IP Packet Switching

COS 461: Computer Networks
Spring 2008 (MW 1:30-2:50 in COS 105)

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http://www.cs.princeton.edu/courses/archive/spring09/cos461/

Goals of Today's Lecture

- Connectivity
  - Links and nodes
  - Circuit switching
  - Packet switching
- IP service model
  - Best-effort packet delivery
  - IP as the Internet's "narrow waist"
  - Design philosophy of IP
- IP packet structure
  - Fields in the IP header
  - Traceroute using TTL field
  - Source-address spoofing

Simple Network: Nodes and a Link

- Node: computer
  - End host: general-purpose computer, cell phone, PDA
  - Network node: switch or router
- Link: physical medium connecting nodes
  - Twisted pair: the wire that connects to telephones
  - Coaxial cable: the wire that connects to TV sets
  - Optical fiber: high-bandwidth long-distance links
  - Space: propagation of radio waves, microwaves, …

Network Components

Links

Fibers

Coaxial Cable

Interfaces

Ethernet card

Wireless card

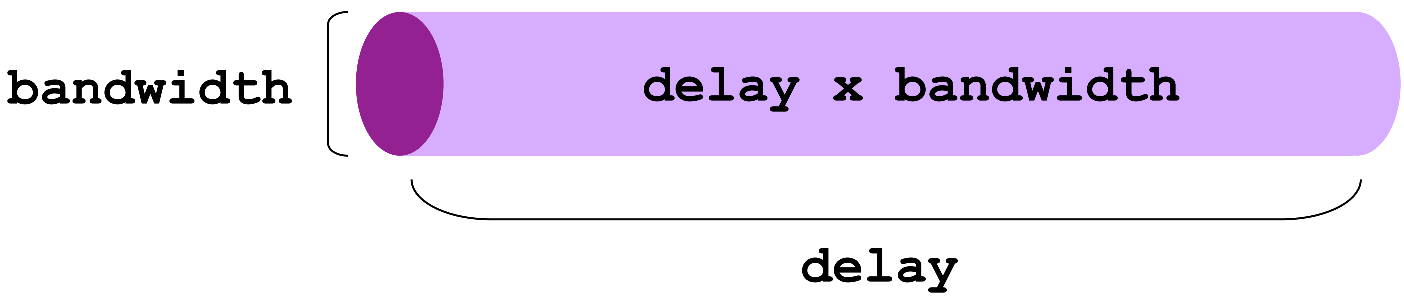
Switches/routers

Large router

Telephone switch

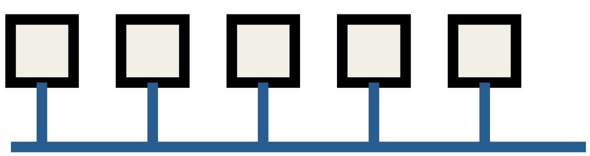
Links: Delay and Bandwidth

- Delay
  - Latency for propagating data along the link
  - Corresponds to the "length" of the link
  - Typically measured in seconds
- Bandwidth
  - Amount of data sent (or received) per unit time
  - Corresponds to the "width" of the link
  - Typically measured in bits per second

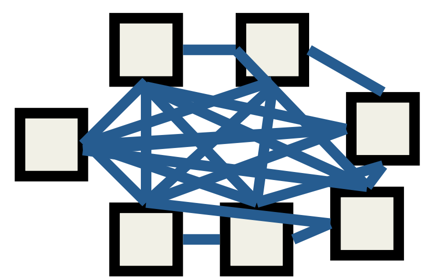


Connecting More Than Two Hosts

- Multi-access link: Ethernet, wireless
  - Single physical link, shared by multiple nodes
  - Limitations on distance and number of nodes
- Point-to-point links: fiber-optic cable
  - Only two nodes (separate link per pair of nodes)
  - Limitations on the number of adapters per node

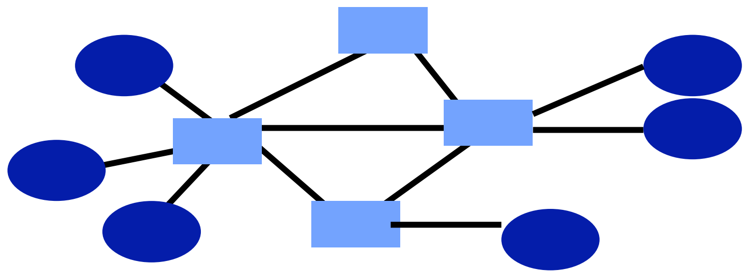


multi-access link



point-to-point links

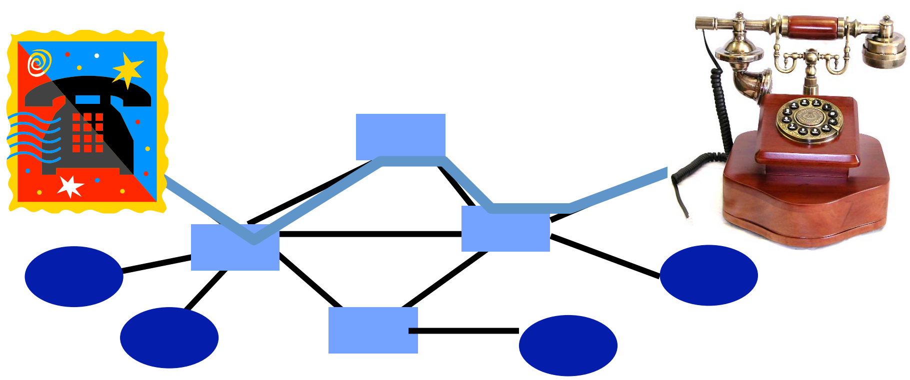
Beyond Directly-Connected Networks



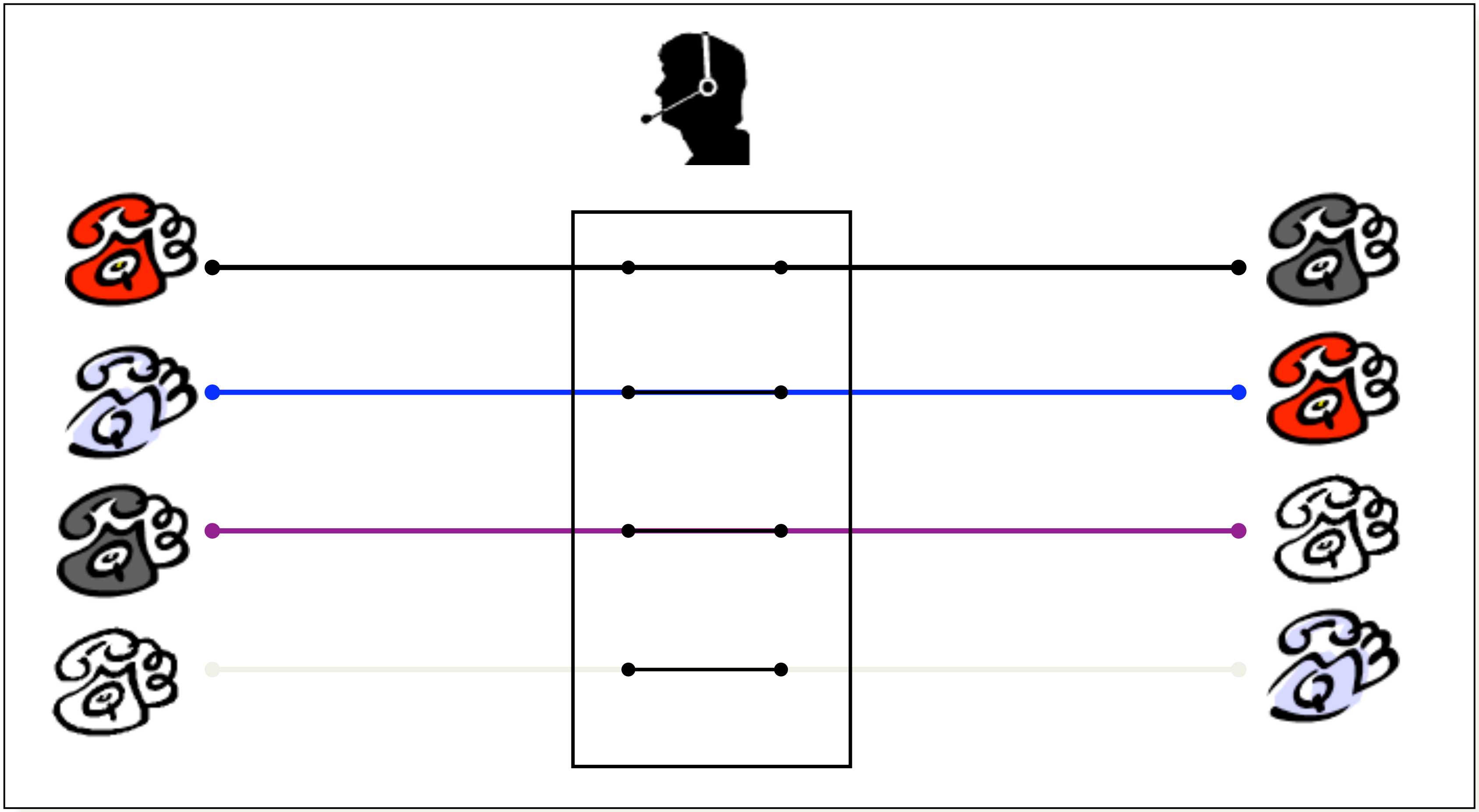
- Switched network
  - End hosts at the edge
  - Network nodes that switch traffic
  - Links between the nodes
- Multiplexing
  - Many end hosts communicate over the network
  - Traffic shares access to the same links

Circuit Switching (e.g., Phone Network)

- Source establishes connection to destination
  - Node along the path store connection info
  - Nodes may reserve resources for the connection
- Source sends data over the connection
  - No destination address, since nodes know path
- Source tears down connection when done

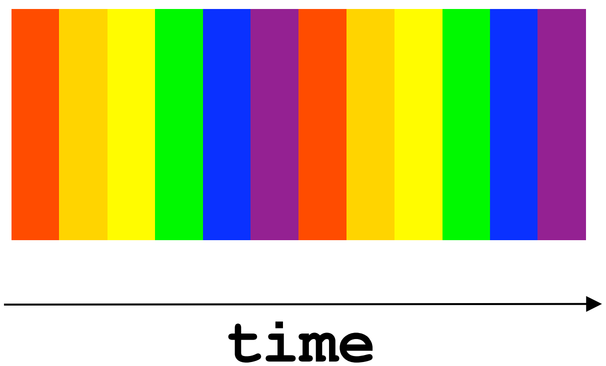


Circuit Switching With Human Operator

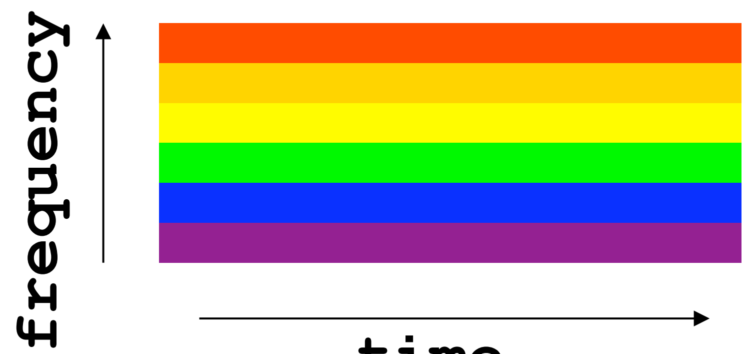


Circuit Switching: Multiplexing a Link

- Time-division
  – Each circuit allocated certain time slots



- Frequency-division
  – Each circuit allocated certain frequencies



Advantages of Circuit Switching

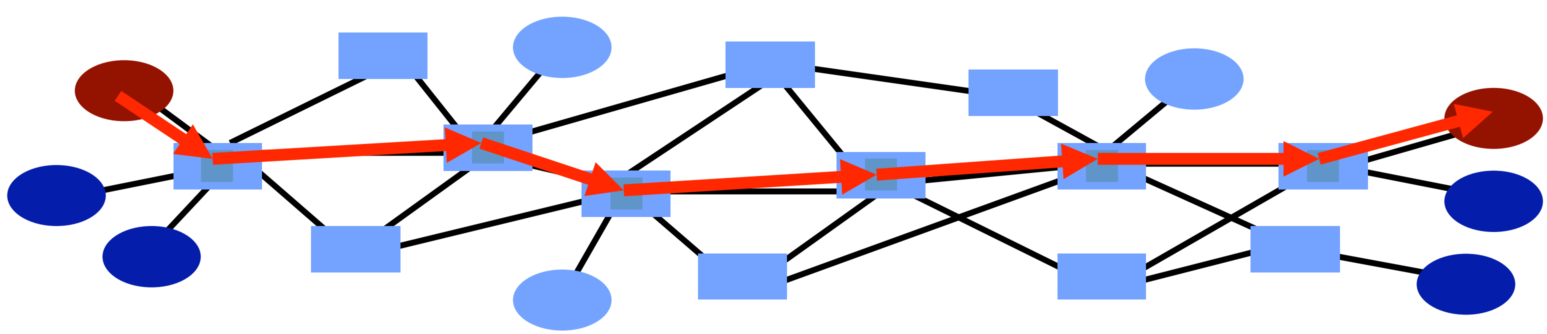
- Guaranteed bandwidth
  - Predictable communication performance
  - Not "best-effort" delivery with no real guarantees
- Simple abstraction
  - Reliable communication channel between hosts
  - No worries about lost or out-of-order packets
- Simple forwarding
  - Forwarding based on time slot or frequency
  - No need to inspect a packet header
- Low per-packet overhead
  - Forwarding based on time slot or frequency
  - No IP (and TCP/UDP) header on each packet

Disadvantages of Circuit Switching

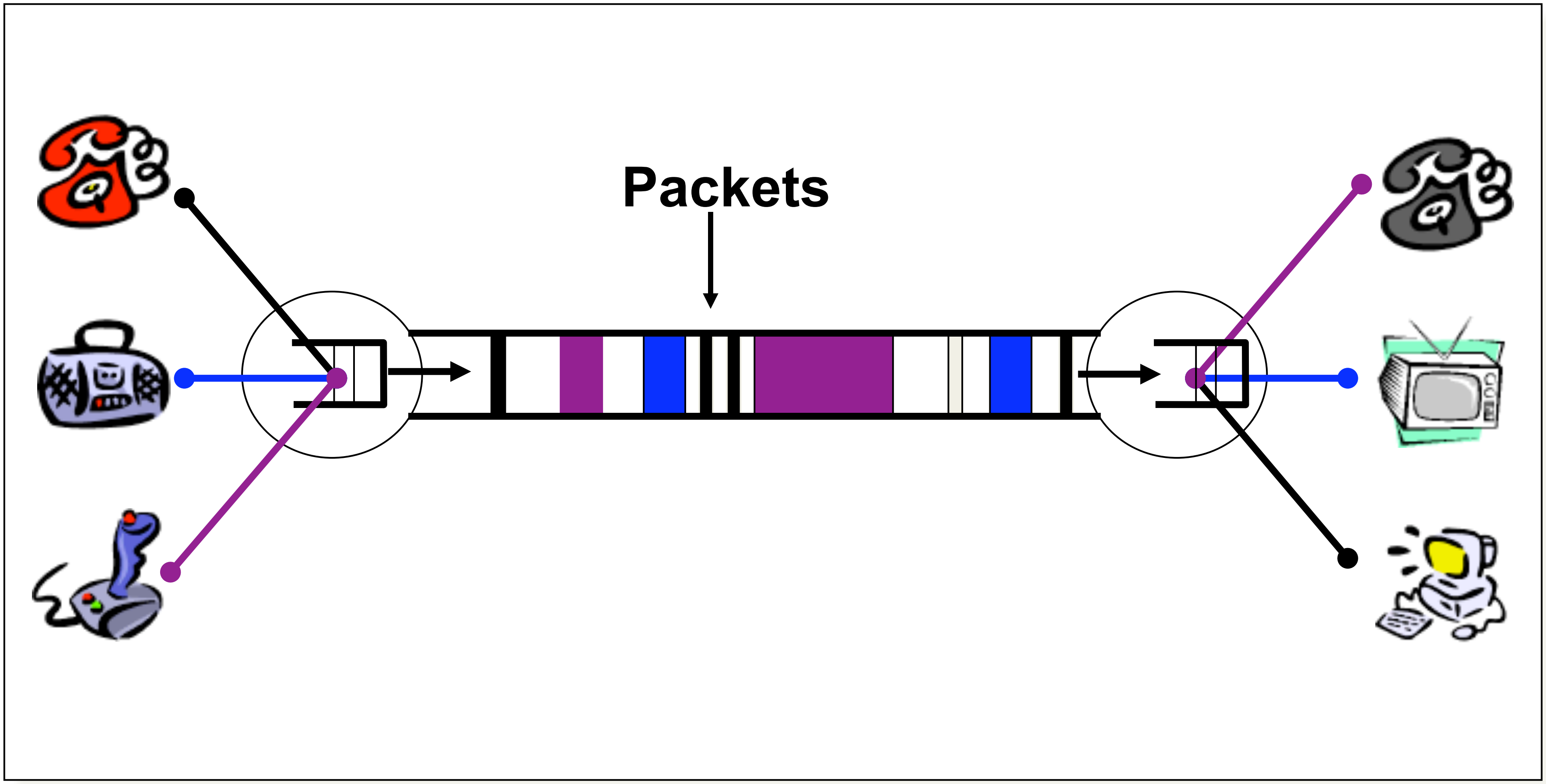
- Wasted bandwidth
  - Bursty traffic leads to idle conn during silent period
  - Unable to achieve gains from statistical multiplexing
- Blocked connections
  - Connection refused when resources are not sufficient
  - Unable to offer “okay” service to everybody
- Connection set-up delay
  - No communication until the connection is set up
  - Unable to avoid extra latency for small data transfers
- Network state
  - Network nodes must store per-connection information
  - Unable to avoid per-connection storage and state

Packet Switching (e.g., Internet)

- Data traffic divided into packets
  - Each packet contains a header (with address)
- Packets travel separately through network
  - Packet forwarding based on the header
  - Network nodes may store packets temporarily
- Destination reconstructs the message

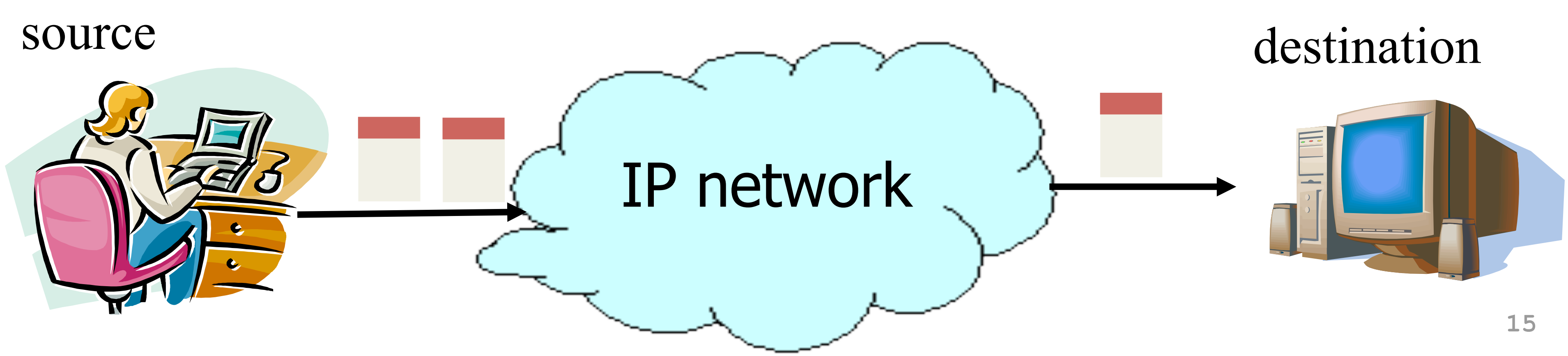


Packet Switching: Statistical Multiplexing



IP Service: Best-Effort Packet Delivery

- Packet switching
  - Divide messages into a sequence of packets
  - Headers with source and destination address
- Best-effort delivery
  - Packets may be lost
  - Packets may be corrupted
  - Packets may be delivered out of order



IP Service Model: Why Packets?

- Data traffic is bursty
  - Logging in to remote machines
  - Exchanging e-mail messages
- Don't want to waste bandwidth
  - No traffic exchanged during idle periods
- Better to allow multiplexing
  - Different transfers share access to same links
- Packets can be delivered by most anything
  - RFC 1149: IP Datagrams over Avian Carriers
- … still, packet switching can be inefficient
  - Extra header bits on every packet

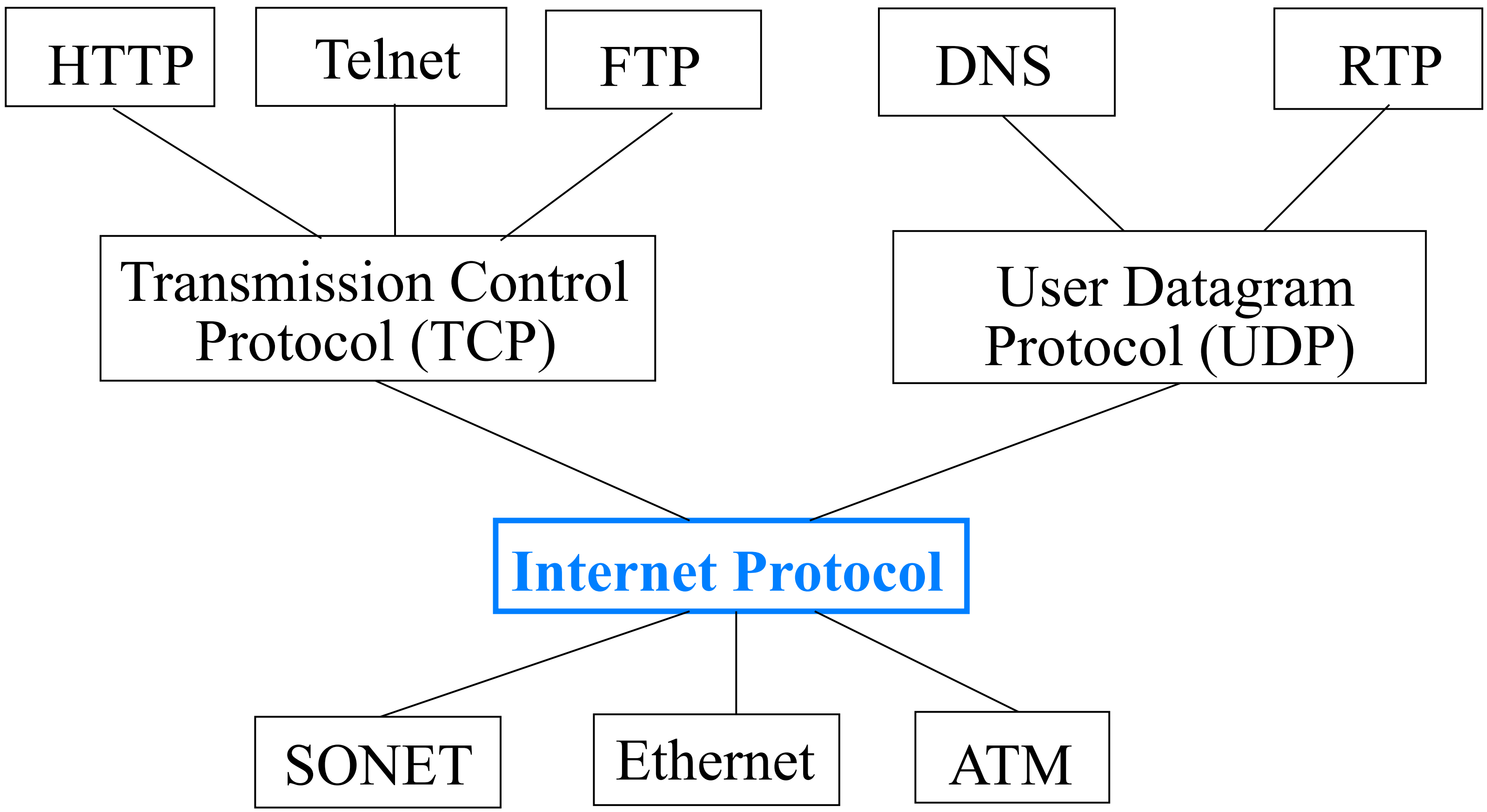
IP Service Model: Why Best-Effort?

- IP means never having to say you're sorry…
  - Don't need to reserve bandwidth and memory
  - Don't need to do error detection & correction
  - Don't need to remember from one packet to next
- Easier to survive failures
  - Transient disruptions are okay during failover
- … but, applications *do* want efficient, accurate transfer of data in order, in a timely fashion

IP Service: Best-Effort is Enough

- No error detection or correction
  - Higher-level protocol can provide error checking
- Successive packets may not follow the same path
  - Not a problem as long as packets reach the destination
- Packets can be delivered out-of-order
  - Receiver can put packets back in order (if necessary)
- Packets may be lost or arbitrarily delayed
  - Sender can send the packets again (if desired)
- No network congestion control (beyond "drop")
  - Sender can slow down in response to loss or delay

Layering in the IP Protocols



History: Why IP Packets?

- IP proposed in the early 1970s
  - Defense Advanced Research Project Agency (DARPA)
- Goal: connect existing networks
  - To develop an effective technique for multiplexed utilization of existing interconnected networks
  - E.g., connect packet radio networks to the ARPAnet
- Motivating applications
  - Remote login to server machines
  - Inherently bursty traffic with long silent periods
- Prior ARPAnet experience with packet switching
  - Previous DARPA project
  - Demonstrated store-and-forward packet switching

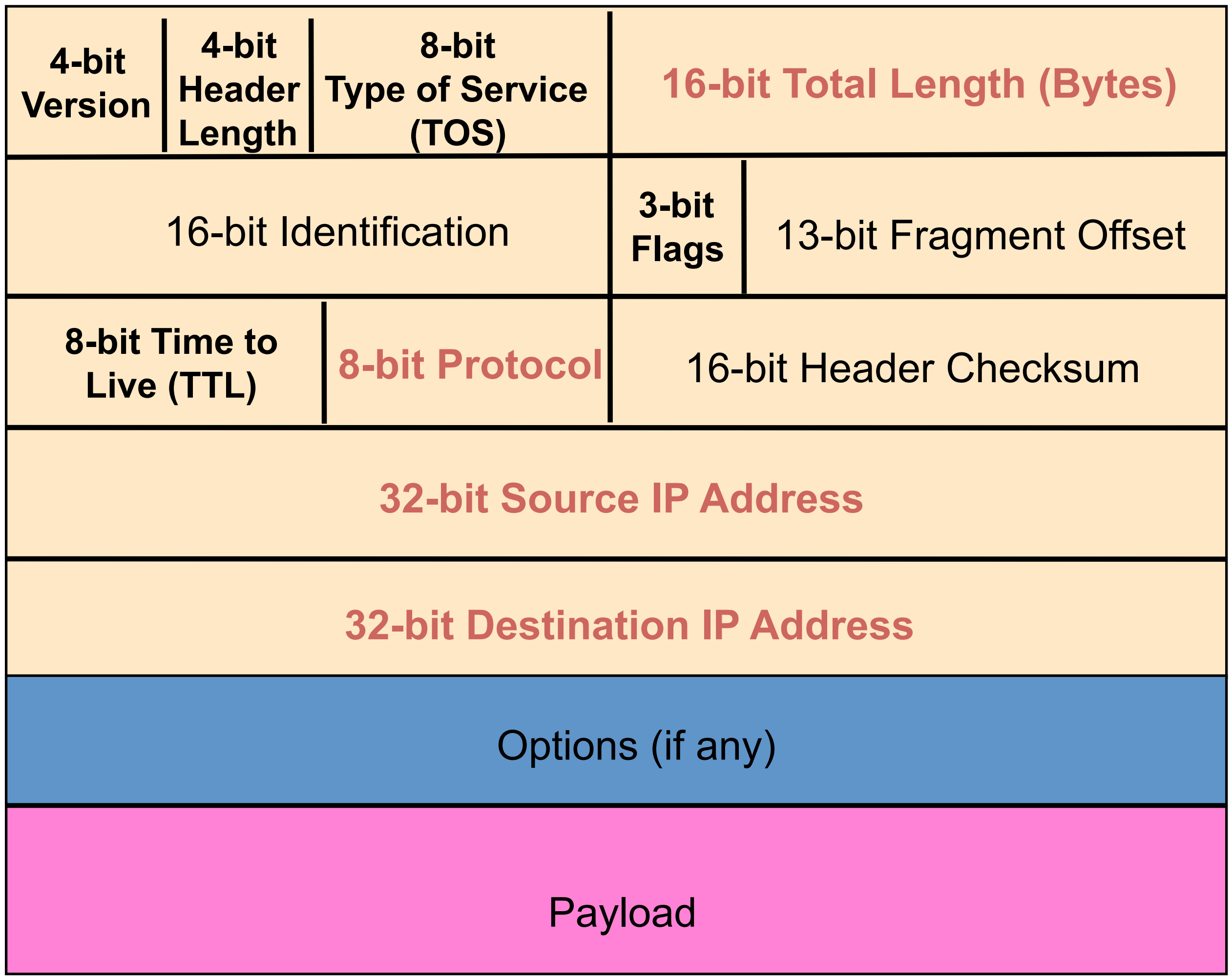
Other Main Driving Goals (In Order)

- Communication should continue despite failures
  - Survive equipment failure or physical attack
  - Traffic between two hosts continue on another path
- Support multiple types of communication services
  - Differing requirements for speed, latency, & reliability
  - Bidirectional reliable delivery vs. message service
- Accommodate a variety of networks
  - Both military and commercial facilities
  - Minimize assumptions about the underlying network

Other Driving Goals, Somewhat Met

- Permit distributed management of resources
  - Nodes managed by different institutions
  - … though this is still rather challenging
- Cost-effectiveness
  - Statistical multiplexing through packet switching
  - … though packet headers and retransmissions wasteful
- Ease of attaching new hosts
  - Standard implementations of end-host protocols
  - … though still need a fair amount of end-host software
- Accountability for use of resources
  - Monitoring functions in the nodes
  - … though this is still fairly limited and immature

IP Packet Structure



IP Header: Version, Length, ToS

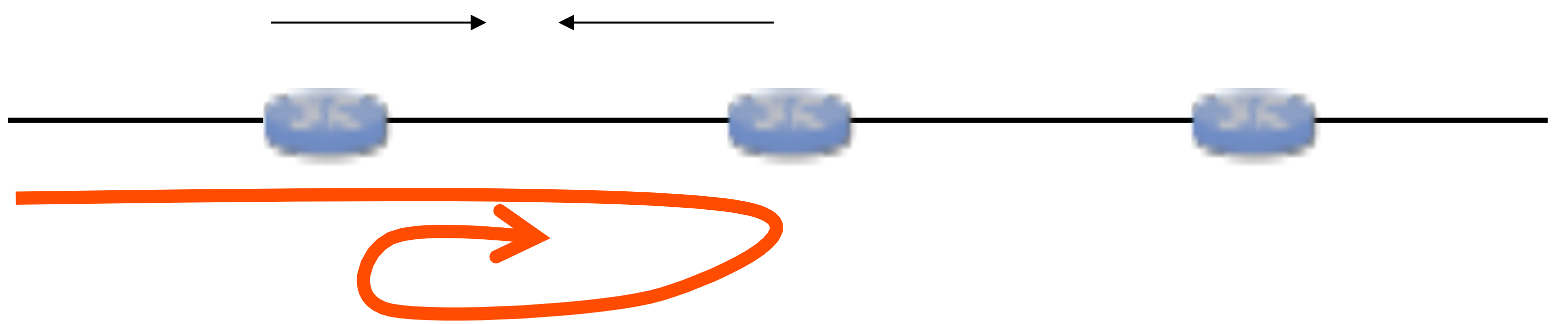
- Version number (4 bits)
  - Indicates the version of the IP protocol
  - Necessary to know what other fields to expect
  - Typically "4" (for IPv4), and sometimes "6" (for IPv6)
- Header length (4 bits)
  - Number of 32-bit words in the header
  - Typically "5" (for a 20-byte IPv4 header)
  - Can be more when "IP options" are used
- Type-of-Service (8 bits)
  - Allow packets to be treated differently based on needs
  - E.g., low delay for audio, high b/w for bulk transfer

IP Header: Length, Fragments, TTL

- Total length (16 bits)
  - Number of bytes in the packet
  - Maximum size is 63,535 bytes (2^{16} -1)
  - … though underlying links may impose harder limits
- Fragmentation information (32 bits)
  - Packet identifier, flags, and fragment offset
  - Supports dividing a large IP packet into fragments
  - … in case a link cannot handle a large IP packet
  - … so why do we typically send max MTU packets?
- Time-To-Live (8 bits)
  - Used to identify packets stuck in forwarding loops
  - … and eventually discard them from the network

IP Header: More on Time-to-Live (TTL)

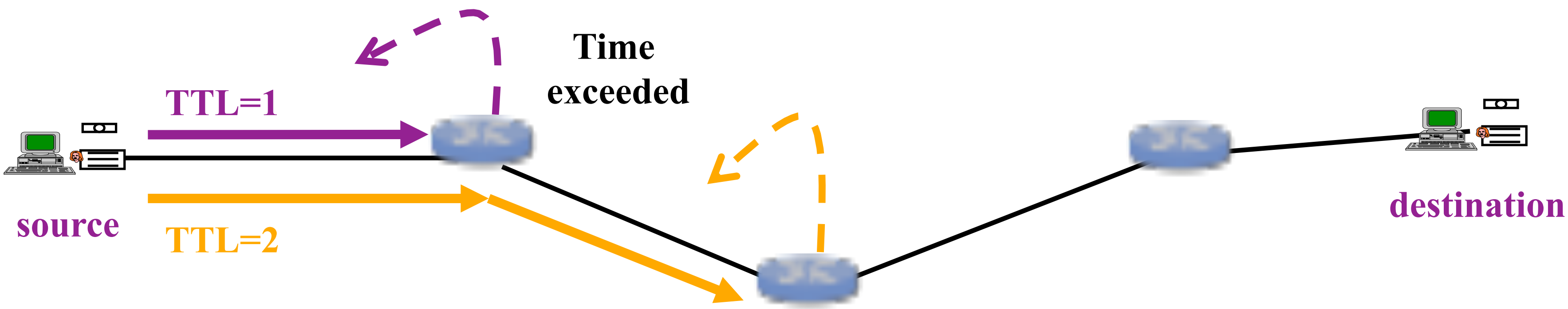
- Potential robustness problem
  - Forwarding loops can cause packets to cycle forever
  - Confusing if the packet arrives much later



- Time-to-live field in packet header
  - TTL field decremented by each router on the path
  - Packet is discarded when TTL field reaches 0…
  - …and "time exceeded" message is sent to the source

IP Header: Use of TTL in Traceroute

- Time-To-Live field in IP packet header
  - Source sends a packet with a TTL of *n*
  - Each router along the path decrements the TTL
  - "TTL exceeded" sent when TTL reaches *0*
- Traceroute tool exploits this TTL behavior



Send packets with TTL=1, 2, …
and record source of "time exceeded" message

Example Traceroute: Berkeley to CNN

Hop number, IP address, DNS name

1	169.229.62.1	inr-daedalus-0.CS.Berkeley.EDU
2	169.229.59.225	soda-cr-1-1-soda-br-6-2
3	128.32.255.169	vlan242.inr-202-doecev.Berkeley.EDU
4	128.32.0.249	gigE6-0-0.inr-666-doecev.Berkeley.EDU
5	128.32.0.66	qsv-juniper--ucb-gw.calren2.net
6	209.247.159.109	POS1-0.hsipaccess1.SanJose1.Level3.net
7	*	?
8	64.159.1.46	?
9	209.247.9.170	pos8-0.hsa2.Atlanta2.Level3.net
10	66.185.138.33	pop2-atm-P0-2.atdn.net
11	*	?
12	66.185.136.17	pop1-atl-P4-0.atdn.net
13	64.236.16.52	www4.cnn.com

No response from router

No name resolution

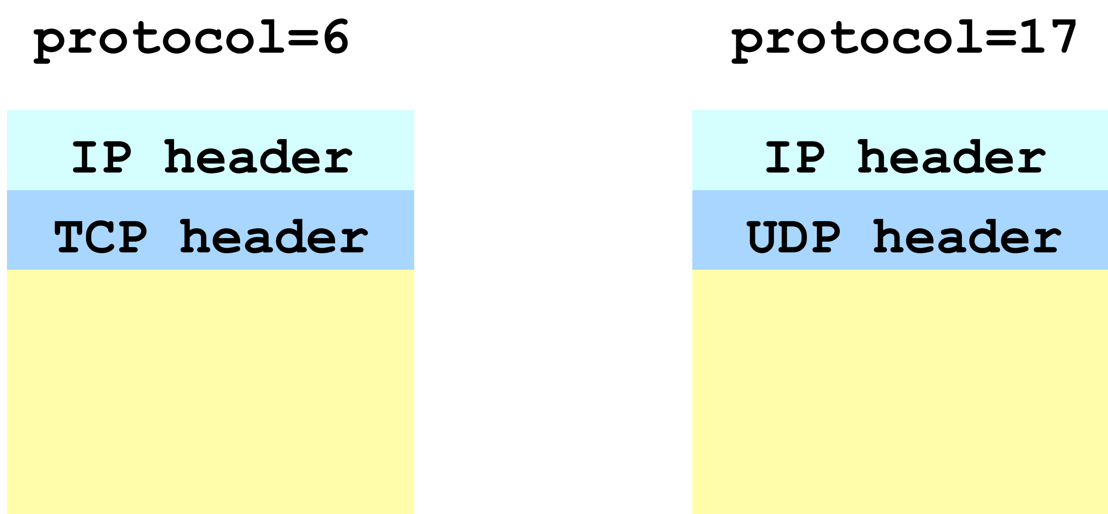
Try Running Traceroute Yourself

- On UNIX machine
  - Traceroute
  - E.g., “traceroute cnn.com” or “traceroute 12.1.1.1”
- On Windows machine
  - Tracert
  - E.g., “tracert cnn.com” or “tracert 12.1.1.1”

- Common uses of traceroute
  - Discover the topology of the Internet
  - Debug performance and reachability problems

IP Header Fields: Transport Protocol

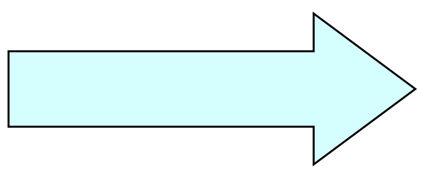
- Protocol (8 bits)
  - Identifies the higher-level protocol
    - E.g., "6" for the Transmission Control Protocol (TCP)
    - E.g., "17" for the User Datagram Protocol (UDP)
  - Important for demultiplexing at receiving host
    - Indicates what kind of header to expect next



IP Header: Checksum on the Header

- Checksum (16 bits)
  - Sum of all 16-bit words in the IP packet header
  - If any bits of the header are corrupted in transit
  - … the checksum won't match at receiving host
  - Receiving host discards corrupted packets
    - Sending host will retransmit the packet, if needed

```
  134
+ 212
-----
= 346
```



```
  134
+ 216
-----
= 350
```

Mismatch!

IP Header: To and From Addresses

- Two IP addresses
  - Source IP address (32 bits)
  - Destination IP address (32 bits)
- Destination address
  - Unique identifier for the receiving host
  - Allows each node to make forwarding decisions
- Source address
  - Unique identifier for the sending host
  - Recipient can decide whether to accept packet
  - Enables recipient to send a reply back to source

Source Address: What if Source Lies?

- Source address should be the sending host
  - But, who's checking, anyway?
  - You could send packets with any source you want

- Why would someone want to do this?
  - Launch a denial-of-service attack
    - Send excessive packets to the destination
    - … to overload the node, or the links leading to the node
  - Evade detection by "spoofing"
    - But, the victim could identify you by the source address
    - So, you can put someone else's source address in the packets
  - Also, an attack against the spoofed host
    - Spoofed host is wrongly blamed
    - Spoofed host may receive return traffic from the receiver

Summary: Packet Switching Review

- Efficient
  - Can send from any input that is ready
- General
  - Multiple types of applications
- Accommodates bursty traffic
  - Addition of queues
- Store and forward
  - Packets are self contained units
  - Can use alternate paths – reordering
- Contention (i.e., no isolation)
  - Congestion
  - Delay

Next Lecture

- IP routers
  - Packet forwarding
  - Components of a router
- Reading for this week
  - Chapter 3: Sections 3.1 and 3.4
  - Chapter 4: Sections 4.1.1 -- 4.1.4
- Please subscribe to the course mailing list
  - https://lists.cs.princeton.edu/mailman/listinfo/cos461