12. How the Internet Works (Part 1)

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(Some slides borrowed from Ben Zhao)
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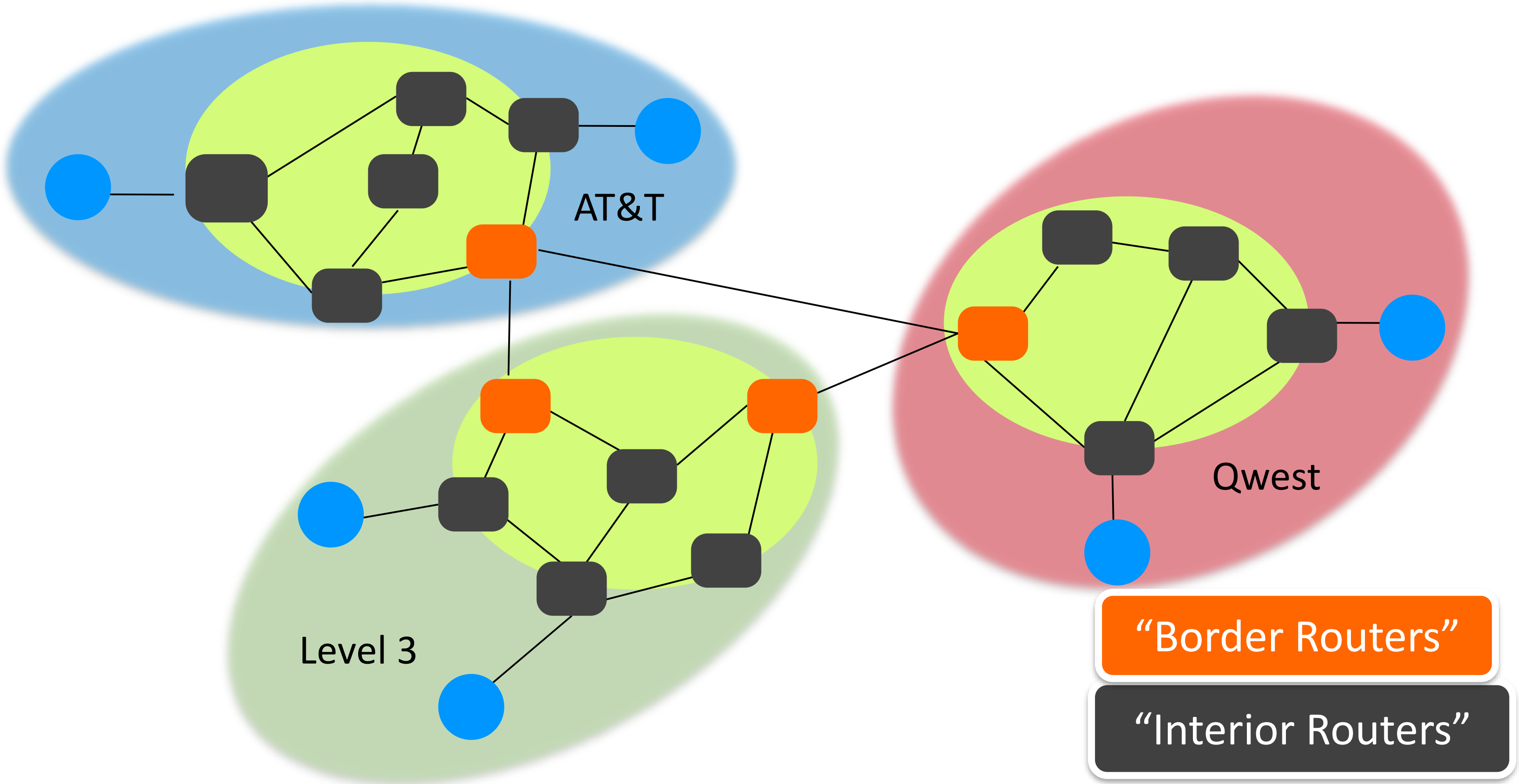
CMSC 23200 / 33250

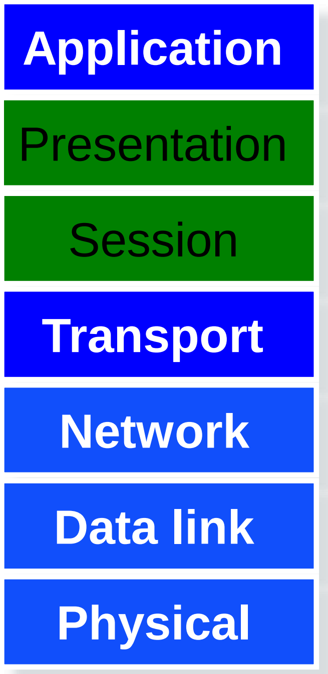
THE UNIVERSITY OF CHICAGO

The Internet From 10,000 Feet



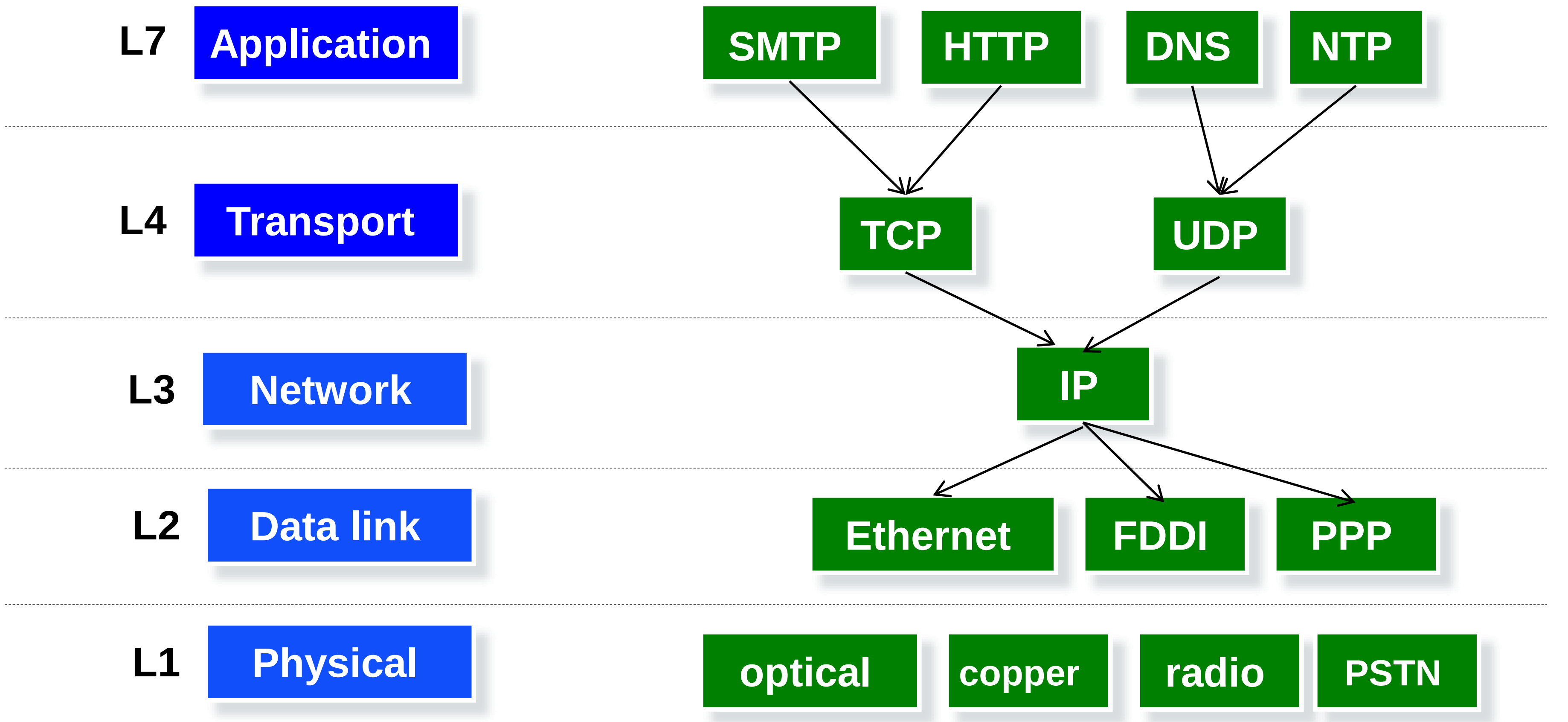
Layers (OSI Model)

- Layer = a part of a system with well-defined interfaces to other parts
- A layer interacts only with layer above and layer below



Networking's own version of modularity

Protocols at different layers



Goal: Be addressable on a local network

Solution: MAC Addresses (Link Layer)

MAC (Media Access Control) Address

- Unique-*ish* 48-bit number associated with network interface controller (NIC)

12:34:56:78:9A:BC

- Usually assigned by manufacturers
  - In theory, doesn't ever change for a piece of hardware
  - In practice, MAC addresses can be spoofed
- See *ifconfig* and similar commands

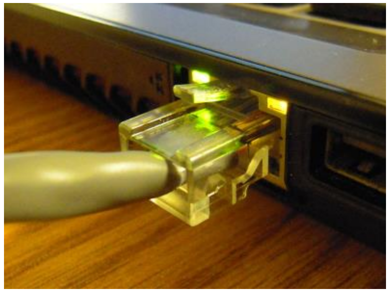
MAC (Media Access Control) Address

- Broadcast address received by everyone (as opposed to unicast/multicast)

  FF:FF:FF:FF:FF:FF

- NICs filter traffic by MAC Address
  - Exception: promiscuous/monitor modes (relevant to Assignment 5)
- On the link layer, data is split into packets/frames (often 1500 bytes)

MAC Addresses Used on Link Layer

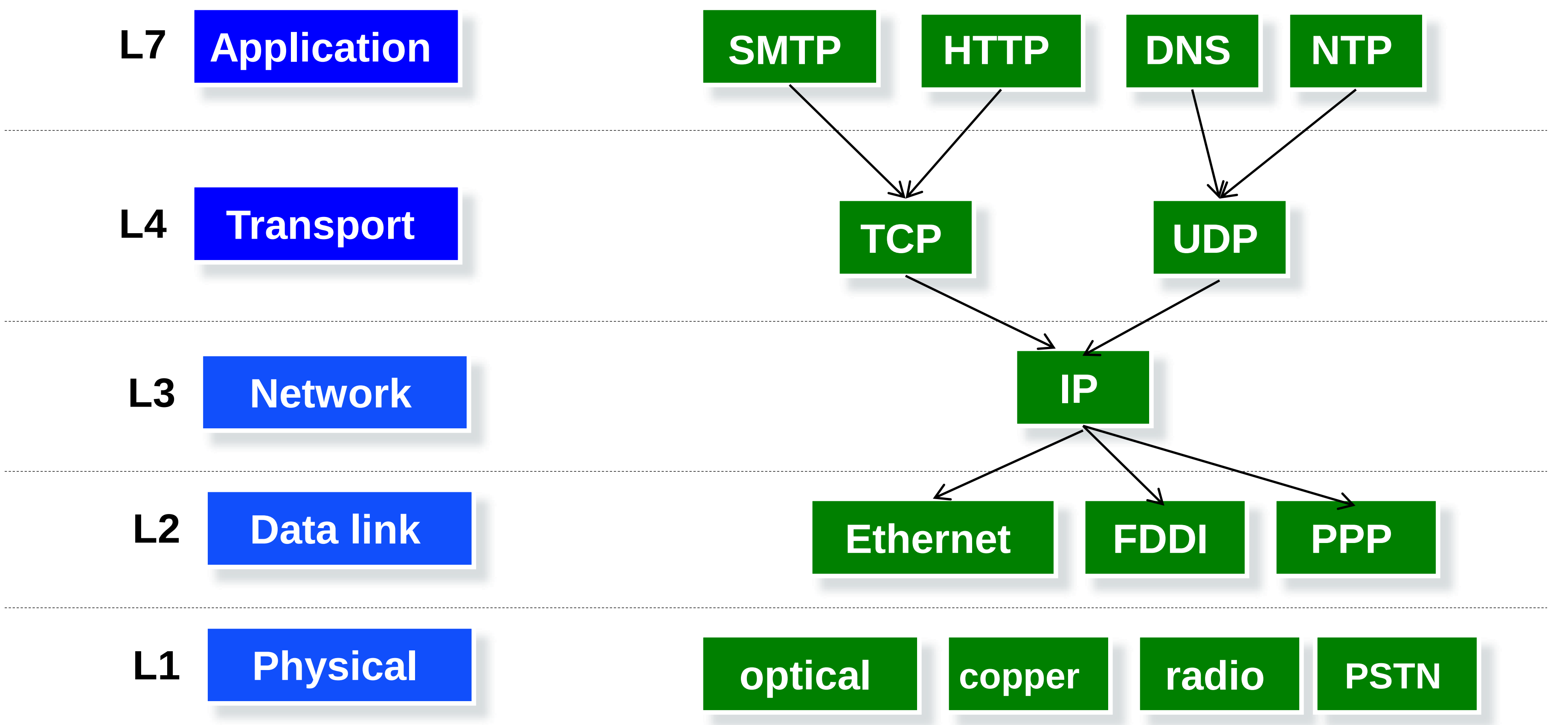


- Ethernet (plugged in)
  - Some hardware (e.g., hubs) repeats all traffic
  - Some hardware (e.g., switches) filters by MAC address
- Wi-Fi (802.11)
  - Your Wi-Fi card typically filters only unicast traffic for you and broadcast traffic
  - Exception: promiscuous/monitor modes (relevant to Assignment 5)

Wi-Fi Encryption

- WEP (Wired Equivalent Privacy)
  - Broken; hard to configure
  - Abandoned in 2004
- WPA (Wi-Fi Protected Access)
  - Vulnerable, particularly the WPS feature
- WPA2
  - Uses AES
- WPA3 recently introduced
  - Device-specific encryption on public networks

Protocols at different layers



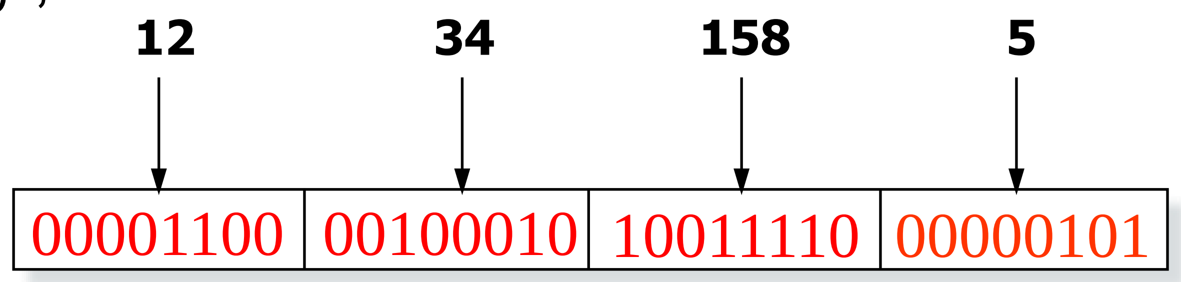
Goal: Be addressable on the Internet

Solution: IP Addresses (Network Layer)

IP Addresses (IPv4)

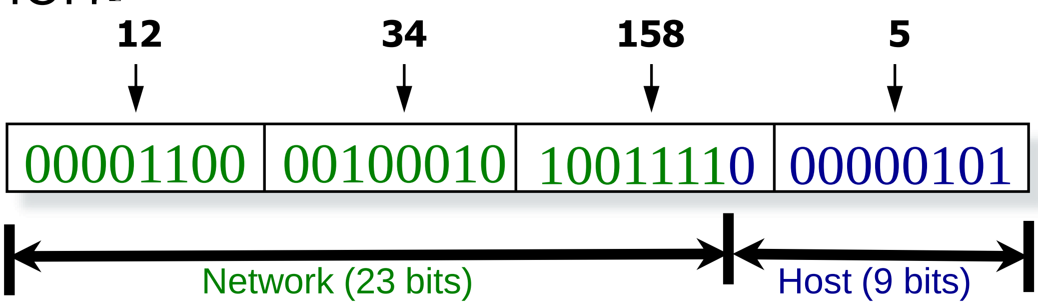
- Unique-*ish* 32-bit number associated with host   00001100 00100010 10011110 00000101

- Represented with "dotted quad" notation
  - e.g., 12.34.158.5



Hierarchy in IP Addressing

- 32 bits are partitioned into a prefix and suffix components
- Prefix is the network component; suffix is host component

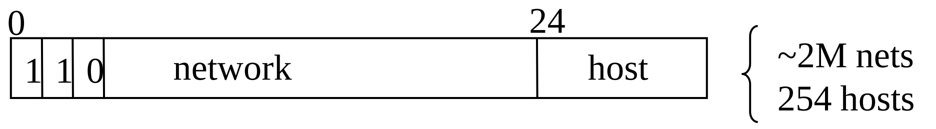


  - Interdomain routing operates on the network prefix

Early Design: “Classful” Addressing

- Three main classes
  - Class A


  - Class B


  - Class C


Problem: Networks only come in three sizes!

Today's Addressing

- CIDR = Classless Interdomain Routing
- Idea: Flexible division between network and host addresses
  - Offer better tradeoff between size of routing table and use of IP address space

CIDR (example)

- Suppose a network has 50 computers
  - allocate 6 bits for host addresses (since $2^5 < 50 < 2^6$)
  - remaining 32 - 6 = 26 bits as network prefix
- Flexible boundary means the boundary must be explicitly specified with the network address!
  - informally, "slash 26" → 128.23.9/26
  - formally, prefix represented with a 32-bit mask: 255.255.255.192
    where all network prefix bits set to "1" and host suffix bits to "0"

Allocation Done Hierarchically

- Internet Corporation for Assigned Names & Numbers (ICANN) gives large blocks to…
  - Regional Internet Registries, such as American Registry for Internet Names (ARIN), which give blocks to…
- Large institutions (ISPs), which give addresses to…
- Individuals and smaller institutions

e.g. ICANN ➔ ARIN ➔ Qwest ➔ UChicago ➔ CS

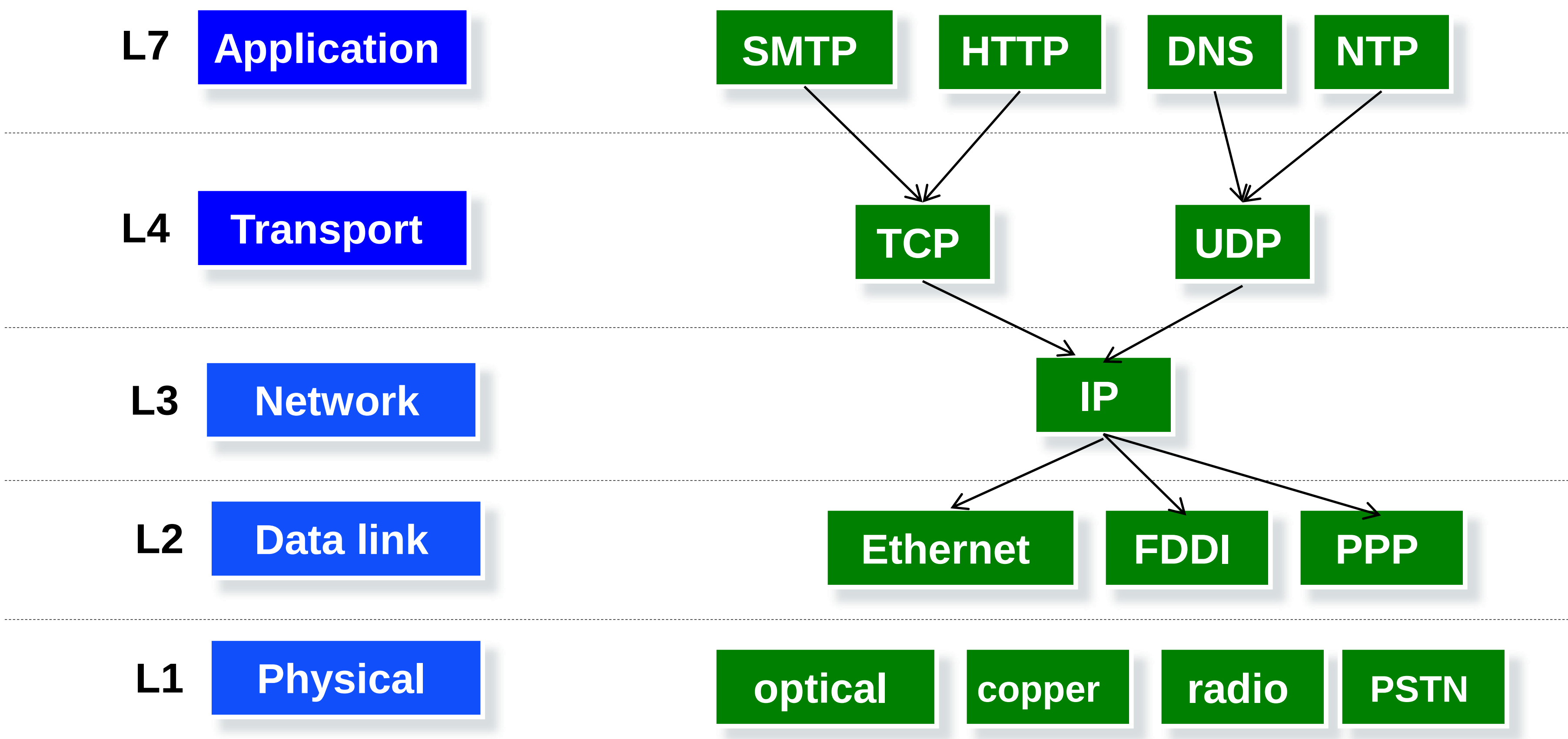
Example in More Detail

- ICANN gives ARIN several /8s
- ARIN gives Qwest one /8, 128.0/8
  - Network Prefix: 10000000
- Qwest gives UChicago a /16, 128.135/16
  - Network Prefix: 1000000010000111
- UChicago gives CS a /24, 128.135.11/24
  - Network Prefix: 100000001000011100001011
- CS gives me a specific address 128.135.11.176
  - Address: 10000000100001110000101110110000

IP Address FAQs

- How do you get an IP Address?
  - Typically use Dynamic Host Configuration Protocol (DHCP) upon connection to networks
- Does your IP address change over time?
  - Yes, frequently when you switch networks or reconnect
- Why is my router usually 192.168.1.1?
  - Private IP Addresses: 192.168.*.* and 10.*.*.* and 172.16.*.* through 172.31.*.*
- Can you share an IP address?
  - Yes! Especially behind routers / NATs / middleboxes

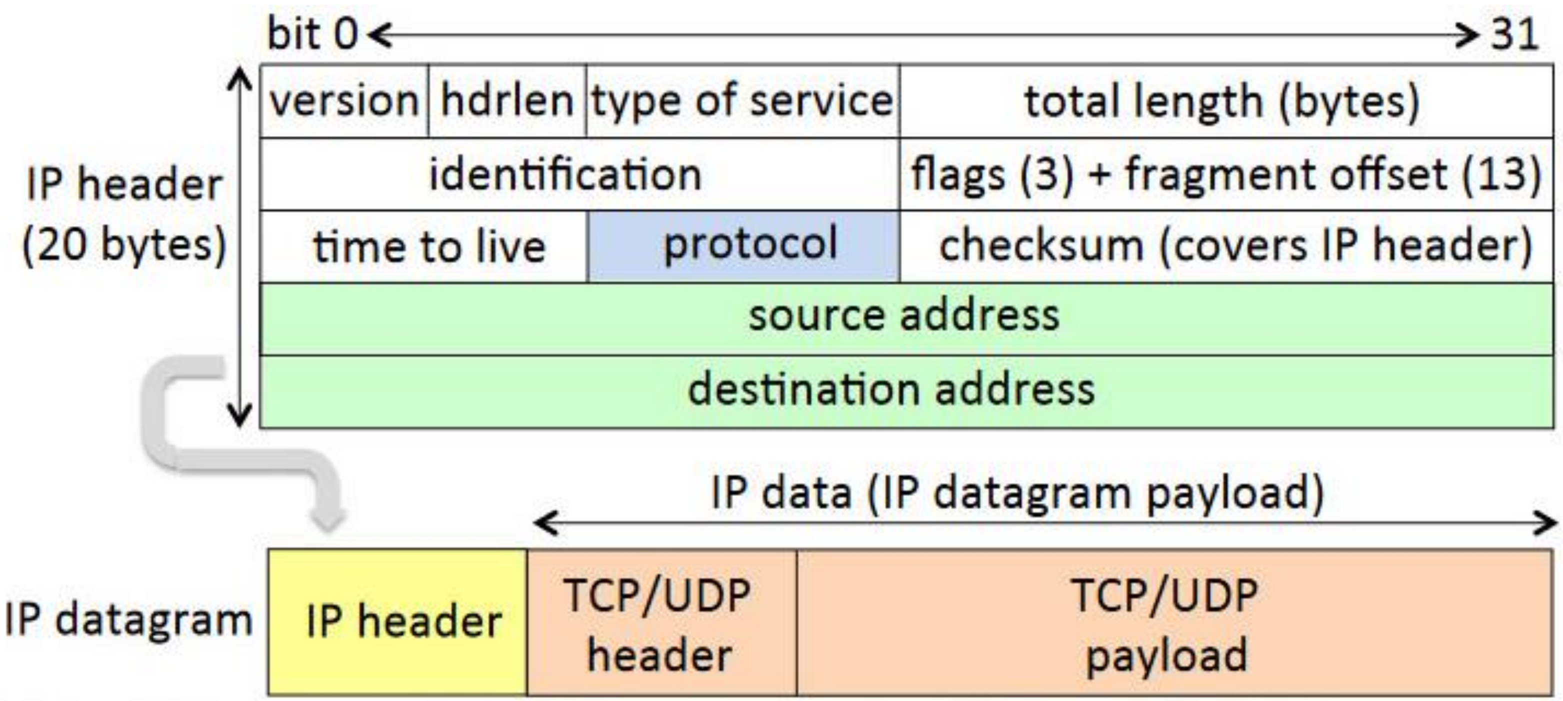
Protocols at different layers



Goal: Get data to its destination

Solution (Protocol): IP at the network layer

IP (Internet Protocol)



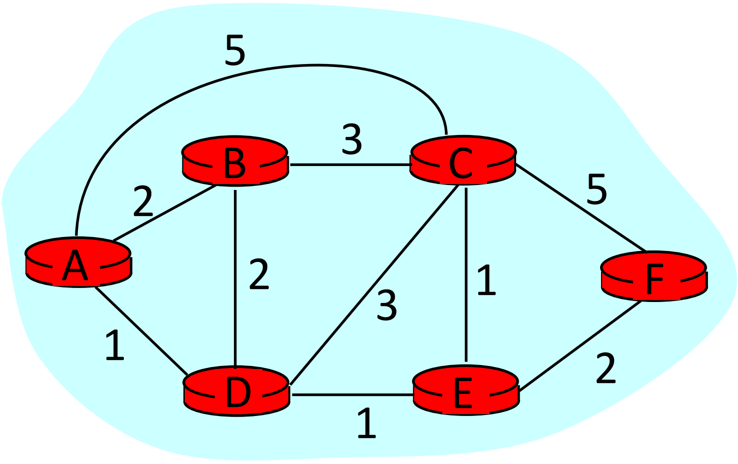
Goal: Get data to its destination

Solution (Part 2): Routing

Routing

- Goal: determine “good” path through network from source to destination

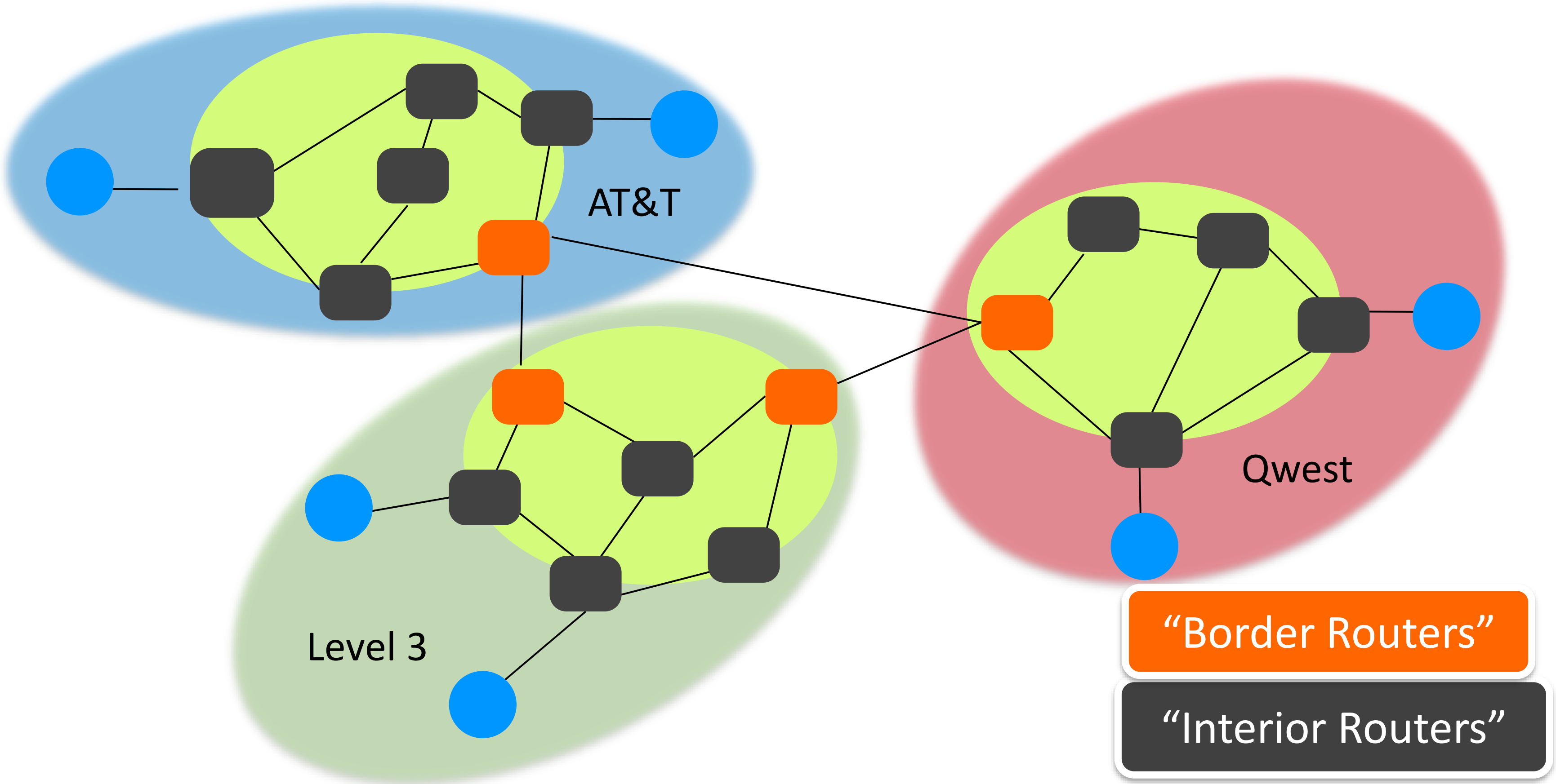
- Network modeled as a graph
  - Routers → nodes, Link →edges
    - Edge cost: delay, congestion level,..
  - A node knows only its neighbors and the cost to reach them



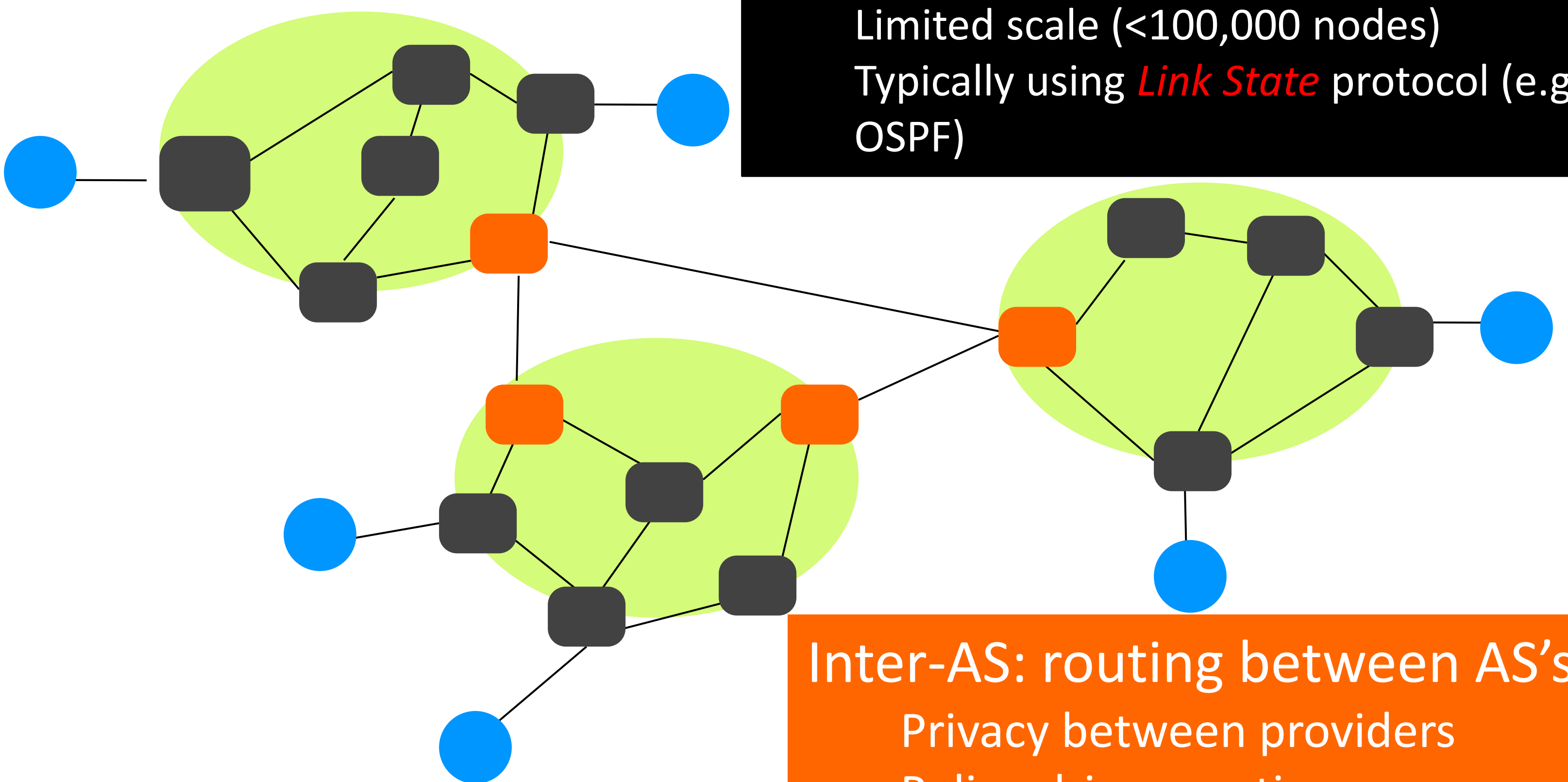
- How does each node learns how to reach every other node along the shortest path?

Autonomous System (AS)

- Collection of IP prefixes under the control of a single administrative entity
- 92,000+ ASes as of August 2019



Intra-AS & Inter-AS Routing



Intra-AS: routing within a single AS

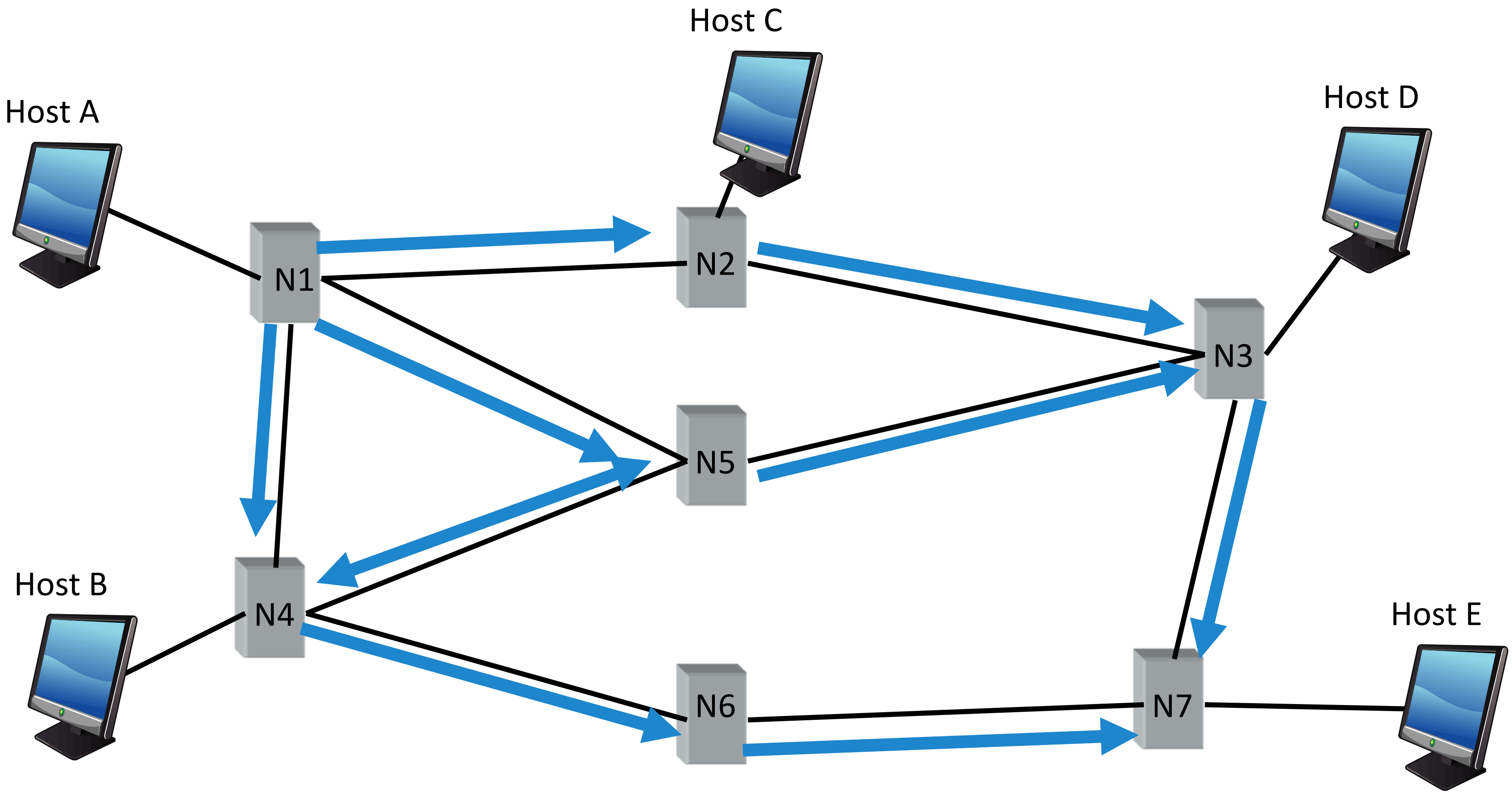
- Trusted domain (within one company)
- Limited scale (<100,000 nodes)
- Typically using *Link State* protocol (e.g. OSPF)

Inter-AS: routing between AS's

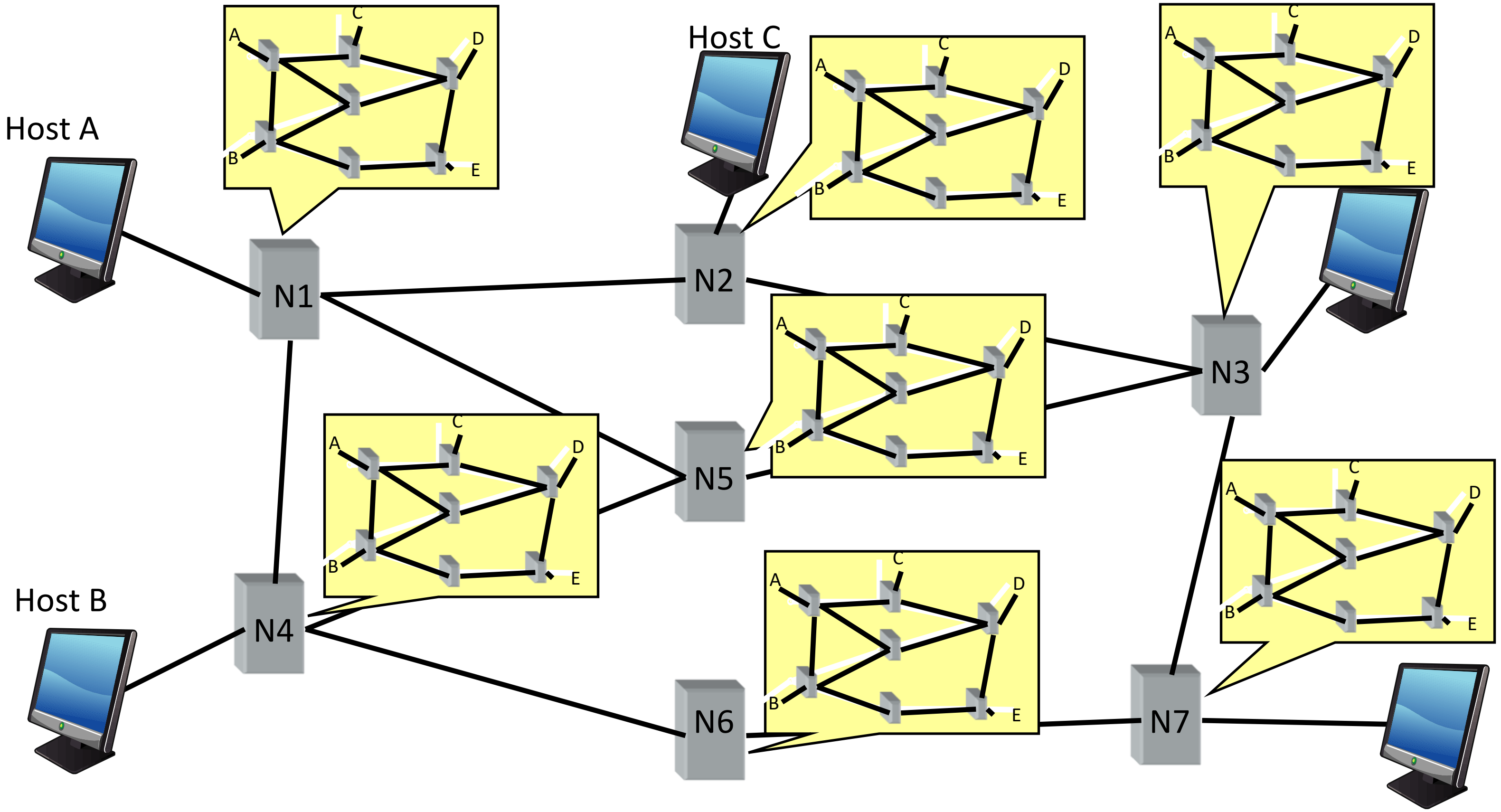
- Privacy between providers
- Policy-driven routing
- BGP, a *Path Vector* protocol
  - Variant of *Distance Vector* routing

Link State: Control Traffic

- Each node floods its local information to every other node in network
- Each node ends up knowing entire network topology
  → use Dijkstra to compute shortest path to every other node

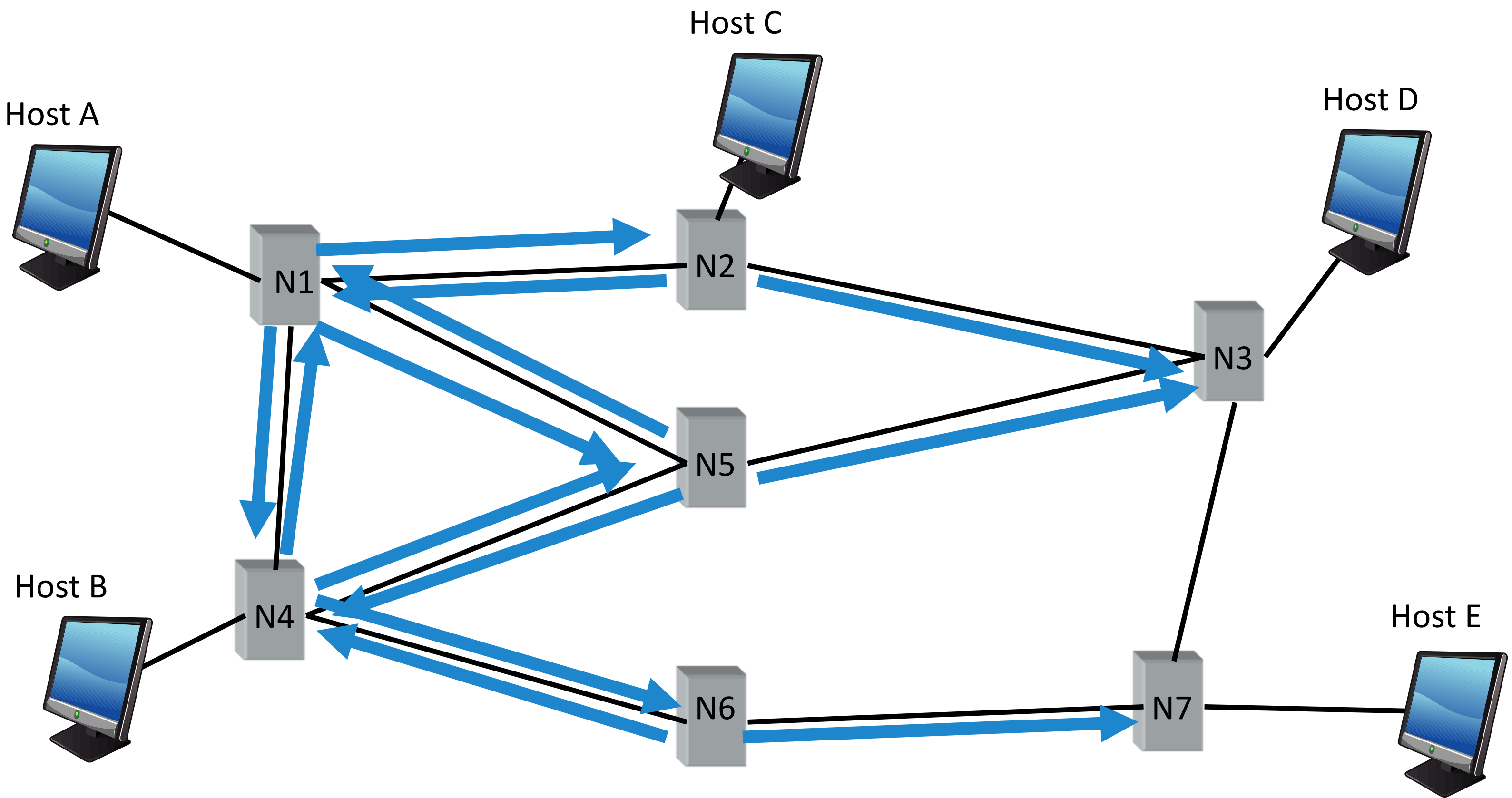


Link State: Node State

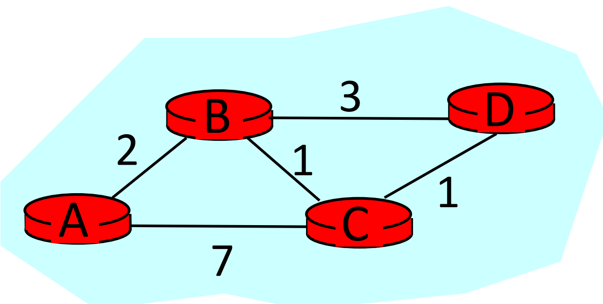


Distance Vector: Control Traffic

- When the routing table of a node changes, it sends table to neighbors
  - A node updates its table with information received from neighbors



Example: Distance Vector Algorithm



Node A

Dest.	Cost	NextHop
B	2	B
C	7	C
D	∞	-

Node B

Dest.	Cost	NextHop
A	2	A
C	1	C
D	3	D

Node C

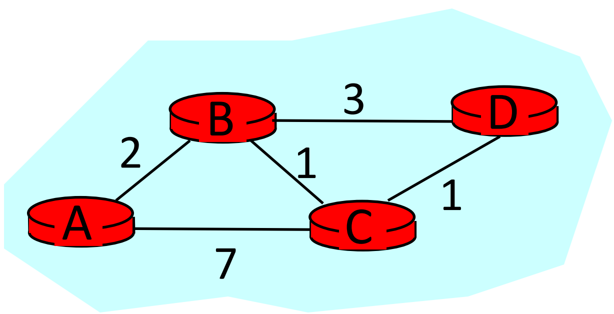
Dest.	Cost	NextHop
A	7	A
B	1	B
D	1	D

Node D

Dest.	Cost	NextHop
A	∞	-
B	3	B
C	1	C

Initialization:
  for all neighbors *V* **do**
   if *V* adjacent to *A*
    D(*A*, *V*) = c(*A*,*V*);
  else
    D(*A*, *V*) = ∞;
…

Example: 1st Iteration (C → A)




```
...
loop:
...
else if (update D(V, Y) received from V)
  for all destinations Y do
    if (destination Y through V)
      D(A,Y) = D(A,V) + D(V, Y);
    else
      D(A, Y) = min(D(A, Y),
                    D(A, V) + D(V, Y));
if (there is a new minimum for dest. Y)
  send D(A, Y) to all neighbors
forever
```

Node A

Dest.	Cost	NextHop
B	2	B
C	7	C
D	∞	-

Node B

Dest.	Cost	NextHop
A	2	A
C	1	C
D	3	D

(D(C,A), D(C,B), D(C,D))

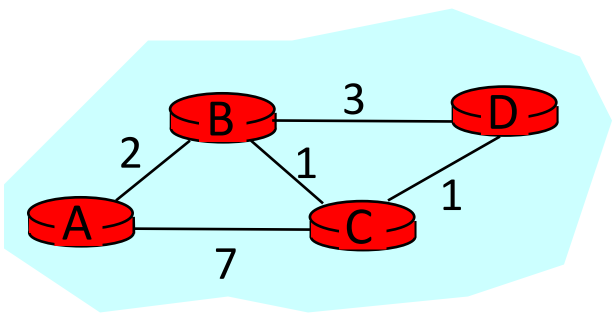
Node C

Dest.	Cost	NextHop
A	7	A
B	1	B
D	1	D

Node D

Dest.	Cost	NextHop
A	∞	-
B	3	B
C	1	C

Example: 1st Iteration (C → A)



Node A

Dest.	Cost	NextHop
B	2	B
C	7	C
D	**8**	**C**

Node B

Dest.	Cost	NextHop
A	2	A
C	1	C
D	3	D

D(A,D)= min(D(A, D),D(A,C)+D(C,D)
= min(∞ , 7 + 1) = 8

(D(C,A), D(C,B), D(C,D))

Node C

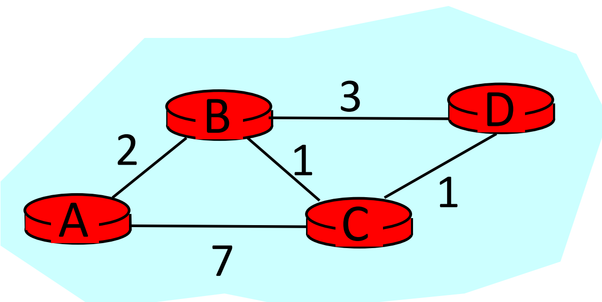
Dest.	Cost	NextHop
A	7	A
B	1	B
D	1	D

Node D

Dest.	Cost	NextHop
A	∞	-
B	3	B
C	1	C

```
…
loop:
…
  else if (update D(V, Y) received from V)
    for all destinations Y do
      if (destination Y through V)
        D(A,Y) = D(A,V) + D(V, Y);
      else
        D(A, Y) = min(D(A, Y),
                      D(A, V) + D(V, Y));
  if (there is a new minimum for dest. Y)
    send D(A, Y) to all neighbors
forever
```

Example: 1st Iteration (C → A)



Node A

Dest.	Cost	NextHop
B	2	B
C	7	C
D	8	C

Node B

Dest.	Cost	NextHop
A	2	A
C	1	C
D	3	D

Node C

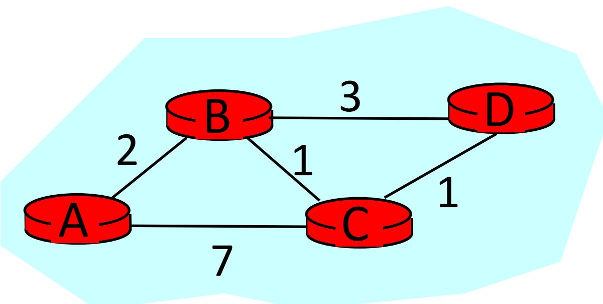
Dest.	Cost	NextHop
A	7	A
B	1	B
D	1	D

Node D

Dest.	Cost	NextHop
A	∞	-
B	3	B
C	1	C

```
…
loop:
…
else if (update D(V, Y) received from V)
  for all destinations Y do
    if (destination Y through V)
      D(A,Y) = D(A,V) + D(V, Y);
    else
      D(A, Y) = min(D(A, Y),
                    D(A, V) + D(V, Y));
if (there is a new minimum for dest. Y)
  send D(A, Y) to all neighbors
forever
```

Example: 1st Iteration (B→A, C→A)



Node A

Dest.	Cost	NextHop
B	2	B
C	**3**	**B**
D	**5**	**B**

Node B

Dest.	Cost	NextHop
A	2	A
C	1	C
D	3	D

D(A,D) = min(D(A,D), D(A,B) + D(B,D))
= min(8, 2 + 3) = 5

D(A,C) = min(D(A,C), D(A,B) + D(B,C))
= min(7, 2 + 1) = 3

```
…
loop:
…
else if (update D(V, Y) received from V)
  for all destinations Y do
    if (destination Y through V)
      D(A,Y) = D(A,V) + D(V, Y);
    else
      D(A, Y) = min(D(A, Y),
                    D(A, V) + D(V, Y));
if (there is a new minimum for dest. Y)
  send D(A, Y) to all neighbors
forever
```

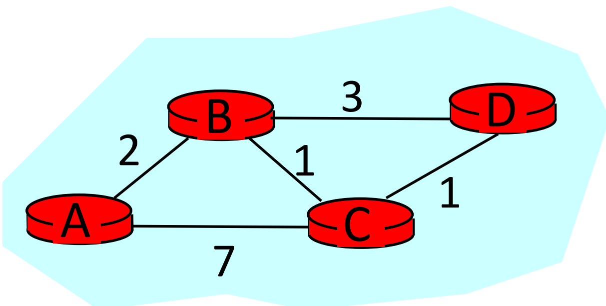
Node C

Dest.	Cost	NextHop
A	7	A
B	1	B
D	1	D

Node D

Dest.	Cost	NextHop
A	∞	-
B	3	B
C	1	C

Example: End of 1st Iteration




```
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...
  else if (update D(V, Y) received from V)
    for all destinations Y do
      if (destination Y through V)
        D(A,Y) = D(A,V) + D(V, Y);
      else
        D(A, Y) = min(D(A, Y),
                      D(A, V) + D(V, Y));
  if (there is a new minimum for dest. Y)
    send D(A, Y) to all neighbors
forever
```

Node A

Dest.	Cost	NextHop
B	2	B
C	**3**	**B**
D	**5**	**B**

Node B

Dest.	Cost	NextHop
A	2	A
C	1	C
D	**2**	**C**

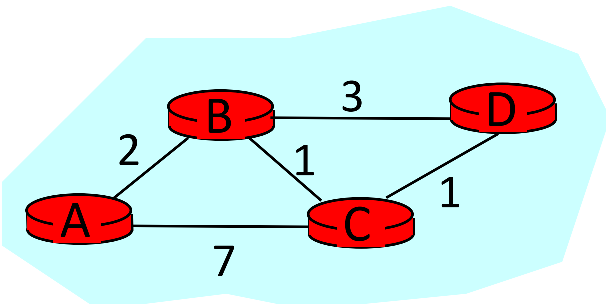
Node C

Dest.	Cost	NextHop
A	**3**	**B**
B	1	B
D	1	D

Node D

Dest.	Cost	NextHop
A	**4**	**B**
B	3	B
C	1	C

Example: End of 3rd Iteration




```
...
loop:
...
else if (update D(V, Y) received from V)
  for all destinations Y do
    if (destination Y through V)
      D(A,Y) = D(A,V) + D(V, Y);
    else
      D(A, Y) = min(D(A, Y),
                    D(A, V) + D(V, Y));
if (there is a new minimum for dest. Y)
  send D(A, Y) to all neighbors
forever
```

Node A

Dest.	Cost	NextHop
B	2	B
C	3	B
D	4	B

Node B

Dest.	Cost	NextHop
A	2	A
C	1	C
D	2	C

Node C

Dest.	Cost	NextHop
A	3	B
B	1	B
D	1	D

Node D

Dest.	Cost	NextHop
A	4	C
B	2	C
C	1	C

Nothing changes → algorithm terminates

BGP: a Path-Vector Protocol

- An AS-path: sequence of AS's a route traverses
- Used for loop detection and to apply policy
- *Possible* default choice: route with fewest # of AS's