if some hosts violate congestion control?
- Anyone can add any application
  - Whether or not it is legal, moral, good, etc.
- Spans many countries
  - So no one government can be in charge

Challenging New Requirements

- Disseminating data
- Mobile, multi-homed hosts
- Sometimes-connected hosts
- Large number of hosts
- Real-time applications

The Internet of the Future

- Can we fix what ails the Internet
  - Security, performance, reliability
  - Upgradability, managability
  - <Your favorite gripe here>
- Without throwing out baby with bathwater
  - Ease of adding new hosts
  - Ease of adding new services
  - Ease of adding new link technologies
- An open technical and policy question…