Bridges, IP Basics

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Lecture 7

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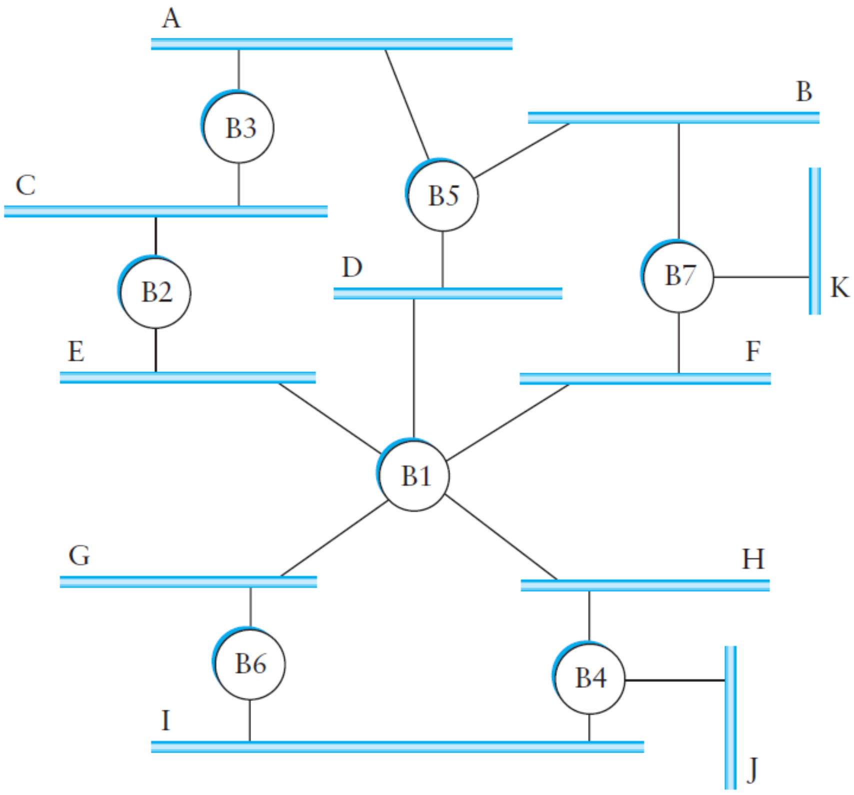
Topics for Today

- Bridges and Spanning Tree Algorithm
- IP
    - Basics
    - Addresses
    - Fragmentation and Reassembly
    - Subnetting

Spanning Tree Concepts

Key concepts:

- A single root bridge is elected
  - Each subnet must have a single path to reach the root bridge
- Each bridge may be connected to (and receive packets from) multiple subnets
  - Only the designated bridge will forward packets toward the root
- Every bridge knows which of its ports is closest to the root bridge
  - Called the root port



Spanning Tree Algorithm

Advertisement
$(ROOT, dist, SENDER)$

- $ROOT$ root node ID
- $dist$ how many hops to the root $ROOT$
- $SENDER$ ID who sent it

Each node begins thinking it's the root and starts advertising that

If a node receives a better advertisement, it stops broadcasting its own messages

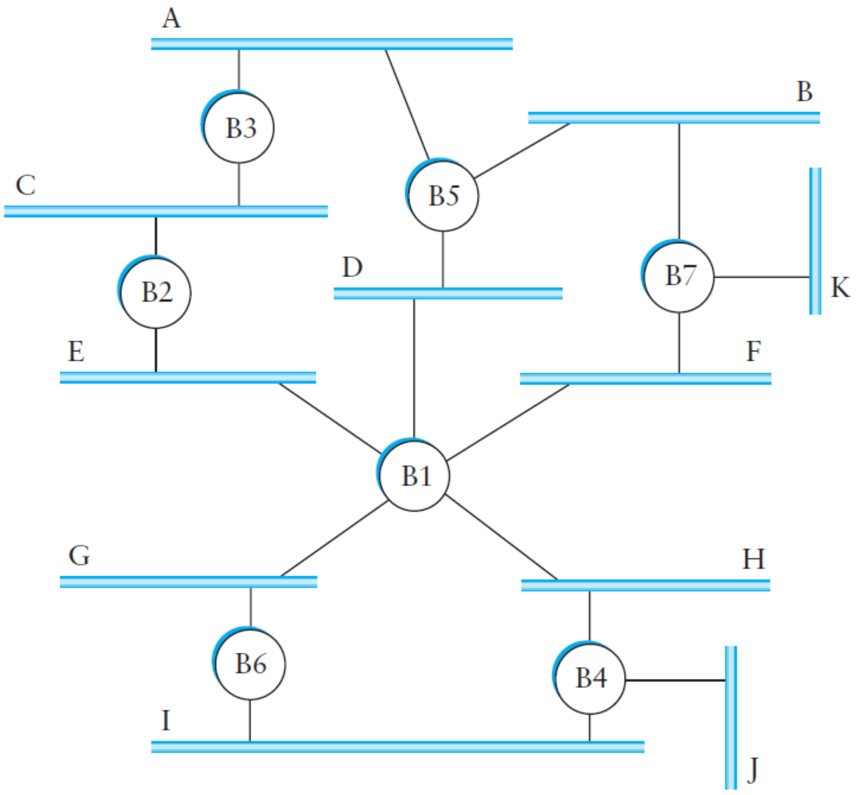
- Better is smaller $ROOT$ ID or same $ROOT$ ID and smaller $dist$
- Last one generating ads wins as root
- Bridge remembers where the shortest, best path – that's the Root Port

Election also for designated bridge (at the same time)

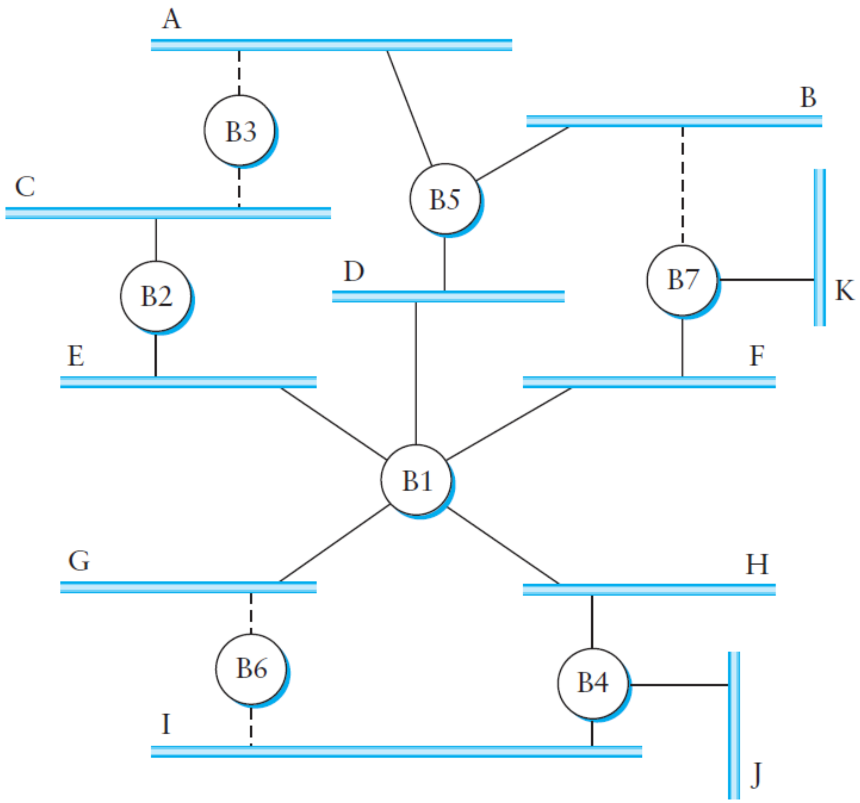
- Smallest $dist$ to $ROOT$ or same $dist$ but smaller ID
- If a bridge hears a shorter, better path on a port, it knows it's not the Designated Bridge for that subnet

Spanning Tree Example

Before



After



Limitations of Bridges

Scaling

- Connections on order of dozens
- Spanning tree algorithm scales linearly
- Transparency incomplete

Congestion can be visible to higher protocol layers

Latency can be larger and more variable

Heterogeneity

- Limited to compatible (similarly addressed) link layers

Spanning Tree Maintenance

The root bridge is the last one generating advertisements

- It sends out advertisements every so often
- If a bridge notices that it hasn't heard an advertisement in a while (timer), it starts the algorithm again

- Automatic detection of failures and network topology changes:
  - Hello time – how often does the bridge send out messages
  - Max age – maximum age for a message before it's dropped
  - Forward delay – how long it takes to move bridge from listening to forwarding

Rapid Spanning Tree Protocol

- Updates protocol from 2004

Less bridge port states

- Discarding
- Learning
- Forwarding

Alternate Port role

- A second way to get to the root
- Alternate to the root port

Backup Port role

- Another way to reach the same LAN
- Same switch, just different ports

Every bridge sends packets every Hello time

- Not just in response to root’s messages

Faster sync between bridges

- Negotiate, don’t just listen for advertisements
- Finish in 3x Hello time

So Far

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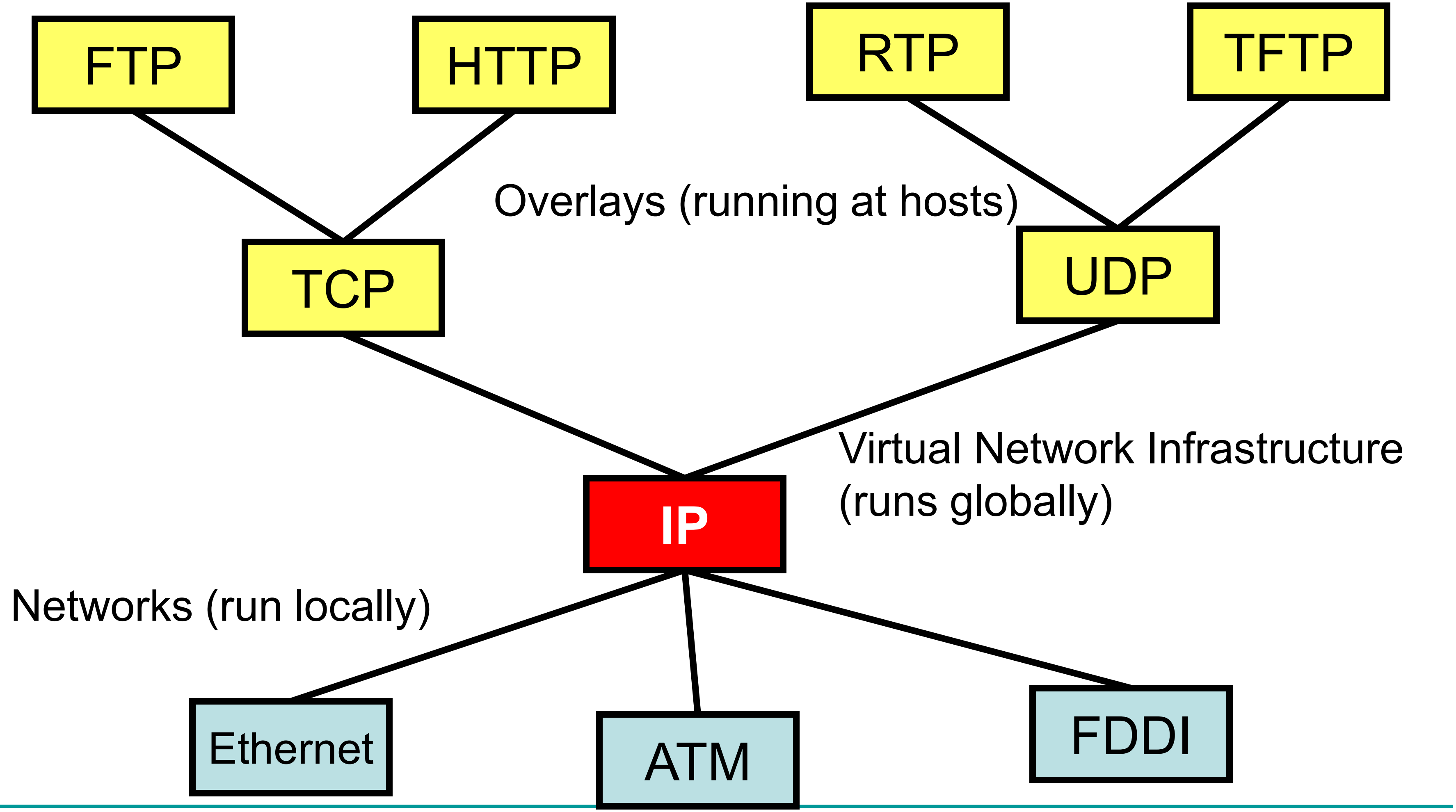
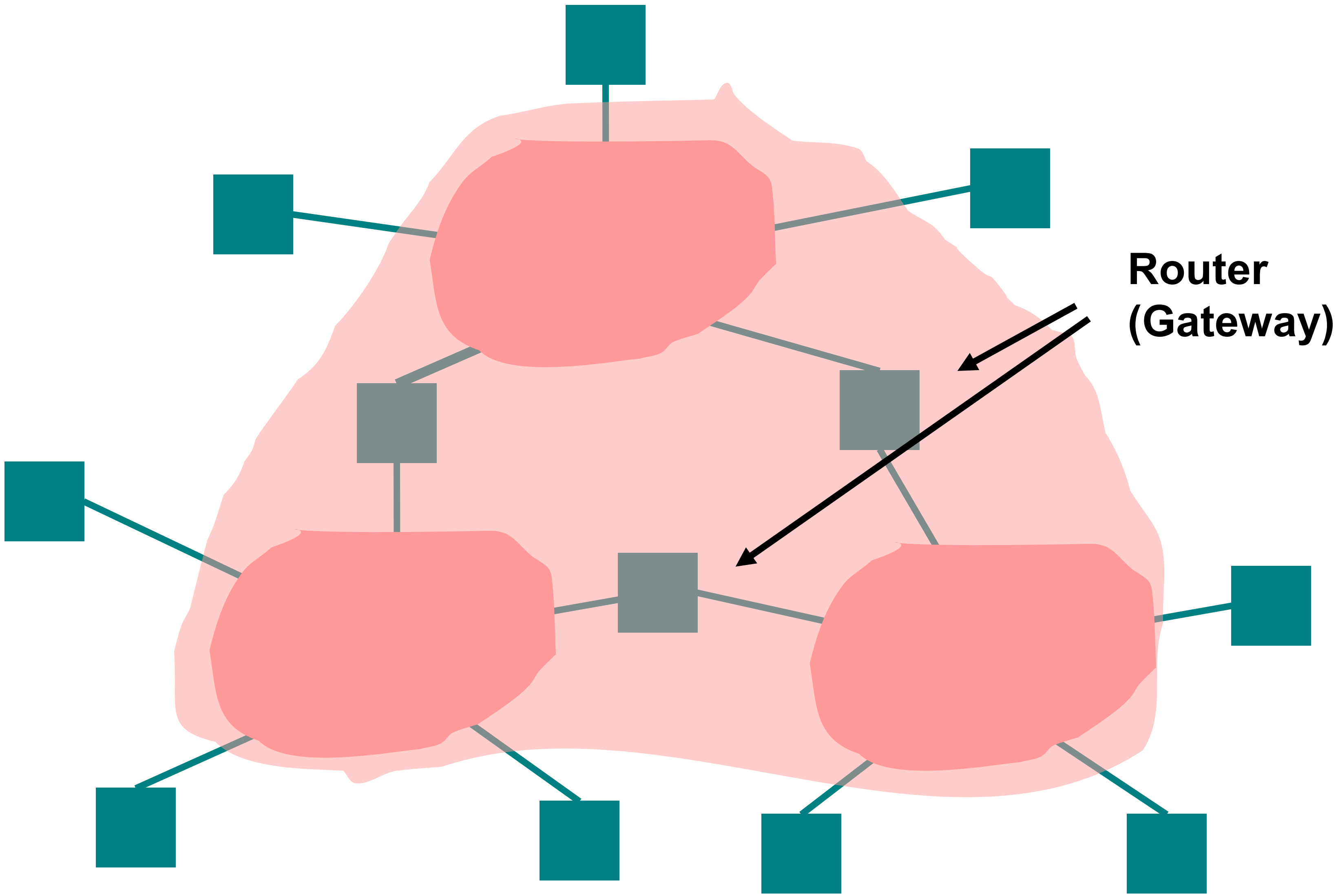
- IP
  - Basics
  - Addresses
  - Fragmentation and Reassembly
  - Subnetting

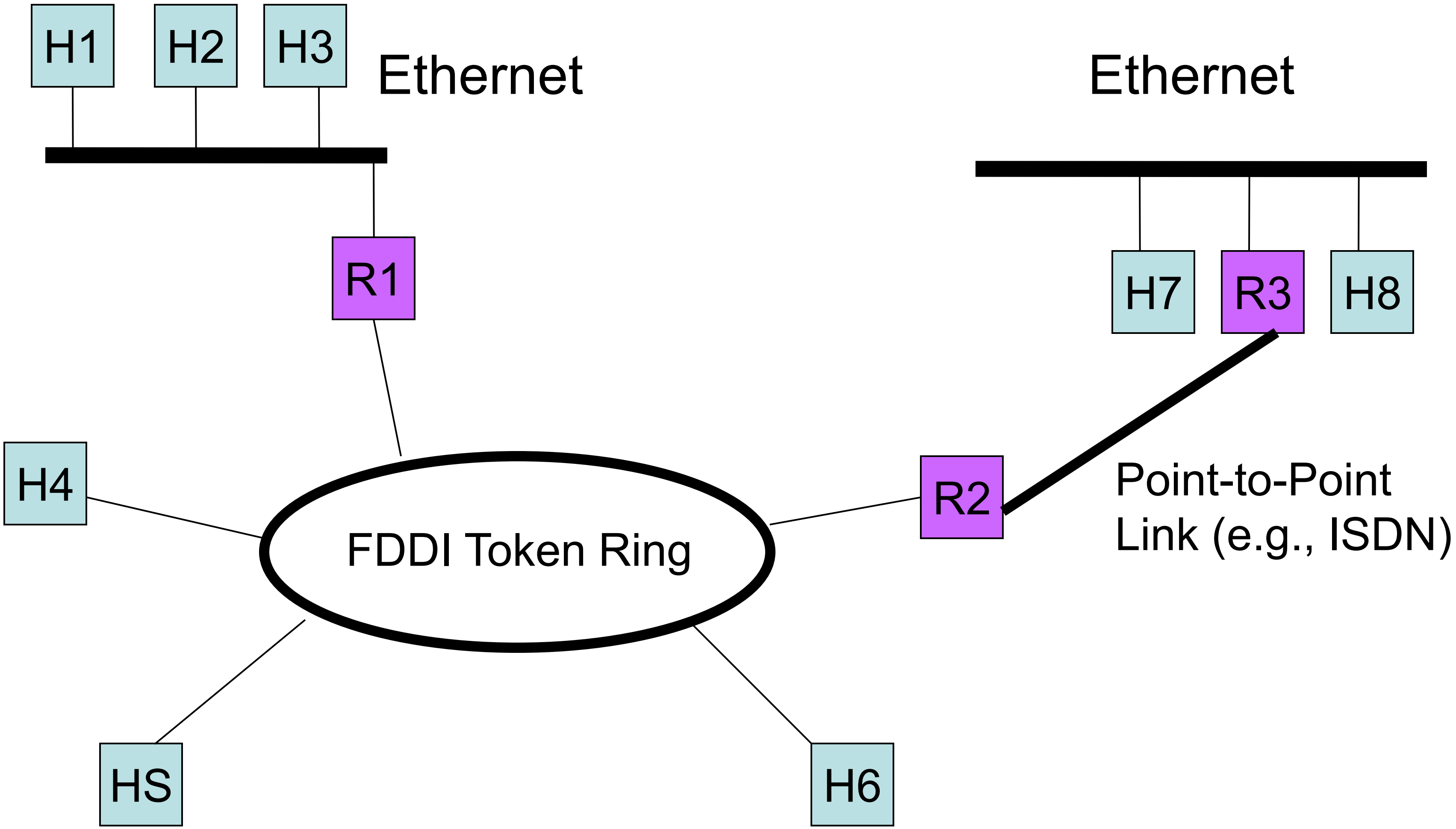
Internet Protocol Interoperability



Internetworks



Internetworks



IP Concepts

Address

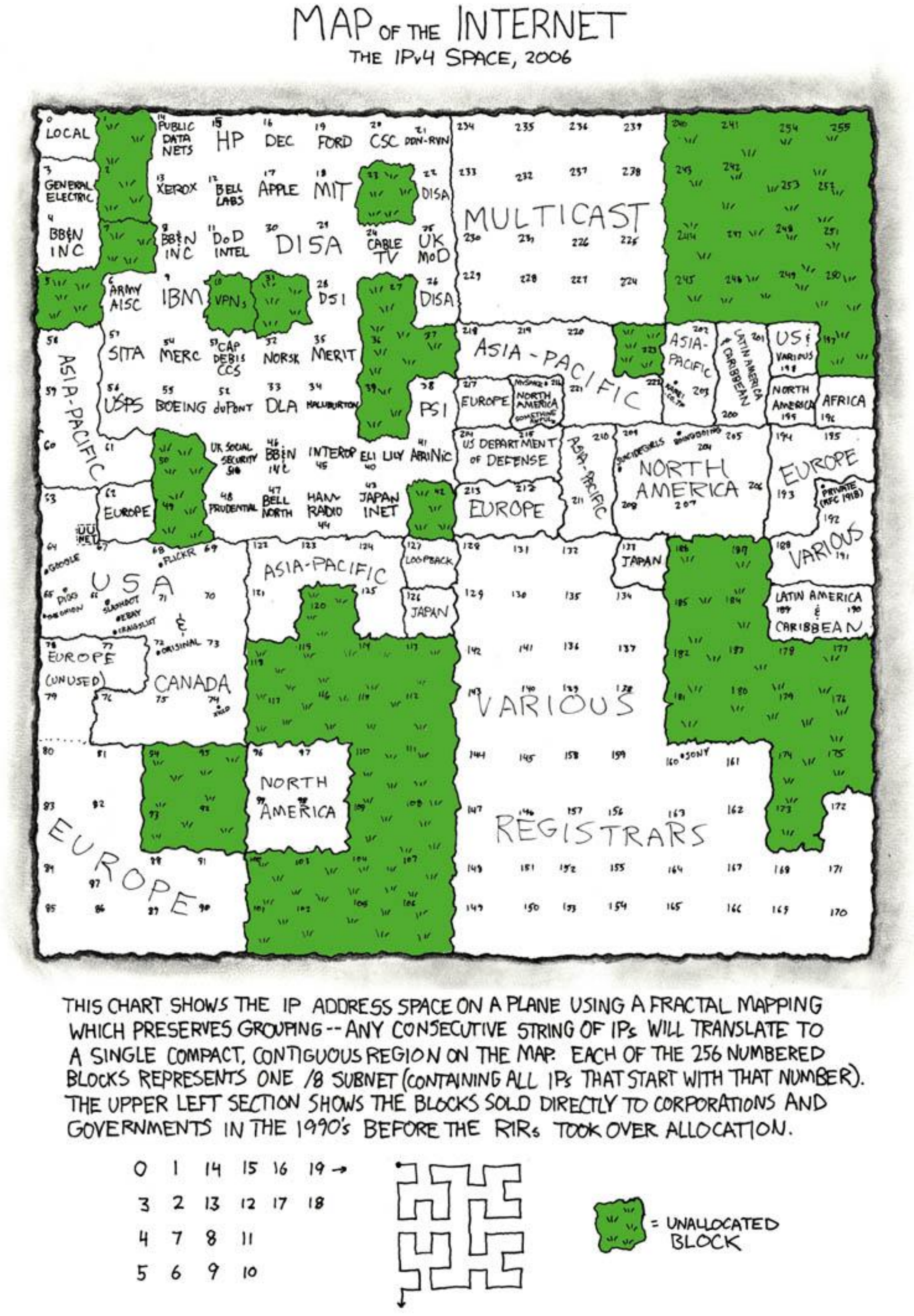
Router

Forwarding

Fragmentation

IP Addresses

- 4 byte addresses
  - Written 255.255.255.255
- Hierarchical



MAP OF THE INTERNET
THE IPv4 SPACE, 2006

THIS CHART SHOWS THE IP ADDRESS SPACE ON A PLANE USING A FRACTAL MAPPING WHICH PRESERVES GROUPING -- ANY CONSECUTIVE STRING OF IPs WILL TRANSLATE TO A SINGLE COMPACT, CONTIGUOUS REGION ON THE MAP. EACH OF THE 256 NUMBERED BLOCKS REPRESENTS ONE /8 SUBNET (CONTAINING ALL IPs THAT START WITH THAT NUMBER). THE UPPER LEFT SECTION SHOWS THE BLOCKS SOLD DIRECTLY TO CORPORATIONS AND GOVERNMENTS IN THE 1990's BEFORE THE RIRs TOOK OVER ALLOCATION.

Service Model

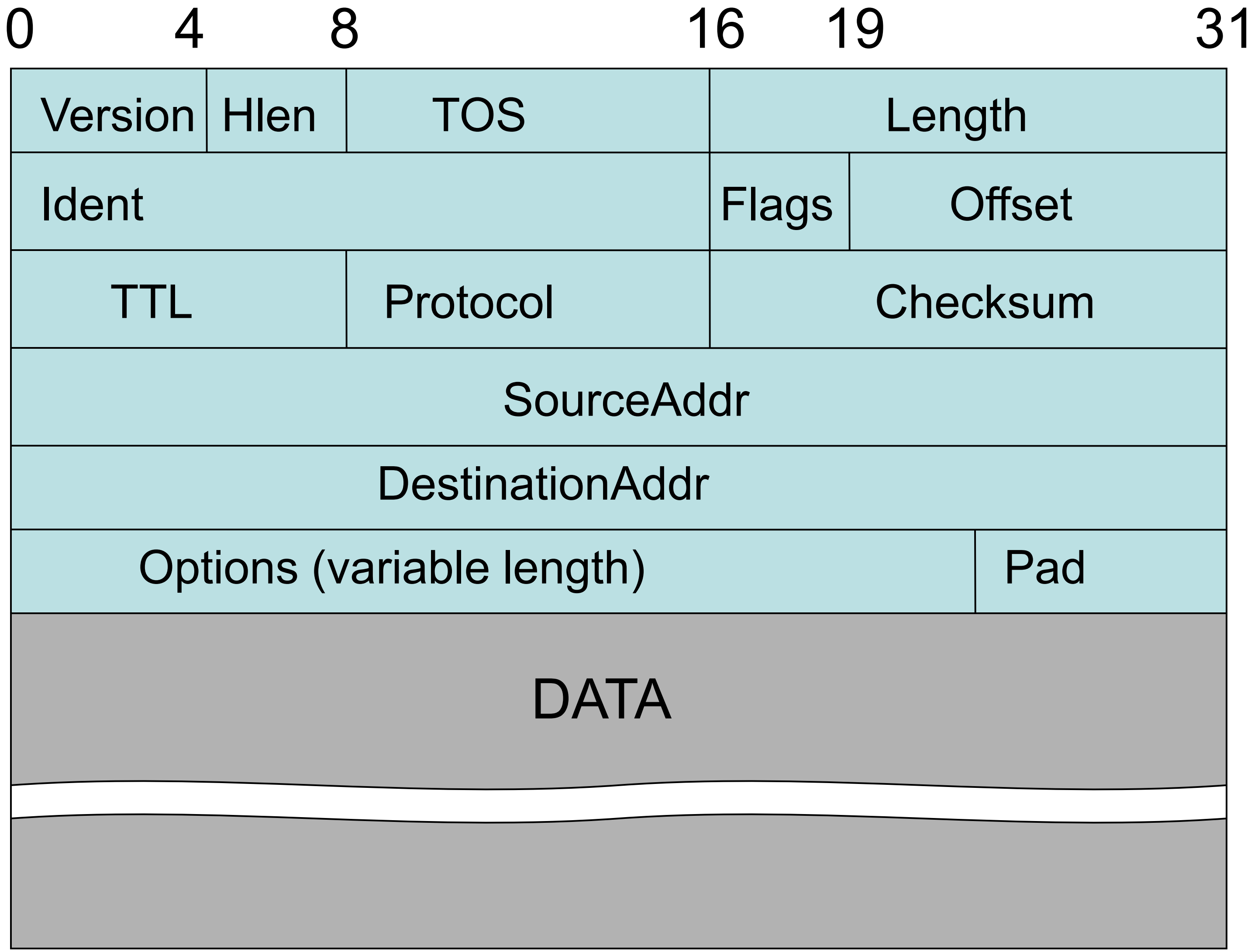
Minimal service mode

- All nets can implement
- “Tin cans and a string” extremum

Features:

- Standard packet format
- Best-effort datagram delivery (unreliable)
- “*Run over anything*”

IPv4 Packet Format



0 4 8 16 19 31

Version | Hlen | TOS | Length

Ident | Flags | Offset

TTL | Protocol | Checksum

SourceAddr

DestinationAddr

Options (variable length) | Pad

DATA

Fields of IPv4 Header

Version

- Version of IP, example header is IPv4
- First field so easy to implement case statement

Hlen

- Header length, in 32-bit *words*

TOS

- Type of Service (rarely used)
- Priorities, delay, throughput, reliability

Length

- Length of datagram, in *Bytes*
- 16 bits, hence max. of 65,536 Bytes

Fields for *fragmentation* and *reassembly*

- Identifier
- Flags
- Offset

Header fields, continued

TTL

- Time to live (in reality, hop count)
- 64 is the current default (128 also used)

Protocol

- Examples: TCP (6), UDP(17)

Checksum

- Checksum of header (not CRC)
- If header fails checksum, discard the whole packet

SourceAddr, DestinationAddr

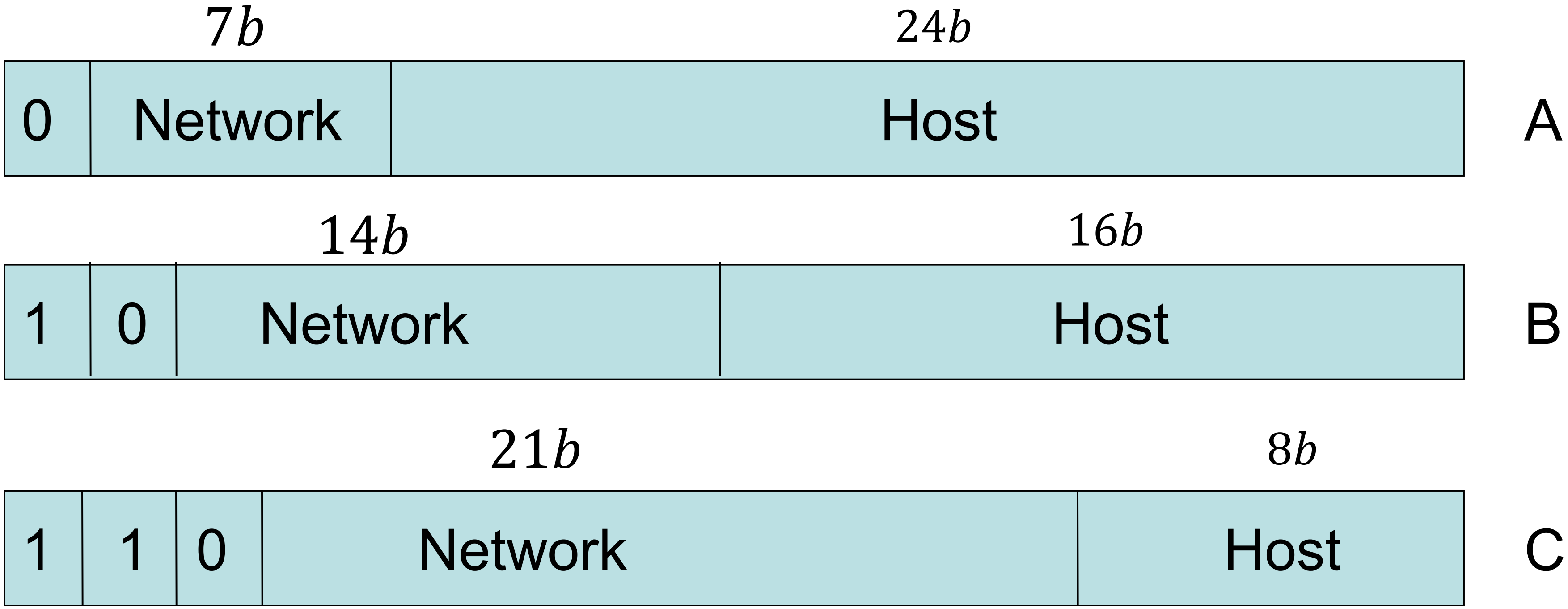
- 32-bit IP addresses
- Global, IP-defined

Options

- Length can be computed using Hlen

IP addresses

- Hierarchical, not flat as in Ethernet



$7b$ $24b$

0 Network Host A

$14b$ $16b$

1 0 Network Host B

$21b$ $8b$

1 1 0 Network Host C

- Written as four decimal numbers separated by dots: 158.130.14.2

IP Address Ranges

0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0.0.0.0	Any IP
0 0 0 0 0 0 0 1	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	1.0.0.0	Class A
0 0 0 0 0 0 1 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	2.0.0.0	
0 1 1 1 1 1 1 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	126.0.0.0	
0 1 1 1 1 1 1 1	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	127.0.0.0	Localhost
1 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	128.0.0.0	Class B
1 0 0 0 0 0 0 0	0 0 0 0 0 0 0 1	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	128.1.0.0	
1 0 0 0 0 0 0 0	0 0 0 0 0 0 1 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	128.2.0.0	
1 0 0 0 0 0 0 0	0 0 0 0 0 0 1 1	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	128.3.0.0	
1 0 1 1 1 1 1 1	1 1 1 1 1 1 1 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	191.254.0.0	
1 0 1 1 1 1 1 1	1 1 1 1 1 1 1 1	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	191.255.0.0	
1 1 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	192.0.0.0	Class C
1 1 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 1	0 0 0 0 0 0 0 0	192.0.1.0	
1 1 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 1 0	0 0 0 0 0 0 0 0	192.0.2.0	
1 1 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 1 1	0 0 0 0 0 0 0 0	192.0.3.0	
1 1 0 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 0	0 0 0 0 0 0 0 0	223.255.254.0	
1 1 0 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	0 0 0 0 0 0 0 0	223.255.255.0	
1 1 1 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	224.0.0.0	Class D
1 1 1 0 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	239.255.255.255	
1 1 1 1 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	240.0.0.0	Class E
1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	255.255.255.255	

Network Classes

Class	# of nets	# of hosts per net
A	128	$\sim 16\ million$
B	16,384	65,534
C	$\sim 2\ million$	254

IP addresses and networks

Every network device has an IP address

Every IP packet (datagram) contains the destination IP address

Network part of the IP address uniquely identifies a single physical network

- Part of the larger Internet.

Routers are connected to multiple network interfaces

- A router has multiple network adapters
- Routers can exchange packets on any network they're attached.

IP Forwarding algorithm

Executed by the router:

```
If I'm on the same network as the destination:
    → deliver packet to destination (ARP)
else: look up the forwarding table:
    if the destination network is in forwarding table:
        → deliver packet to NextHop router
    else: deliver packet to default router
```

- Forwarding tables
  - Contain (Network #, NextHop) pairs
  - Additional information
  - Built by routing protocol

So Far

- Bridges and Spanning Tree Algorithm
- IP
  - Basics
  - Addresses
  - Fragmentation and Reassembly
  - Subnetting

Fragmentation and Reassembly

Why?

- Networks differ on maximum packet size

How?

- Fragment packets into pieces
- Each fragment is itself a complete packet
- Receiving host reassembles them

Maximum Transmission Unit (MTU)

- Path MTU is min MTU for path
- Sender typically sends at MTU of first hop

https://www.lehighvalleylive.com/news/2019/05/truck-stuck-in-tunnel-closes-route-519-in-warren-county.html

Some MTU Numbers

Link Layer Technology	Notes	MTU
Ethernet	Standard home/office networking	1500B
PPPOE over Ethernet	Used for connecting DSL modems to ISP networks	1492B
802.11 (Wi-Fi)	Standard Wireless	2304B
Token Ring (802.5)	(Bottom right)	4464B
FDDI	(Bottom left)	4352B

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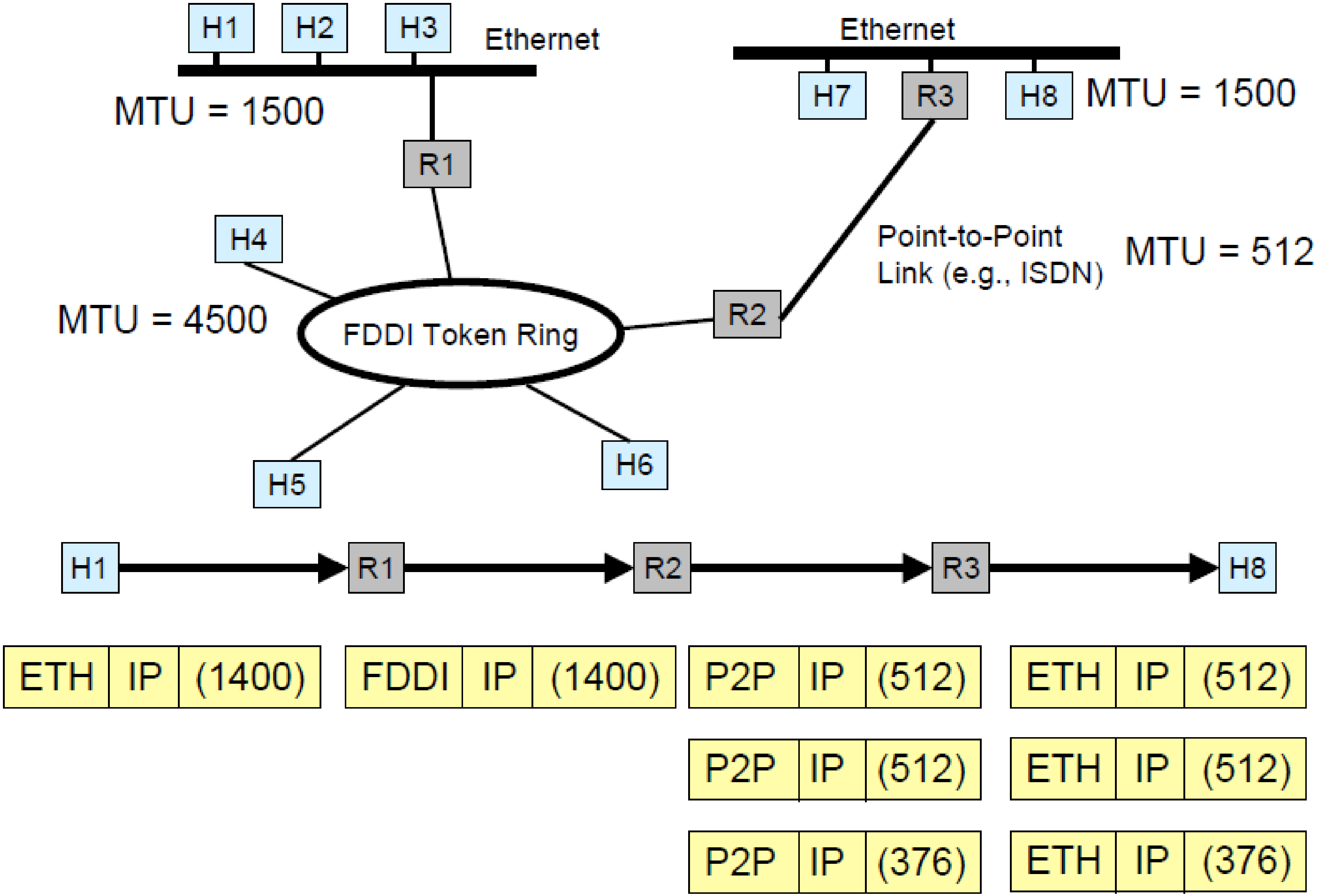


H1 H2 H3 Ethernet

MTU = 1500

R1

H4

MTU = 4500

FDDI Token Ring

H5 H6

R2

Point-to-Point
Link (e.g., ISDN)

MTU = 512

Ethernet

H7 R3 H8 MTU = 1500

H1 → R1 → R2 → R3 → H8

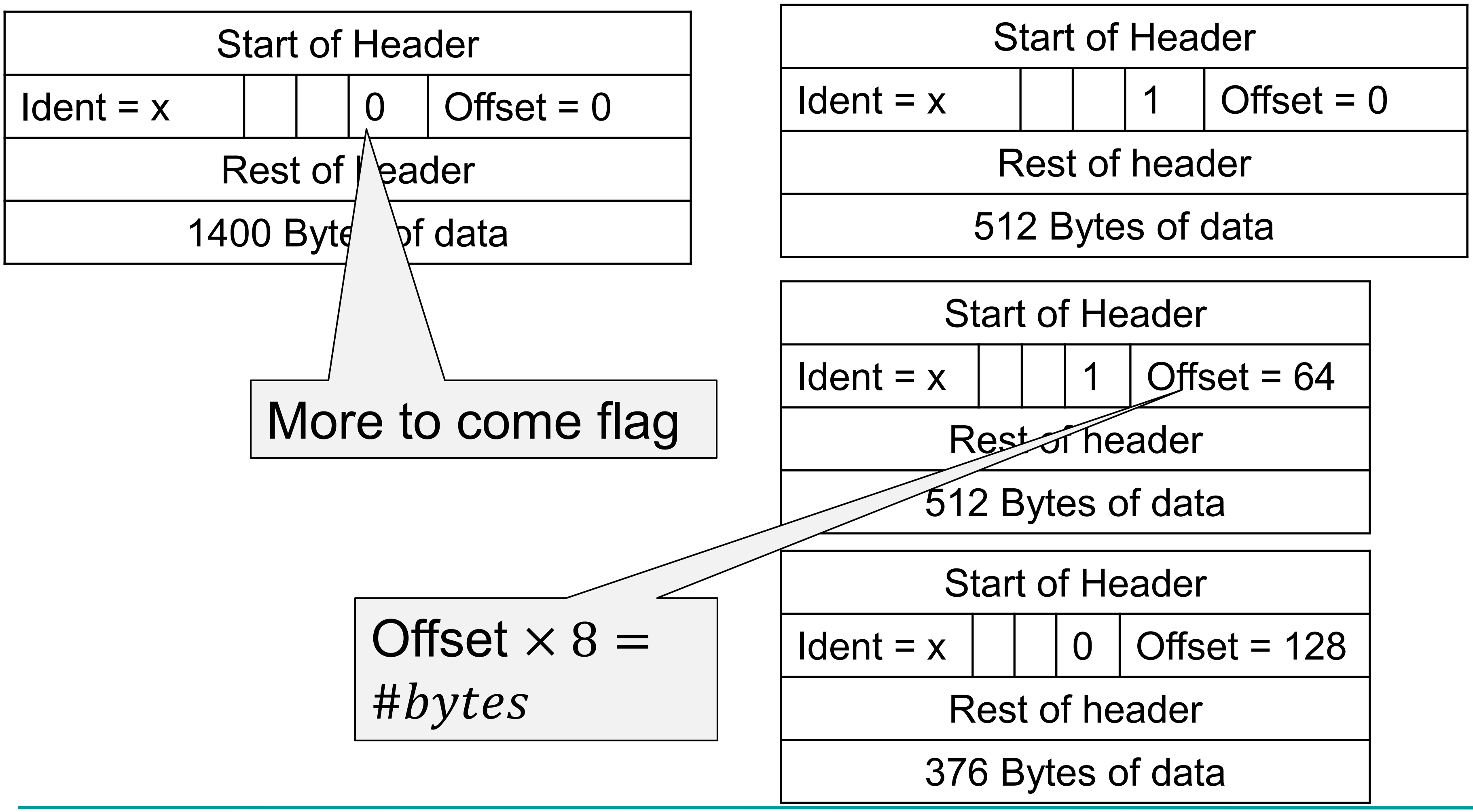
ETH | IP | (1400)

FDDI | IP | (1400)

P2P | IP | (512)
P2P | IP | (512)
P2P | IP | (376)

ETH | IP | (512)
ETH | IP | (512)
ETH | IP | (376)

Packet Fragmentation



Unfragmented Packet

Start of Header				
Ident = x			0	Offset = 0
Rest of header				
1400 Bytes of data				

More to come flag

$\text{Offset} \times 8 = \#bytes$

Fragmented Packet

Start of Header				
Ident = x			1	Offset = 0
Rest of header				
512 Bytes of data				

Start of Header				
Ident = x			1	Offset = 64
Rest of header				
512 Bytes of data				

Start of Header				
Ident = x			0	Offset = 128
Rest of header				
376 Bytes of data				

IPv4 vs IPv6

IPv4

Router or source may fragment packets

- Fragments arrive at destination for reassembly

Sender can set Don’t Fragment flag in header to prevent

- Router sends to ICMP TooBig error as needed

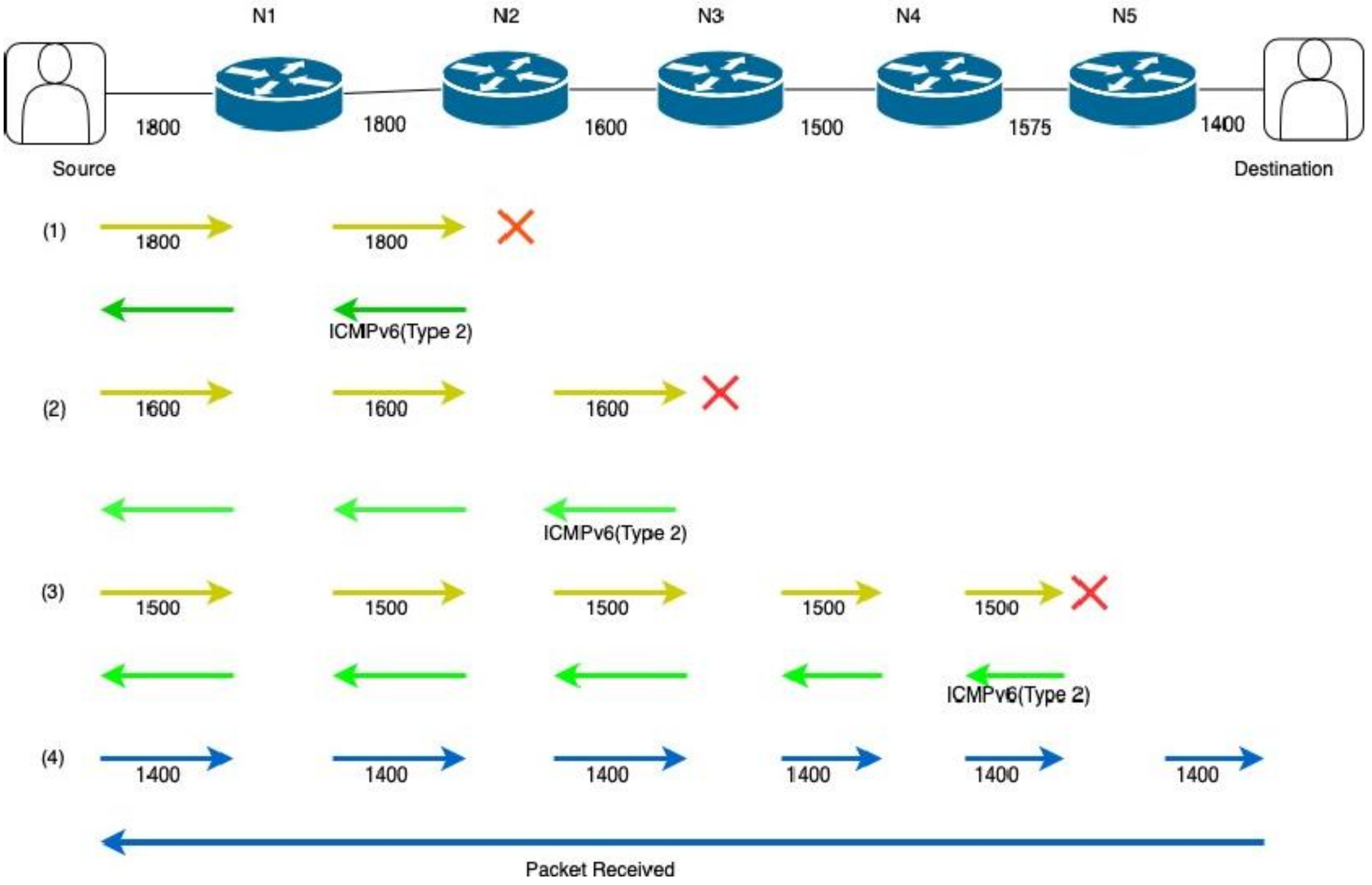
IPv6

Only source fragments

- Fragments arrive at destination for reassembly

Router sends ICMPv6 TooBig message as needed

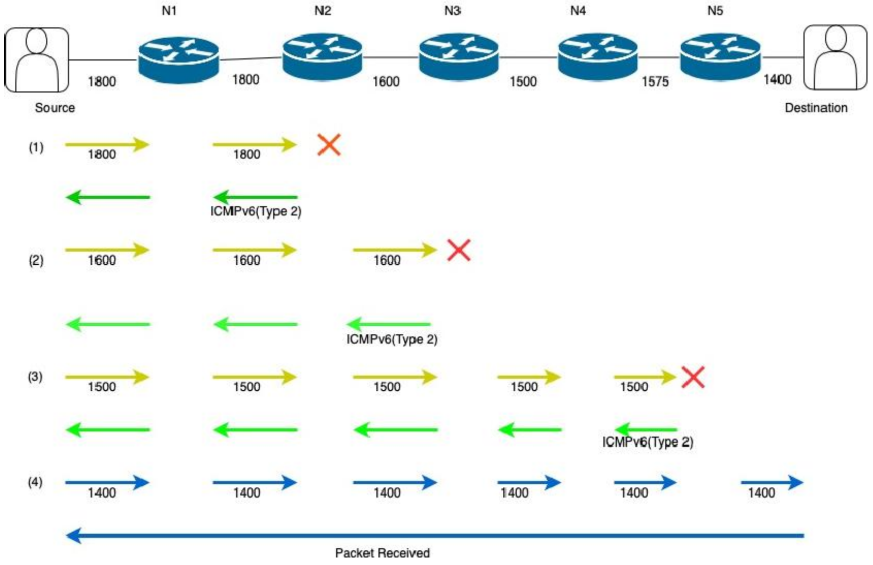
Path MTU Discovery



Hussain, Ishfaq and Janibul Bashir. "Measuring time delay in path MTU discovery in transmitting a packet in IPv4 and IPv6 network." ArXiv abs/2011.06935 (2020): n. pag.

Path MTU Discovery

1. Sender sends with DF flag in IPv4 or and IPv6
2. Router responds with TooBig message with its MTU
3. Sender records response and updates packet size
4. Sender discovers path MTU



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Scaling Problems

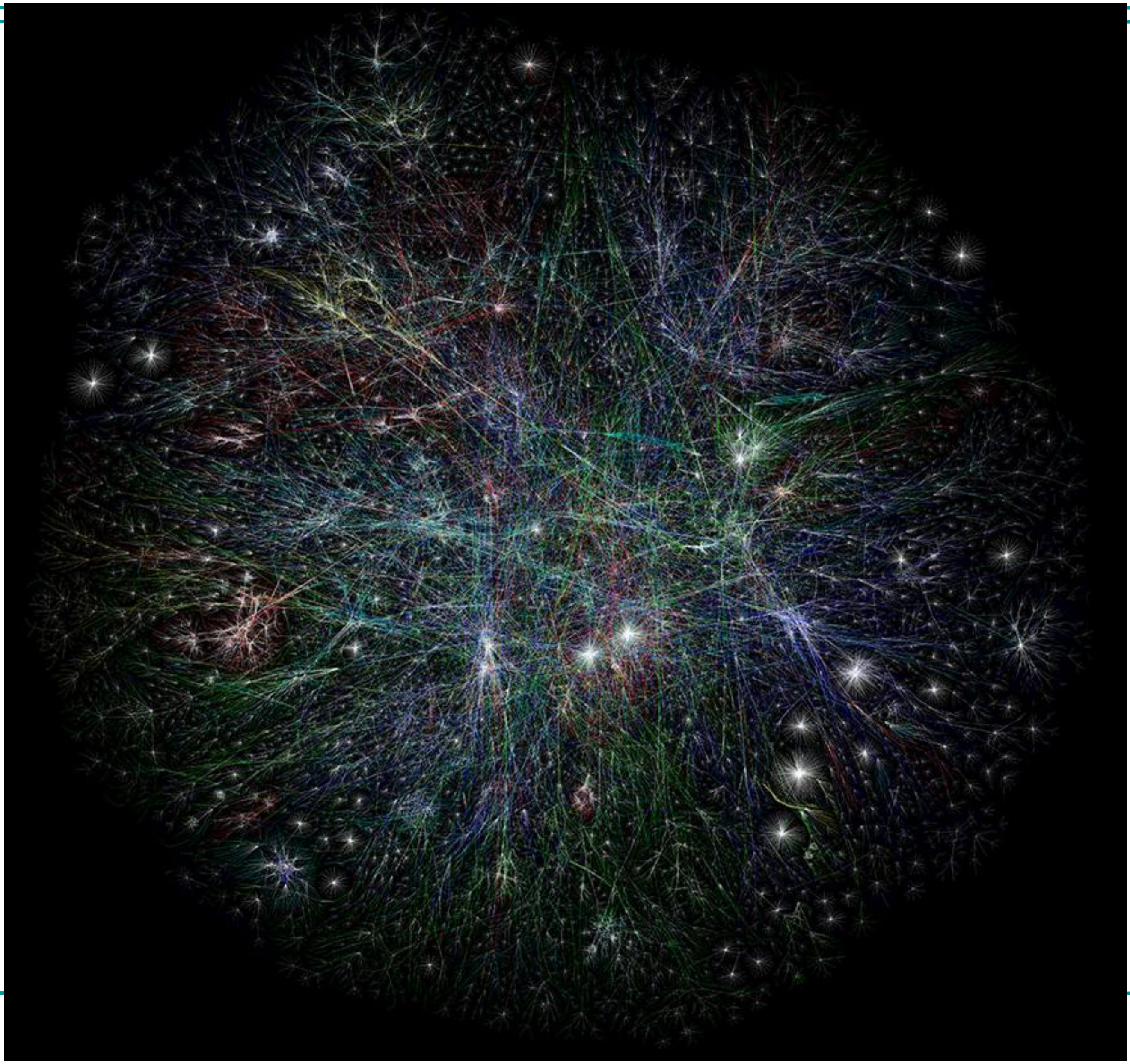
Not enough network numbers.

- Class C network with 2 nodes wastes 253 IP addresses
- Class B network with ~ 300 nodes wastes $64{,}000$ IP addresses

Only $2^{14} \sim 16{,}500$ Class B networks

Routing information too cumbersome.

- More networks means larger routing tables



Subnetting

- Idea: One IP network number allocated to several physical networks.
  - The multiple physical networks are called *subnets*
  - Should be close together (why?)
  - Useful when a large company (or university!) has many physical networks.

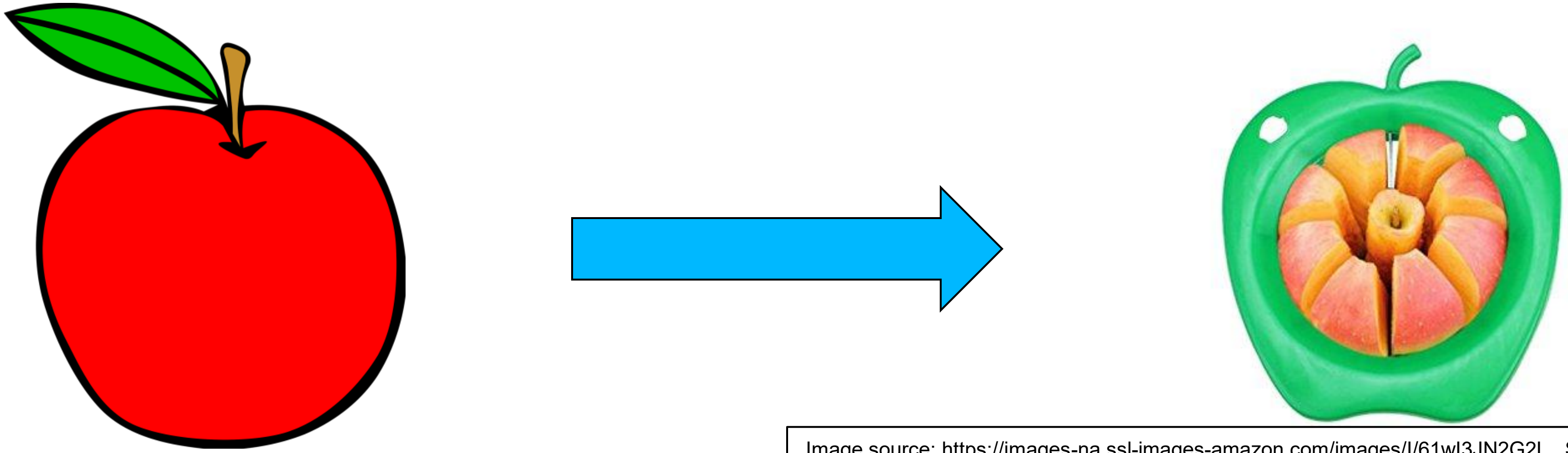


Image source: https://images-na.ssl-images-amazon.com/images/I/61wI3JN2G2L._SY355_.jpg

Subnetting Houses

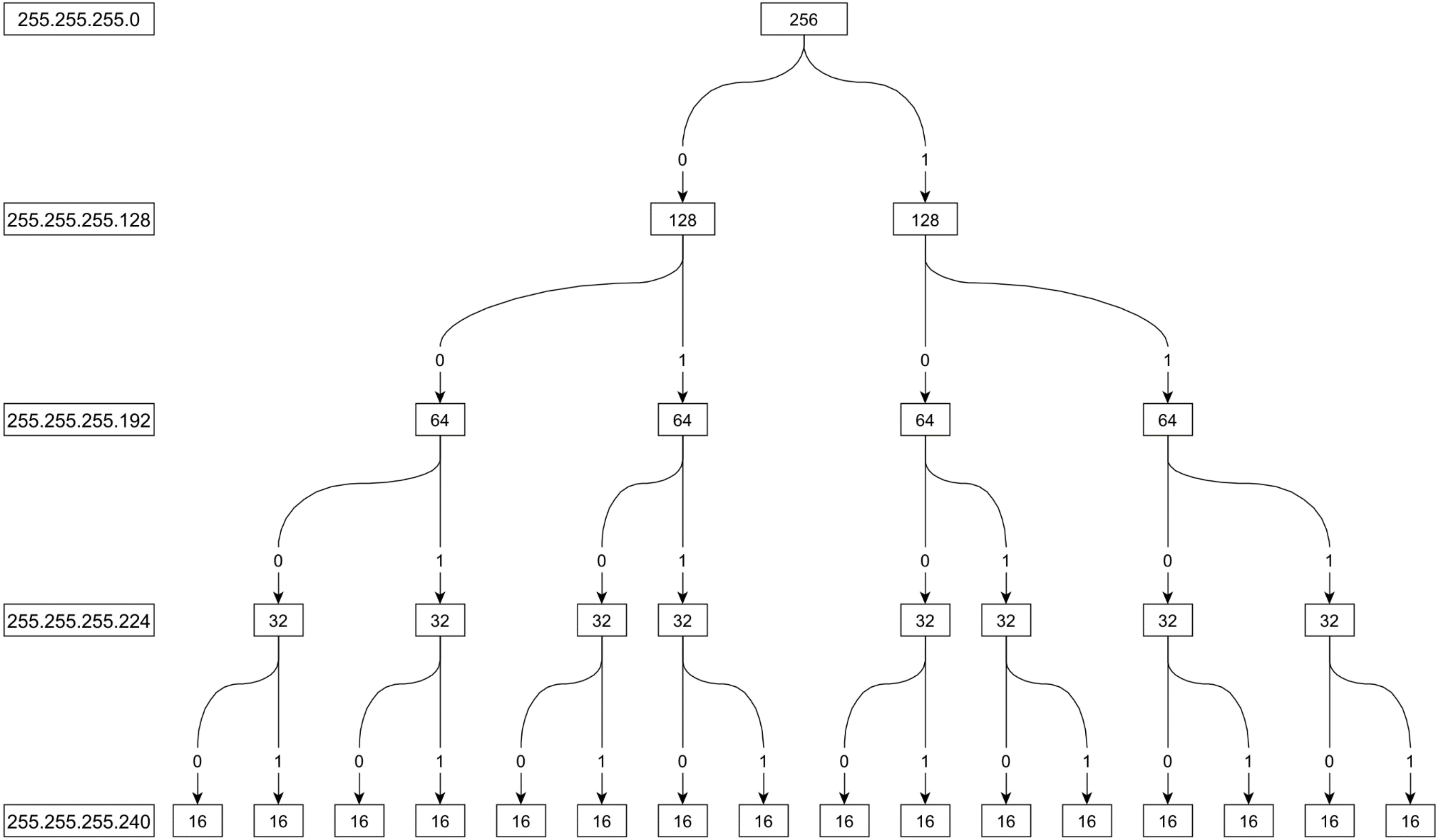
- A small yishuv has 200 houses
  - Every house has a number - not necessarily organized in order
  - To send Moshe a letter:
    - Moshe, House 121, Moshav Yula
  - The mail deliverer memorizes where each house is
  - A visitor asks for directions based on the house number

- What if there are 10,000 houses?
  - We can still give numbers to each house
    - Moshe, House 3093, Moshav Yula
  - Something is not quite right, though – how will the mail deliverer know where each house is?
  - There are too many houses to keep track of this way

Subnetting Houses

- One option: Divide the city into streets
  - Organize the houses onto streets with names
    - May require us to renumber some houses if they weren’t done right
  - Make the address – Street + number
  - To send a letter to Moshe:
    - All houses 3000-3099 are on Rechov Hula
    - Moshe, House 3093, Yula → Moshe, Rechov Hula 93, Yula
  - We make a mapping from the house number to a street
    - Here 3000-3099 are all on Rechov Hula
    - Say 4000-4099 are on Rechov Goober
    - We can write that as 30XX are on Rechov Hula, 40XX are on Rechov Goober
    - Given a house number we can figure out the street based on it

Prefix Hierarchy



255.255.255.0 256

0 1

255.255.255.128 128 128

0 1 0 1

255.255.255.192 64 64 64 64

0 1 0 1 0 1 0 1

255.255.255.224 32 32 32 32 32 32 32 32

0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1

255.255.255.240 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16

Conclusion

- Bridges and Spanning Tree Algorithm
- IP
  - Basics
  - Addresses
  - Fragmentation and Reassembly
  - Subnetting