CS 43: Computer Networks

19: IP, NAT, DHCCP

November 14, 2019

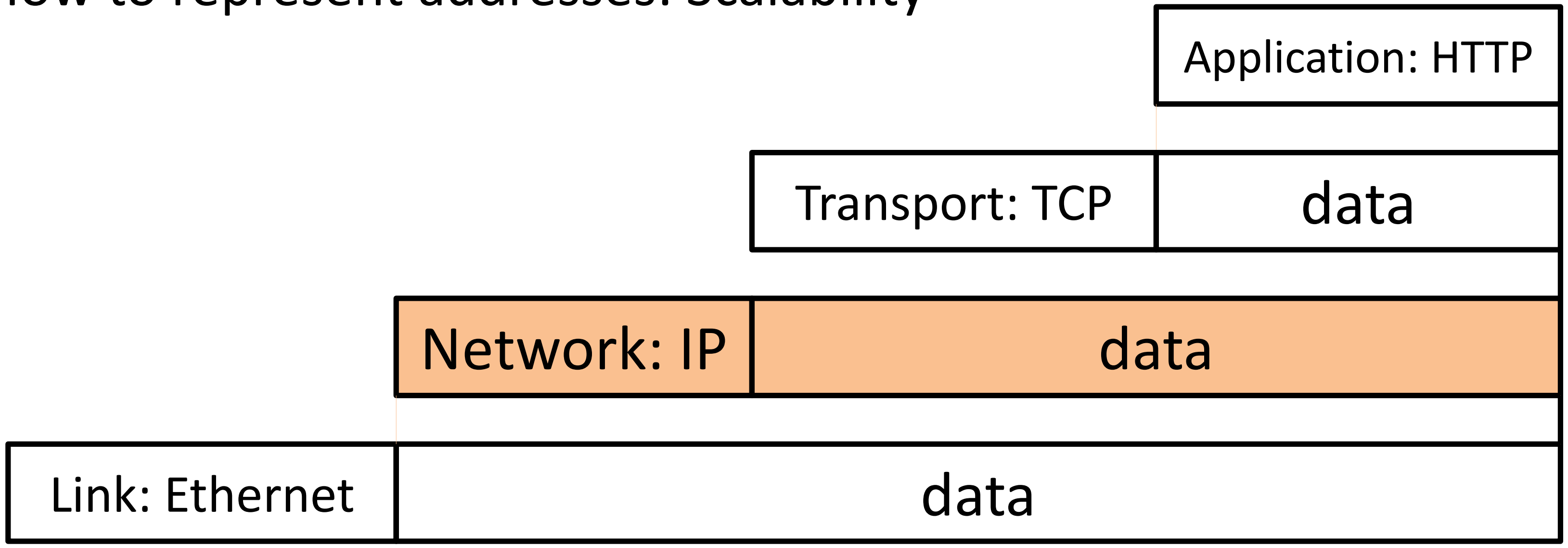
SWARTHMORE COLLEGE

Reading Quiz

Network Layer

- Function: Route packets end-to-end on a network, through multiple hops

- Key challenge
  - How to route packets: Convergence
  - How to represent addresses: Scalability

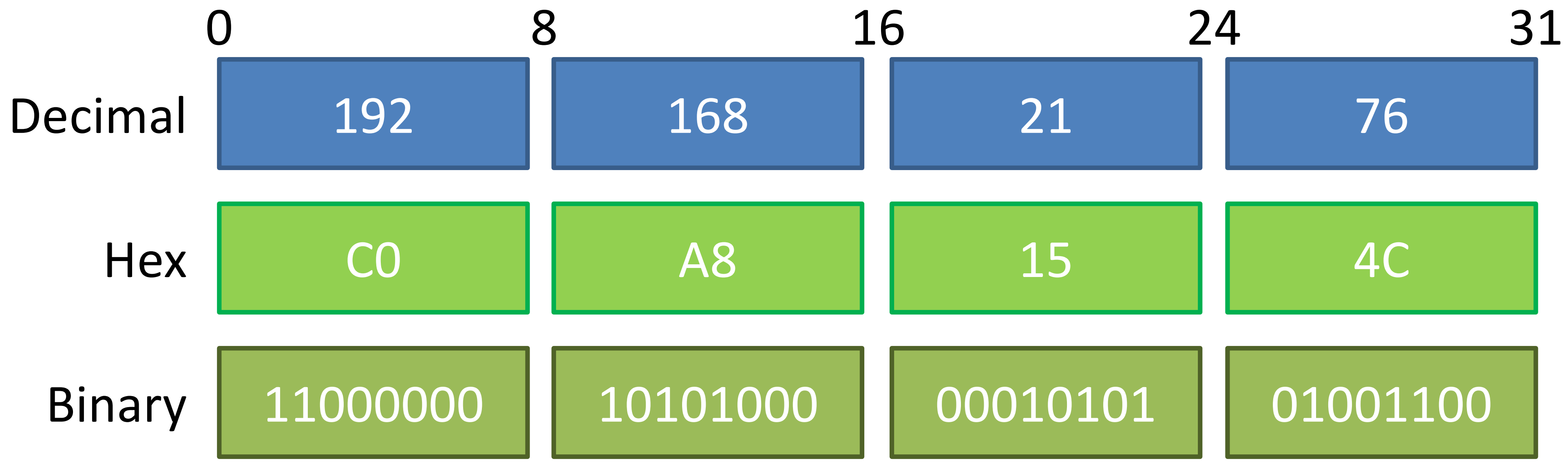


Network Layer Functions

- Forwarding: move packets from router's input to appropriate router output
  - Look up in a table
- Routing: determine route taken by packets from source to destination.
  - Populating the table

IP Addressing

- IP: 32-bit addresses
  - Usually written in dotted notation, e.g. 192.168.21.76
  - Each number is a byte
  - Stored in Big Endian order (network byte order)



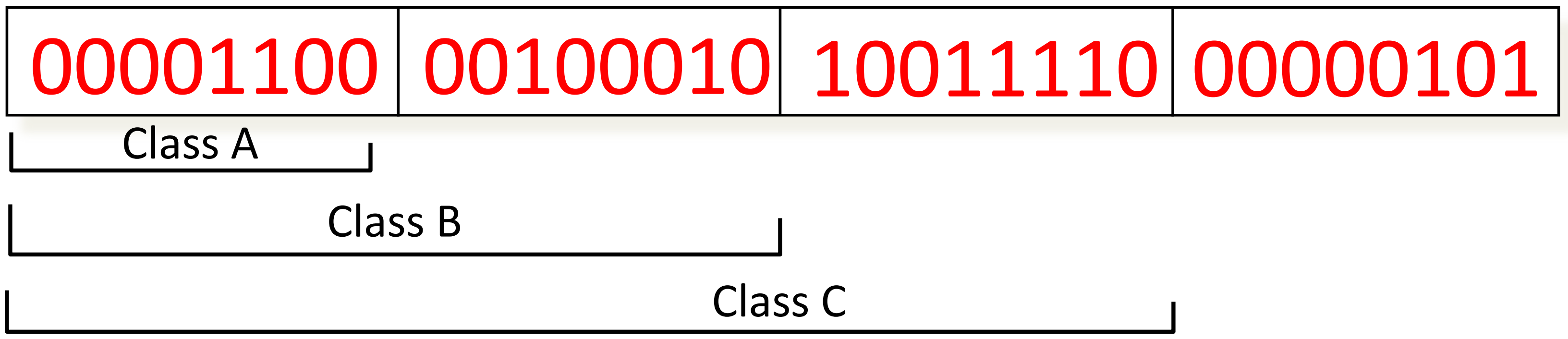
Decimal	192	168	21	76
Hex	C0	A8	15	4C
Binary	11000000	10101000	00010101	01001100

Who gets an address? How many?

- Back in the old days, you called up Jon Postel
  - “How many addresses do you need?”
  - “Here you go! I may have rounded a bit.”

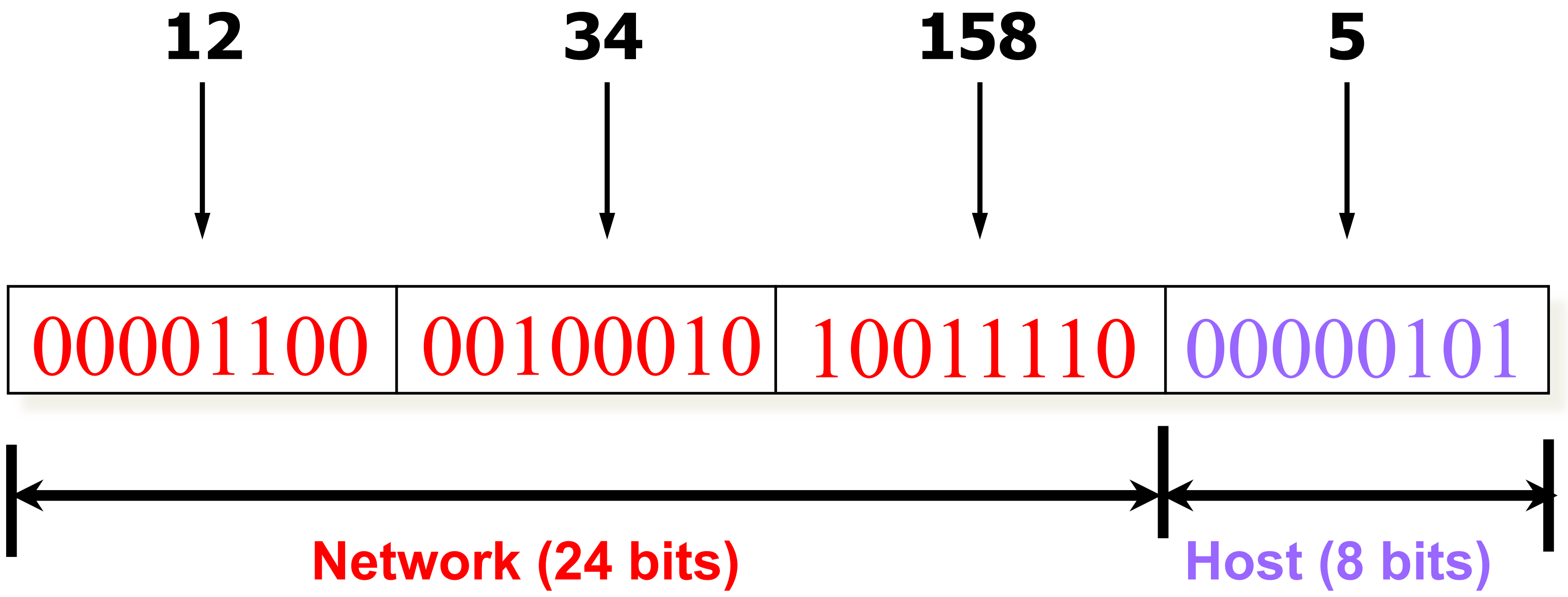
Who gets an address? How many?

- Classful Addressing
  - Class A: 8-bit prefix, 24 bits for hosts (16,777,216)
  - Class B: 16-bit prefix, 16 bits for hosts (65,536)
  - Class C: 24-bit prefix, 8 bits for hosts (256)



Who gets an address? How many?

- Network and host portions (left and right)
- 12.34.158.0/24 is a 24-bit **prefix** with 2^8 addresses



CIDR

- Classless Interdomain Routing
  - Prefix (subnet) length is no longer fixed
  - (Can be division of bits rather than just 8/24, 16/16, and 24/8)

Why do we give out addresses in CIDR blocks? How many of these statements are true? (Which ones?)

- It requires fewer resources at routers.
- It requires fewer resources at end hosts.
- It reduces the number of block allocations that need to be managed.
- It better utilizes the IP address space.

A – 0, B – 1, C – 2, D – 3, E – 4

CIDR

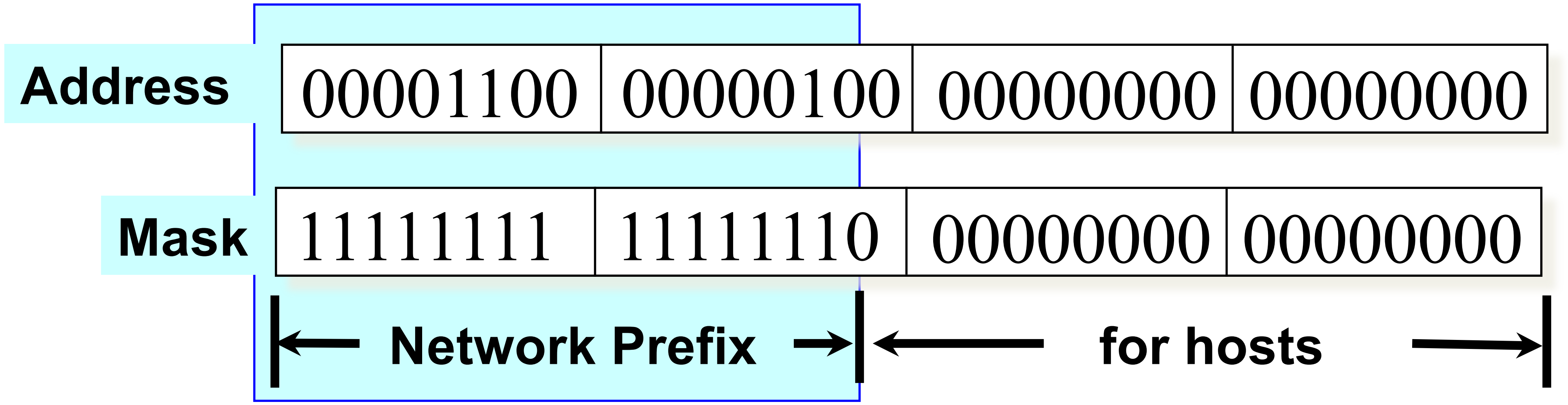
- Classless Interdomain Routing
  - Prefix (subnet) length is no longer fixed
  - Address blocks come with a **subnet mask**

- Subnet mask written in two ways:
  - Dotted decimal: 255.255.240.0
  - /20
  - Both mean:

$$\underbrace{11111111\quad 11111111\quad 1111}_{/20}0000\quad 00000000$$

Classless Inter-Domain Routing (CIDR)

IP Address : 12.4.0.0 IP Mask: 255.254.0.0



Written as 12.4.0.0/15

Use two 32-bit numbers to represent a network.
Network number = IP address + Mask

CIDR

- Addresses divided into two pieces:
  - Prefix portion (network address)
  - Host portion

- Given an IP address and mask, we can determine:
  - The prefix (network address) by ANDing
  - The broadcast address by ORing inverted mask

Network Address (Subnet Address)

- E.g., 230.8.1.3/18   /18 => mask is 255.255.192.0

11100110	**00001000**	**00000001**	**00000011**	IP address
11111111	**11111111**	**11000000**	**00000000**	/18 Subnet mask

Network Address (Subnet Address)

- E.g., 230.8.1.3/18 /18 => mask is 255.255.192.0

11100110	00001000	00000001	00000011	IP address
11111111	11111111	11000000	00000000	/18 Subnet mask
11100110	00001000	00000000	00000000	and the two

Network address advertised by router: 230.8.0.0

Why might a device care about its "Network Address"?

- Answers the question: is the destination on the same subnet as me?

- Address + subnet mask -> Network address

- If destination is on same network:
  - Send directly to them
- Else:
  - Send to gateway router

Broadcast Address

- E.g., 230.8.1.3/18

11100110	**00001000**	**00000001**	**00000011**	IP address
~~**11111111**~~	~~**11111111**~~	~~**11000000**~~	~~**00000000**~~	/18 Subnet mask
00000000	**00000000**	**00111111**	**11111111**	complement of the subnet mask

Broadcast Address

- E.g., 230.8.1.3/18

11100110	**00001000**	**00000001**	**00000011**	IP address
00000000	**00000000**	**00111111**	**11111111**	complement of the subnet mask

Broadcast Address

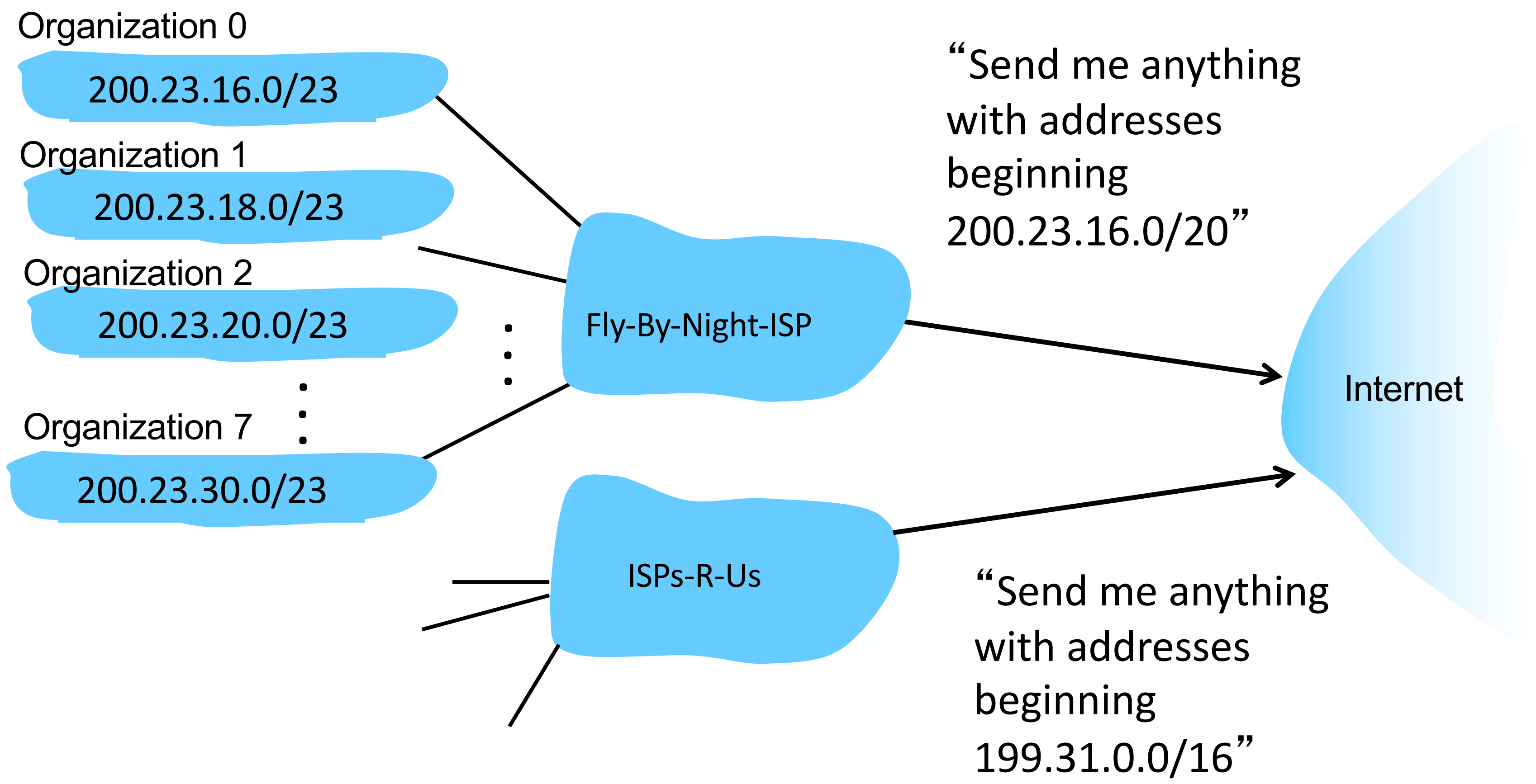
- E.g., 230.8.1.3/18

11100110	**00001000**	**00000001**	**00000011**	IP address
00000000	**00000000**	**00111111**	**11111111**	complement of the subnet mask
11100110	**00001000**	**00111111**	**11111111**	OR of the IP address and the complement of the subnet mask

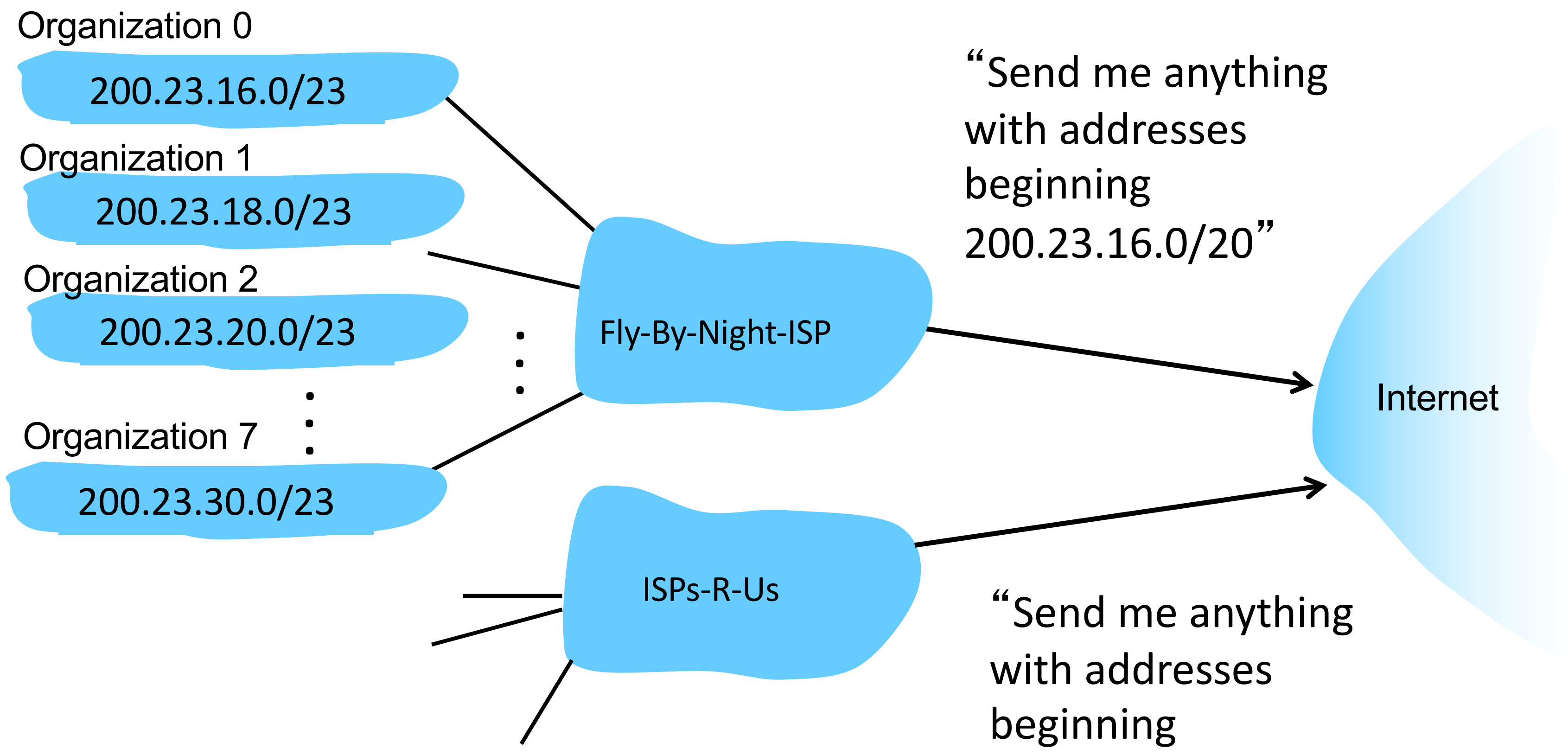
Broadcast address: 230.8.63.255

Hierarchical Addressing: Route Aggregation

Hierarchical addressing allows efficient advertisement of routing information:



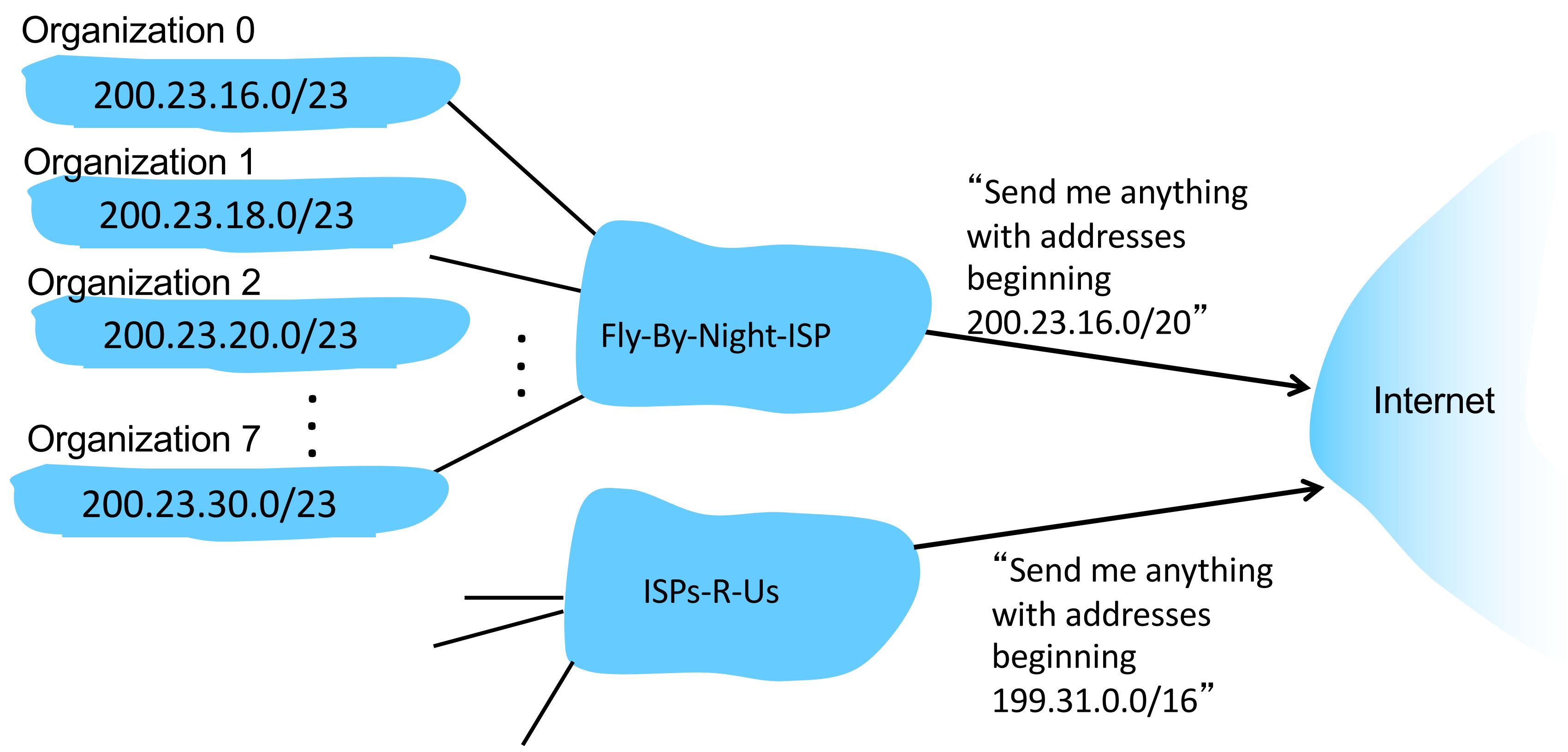
What should we do if organization 1 decides to switch to ISPs-R-Us?



"Send me anything with addresses beginning 200.23.16.0/20"

"Send me anything with addresses beginning 199.31.0.0/16"

What should we do if organization 1 decides to switch to ISPs-R-Us?



A. Move 200.23.18.0/23 to ISPs-R-Us (and break up Fly-By-Night's /20 block).
B. Give new addresses to Organization 1 (and force them to change all their addresses).
C. Some other solution.

Hierarchical Addressing: Route Aggregation

“Send me anything with addresses beginning 200.23.16.0/20” translates to the following:

```
                      200        23         16          0
200.23.16.0/20 = 11001000  00010111  00010000   00000000      /20 Prefix
                 |______________/20 prefix__|

  200.23.16.0 = 11001000  00010111  00010000   00000000    ]  Range
                                |                          ]  represented by
200.23.31.255 = 11001000  00010111  00011111   11111111    ]  the /20 prefix
```

/20 prefix contains the range of IP addresses that match the the first 20 bits, and can have any value for the remaining 12 bits in the range of :

[first 20 bits] 0000 00000000

[first 20 bits] 1111 11111111

A total of 2^12 = 4,096 IP addresses

Route aggregation in Fly-By-Night ISP

Fly-By-Night-ISP

200.23.16.0/20 = 11001000 00010111 00010000 00000000

Individual Organizations: All of these organizations IP addresses lie withinFly-by-Night's /20 prefix (first 20 bits are the same)

- they more specifically match on the three more bits to form a /23 prefix (first 23 bits of all IP addresses within their organization are the same).
- The last 9 (32-23) bits provide 2^9 = 512 unique IP addresses within each organization.

/23 prefixes

200.23.16.0/23 = 11001000 00010111 00010000 00000000

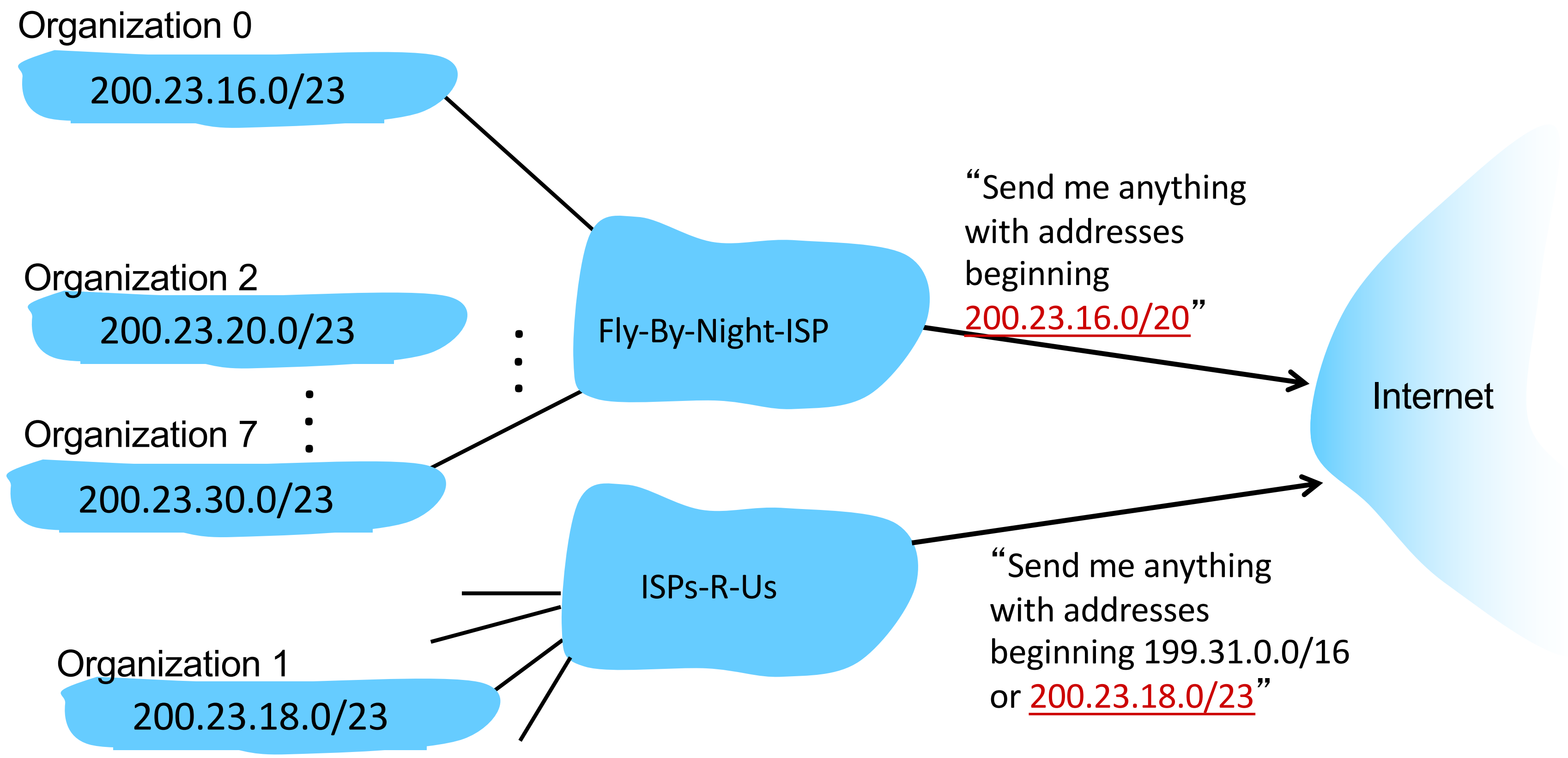
200.23.18.0/23 = 11001000 00010111 00010010 00000000

200.23.20.0/23 = 11001000 00010111 00010100 00000000

200.23.30.0/23 = 11001000 00010111 00011110 00000000

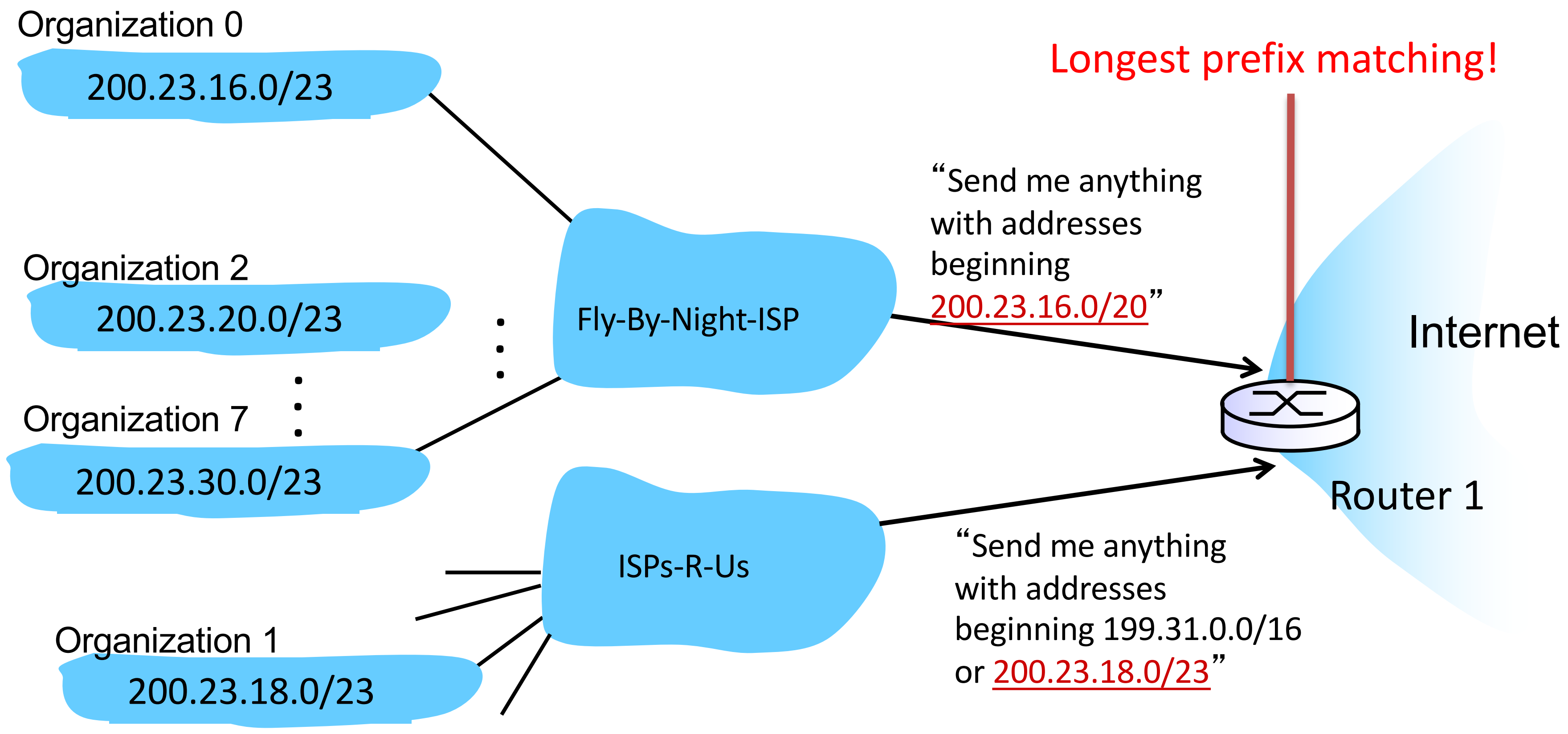
Hierarchical addressing: More Specific Routes

ISPs-R-Us has a more specific route to Organization 1

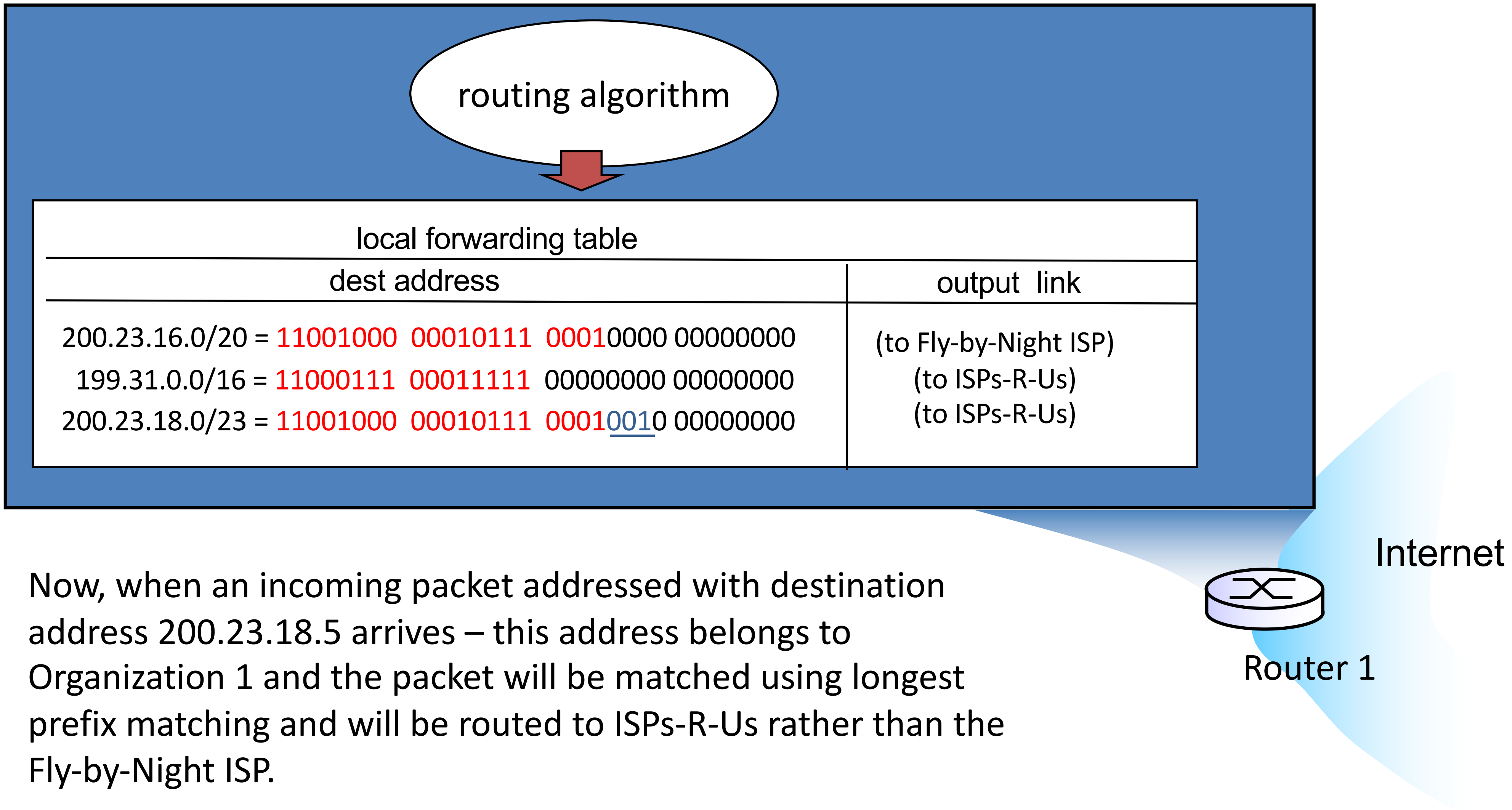


Hierarchical addressing: More Specific Routes

ISPs-R-Us has a more specific route to Organization 1



Longest Prefix Matching at Router 1



local forwarding table

dest address	output link
200.23.16.0/20 = 11001000 00010111 00010000 00000000	(to Fly-by-Night ISP)
199.31.0.0/16 = 11000111 00011111 00000000 00000000	(to ISPs-R-Us)
200.23.18.0/23 = 11001000 00010111 00010010 00000000	(to ISPs-R-Us)

Now, when an incoming packet addressed with destination address 200.23.18.5 arrives – this address belongs to Organization 1 and the packet will be matched using longest prefix matching and will be routed to ISPs-R-Us rather than the Fly-by-Night ISP.

How does an end host get an IP address?

- Static IP: hard-coded
  - Windows: control-panel->network->configuration->tcp/ip->properties
  - UNIX: /etc/rc.config

- DHCP: Dynamic Host Configuration Protocol: dynamically get address from as server
  - "plug-and-play"

DHCP: Dynamic Host Configuration Protocol

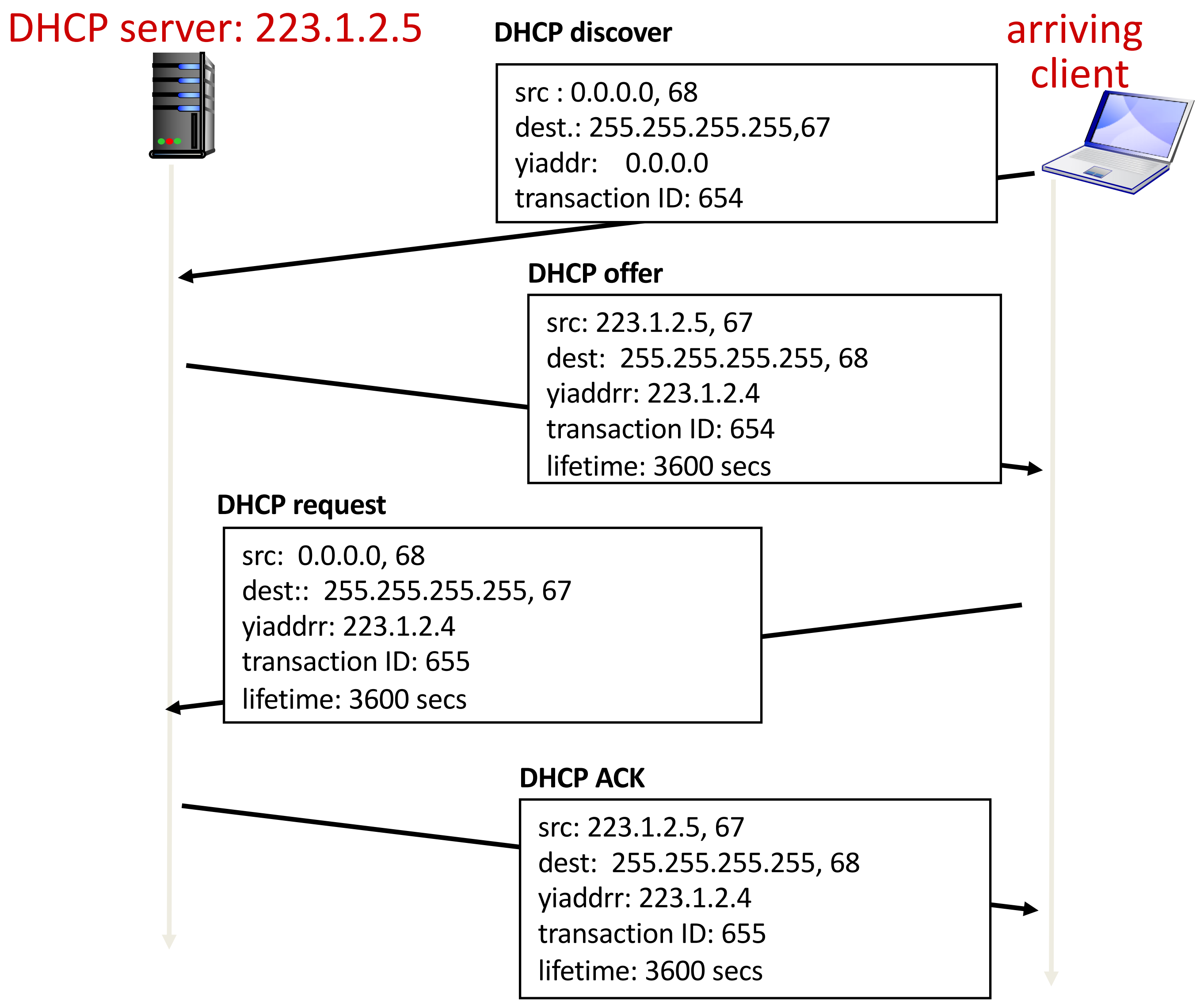
Goal: allow host to dynamically obtain its IP address from network server when it joins network

- can renew its lease on address in use
- allows reuse of addresses
- 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



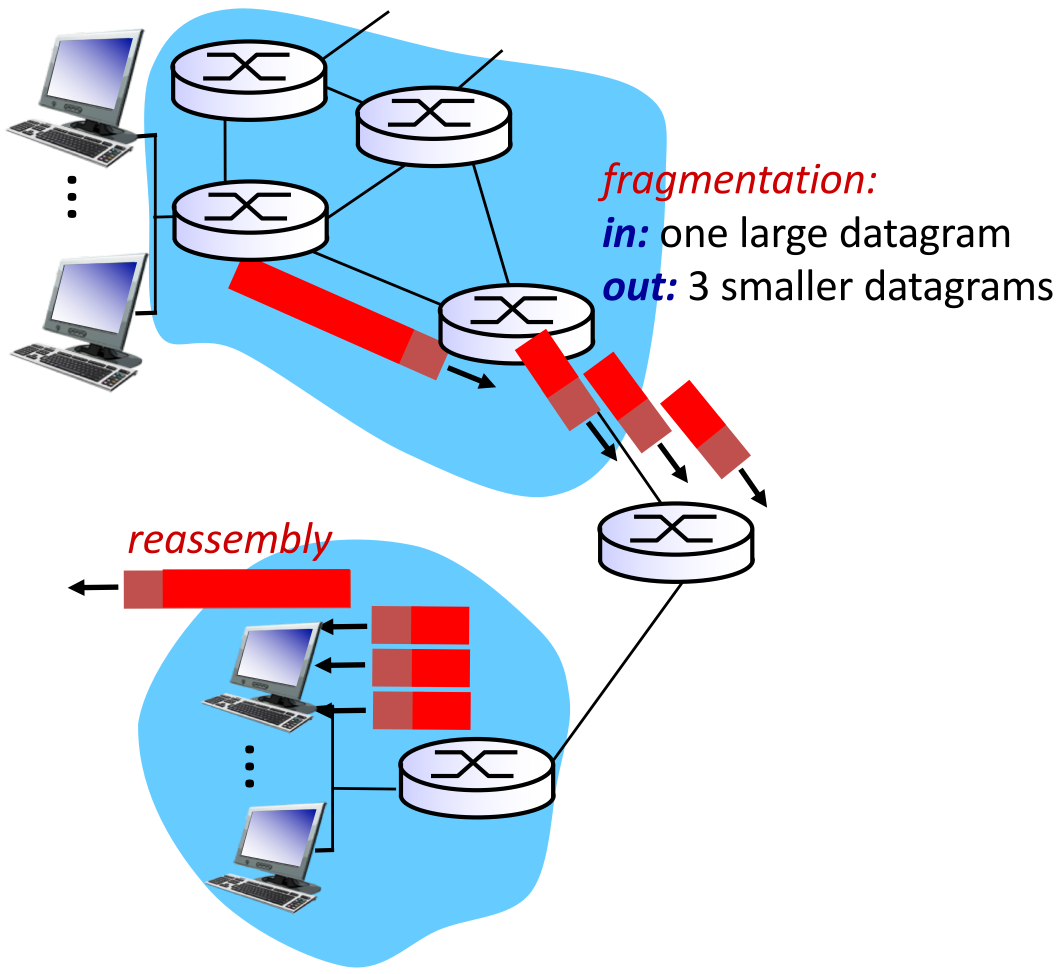
DHCP: More than IP Addresses

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

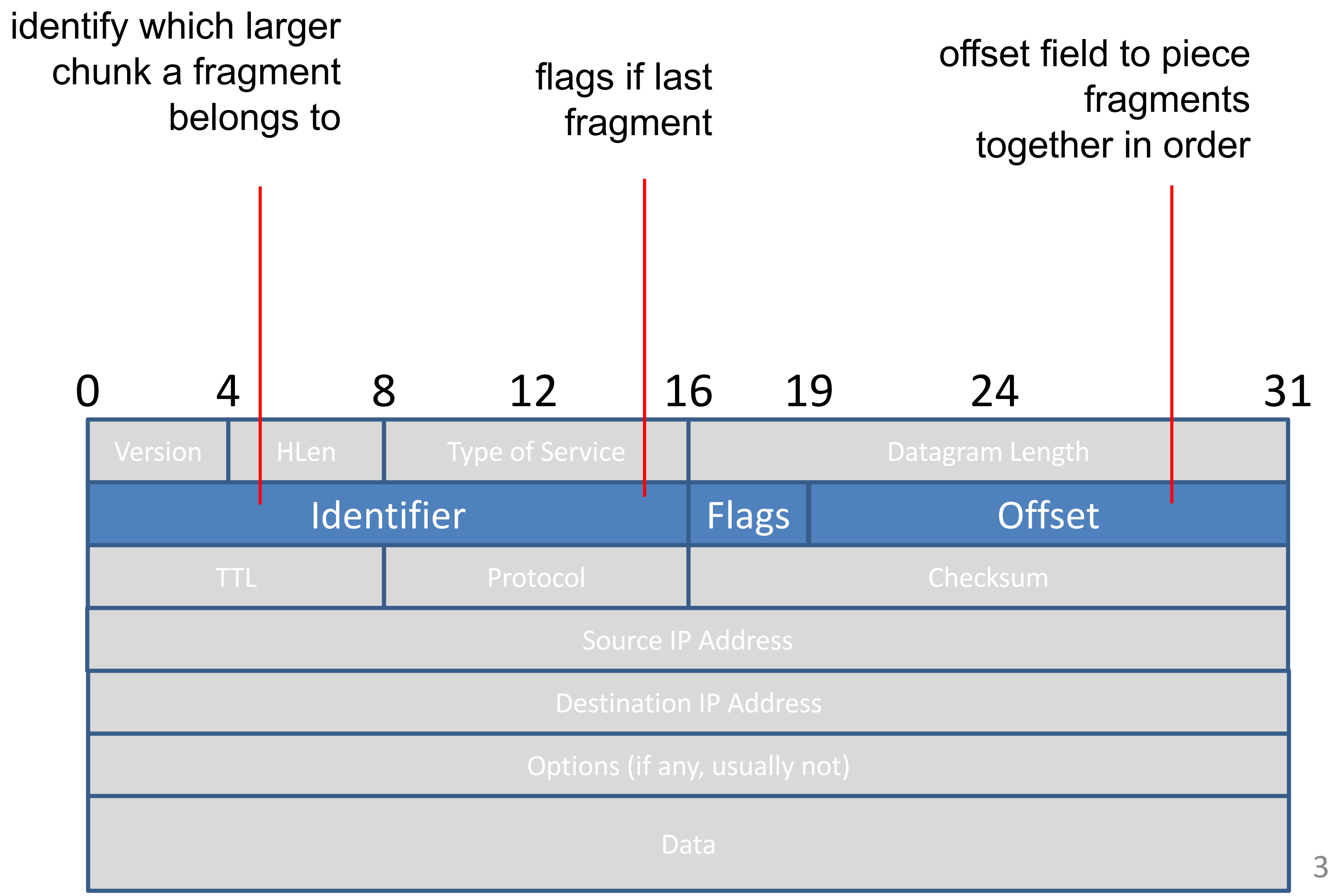
- address of first-hop router for client (default GW)
- name and IP address of DNS server(s)
- subnet mask

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 final destination
  - IP header bits used to identify, order related fragments



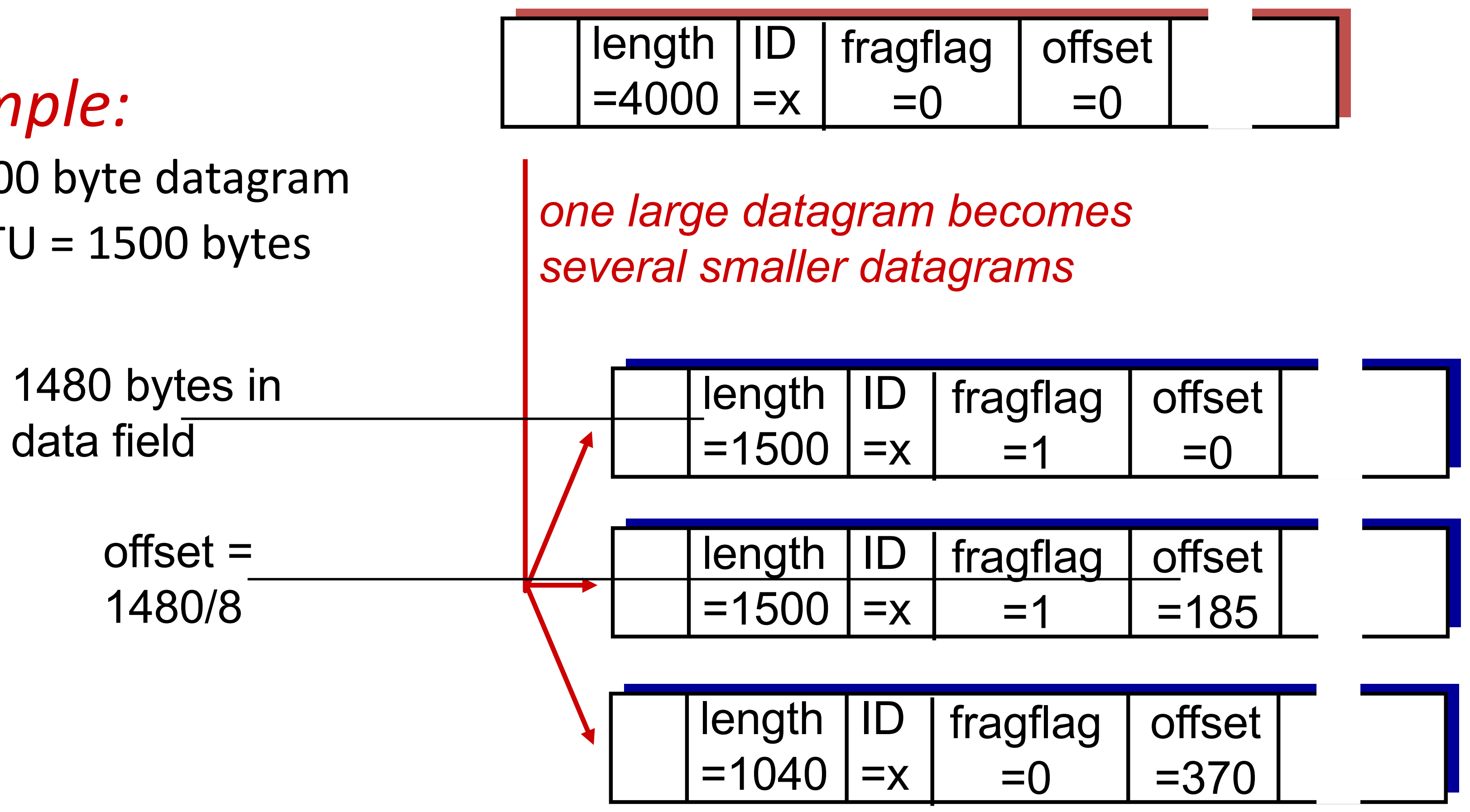
IP Datagram Format



IP Fragmentation, Reassembly

Example:

- 4000 byte datagram
- MTU = 1500 bytes



How can we use this for evil?

A. Send fragments that overlap.

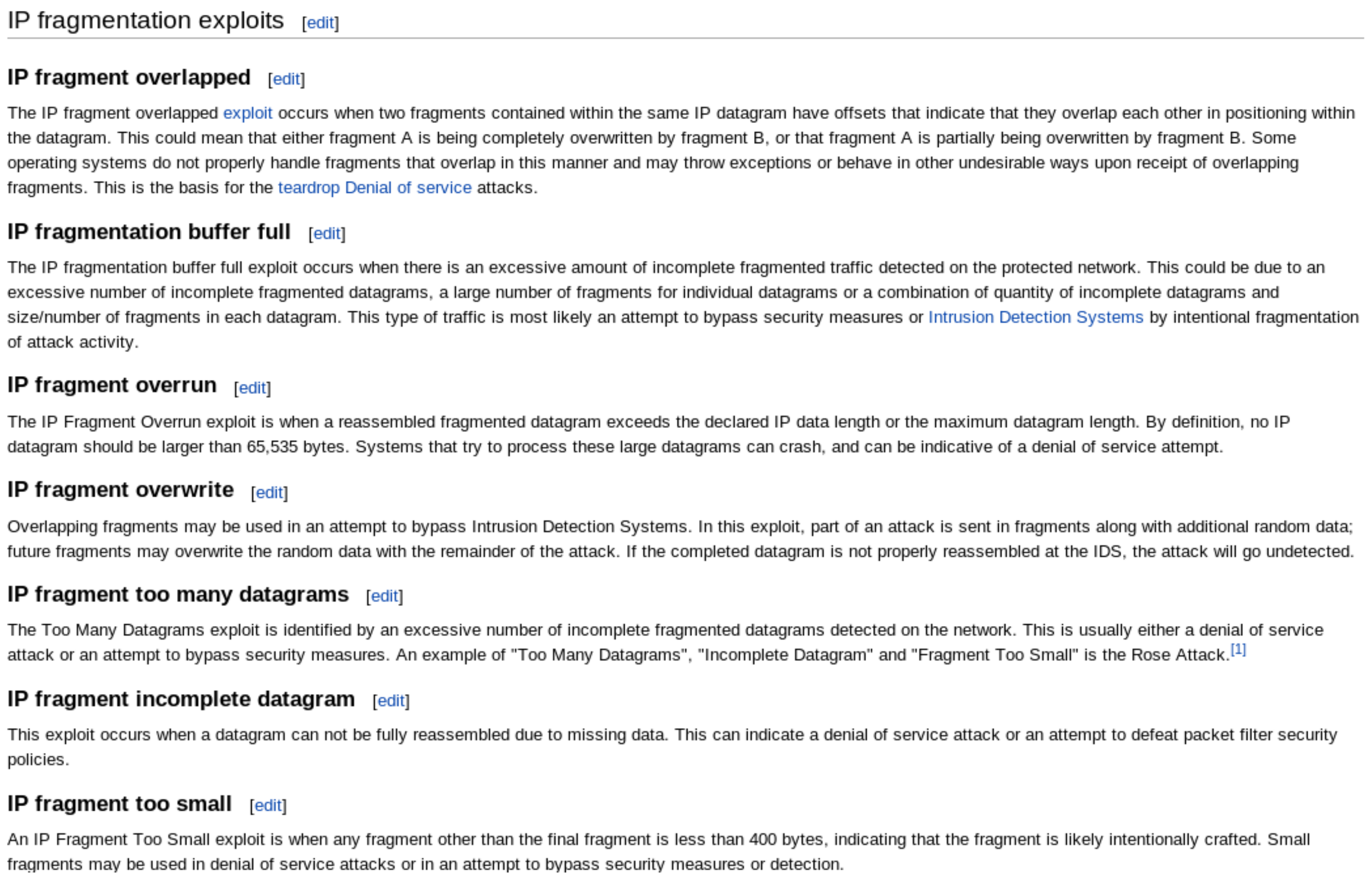
B. Send many tiny fragments, none of which have offset 0.

C. Send fragments that, when assembled, are bigger than the maximum IP datagram.

D. More than one of the above.

E. Nah, networks (and operating systems) are too robust for this to cause problems.

IP Fragmentation Attacks…



IP fragmentation exploits [edit]

IP fragment overlapped [edit]

The IP fragment overlapped exploit occurs when two fragments contained within the same IP datagram have offsets that indicate that they overlap each other in positioning within the datagram. This could mean that either fragment A is being completely overwritten by fragment B, or that fragment A is partially being overwritten by fragment B. Some operating systems do not properly handle fragments that overlap in this manner and may throw exceptions or behave in other undesirable ways upon receipt of overlapping fragments. This is the basis for the teardrop Denial of service attacks.

IP fragmentation buffer full [edit]

The IP fragmentation buffer full exploit occurs when there is an excessive amount of incomplete fragmented traffic detected on the protected network. This could be due to an excessive number of incomplete fragmented datagrams, a large number of fragments for individual datagrams or a combination of quantity of incomplete datagrams and size/number of fragments in each datagram. This type of traffic is most likely an attempt to bypass security measures or Intrusion Detection Systems by intentional fragmentation of attack activity.

IP fragment overrun [edit]

The IP Fragment Overrun exploit is when a reassembled fragmented datagram exceeds the declared IP data length or the maximum datagram length. By definition, no IP datagram should be larger than 65,535 bytes. Systems that try to process these large datagrams can crash, and can be indicative of a denial of service attempt.

IP fragment overwrite [edit]

Overlapping fragments may be used in an attempt to bypass Intrusion Detection Systems. In this exploit, part of an attack is sent in fragments along with additional random data; future fragments may overwrite the random data with the remainder of the attack. If the completed datagram is not properly reassembled at the IDS, the attack will go undetected.

IP fragment too many datagrams [edit]

The Too Many Datagrams exploit is identified by an excessive number of incomplete fragmented datagrams detected on the network. This is usually either a denial of service attack or an attempt to bypass security measures. An example of "Too Many Datagrams", "Incomplete Datagram" and "Fragment Too Small" is the Rose Attack.[1]

IP fragment incomplete datagram [edit]

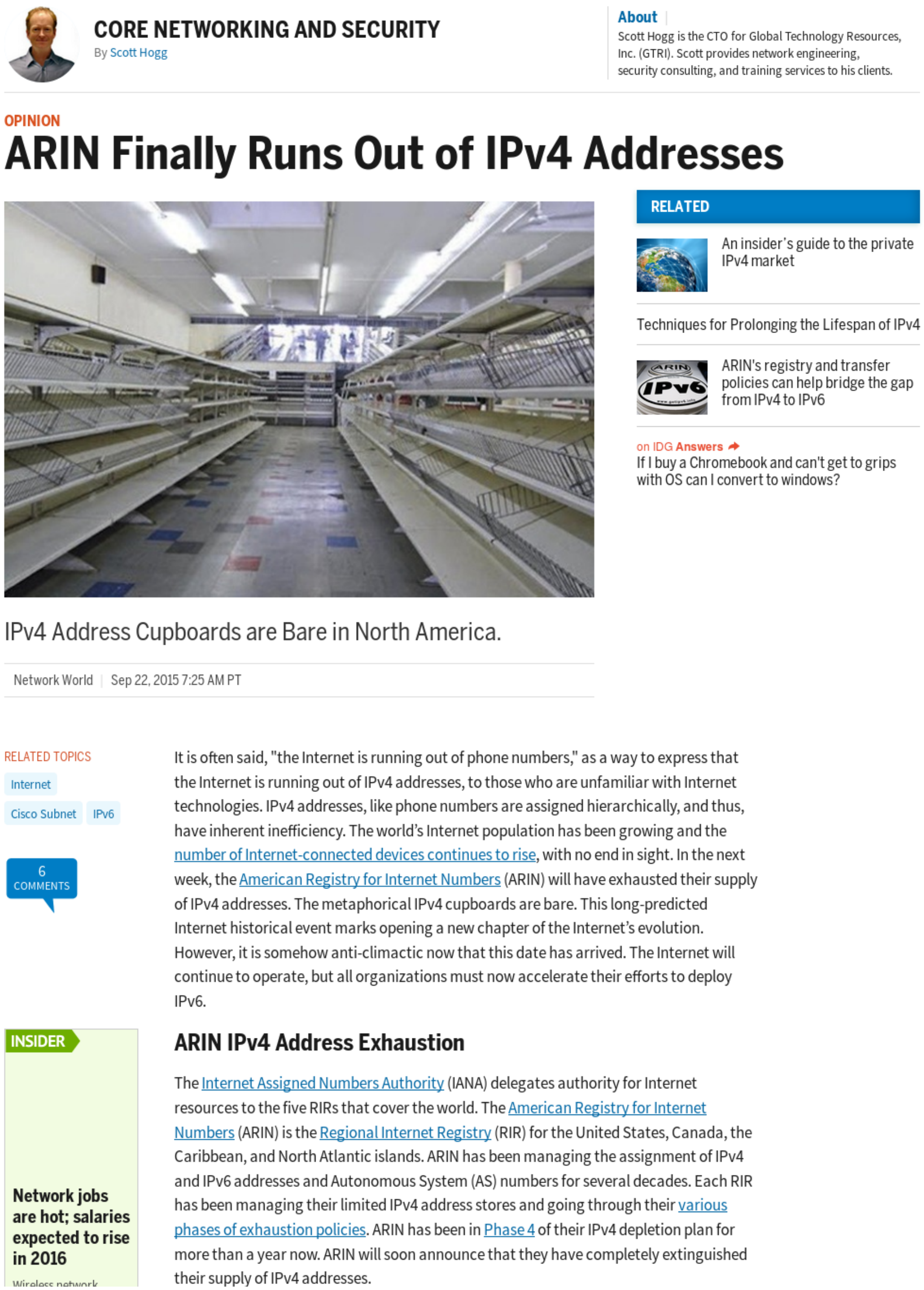
This exploit occurs when a datagram can not be fully reassembled due to missing data. This can indicate a denial of service attack or an attempt to defeat packet filter security policies.

IP fragment too small [edit]

An IP Fragment Too Small exploit is when any fragment other than the final fragment is less than 400 bytes, indicating that the fragment is likely intentionally crafted. Small fragments may be used in denial of service attacks or in an attempt to bypass security measures or detection.

Recall: IPv4 Addresses

- 32-bit number, must be globally unique
- 2^{32} => 4,294,967,296 possible addresses
- How many do you have?



CORE NETWORKING AND SECURITY
By Scott Hogg

About
Scott Hogg is the CTO for Global Technology Resources, Inc. (GTRI). Scott provides network engineering, security consulting, and training services to his clients.

OPINION

ARIN Finally Runs Out of IPv4 Addresses

IPv4 Address Cupboards are Bare in North America.

Network World | Sep 22, 2015 7:25 AM PT

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6 COMMENTS

It is often said, "the Internet is running out of phone numbers," as a way to express that the Internet is running out of IPv4 addresses, to those who are unfamiliar with Internet technologies. IPv4 addresses, like phone numbers are assigned hierarchically, and thus, have inherent inefficiency. The world's Internet population has been growing and the number of Internet-connected devices continues to rise, with no end in sight. In the next week, the American Registry for Internet Numbers (ARIN) will have exhausted their supply of IPv4 addresses. The metaphorical IPv4 cupboards are bare. This long-predicted Internet historical event marks opening a new chapter of the Internet's evolution. However, it is somehow anti-climactic now that this date has arrived. The Internet will continue to operate, but all organizations must now accelerate their efforts to deploy IPv6.

ARIN IPv4 Address Exhaustion

The Internet Assigned Numbers Authority (IANA) delegates authority for Internet resources to the five RIRs that cover the world. The American Registry for Internet Numbers (ARIN) is the Regional Internet Registry (RIR) for the United States, Canada, the Caribbean, and North Atlantic islands. ARIN has been managing the assignment of IPv4 and IPv6 addresses and Autonomous System (AS) numbers for several decades. Each RIR has been managing their limited IPv4 address stores and going through their various phases of exhaustion policies. ARIN has been in Phase 4 of their IPv4 depletion plan for more than a year now. ARIN will soon announce that they have completely extinguished their supply of IPv4 addresses.

INSIDER
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Wireless network

Slide 42

Seriously, we're done now. We're done

Exhausted with never-ending internet exhaustion

By Kieren McCarthy in San Francisco 15 Feb 2017 at 23:07 214 SHARE ▼

You may have heard this before, but we are really, really running out of public IPv4 addresses.

This week, the regional internet registry responsible for Latin America and the Caribbean, LACNIC, announced it has moved to "phase 3" of its plan to dispense with the remaining network addresses, meaning that only companies that have not received any IPv4 space are eligible. There is no phase 4.

That means LACNIC is down to its last 4,698,112 public IPv4 addresses (although that may increase as it recovers a little bit of space over time).

Data Centre ▸ Networks

OK, this time it's for real: The last available IPv4 address block has gone

Now for the last time, will you all please shift to IPv6?!

By Kieren McCarthy in San Francisco 18 Apr 2018 at 22:10 211 SHARE ▼

You may have heard this one before, but we have now really run out of public IPv4 address blocks.

The Internet Assigned Numbers Authority – the global overseers of network addresses – said it had run out of new addresses to dish out to regional internet registries (RIRs) in 2011. One of those RIRs, the Asia-Pacific Network Information Centre, said it was out of available IPv4 addresses later that year.

Then Europe's RIR, Réseaux IP Européens aka RIPE, ran dry in September 2012, followed by the Latin America and Caribbean Network Information Centre (LACNIC) in June 2014. Next, the American Registry for Internet Numbers hit an IPv4 drought in September 2015.

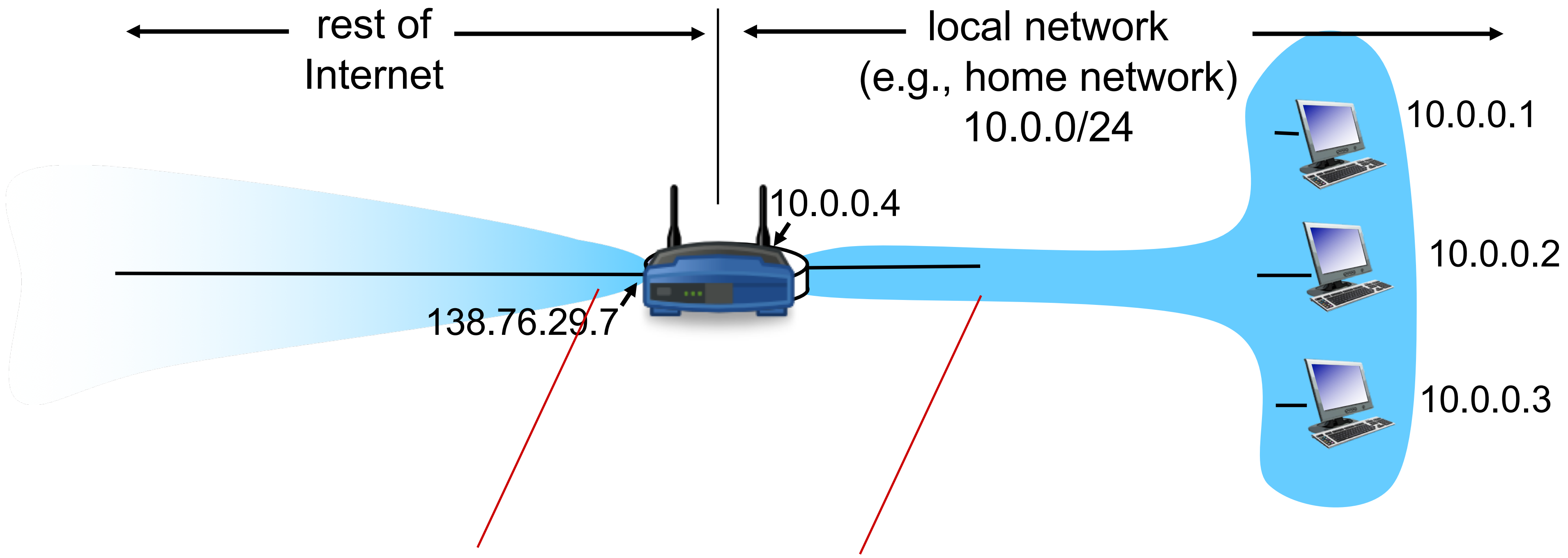
Private Addresses

- Defined in RFC 1918:

– 10.0.0.0/8	(16,777,216 hosts)
– 172.16.0.0/12	(1,048,576 hosts)
– 192.168.0.0/16	(65536 hosts)

- These addresses shouldn’t be routed.
  - Anyone can use them.
  - Often adopted for use with NAT.

NAT: Network Address Translation



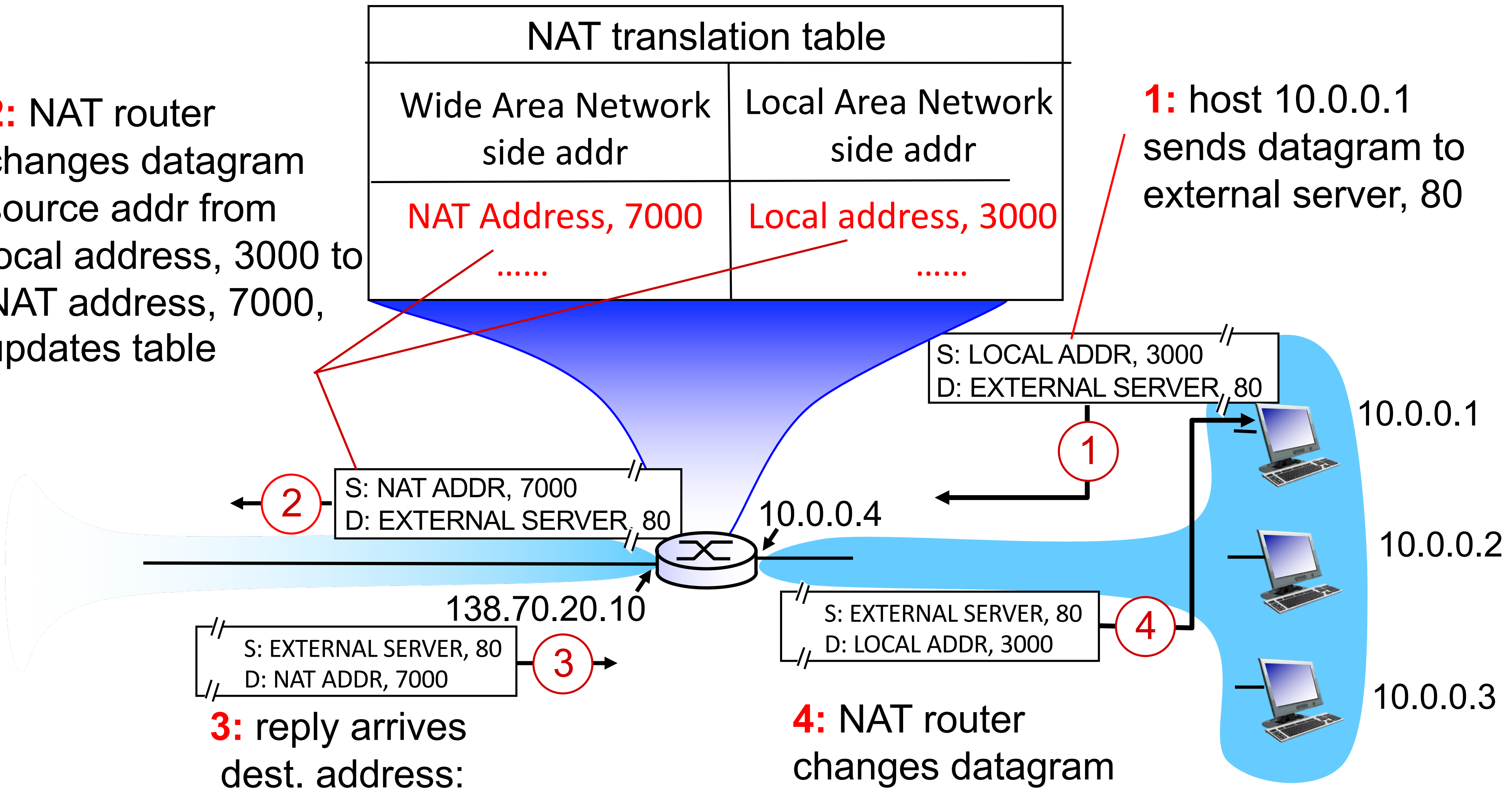
all datagrams leaving local network have same single source NAT IP address: 138.76.29.7,different source port numbers

datagrams with source or destination in this network have 10.0.0/24 address for source, destination

Implementing NAT

- Two hosts communicate with same destination
  - Destination needs to differentiate the two
- Map outgoing packets
  - Change source address and source port
- Maintain a translation table
  - Map of (src addr, port #) to (NAT addr, new port #)
- Map incoming packets
  - Map the destination address/port to the local host

NAT: network address translation



NAT translation table	
Wide Area Network side addr	Local Area Network side addr
NAT Address, 7000	Local address, 3000
……	……

2: NAT router changes datagram source addr from local address, 3000 to NAT address, 7000, updates table

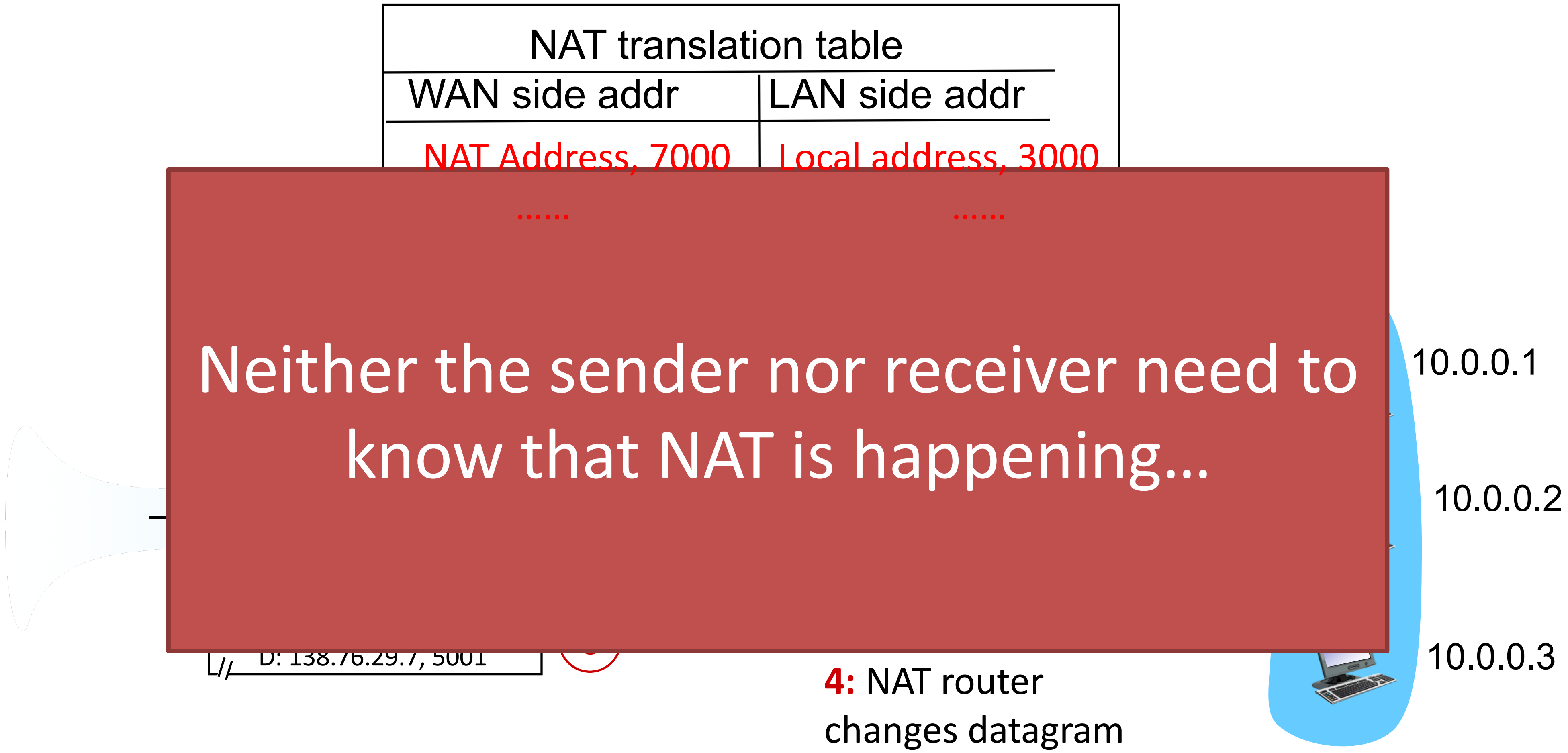
1: host 10.0.0.1 sends datagram to external server, 80

3: reply arrives dest. address: NAT address, 7000

4: NAT router changes datagram dest addr from NAT Address, 7000 to Local Address, 3000

EXTERNAL SERVER: 120.130.140.150
LOCAL ADDR: 10.0.0.1
NAT ADDR: 138.70.20.10

NAT: network address translation



Neither the sender nor receiver need to know that NAT is happening…

4: NAT router changes datagram dest addr from NAT Address, 7000 to Local Address, 3000

NAT Advantages

- Organizations need fewer IP addresses from their ISP.
  - With a 16-bit port field, we can put 65535 connections behind one external IP address!
- Organizations can change internal network IPs without having to change outside world IPs.

What about the following statement?

Devices inside the local network are not explicitly addressable or visible to the outside world.

A. This is an advantage.

B. This is a disadvantage.

How do we feel about NAT?

A. NAT is great! It conserves IP addresses and makes it harder to reach non-public machines.

B. NAT is mostly good, but has a few negative features. No big deal.

C. NAT is mostly bad, but in some cases, it’s a necessary evil.

D. NAT is an abomination that violates the end to end principle, and we should not use it!

Principled Objections Against NAT

- Routers are not supposed to look at port #s
  - Network layer should care only about *IP* header
  - … and not be looking at the *port numbers* at all
- NAT violates the end-to-end argument
  - Network nodes should not modify the packets
- IPv6 is a cleaner solution
  - Better to migrate than to limp along with a hack

That's what happens when network puts power in hands of end users!

IPv6

- Initial motivation: 32-bit address space soon to be completely allocated, any day now™.

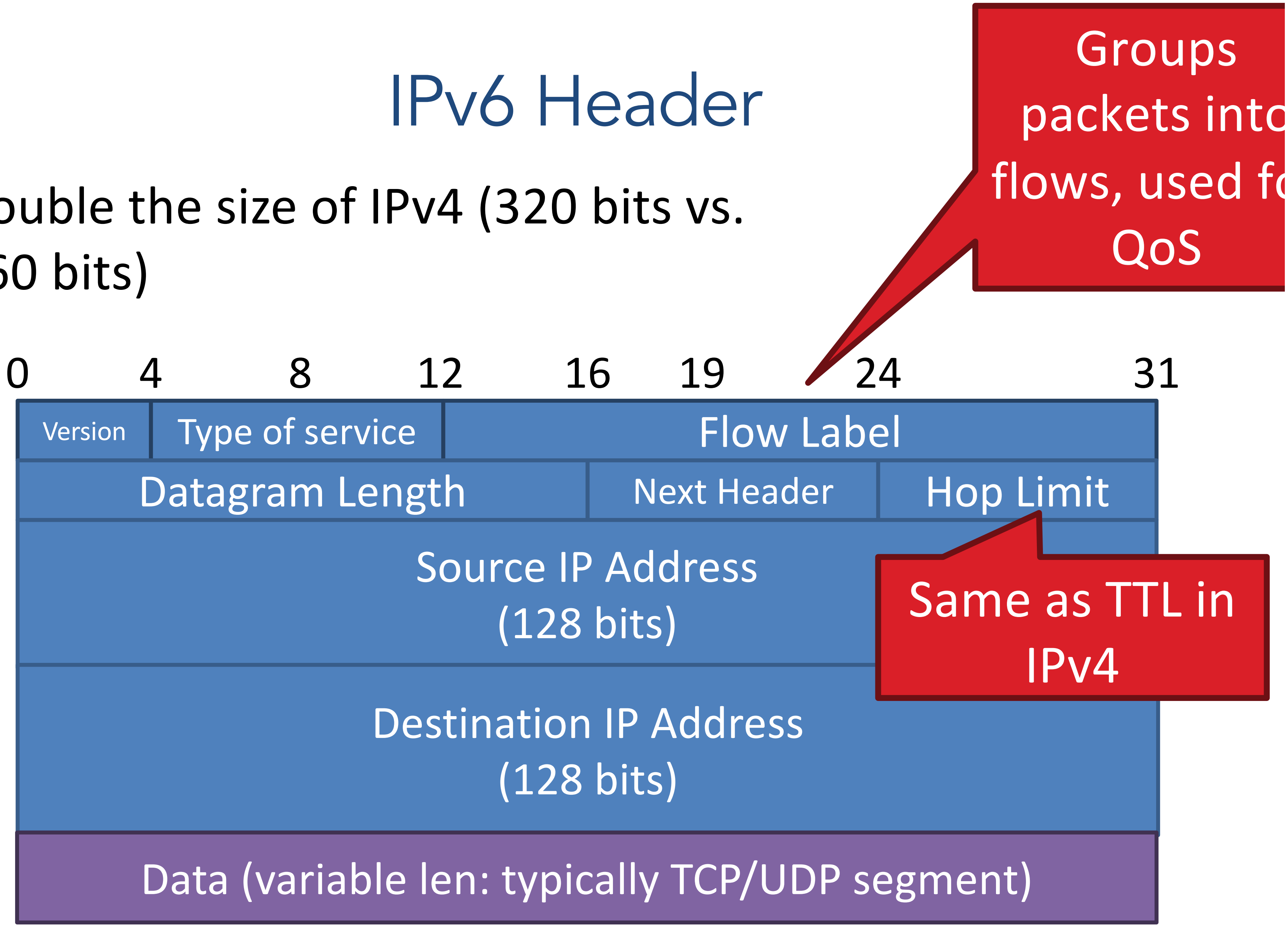
- Additional motivation:
  - header format helps speed processing/forwarding
  - header changes to facilitate QoS

IPv6 datagram format:

- fixed-length 40 byte header
- no fragmentation allowed

IPv6 Header

- Double the size of IPv4 (320 bits vs. 160 bits)



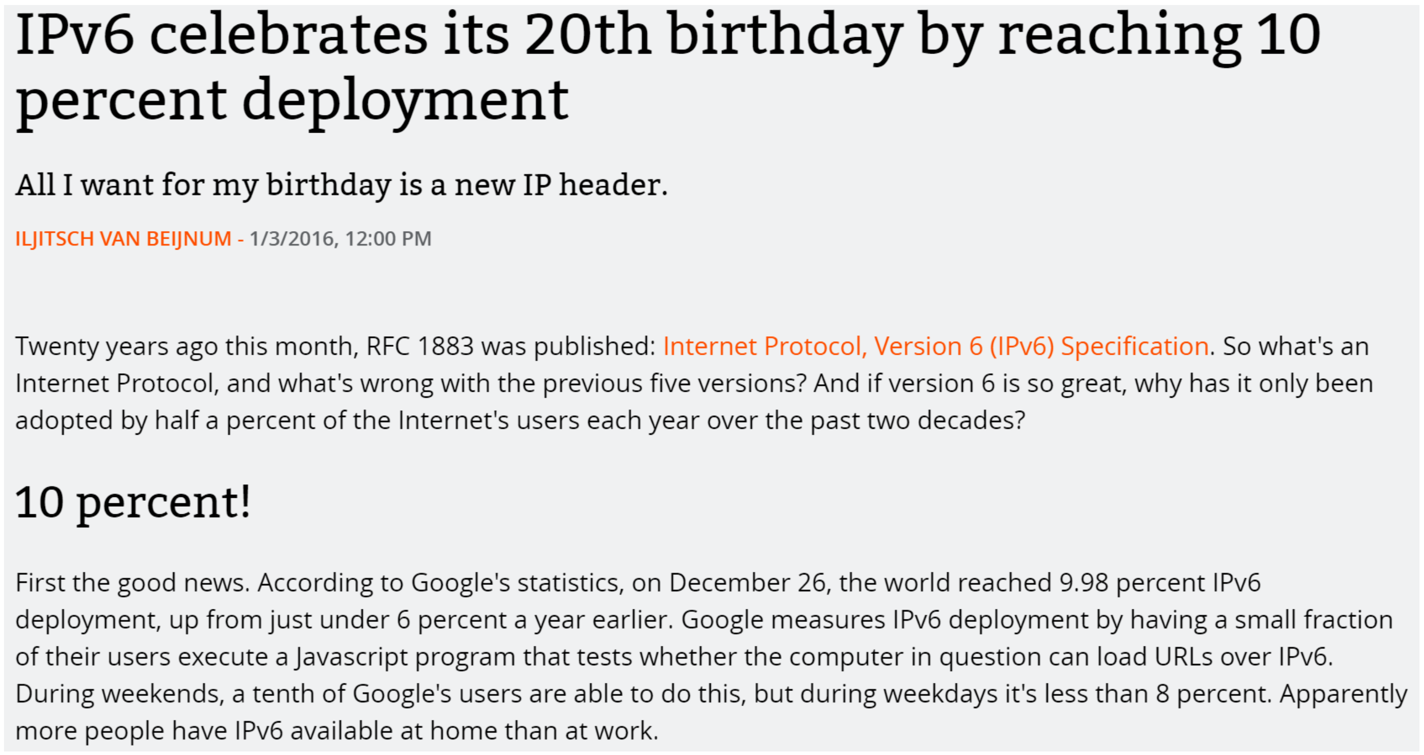
Groups packets into flows, used fo QoS
0
4
8
12
16
19
24
31
Version
Type of service
Flow Label
Datagram Length
Next Header
Hop Limit
Source IP Address (128 bits)
Same as TTL in IPv4
Destination IP Address (128 bits)
Data (variable len: typically TCP/UDP segment)

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

IPv6 (vs. IPv4)

- Simpler, faster, better
- How much traffic on the Internet is IPv6?
- Why!?



IPv6 celebrates its 20th birthday by reaching 10 percent deployment

All I want for my birthday is a new IP header.

ILJITSCH VAN BEIJNUM - 1/3/2016, 12:00 PM

Twenty years ago this month, RFC 1883 was published: Internet Protocol, Version 6 (IPv6) Specification. So what's an Internet Protocol, and what's wrong with the previous five versions? And if version 6 is so great, why has it only been adopted by half a percent of the Internet's users each year over the past two decades?

10 percent!

First the good news. According to Google's statistics, on December 26, the world reached 9.98 percent IPv6 deployment, up from just under 6 percent a year earlier. Google measures IPv6 deployment by having a small fraction of their users execute a Javascript program that tests whether the computer in question can load URLs over IPv6. During weekends, a tenth of Google's users are able to do this, but during weekdays it's less than 8 percent. Apparently more people have IPv6 available at home than at work.

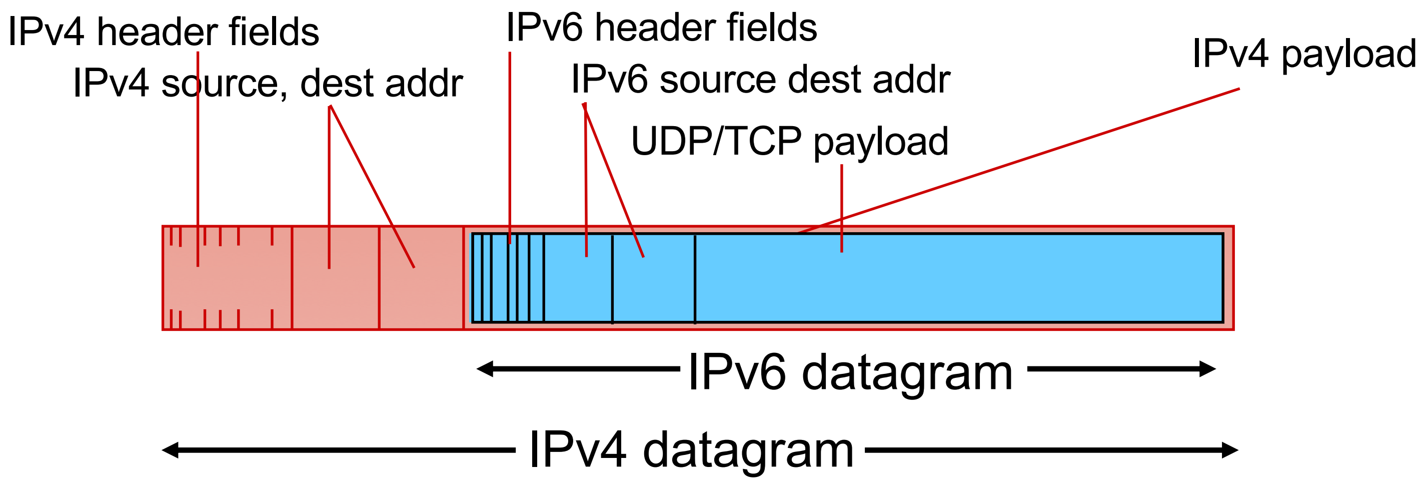
Transitioning to IPv6

- Option 1: "Flag day"
  - How do we get *everyone* on the Internet to agree?
  - Whose authority to decide when?
  - Can you imagine how much would break?

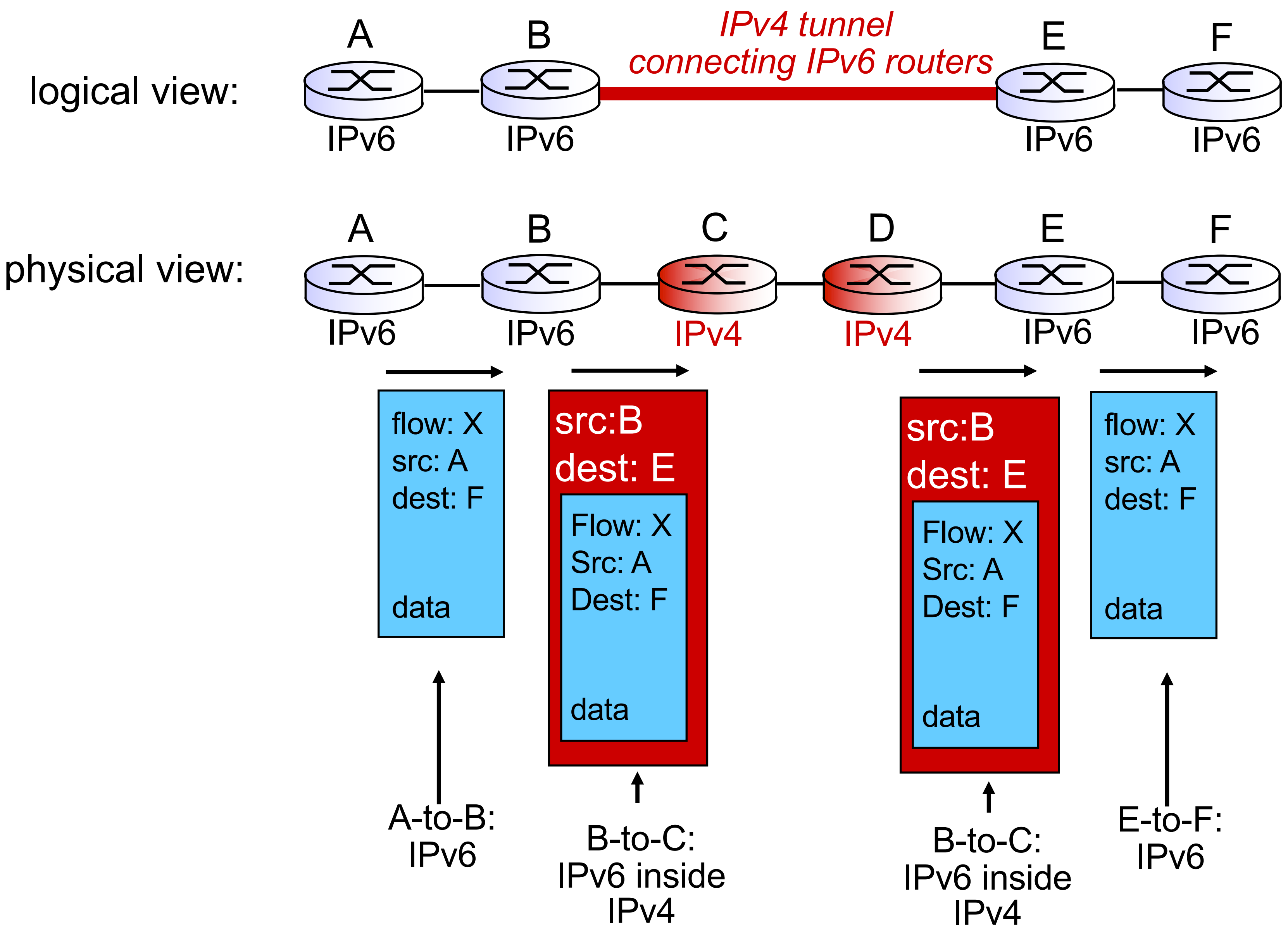
- Option 2: Slow transition
  - Some hosts/routers speak both versions
  - Must have some way to deal with those who don't
  - Lack of incentive to switch

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
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

ICMP: Internet Control Message Protocol

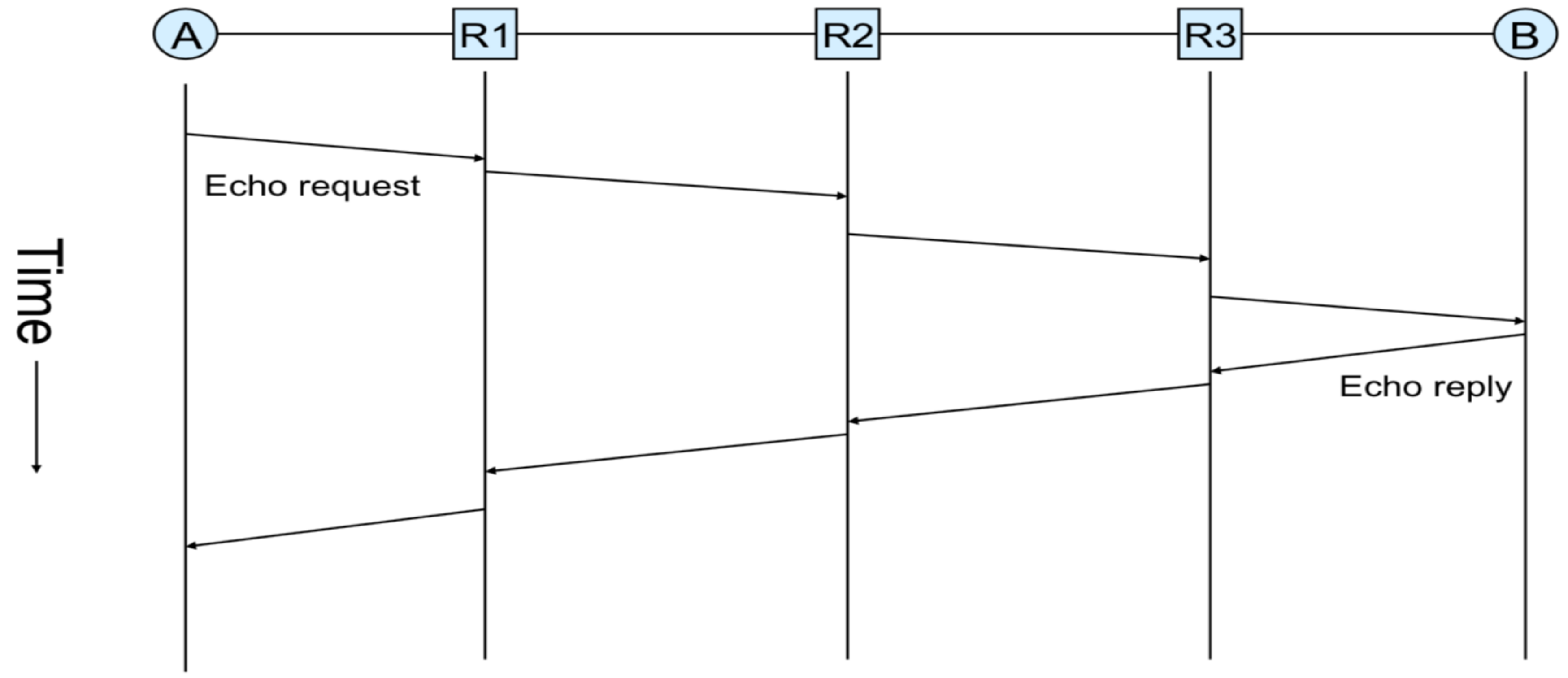
- Used to communicate network information
  - “Control messages”, i.e., not data themselves
  - Error reporting
    - Unreachable host
    - Unreachable network
    - Unreachable port
    - TTL expired
  - Test connectivity
    - Echo request/response (ping)

ICMP: Internet Control Message Protocol

- Header:
  - 1-byte type
  - 1-byte code
  - 2-byte checksum
  - 4 bytes vary by type
- Sits above IP
  - Type 1 in IP header
  - Usually considered part of IP

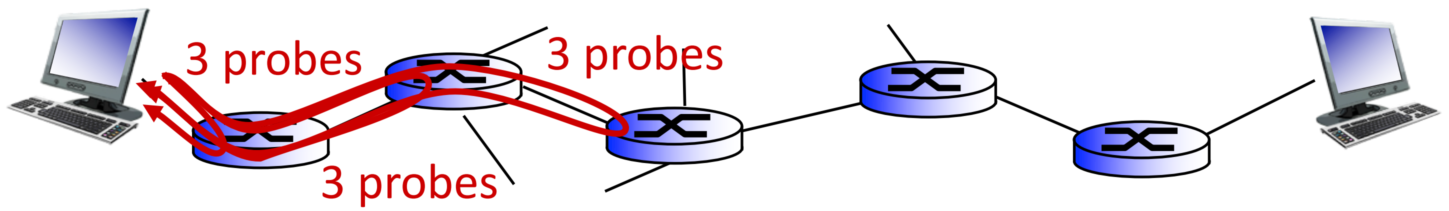
Type	Code	Description
0	0	echo reply (ping)
3	0	dest. network unreachable
3	1	dest host unreachable
3	2	dest protocol unreachable
3	3	dest port unreachable
3	6	dest network unknown
3	7	dest host unknown
4	0	source quench (congestion control - not used)
8	0	echo request (ping)
9	0	route advertisement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

Ping



Traceroute and ICMP

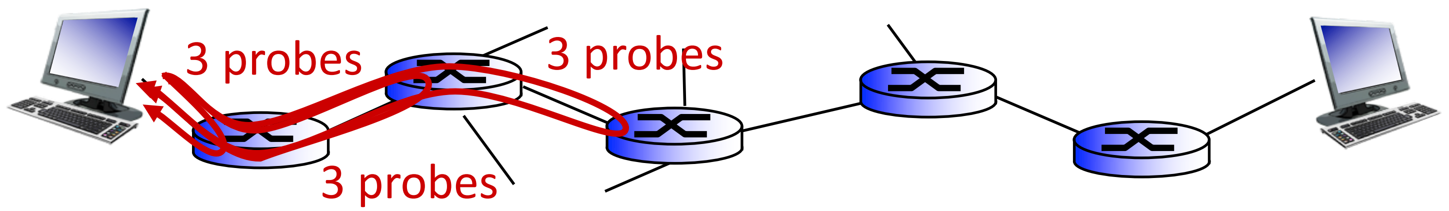
- Source sends sets of UDP segments (usually 3) to dest
  - first set has TTL =1
  - second set has TTL=2, etc.
  - unlikely port number
- When *n*th set of datagrams arrives to nth router:
  - router discards datagrams
  - and sends source ICMP messages (type 11, code 0)
  - ICMP messages includes name of router & IP address
- When ICMP messages arrives, source records RTTs



Traceroute and ICMP

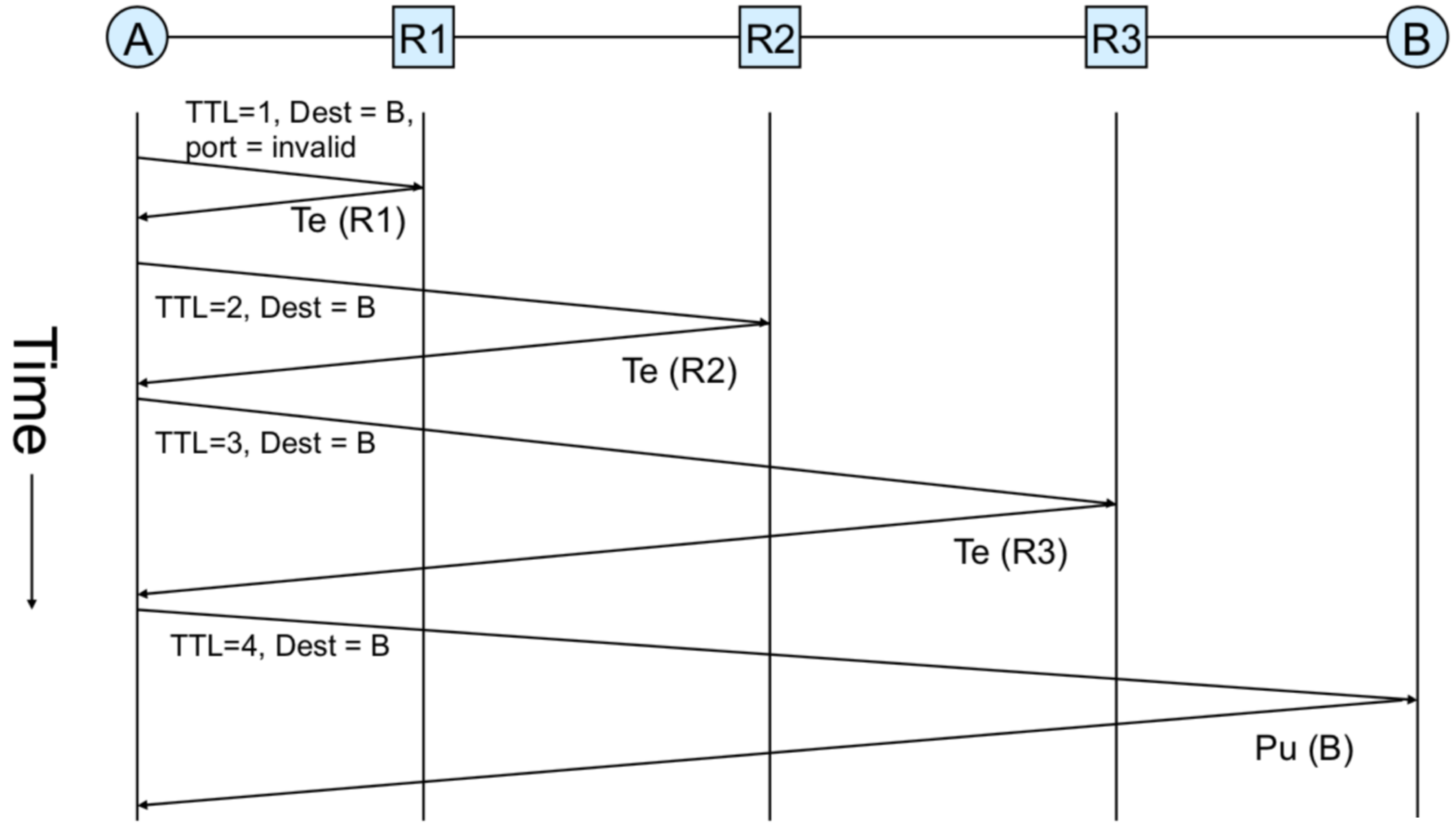
stopping criteria:

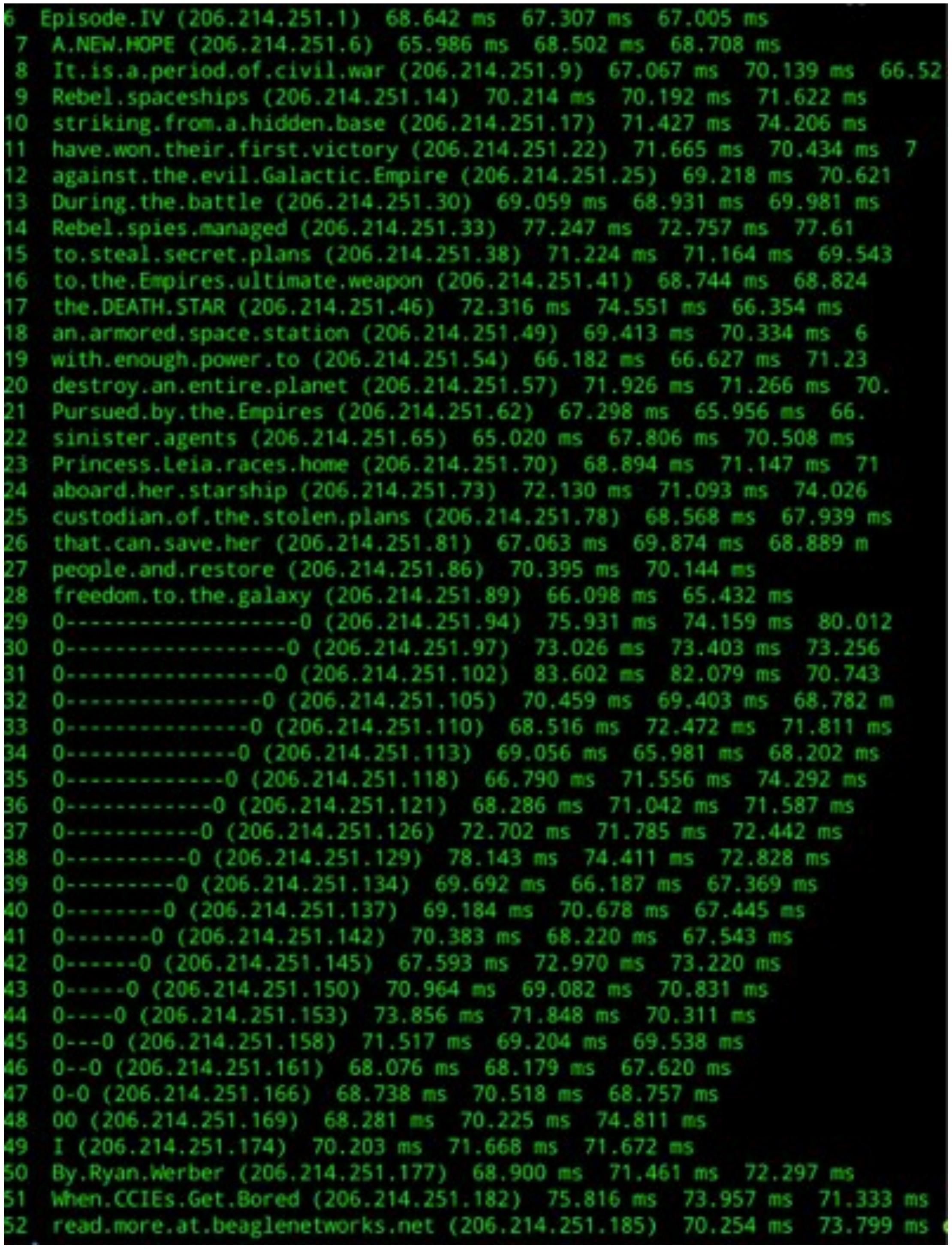
- UDP segment eventually arrives at destination host
- destination returns ICMP “port unreachable” message (type 3, code 3)
- source stops



Traceroute Demo

Te = Time exceeded
Pu = Port unreachable





```
6  Episode.IV (206.214.251.1)  68.642 ms  67.307 ms  67.005 ms
 7  A.NEW.HOPE (206.214.251.6)  65.986 ms  68.502 ms  68.708 ms
 8  It.is.a.period.of.civil.war (206.214.251.9)  67.067 ms  70.139 ms  66.52
 9  Rebel.spaceships (206.214.251.14)  70.214 ms  70.192 ms  71.622 ms
10  striking.from.a.hidden.base (206.214.251.17)  71.427 ms  74.206 ms
11  have.won.their.first.victory (206.214.251.22)  71.665 ms  70.434 ms  7
12  against.the.evil.Galactic.Empire (206.214.251.25)  69.218 ms  70.621
13  During.the.battle (206.214.251.30)  69.059 ms  68.931 ms  69.981 ms
14  Rebel.spies.managed (206.214.251.33)  77.247 ms  72.757 ms  77.61
15  to.steal.secret.plans (206.214.251.38)  71.224 ms  71.164 ms  69.543
16  to.the.Empires.ultimate.weapon (206.214.251.41)  68.744 ms  68.824
17  the.DEATH.STAR (206.214.251.46)  72.316 ms  74.551 ms  66.354 ms
18  an.armored.space.station (206.214.251.49)  69.413 ms  70.334 ms  6
19  with.enough.power.to (206.214.251.54)  66.182 ms  66.627 ms  71.23
20  destroy.an.entire.planet (206.214.251.57)  71.926 ms  71.266 ms  70.
21  Pursued.by.the.Empires (206.214.251.62)  67.298 ms  65.956 ms  66.
22  sinister.agents (206.214.251.65)  65.020 ms  67.806 ms  70.508 ms
23  Princess.Leia.races.home (206.214.251.70)  68.894 ms  71.147 ms  71
24  aboard.her.starship (206.214.251.73)  72.130 ms  71.093 ms  74.026
25  custodian.of.the.stolen.plans (206.214.251.78)  68.568 ms  67.939 ms
26  that.can.save.her (206.214.251.81)  67.063 ms  69.874 ms  68.889 m
27  people.and.restore (206.214.251.86)  70.395 ms  70.144 ms
28  freedom.to.the.galaxy (206.214.251.89)  66.098 ms  65.432 ms
29  0-------------------0 (206.214.251.94)  75.931 ms  74.159 ms  80.012
30  0------------------0 (206.214.251.97)  73.026 ms  73.403 ms  73.256
31  0-----------------0 (206.214.251.102)  83.602 ms  82.079 ms  70.743
32  0----------------0 (206.214.251.105)  70.459 ms  69.403 ms  68.782 m
33  0---------------0 (206.214.251.110)  68.516 ms  72.472 ms  71.811 ms
34  0--------------0 (206.214.251.113)  69.056 ms  65.981 ms  68.202 ms
35  0-------------0 (206.214.251.118)  66.790 ms  71.556 ms  74.292 ms
36  0------------0 (206.214.251.121)  68.286 ms  71.042 ms  71.587 ms
37  0-----------0 (206.214.251.126)  72.702 ms  71.785 ms  72.442 ms
38  0----------0 (206.214.251.129)  78.143 ms  74.411 ms  72.828 ms
39  0---------0 (206.214.251.134)  69.692 ms  66.187 ms  67.369 ms
40  0--------0 (206.214.251.137)  69.184 ms  70.678 ms  67.445 ms
41  0-------0 (206.214.251.142)  70.383 ms  68.220 ms  67.543 ms
42  0------0 (206.214.251.145)  67.593 ms  72.970 ms  73.220 ms
43  0-----0 (206.214.251.150)  70.964 ms  69.082 ms  70.831 ms
44  0----0 (206.214.251.153)  73.856 ms  71.848 ms  70.311 ms
45  0---0 (206.214.251.158)  71.517 ms  69.204 ms  69.538 ms
46  0--0 (206.214.251.161)  68.076 ms  68.179 ms  67.620 ms
47  0-0 (206.214.251.166)  68.738 ms  70.518 ms  68.757 ms
48  00 (206.214.251.169)  68.281 ms  70.225 ms  74.811 ms
49  I (206.214.251.174)  70.203 ms  71.668 ms  71.672 ms
50  By.Ryan.Werber (206.214.251.177)  68.900 ms  71.461 ms  72.297 ms
51  When.CCIEs.Get.Bored (206.214.251.182)  75.816 ms  73.957 ms  71.333 ms
52  read.more.at.beaglenetworks.net (206.214.251.185)  70.254 ms  73.799 ms
```

Summary

- IPv6: solution to IP address scarcity
  - Low adoption so far, but improving

- Lots of mechanisms surrounding IP
  - NAT: translate routable IP address to multiple private IP addresses using ports/header rewriting
  - ICMP: small status messages, usually report errors