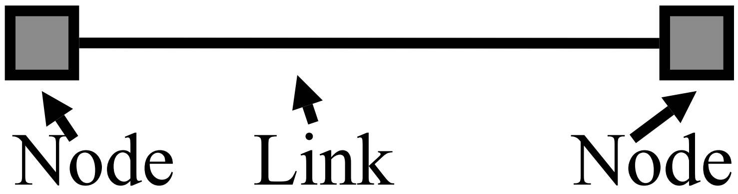
CE 443
IP Packet Switching Networks

Acknowledgments: Lecture slides are from Computer networks course thought by Jennifer Rexford at Princeton University. When slides are obtained from other sources, a a reference will be noted on the bottom of that slide. A full list of references is provided on the last slide.

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

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

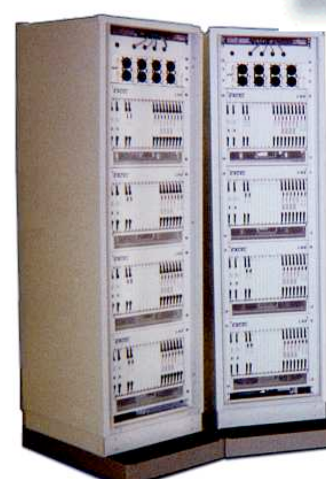
Interfaces

Ethernet card

Wireless card

Switches/routers

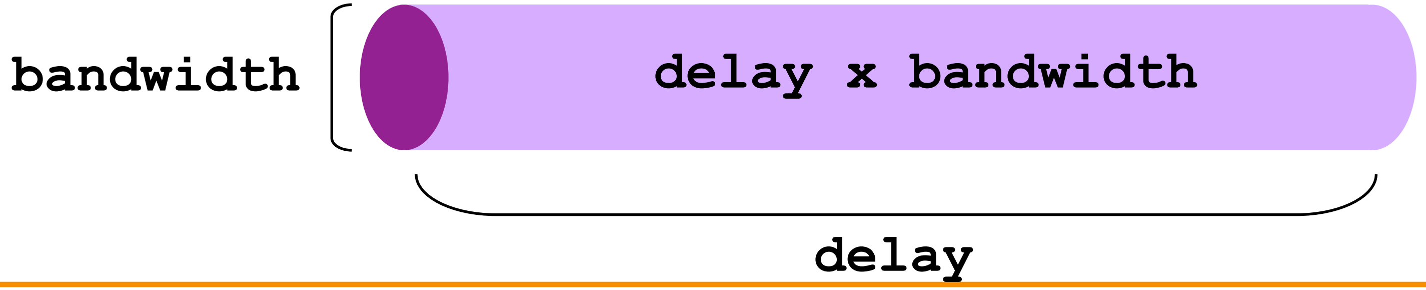
Large router



Telephone switch

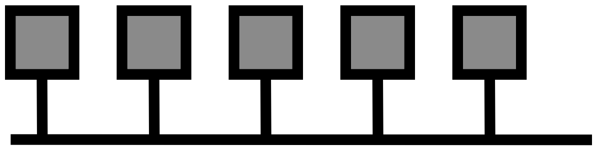
Links: Delay and Bandwidth

- 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

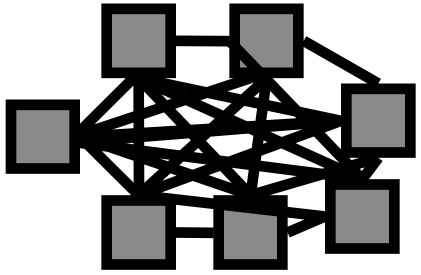


Connecting More Than Two Hosts

- 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

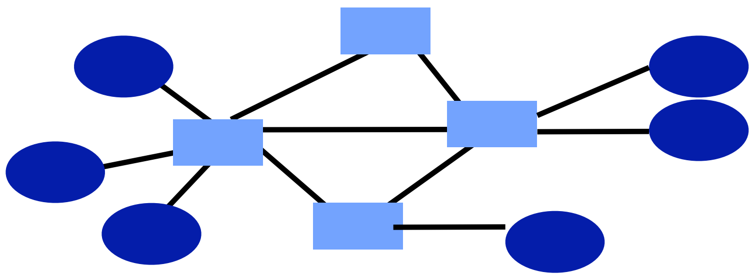


multi-access link



point-to-point links

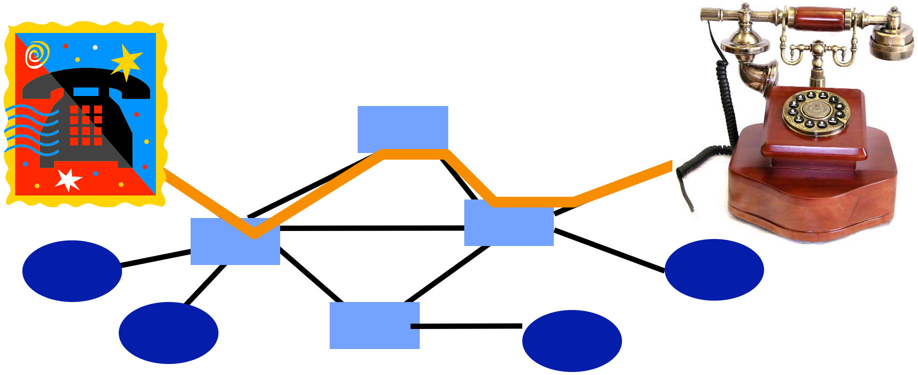
Beyond Directly-Connected Networks



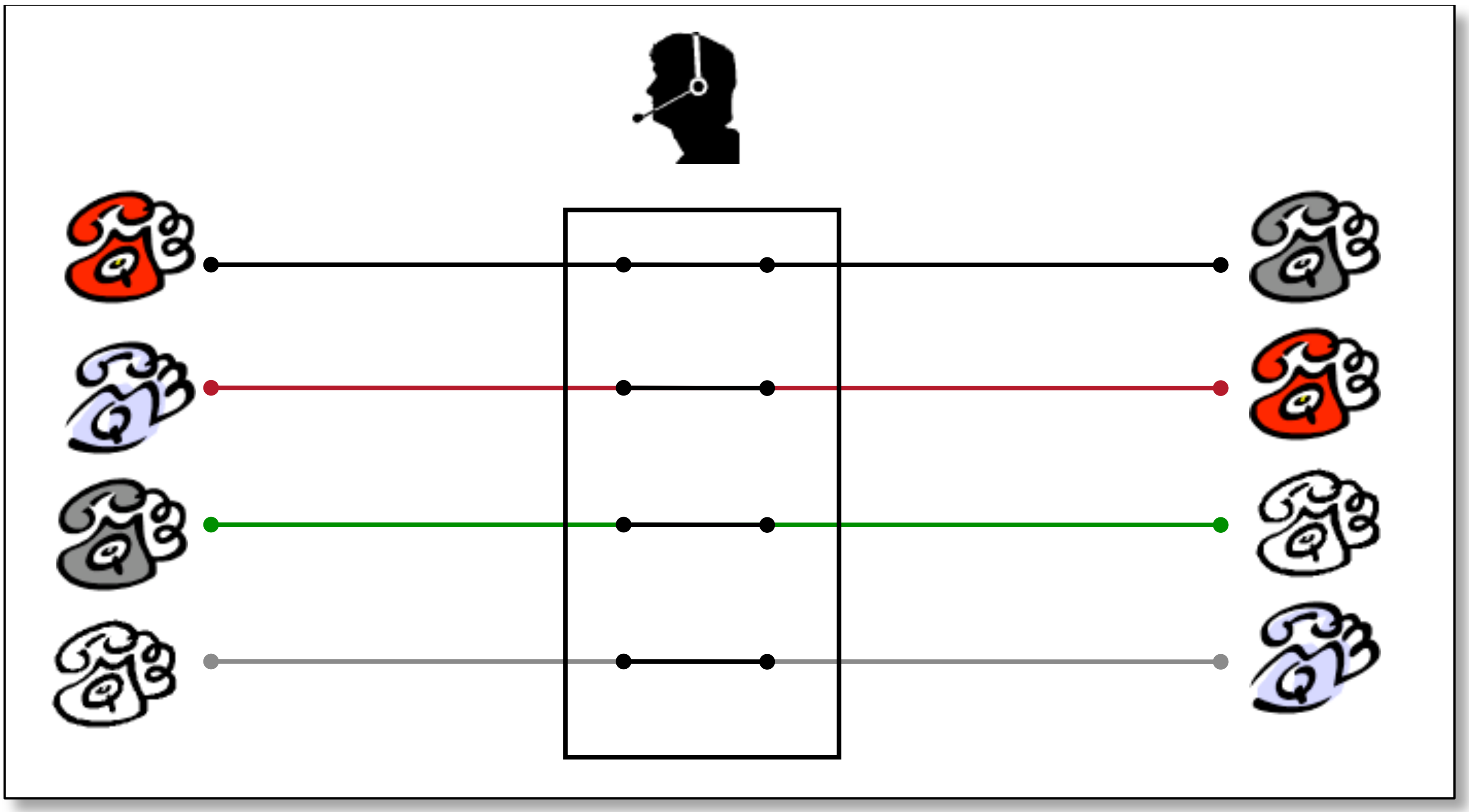
- Switched network
  - End hosts at the edge
  - Network nodes that switch traffic
  - Links between the nodes
- Multiplexing
  - Many end hosts communicate over the network
  - Traffic shares access to the same links

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

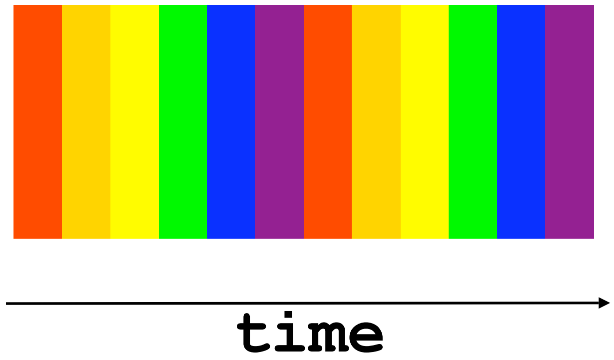


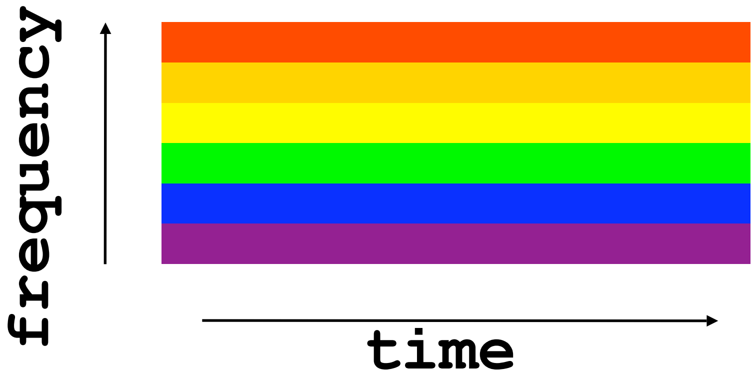
Circuit Switching With Human Operator



Circuit Switching: Multiplexing a Link

- Time-division
  - Each circuit allocated certain time slots
- Frequency-division
  - Each circuit allocated certain frequencies





Advantages of Circuit Switching

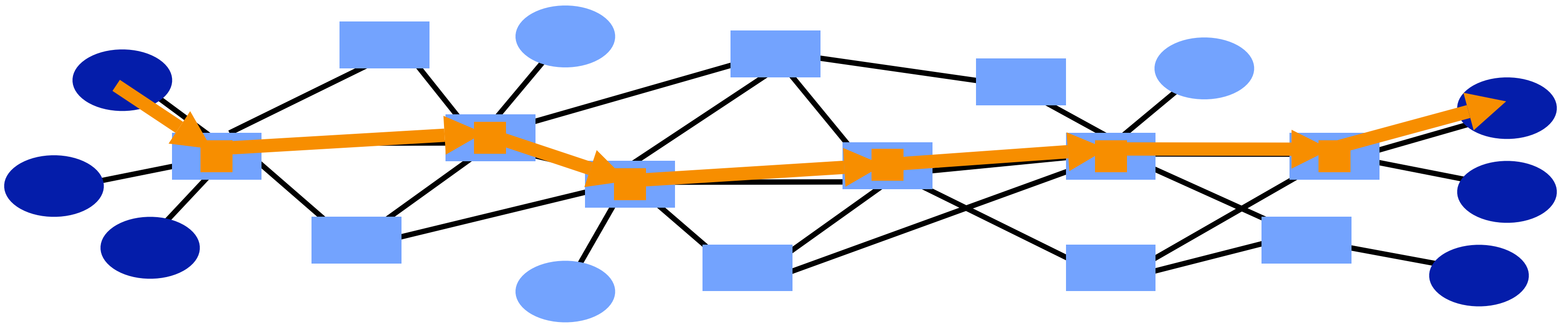
- Guaranteed bandwidth
  - Predictable communication performance
  - Not "best-effort" delivery with no real guarantees
- Simple abstraction
  - Reliable communication channel between hosts
  - No worries about lost or out-of-order packets
- Simple forwarding
  - Forwarding based on time slot or frequency
  - 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

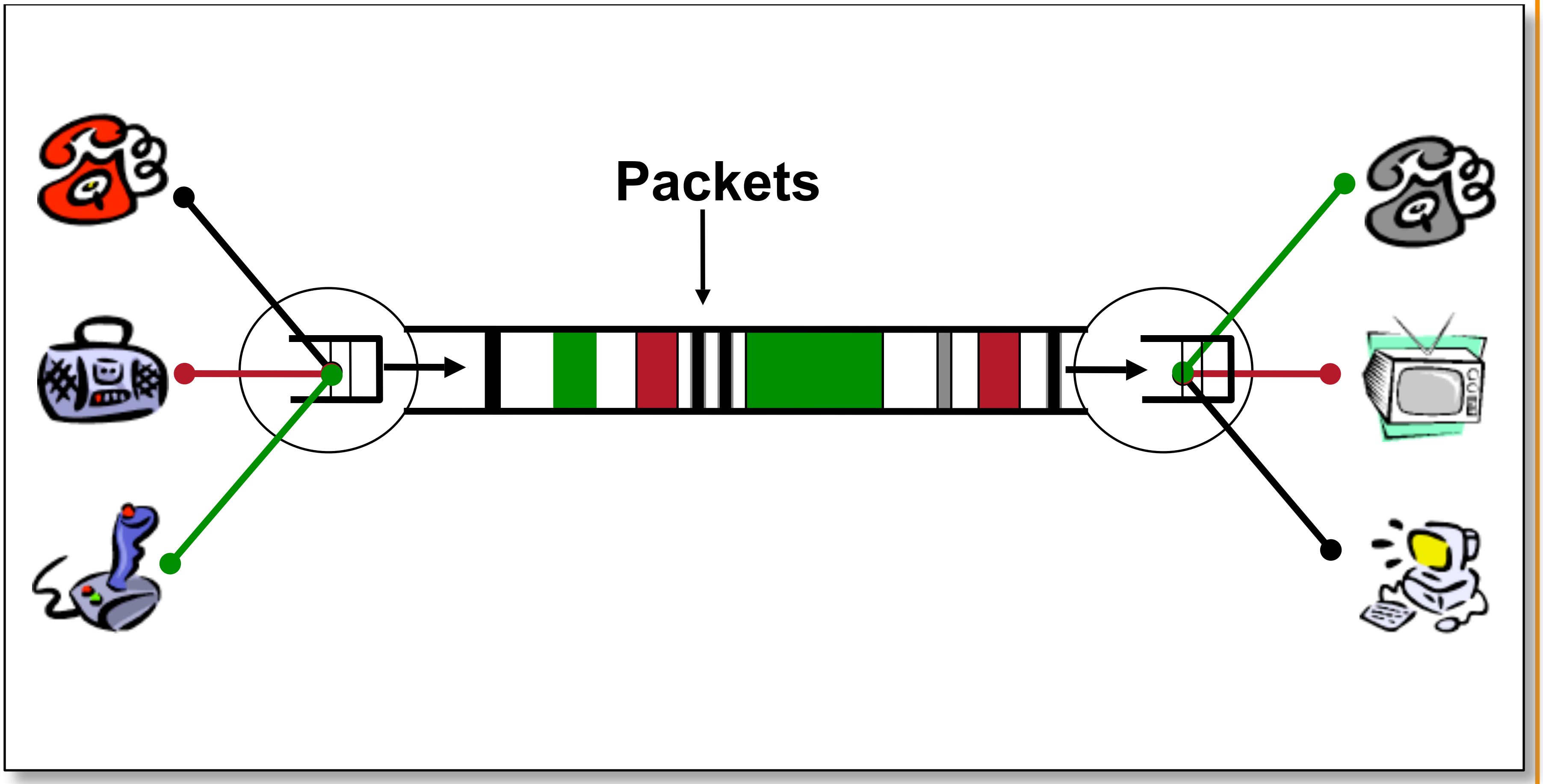
- Wasted bandwidth
  - Bursty traffic leads to idle connection during silent period
  - Unable to achieve gains from statistical multiplexing
- Blocked connections
  - Connection refused when resources are not sufficient
  - Unable to offer "okay" service to everybody
- Connection set-up delay
  - No 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

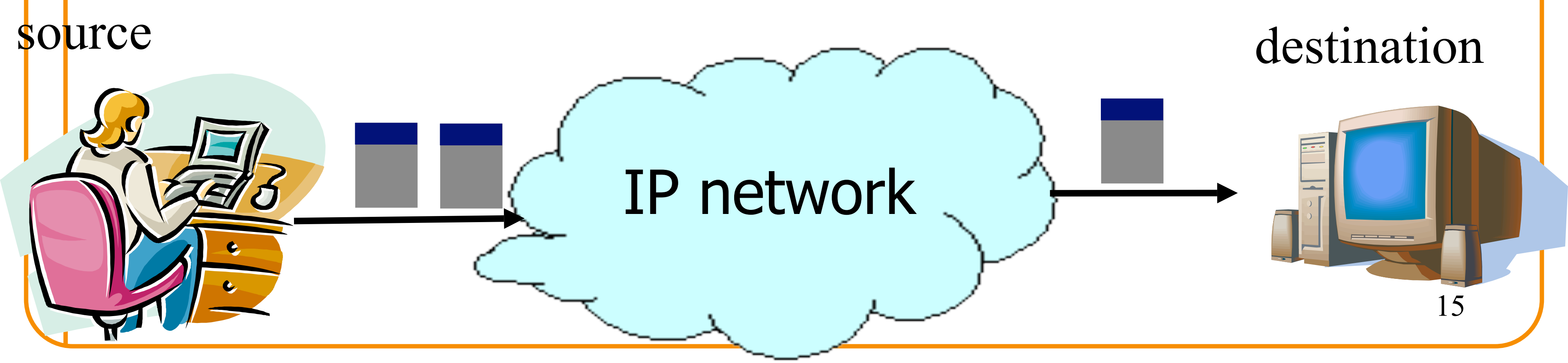


Packet Switching: Statistical Multiplexing



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 (aka birds)
- … still, packet switching can be inefficient
  - Extra header bits on every packet

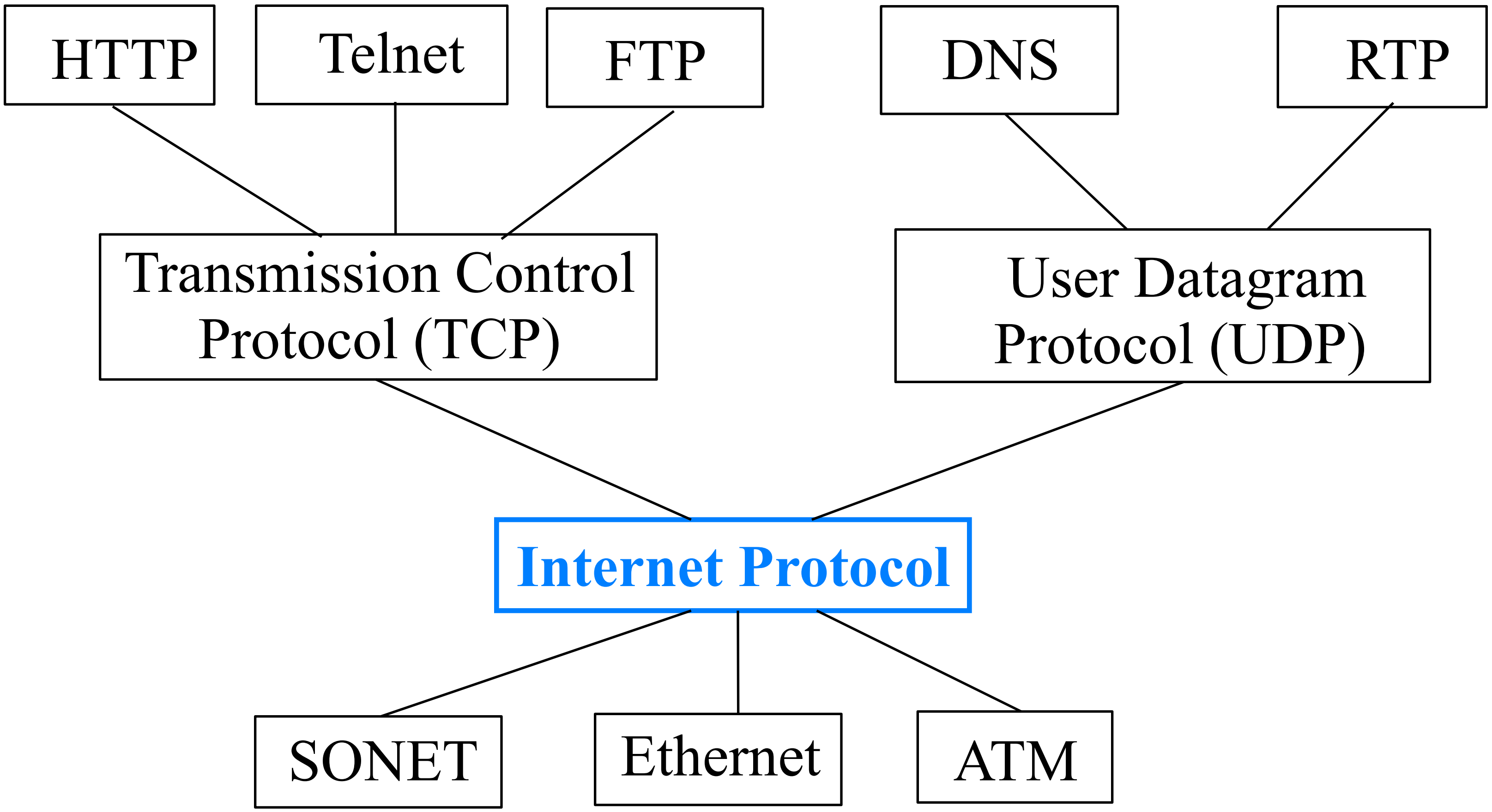
IP Service Model: Why Best-Effort?

- 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

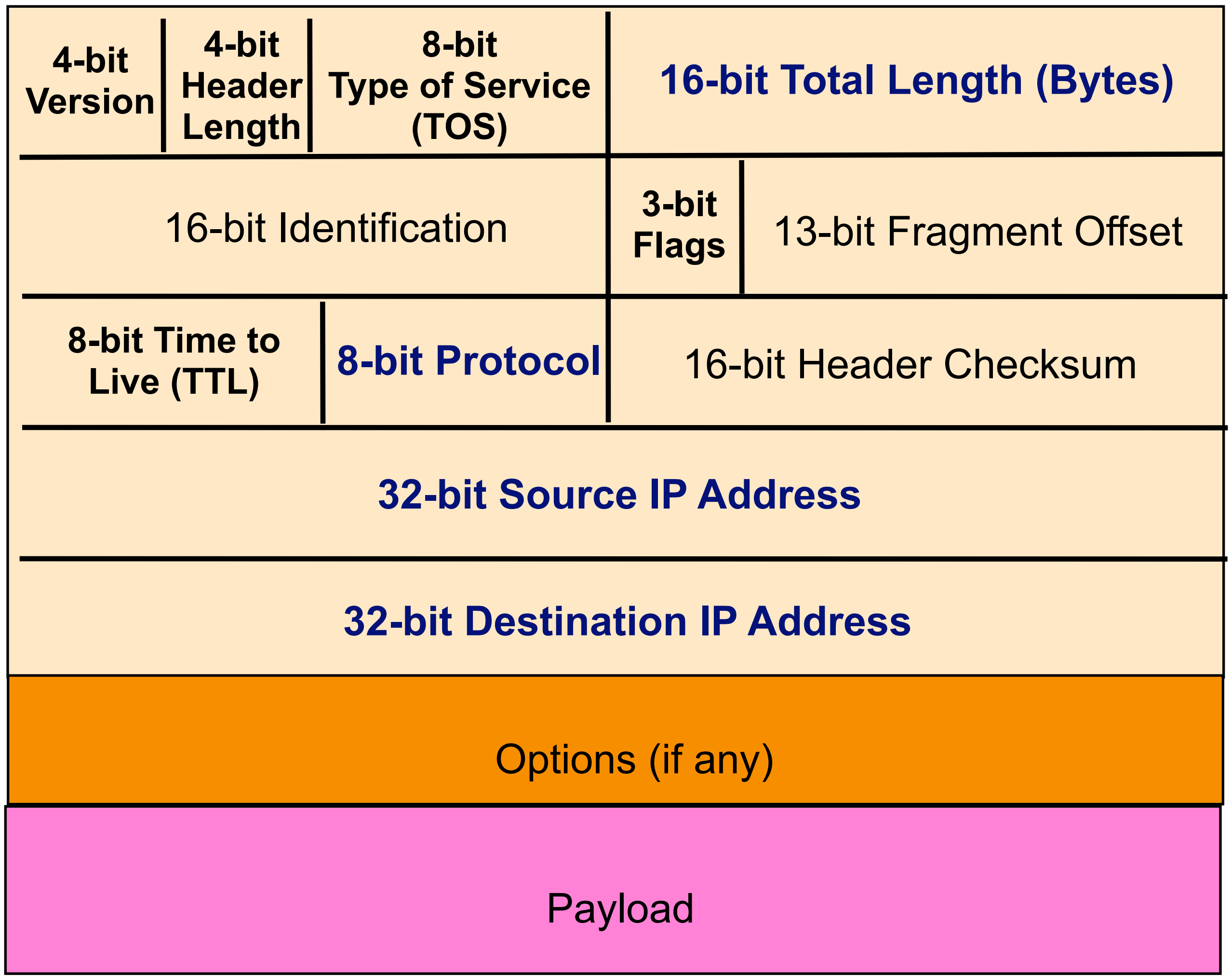
Other Main Driving Goals (In Order)

- 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

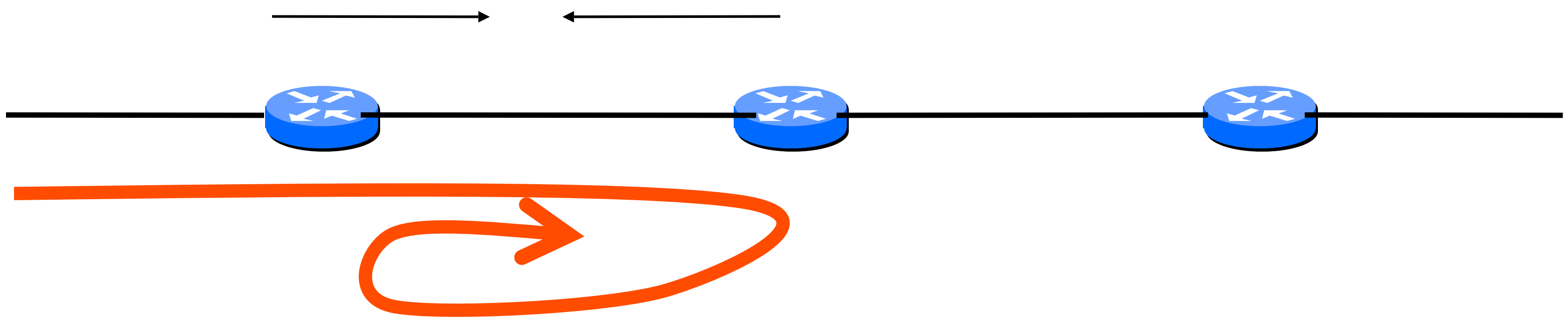
- Version number (4 bits)
  - Indicates the version of the IP protocol
  - Necessary to know what other fields to expect
  - Typically "4" (for IPv4), and sometimes "6" (for IPv6)
- Header length (4 bits)
  - Number of 32-bit words in the header
  - Typically "5" (for a 20-byte IPv4 header)
  - Can be 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 bandwidth 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
- 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)

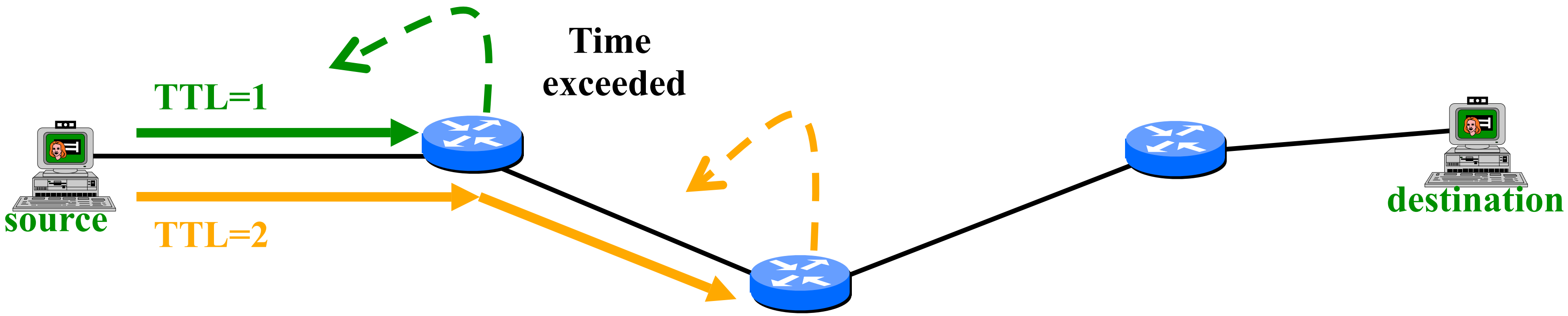
- Potential robustness problem
  - Forwarding loops can cause packets to cycle forever
  - Confusing if the packet arrives much later



- 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

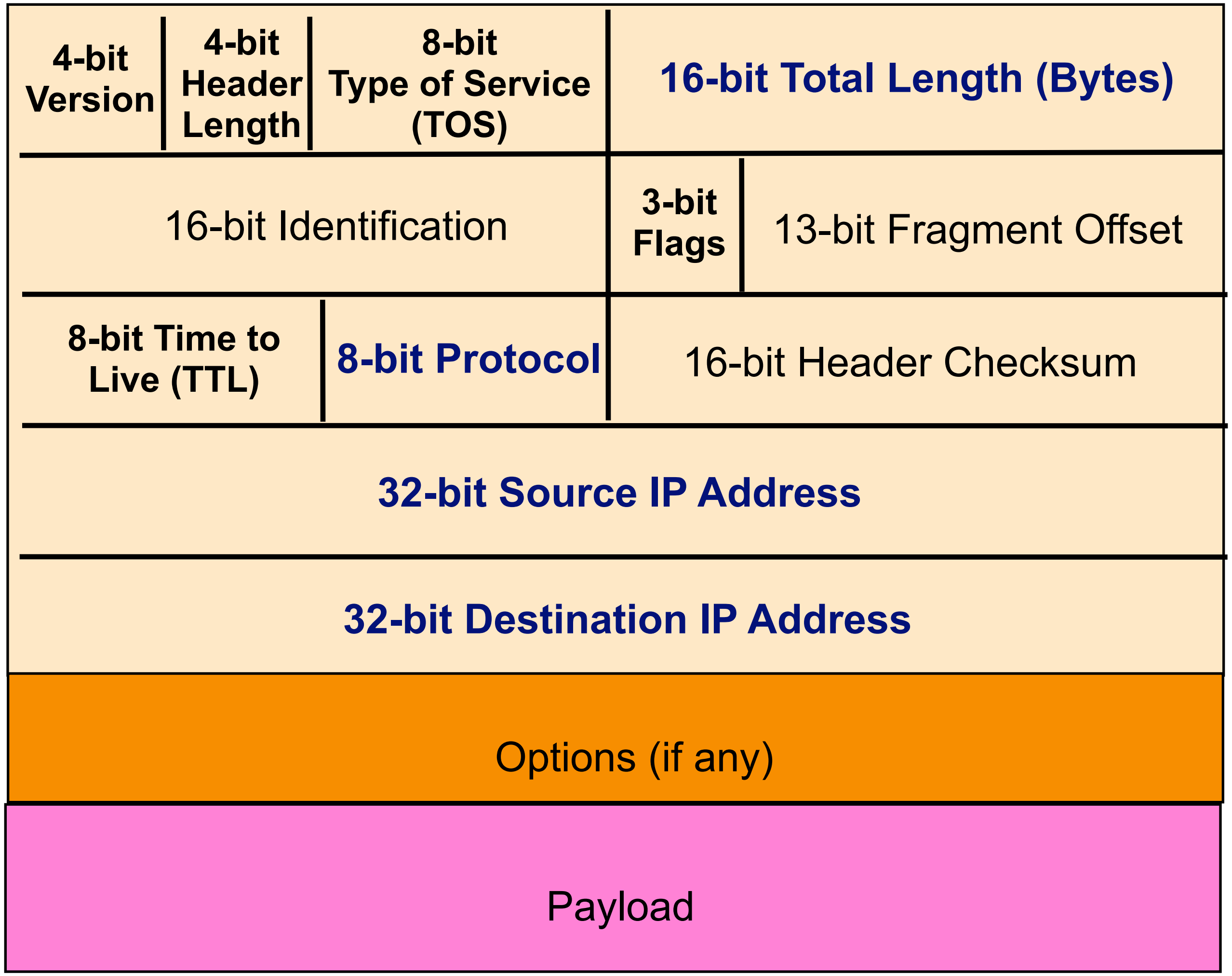
Example Traceroute: Sharif to Google

```
traceroute google.com
traceroute: Warning: google.com has multiple addresses; using 74.125.67.100
traceroute to google.com (74.125.67.100), 64 hops max, 40 byte packets
 1  CE-GW.GIG3-2.V302.RSP.sharif.edu (213.233.168.1)  0.788 ms  0.322 ms  0.310 ms
 2  ge4-8.core-router.sharif.ir (81.31.160.1)  0.439 ms  0.358 ms  0.545 ms
 3  78.38.255.5 (78.38.255.5)  12.618 ms  14.014 ms  9.951 ms
 4  217.218.127.34 (217.218.127.34)  12.872 ms  11.257 ms  10.940 ms
 5  195.146.63.70 (195.146.63.70)  10.874 ms  8.875 ms  11.475 ms
 6  pal5-tci-4.pal.seabone.net (195.22.198.77)  246.117 ms  243.905 ms  240.006 ms
 7  72.14.217.144 (72.14.217.144)  266.452 ms  235.764 ms  229.588 ms
.........
16  72.14.239.127 (72.14.239.127)  259.490 ms  260.632 ms 72.14.239.131 (72.14.239.131)  276.943 ms
17  64.233.174.46 (64.233.174.46)  260.158 ms 209.85.255.190 (209.85.255.190)  262.709 ms  262.892 ms
18  gw-in-f100.google.com (74.125.67.100)  260.377 ms  252.729 ms  262.514 ms
```

Try Running Traceroute Yourself

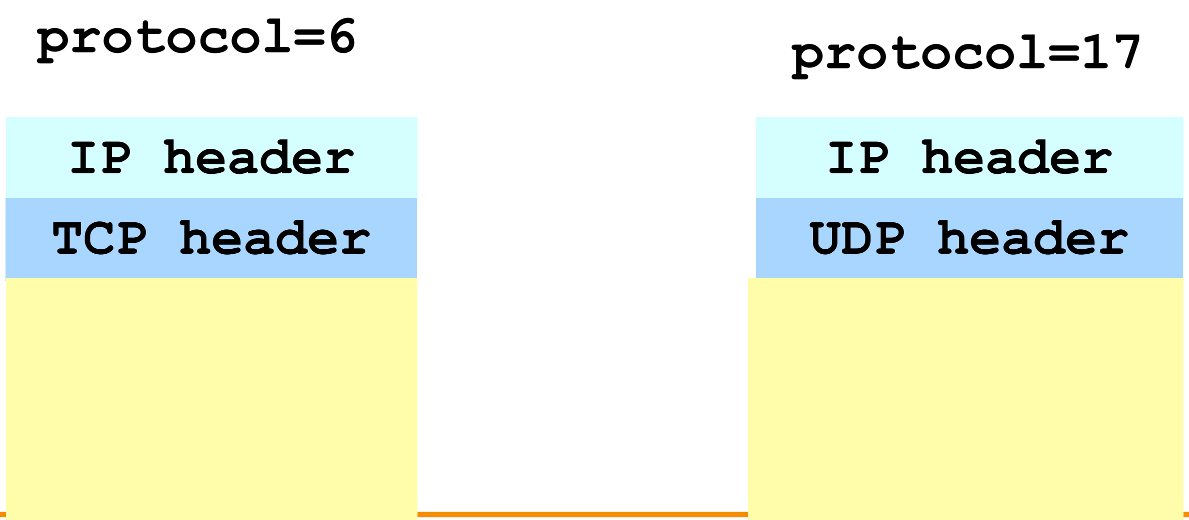
- On UNIX machine
  - Traceroute
  - E.g., "traceroute google.com" or "traceroute 74.125.67.100"
- On Windows machine
  - Tracert
  - E.g., "tracert google.com" or "tracert 74.125.67.100"
- Common uses of traceroute
  - Discover the topology of the Internet
  - Debug performance and reachability problems

IP Packet Structure



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            134
+ 212    →     + 216
-----          -----
= 346          = 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

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