The Network Layer: Protocols DHCP, ICMP, NAT, IPv6

CS 352, Lecture 14, Spring 2020

http://www.cs.rutgers.edu/~sn624/352

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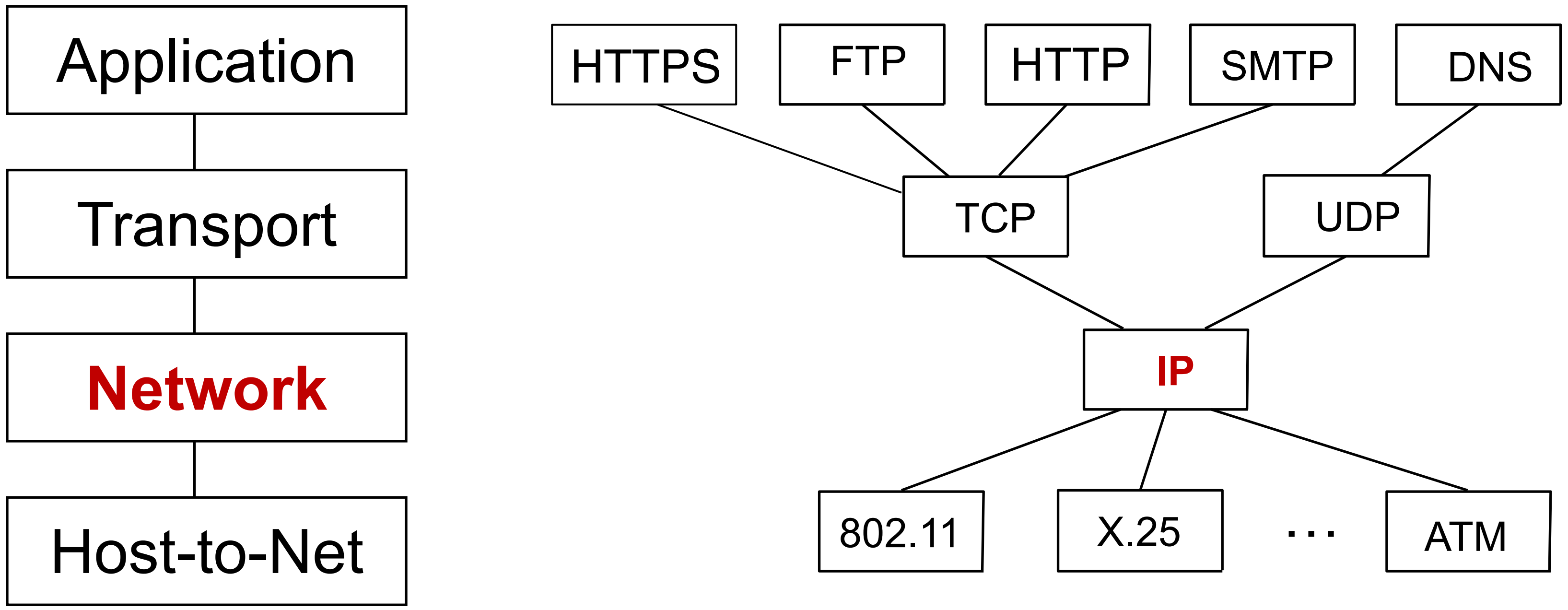
Course announcements

- Quiz 5 due Tuesday
    - Will be released later today
- Recording of Wednesday's lecture available
    - See Piazza for details
    - We are working on converting video into a format that's more accessible than WebEx's ARF… stay tuned

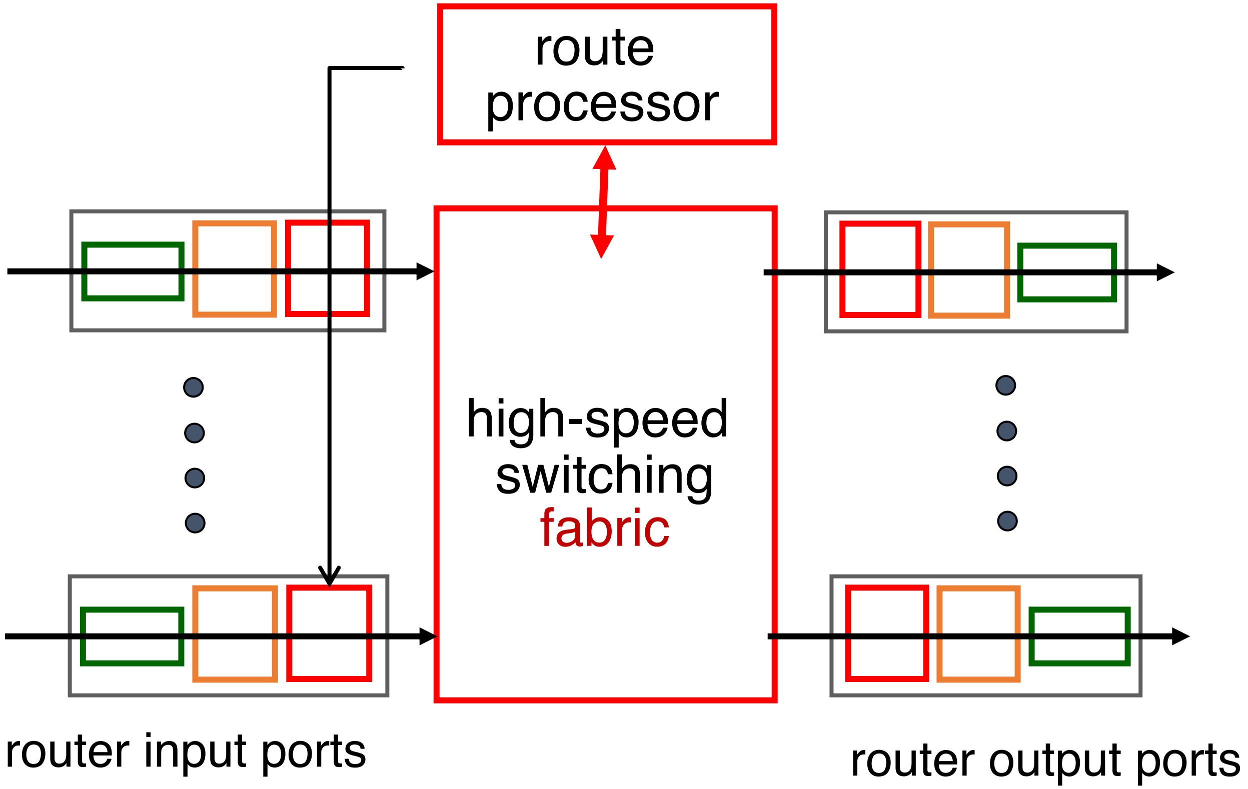
Where we are: The network layer



The network layer exists on every endpoint and router.

Review of concepts

- Router components
- Input port: line termination, forwarding function
  - Forwarding: based on IP destination.
  - Longest-prefix matching
- Switching fabric: memory, bus, crossbar
- Output port: buffer management and scheduling



Poll #1

- If an ISP X owns two prefixes 128.0.0.0/16 and 128.1.0.0/16, which IP prefix can the rest of the Internet use in its forwarding rules to route data towards X?
    - (a) 128.0.0.0/8
    - (b) 128.0.0.0/24
    - (c) 128.0.0.0/15
    - (d) None of the above

Poll #2

- Suppose a router has two forwarding rules. Which port should pkt with destination IP 192.168.0.56 go out of?

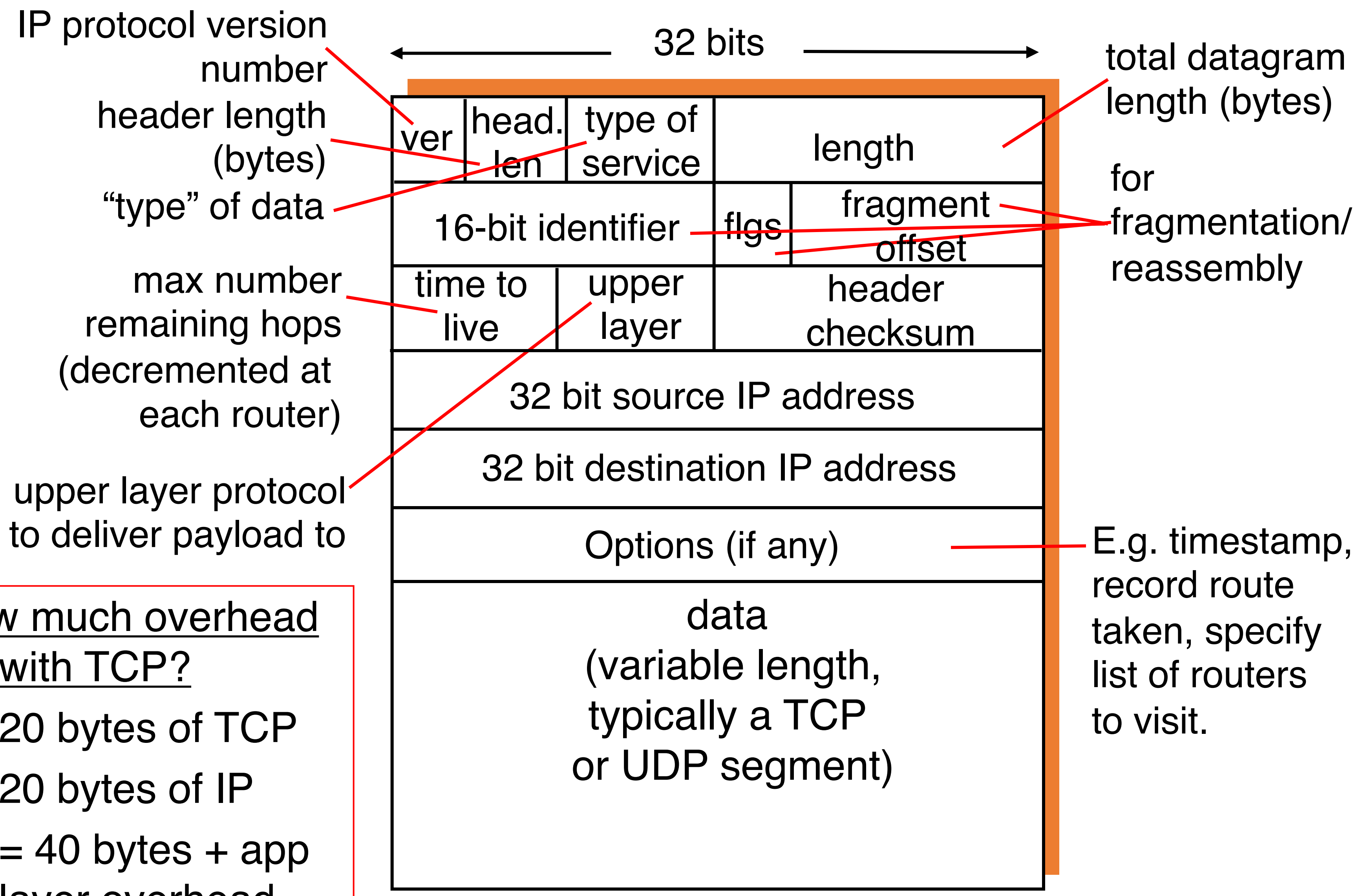
  192.168.0.0/16 -> port 1

  192.168.0.0/24 -> port 2

  - (a) port 1
  - (b) port 2
  - (c) neither port
  - (d) both ports

The Internet Protocol (IP)

IP datagram format

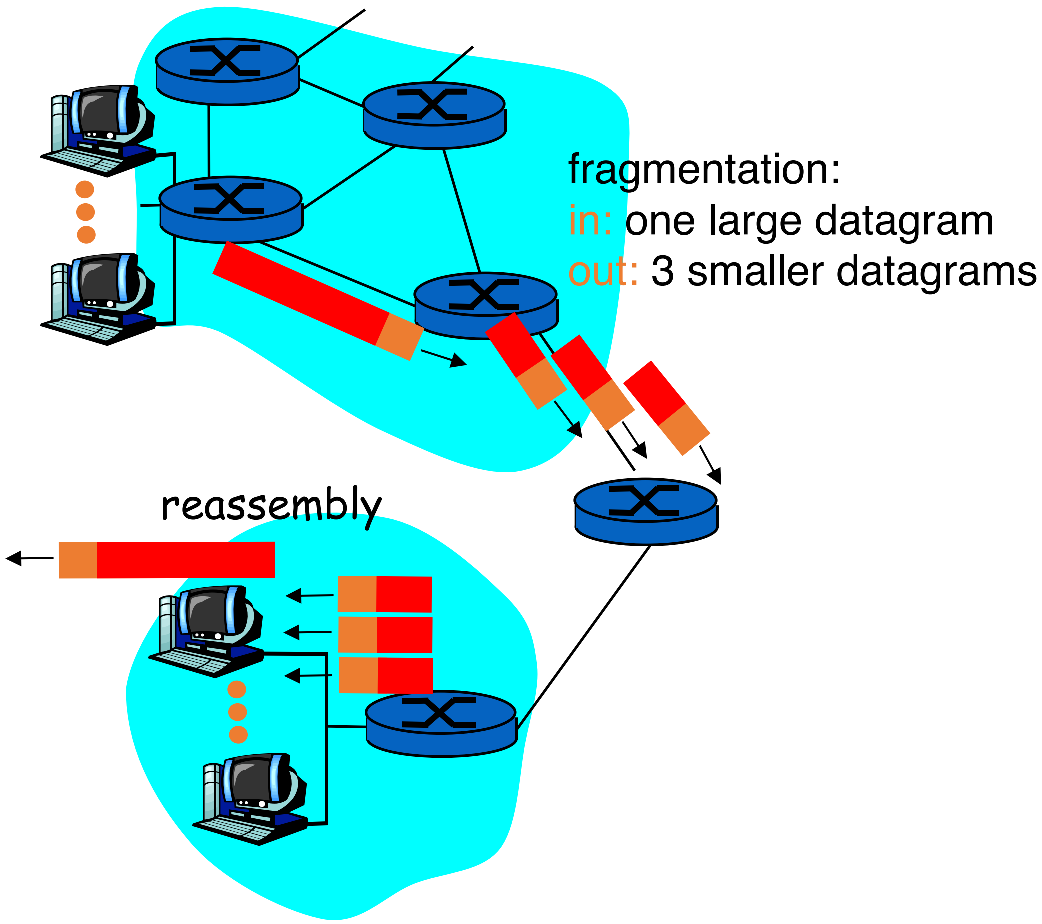


how much overhead with TCP?

- 20 bytes of TCP
- 20 bytes of IP
- = 40 bytes + app layer overhead

IP Fragmentation & Reassembly

- network links have MTU (max.transfer size) - largest possible link-level frame.
  - different link types, different MTUs
- large IP datagram divided ("fragmented") within net
  - one datagram becomes several datagrams
  - reassembled only at the destination, at the IP layer
  - IP header bits used to identify, order related fragments



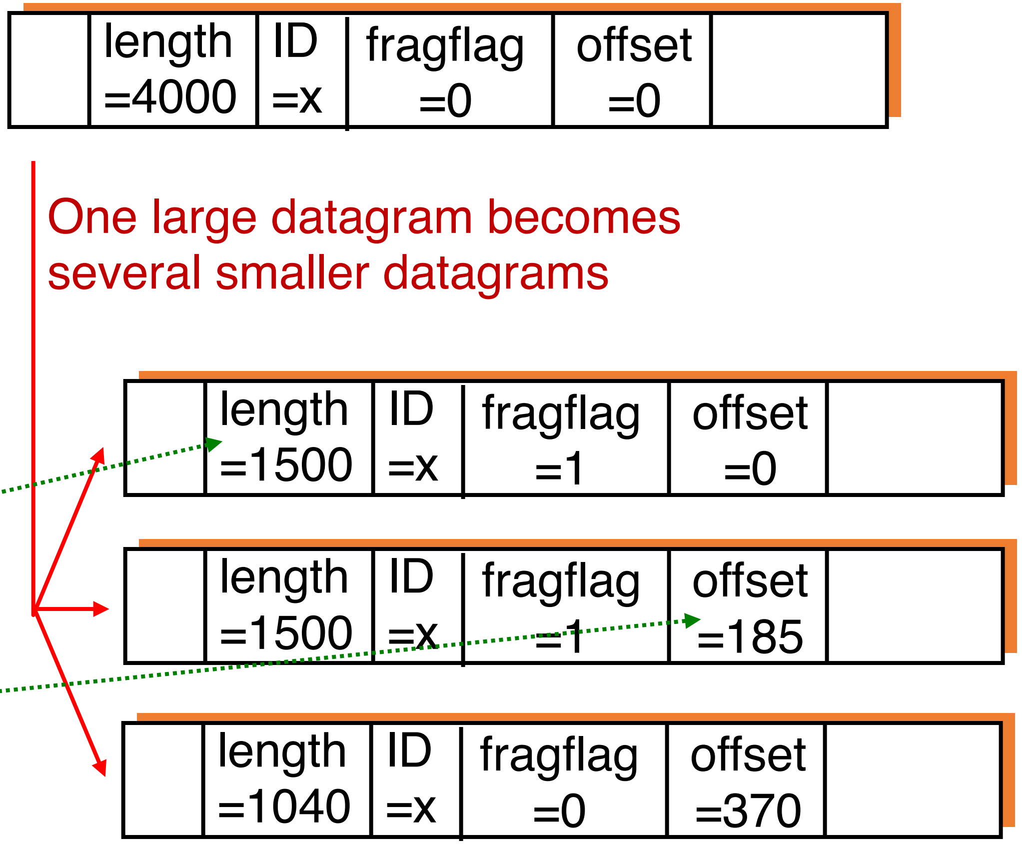
IP Fragmentation and Reassembly

<u>Example</u>

- 4000 byte datagram
- MTU = 1500 bytes
- (includes IP headers)

1480 bytes in data field

offset = 1480/8



Poll #3

- Which header does the IP source and destination live in?
  - (a) TCP header
  - (b) IP header
  - (c) Application-layer header
  - (d) None of the above

Dynamic Host Configuration

How does an endpoint get its IP address?

IP addresses: how to get one?

Q: How does a *host* get IP address?

- Hard-coded by system admin in a file
  - UNIX: /etc/network/interfaces
  - Windows: controlpanel -> network -> configuration -> tcp/ip -> properties
- DHCP: Dynamic Host Configuration Protocol: dynamically get address from as server
  - "plug-and-play"

Similar bootstrapping problems

- How does a host get its IP address?
- How does a host know its local DNS server?
- How does a host know its subnet mask?
- How does a host know which router is its “gateway” to other networks?

DHCP: Dynamic Host Configuration Protocol

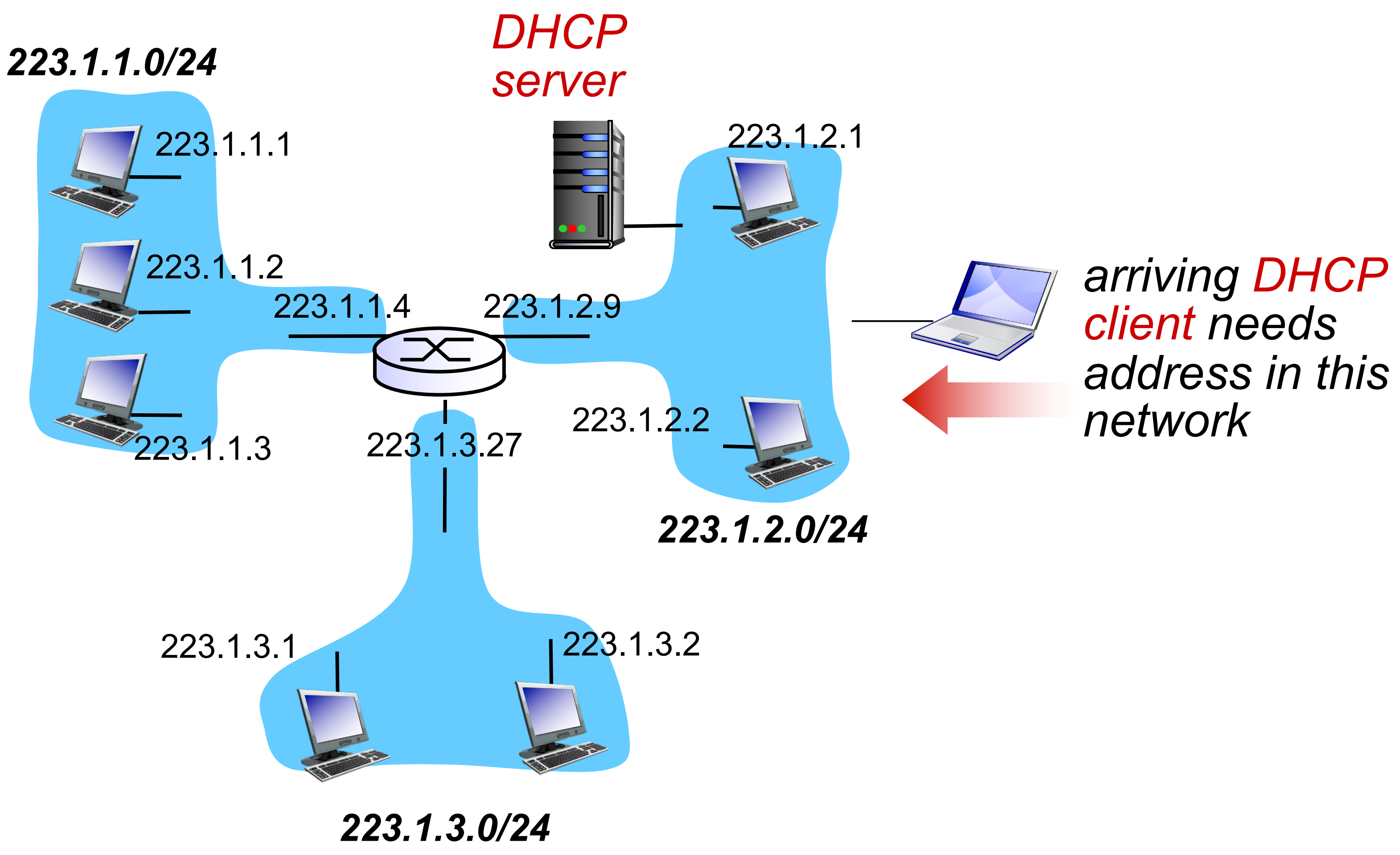
goal: allow host to *dynamically* obtain its IP address from network server when it joins network

- can renew its lease on address in use
- allows reuse of addresses (only hold address while connected/“on”)
- support for mobile users who want to join network

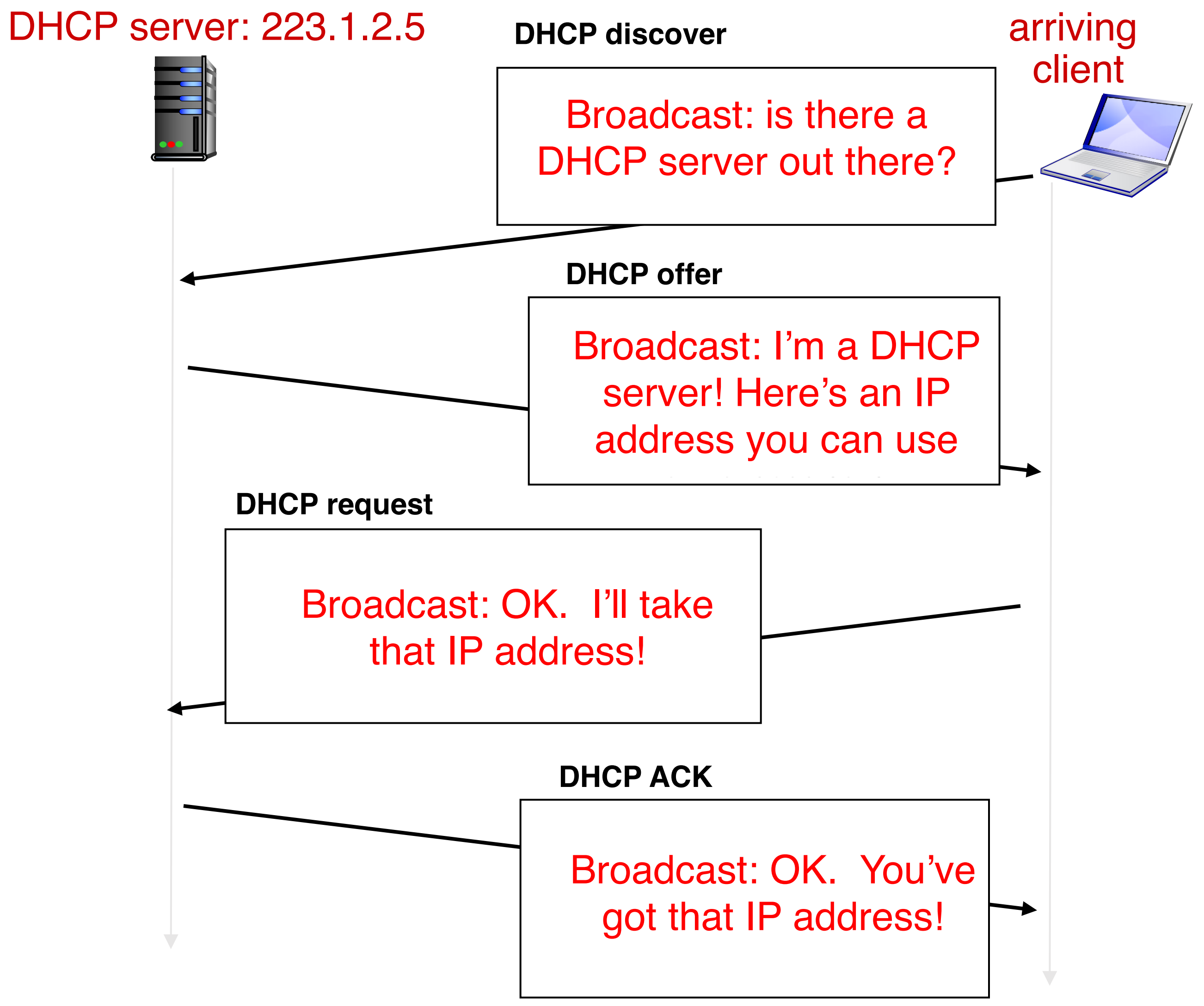
DHCP overview:

- host broadcasts “DHCP discover” msg [optional]
- DHCP server responds with “DHCP offer” msg [optional]
- host requests IP address: “DHCP request” msg
- DHCP server sends address: “DHCP ack” msg

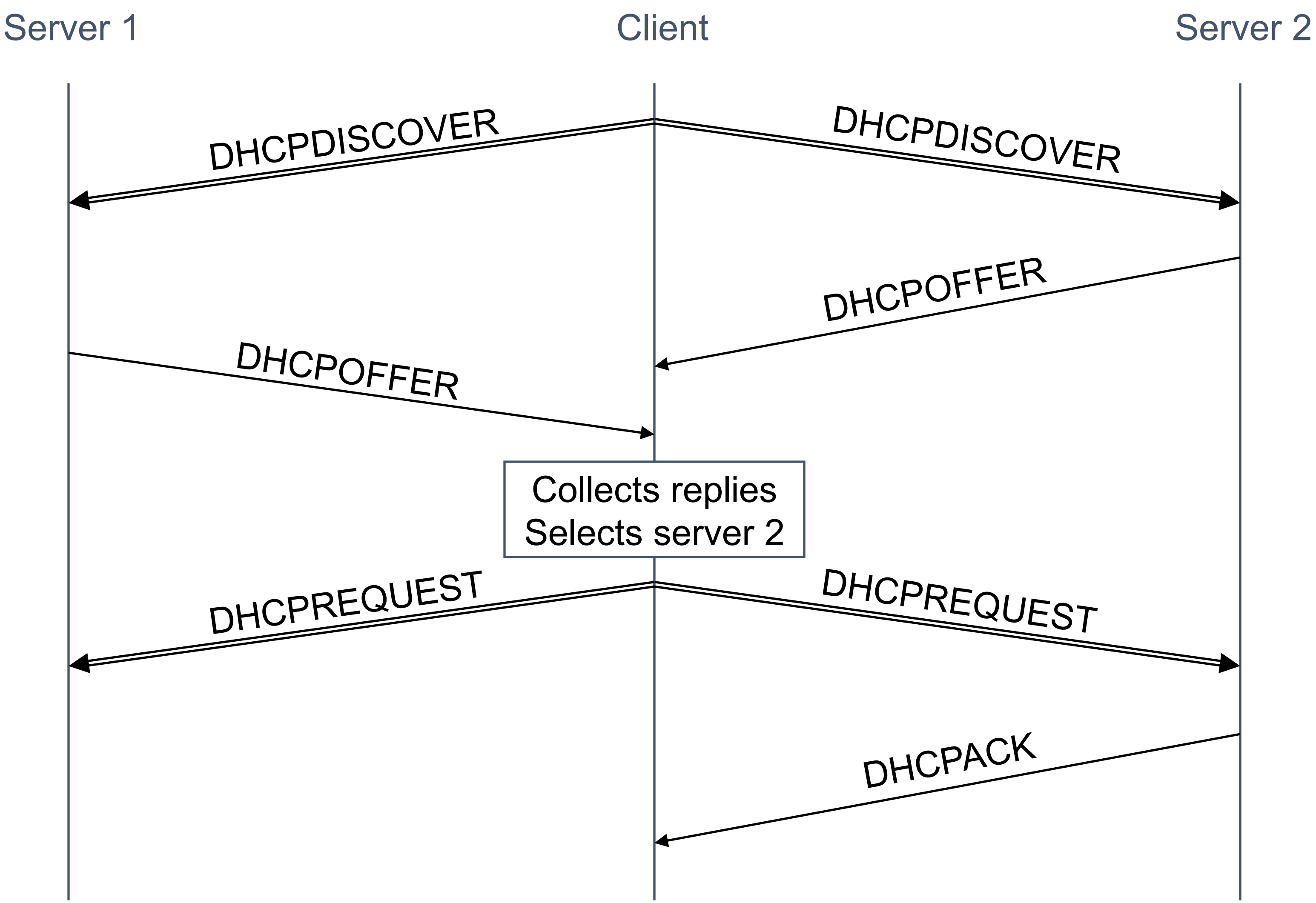
DHCP client-server scenario



DHCP client-server scenario



DHCP Protocol



DHCP: more than IP addresses

DHCP can return more than just allocated IP address on subnet:

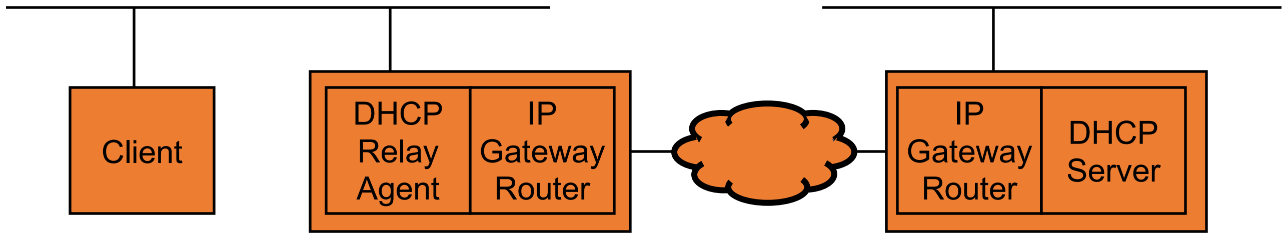
- address of first-hop router for client to reach other subnets
  - Also called the gateway router

- name and IP address of the local DNS server

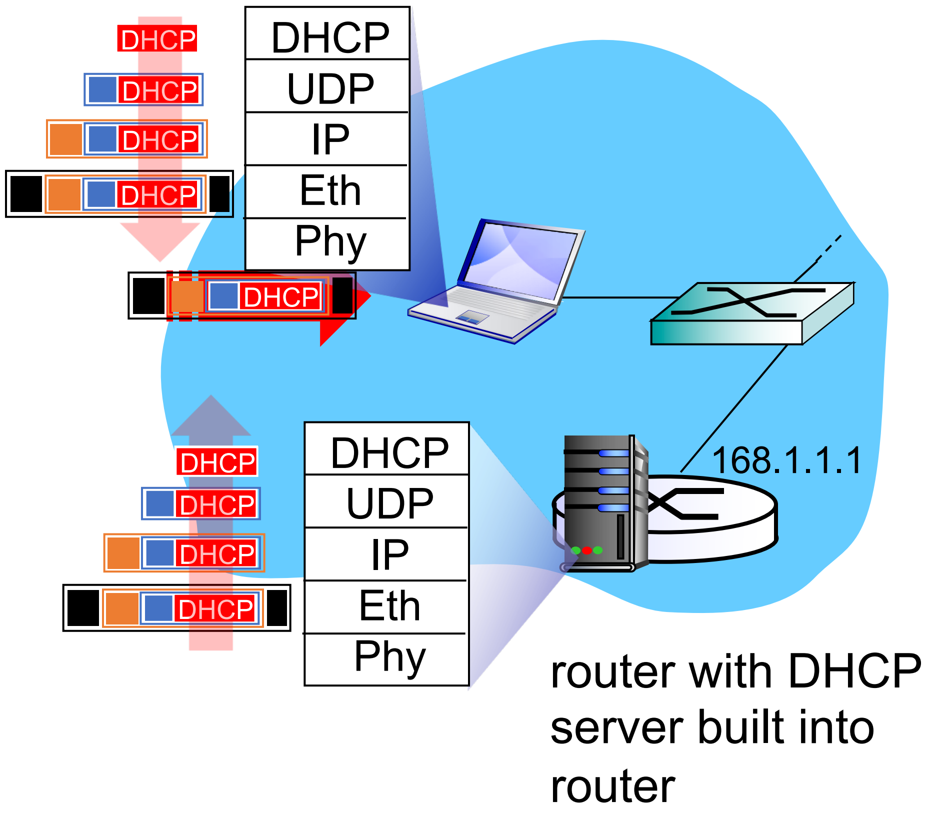
- subnet mask of the IP network the host is on
  - Useful to know whether other endpoint is inside or outside the current IP network

DHCP Relay Agents

- DHCP relay agents allow DHCP servers to handle requests from other subnets

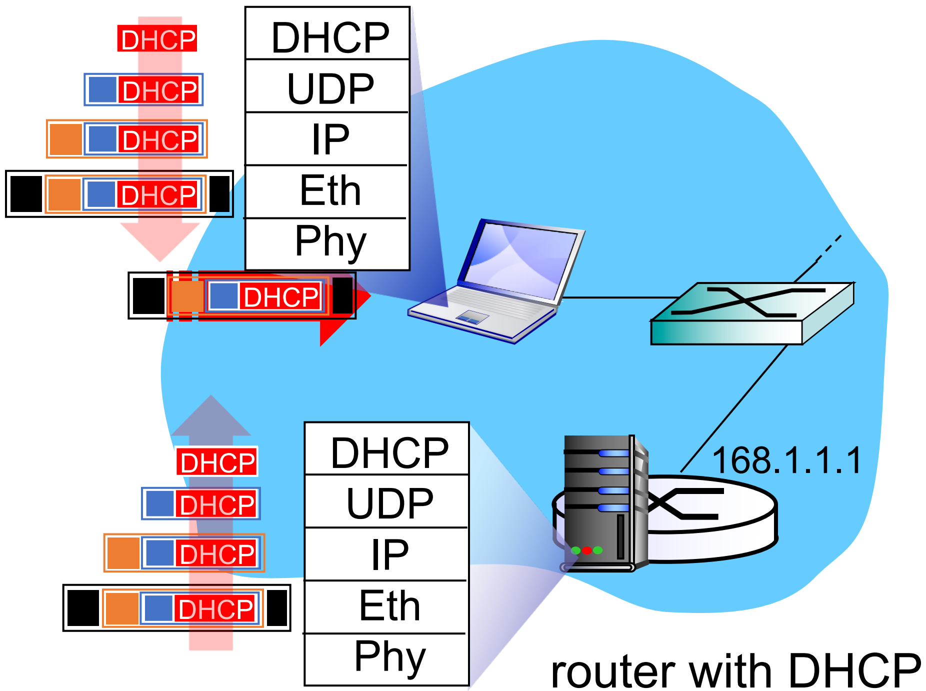


DHCP: An example



- connecting laptop needs its IP address, addr of first-hop router, addr of DNS server: use DHCP
- DHCP request encapsulated in UDP, encapsulated in IP, encapsulated in 802.1 Ethernet
- Ethernet frame broadcast (dest: FFFFFFFFFFFF) on LAN, received at router running DHCP server
- Ethernet demuxed to IP demuxed, UDP demuxed to DHCP

DHCP: An example



router with DHCP server built into router

- DHCP server formulates DHCP ACK containing client's IP address, subnet mask, IP address of first-hop router for client, name & IP address of DNS server
- encapsulation of DHCP server, frame forwarded to client, demuxing up to DHCP at client
- client now knows its IP address, name and IP address of DNS server, IP address of its first-hop router

Poll #4

- What functions does the DHCP protocol serve?
  - (a) discovering a usable IP address when a host joins
  - (b) discovering the local DNS server address
  - (c) discovering the gateway router of the local IP network
  - (d) all of the above

Poll #5

- When a host joins a new network, how does it know the IP address of the DHCP server?
  - (1) this is a static configuration on all endpoints
  - (2) it broadcasts a message to discover DHCP servers
  - (3) neither of the above

Summary

- IP addresses don't have to be manually configured into hosts
- DHCP allows "ignorant" hosts to receive IP addresses (and more) at start-up time
- DHCP solves important bootstrapping problems in attaching new hosts to a network

Internet Control Message Protocol (ICMP)

ICMP

- Protocol for error detection and reporting
    - tightly coupled with IP, unreliable
- ICMP messages delivered in IP packets
- ICMP functions:
    - Announce reachability and network errors
    - Announce “time exceeded” errors for IP packets
    - Announce network congestion
- ICMP assists network troubleshooting in general

ICMP message

IP header Source, Destination Address, TTL, ...
ICMP MSG Message type, Code, Checksum, Data

ICMP: Internet Control Message Protocol

Type	Code	description
0	0	echo reply (ping)
3	0	dest. network unreachable
3	1	dest host unreachable
3	2	dest protocol unreachable
3	3	dest port unreachable
3	6	dest network unknown
3	7	dest host unknown
4	0	source quench (congestion control - not used)
8	0	echo request (ping)
9	0	route advertisement
10	0	router discovery
11	0	TTL expired
12	0	bad IP header

Time for an activity!

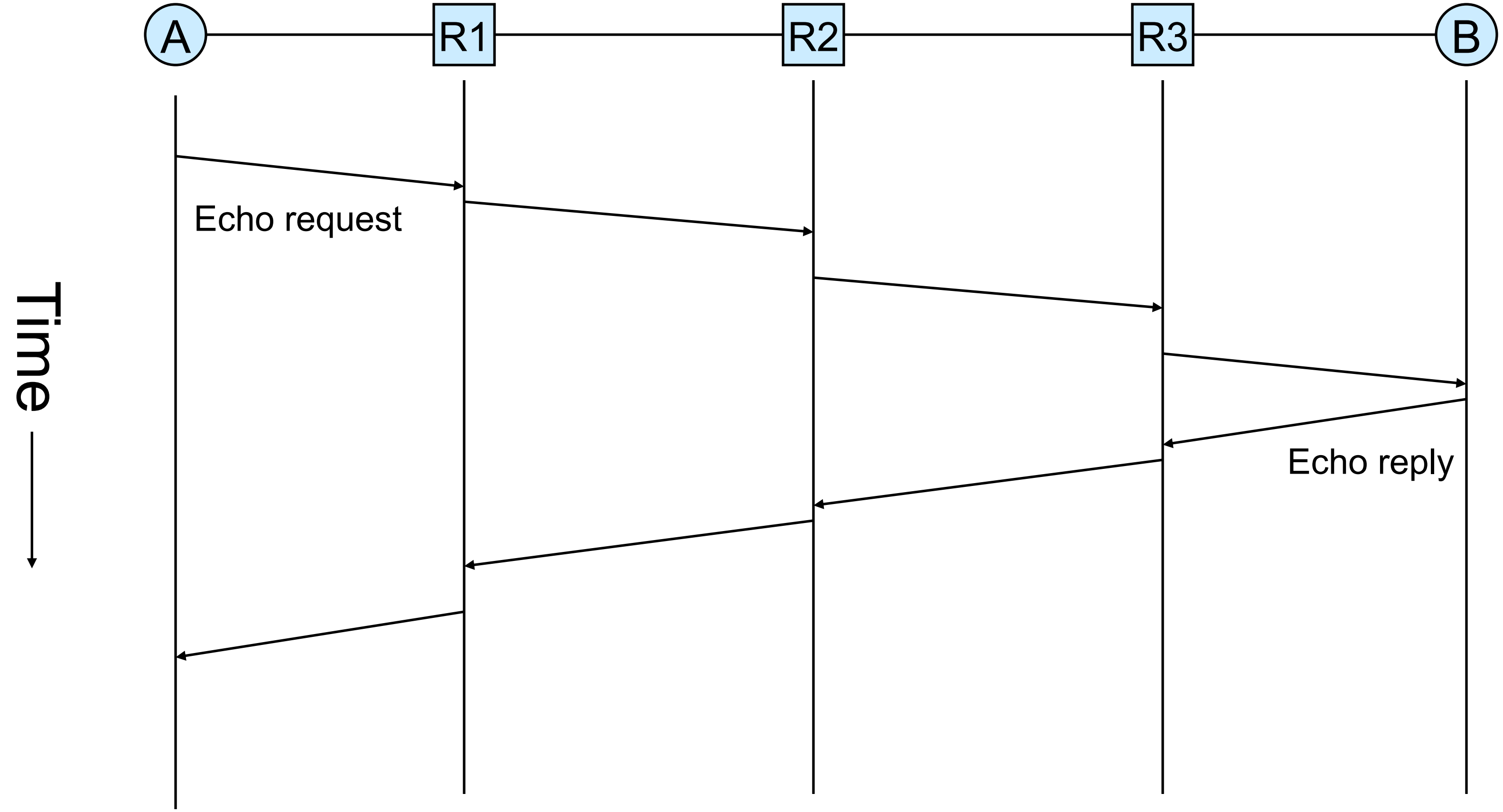
Specific uses of ICMP

- Echo request reply
  - Can be used to check if a host is alive
- Destination unreachable
  - Invalid address and/or port
- TTL expired
  - Routing loops, or too far away

Ping

- Uses ICMP echo request/reply
- Source sends ICMP echo request message to the destination address
- Destination replies with an ICMP echo reply message containing the data in the original echo request message
- Source can calculate round trip time (RTT) of packets
- If no echo reply comes back, then the destination is unreachable

Ping *(cont'd)*



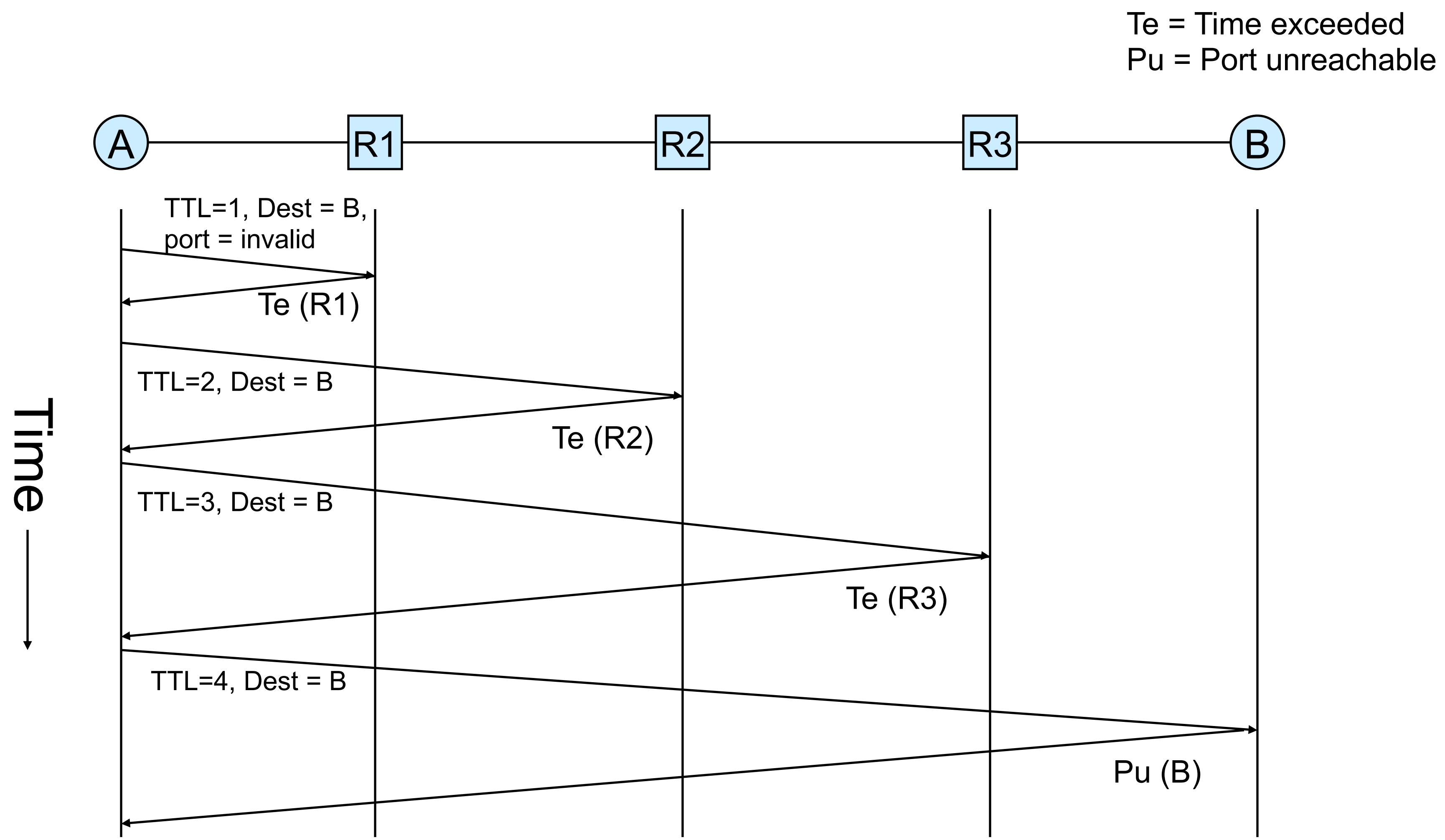
Ping example

```
[flow:352-S20]$  ping google.com
PING google.com (172.217.10.110): 56 data bytes
64 bytes from 172.217.10.110: icmp_seq=0 ttl=56 time=5.727 ms
64 bytes from 172.217.10.110: icmp_seq=1 ttl=56 time=4.701 ms
64 bytes from 172.217.10.110: icmp_seq=2 ttl=56 time=5.954 ms
64 bytes from 172.217.10.110: icmp_seq=3 ttl=56 time=11.981 ms
64 bytes from 172.217.10.110: icmp_seq=4 ttl=56 time=6.084 ms
64 bytes from 172.217.10.110: icmp_seq=5 ttl=56 time=5.829 ms
64 bytes from 172.217.10.110: icmp_seq=6 ttl=56 time=8.667 ms
64 bytes from 172.217.10.110: icmp_seq=7 ttl=56 time=8.916 ms
64 bytes from 172.217.10.110: icmp_seq=8 ttl=56 time=4.537 ms
64 bytes from 172.217.10.110: icmp_seq=9 ttl=56 time=4.980 ms
```

Traceroute

- Traceroute records the route that packets take
- A clever use of the IP TTL (time to live) field
- In general, when a router receives a packet, it decrements the TTL on that packet
- If TTL=0, router sends an ICMP time exceeded message back to sender
- traceroute progressively increases TTL of the packets it sends out
  - Every time an ICMP time exceeded message is received, record the sender's (router's) address
  - Repeat until the destination host is reached or an error message occurs
- If packet reaches the destination, the dest host usually sends an ICMP port unreachable

Traceroute *(cont'd)*



Traceroute example

```
[flow:352]$  traceroute google.com
traceroute to google.com (172.217.10.238), 64 hops max, 52 byte packets
 1  vlan451-sr03-hill-nbp.runet.rutgers.net (172.25.112.1)  9.278 ms  3.210 ms  3.124 ms
 2  xe-1-3-0-0-cr02-hill-nbp.runet.rutgers.net (172.29.6.65)  37.125 ms  2.912 ms  2.899 ms
 3  ae1-2000-cr10-hill-nbp.runet.rutgers.net (172.29.6.42)  3.078 ms  3.086 ms  3.016 ms
 4  ae5-2000-cr02-halsey-nwk.runet.rutgers.net (172.29.6.55)  3.693 ms  3.707 ms  3.793 ms
 5  ae2-0-er10-halsey-ext.runet.rutgers.net (172.29.8.6)  3.699 ms  3.693 ms  3.766 ms
 6  ae1-0-fw01-halsey-nwk.runet.rutgers.net (172.29.8.41)  4.019 ms  3.909 ms  3.750 ms
 7  et-2-2-0-0-er10-halsey-ext.runet.rutgers.net (172.29.8.46)  4.310 ms  4.181 ms  3.948 ms
 8  gateway-pni.google.com (128.6.1.114)  4.426 ms  3.901 ms  4.161 ms
 9  108.170.248.65 (108.170.248.65)  5.024 ms
    108.170.248.1 (108.170.248.1)  6.147 ms  6.165 ms
10  72.14.233.201 (72.14.233.201)  5.316 ms  5.426 ms  5.359 ms
11  lga25s59-in-f14.1e100.net (172.217.10.238)  5.410 ms  5.156 ms  5.135 ms
[flow:352]$
```

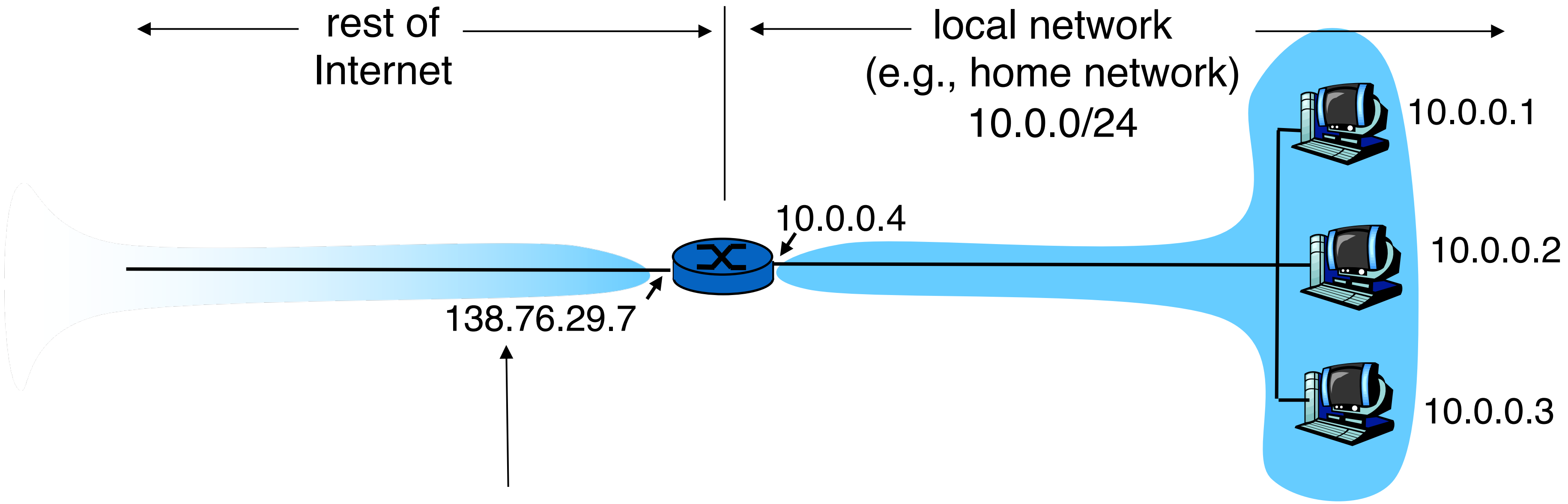
Poll #6

- What's the IP header field that traceroute changes for each packet that it sends out to a given destination?
  - (1) IP source address
  - (2) IP source port
  - (3) IP TTL
  - (4) IP length

Network Address Translation (NAT)

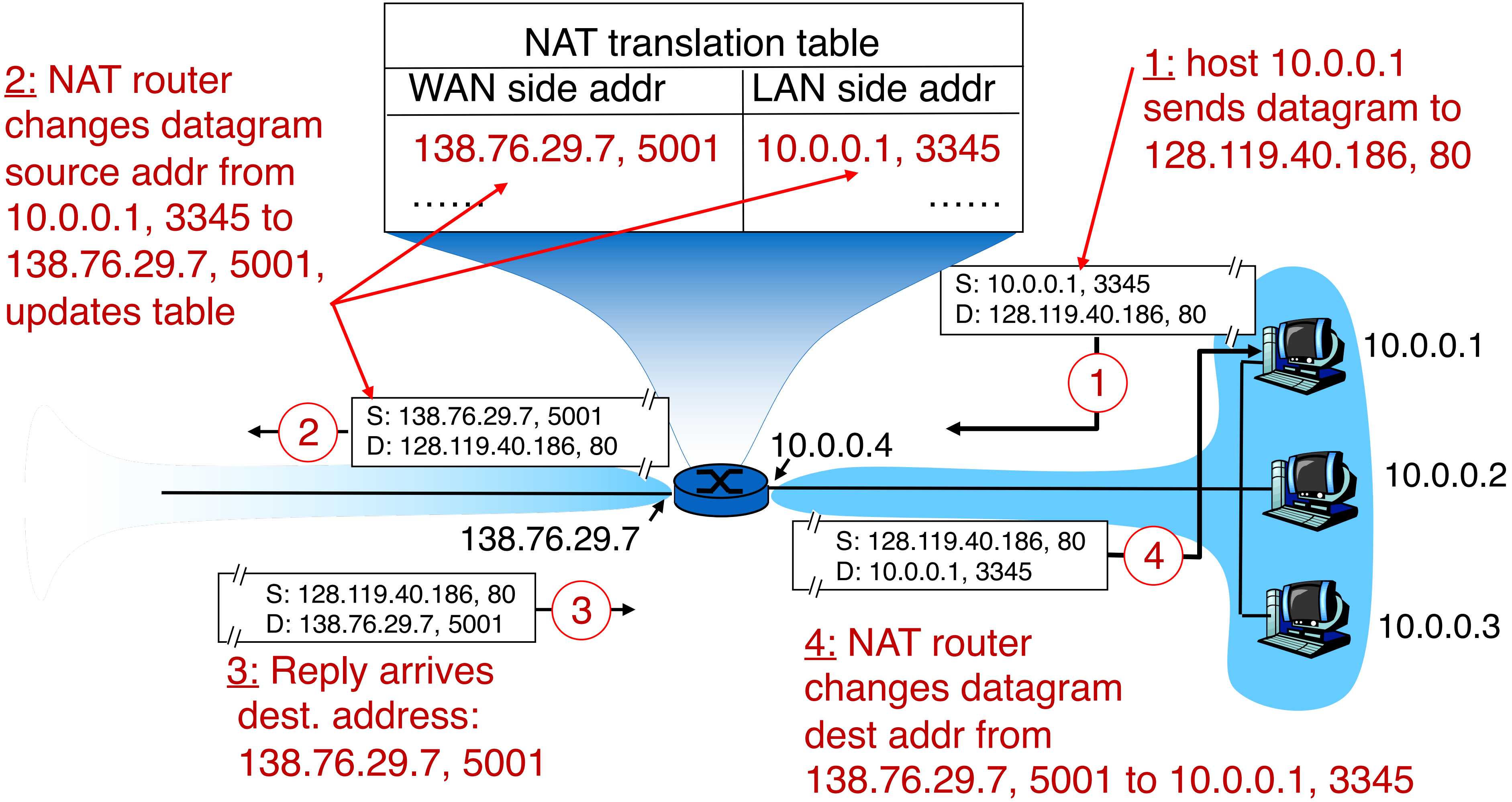
How do you survive in a society where names are scarce?

NAT: Network Address Translation



All datagrams leaving local network have same source IP address: 138.76.29.7, with different source IP port numbers

NAT: Network Address Translation



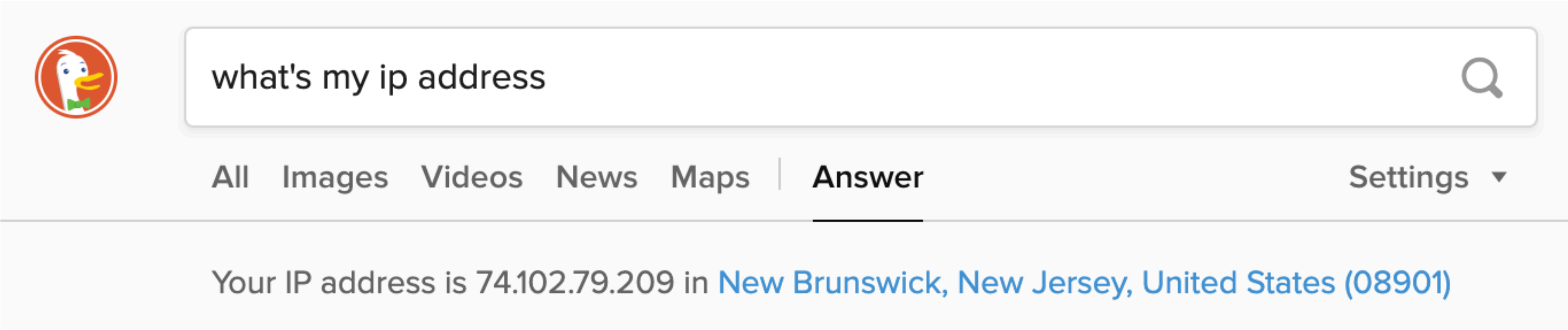
NAT: Network Address Translation

- Features: local network uses just one IP address as far as outside world is concerned:
  - range of addresses not needed from ISP: just one IP address for all devices
  - can change addresses of devices in local network without notifying outside world
  - can change ISP without changing addresses of devices in local network
  - Devices inside local network not explicitly addressable
  - Devices inside local network invisible to the outside world (a security plus) unless the device inside connects first.

Your home WiFi router uses NATs.
If you're home, you're behind a NAT right now.

The impact of NATs

```
[flow:352-S20]$  ifconfig en0
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        ether f0:18:98:1c:fc:36
        inet6 fe80::1036:7dea:82ee:e868%en0 prefixlen 64 secured scopeid 0xa
        inet 192.168.1.151 netmask 0xffffff00 broadcast 192.168.1.255
        nd6 options=201<PERFORMNUD,DAD>
        media: autoselect
        status: active
[flow:352-S20]$
```



NAT: Network Address Translation

- 16-bit port-number field:
  - 60,000 simultaneous connections with a single LAN-side address!

- NAT is controversial:
  - Routers should only work upto the network layer, not transport ports!

  - violates “end-to-end argument”
    - NAT must be taken into account by app designers
    - e.g., P2P applications like skype

  - Purists: address shortage should instead be solved by IPv6

Think about…

- How do the hosts inside the home network get their IP addresses?

- How does your home router get its externally visible IP address?

Poll #7

- The translation table at the NAT router contains
  - (1) Local IP address
  - (2) Local IP port
  - (3) Remote IP address
  - (4) Remote IP port
  - (5) All of the above

Poll #8

- Network Address Translation
  - (1) reduces the demand for fresh IPv4 addresses
  - (2) keeps internal IP addresses hidden from the outside world
  - (3) requires support from the NAT gateway router
  - (4) all of the above

Internet Protocol v6 (IPv6)

Recent Developments: IPv6

- IPv4 has limited address space (32 bits) and is running out of addresses. 32 bits are not enough!

- More devices: phones, watches, your refrigerator(!), …

- Real-time traffic and mobile users are also becoming more common

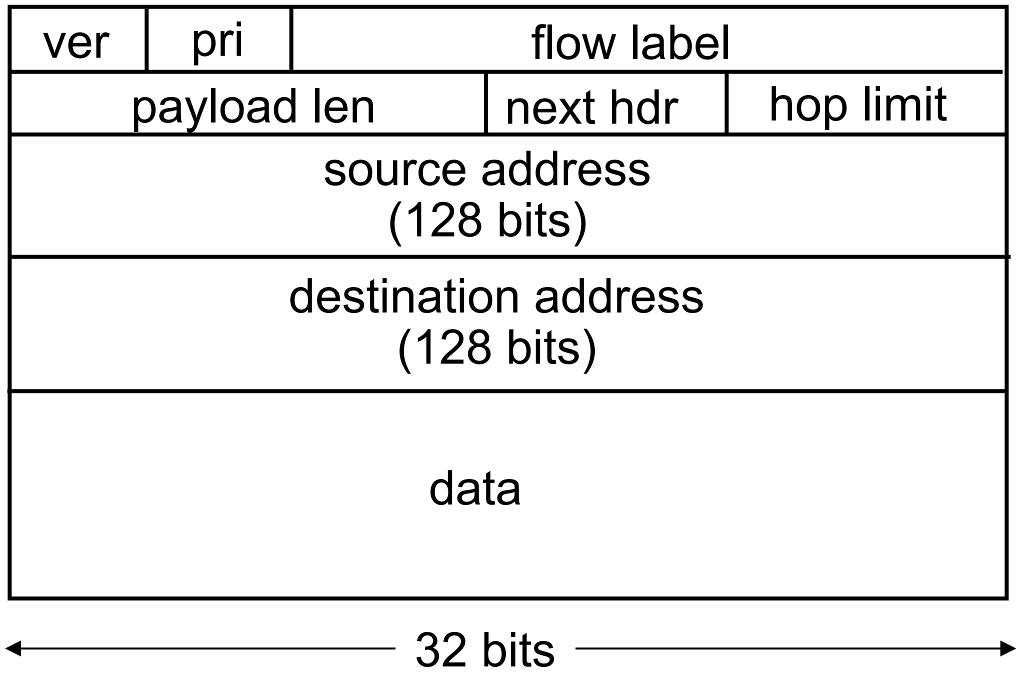
IP version 6

IPv6: Main changes from IPv4

- Large address space:
  - 128-bit addresses (16 bytes)
  - Allows up to 340,282,366,920,938,463,463,374,607,431,768,211,456 unique addresses (3.4×10^{38})
- Fixed length headers (40 bytes)
  - Improves the speed of packet processing in routers
- IPv6 “options” processing happens through a separate mechanism

IPv6 datagram format

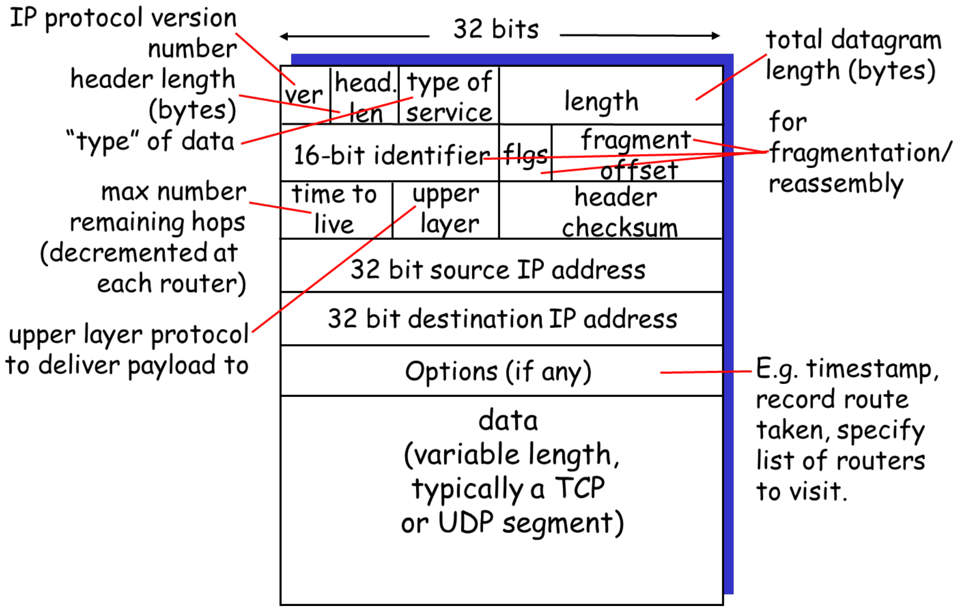
priority: identify priority among datagrams in flow
flow Label: identify datagrams in same "flow"
(concept of"flow" left undefined)
next header: identify upper layer protocol for data

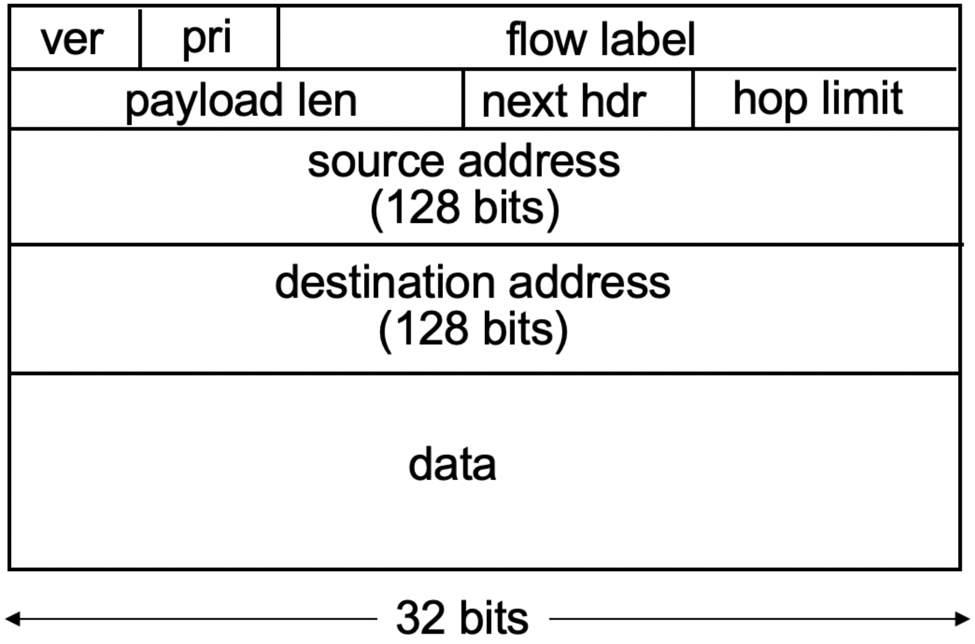


Other changes from IPv4

- *checksum*: removed entirely to reduce processing time at each hop
- *options:* allowed, but outside of header, indicated by "Next Header" field
- *ICMPv6:* new version of ICMP
  - additional message types, e.g. "Packet Too Big"
  - multicast group management functions

IPv4 vs IPv6: Can you tell the differences?





IPv6 Flows

- Support for "flows"
  - Flows help support real-time service in the Internet
  - A "flow" is a number in the IPv6 header that can be used by routers to see which packets belong to the same stream
  - Guarantees can then be assigned to certain flows
  - Example:
    - Packets from flow 10 should receive rapid delivery
    - Packets from flow 12 should receive reliable delivery

IPv6 Addresses

- Classless addressing/routing (similar to CIDR)

- Notation: xx:xx:xx:xx:xx:xx:xx:xx
  - x = 4-bit hex number
  - contiguous 0s are compressed: 47CD::A456:0124
  - IPv6 compatible IPv4 address: ::128.64.18.87
    - First 96 bits are 0
  - Global unicast addresses start with 001….
  - 2000::/3 prefix

IPv6: Adoption

- Google: 8% of clients access services via IPv6
- NIST: 1/3 of all US government domains are IPv6 capable

- *Long (long!) time for deployment, use*
    - 20 years and counting!

- Think of application-level changes in last 20 years: WWW, Facebook, streaming media, Skype, …
- *Why?*