Computer Networks

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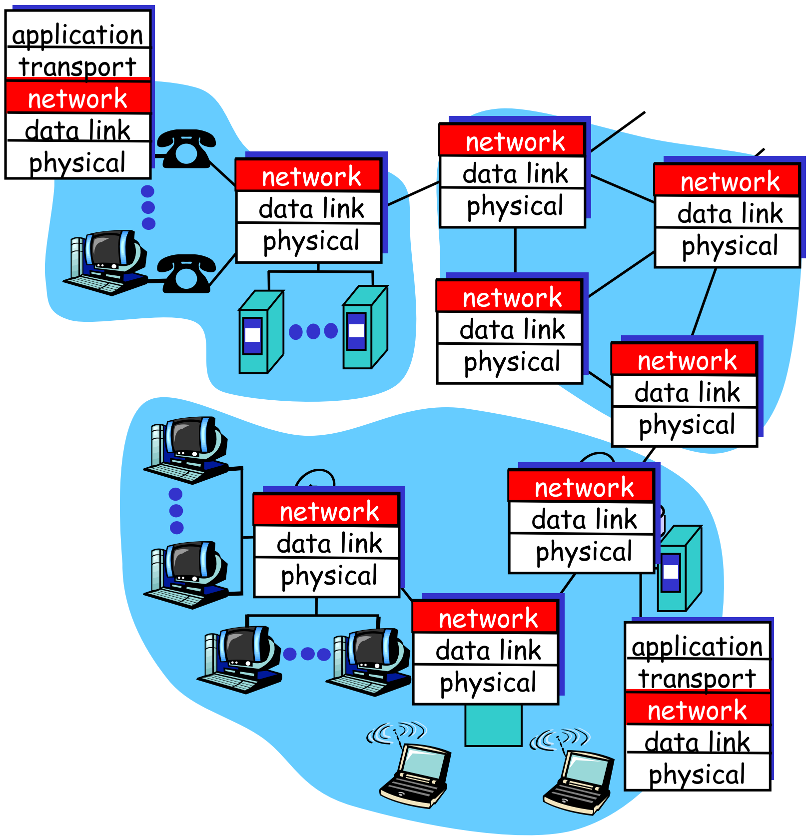
Notes derived from "*Computer Networking: A Top Down Approach*", by Jim Kurose and Keith Ross, Addison-Wesley.

The slides are adapted and modified based on slides from the book's companion Web site, as well as modified slides by Anirban Mahanti and Carey Williamson.

Network Layer

- carries segments from sending to receiving host
- on sending side, encapsulates segments into IP datagrams
- on rcv side, delivers segments to TL
- network layer protocol runs in *every* node (hosts and routers)
- router examines header fields in all IP datagrams passing through it



Two key network-layer functions

network-layer functions:

- *forwarding:* move packets from router's input to appropriate router output
- *routing:* determine route taken by packets from source to destination
  - *routing algorithms*

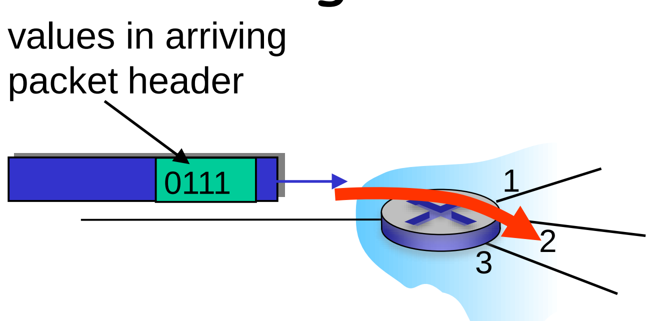
analogy: taking a trip

- *forwarding:* process of getting through single interchange
- *routing:* process of planning trip from source to destination

Network layer: data plane, control plane

Data plane

- local, per-router function
- determines how datagram arriving on router input port is forwarded to router output port
- forwarding function

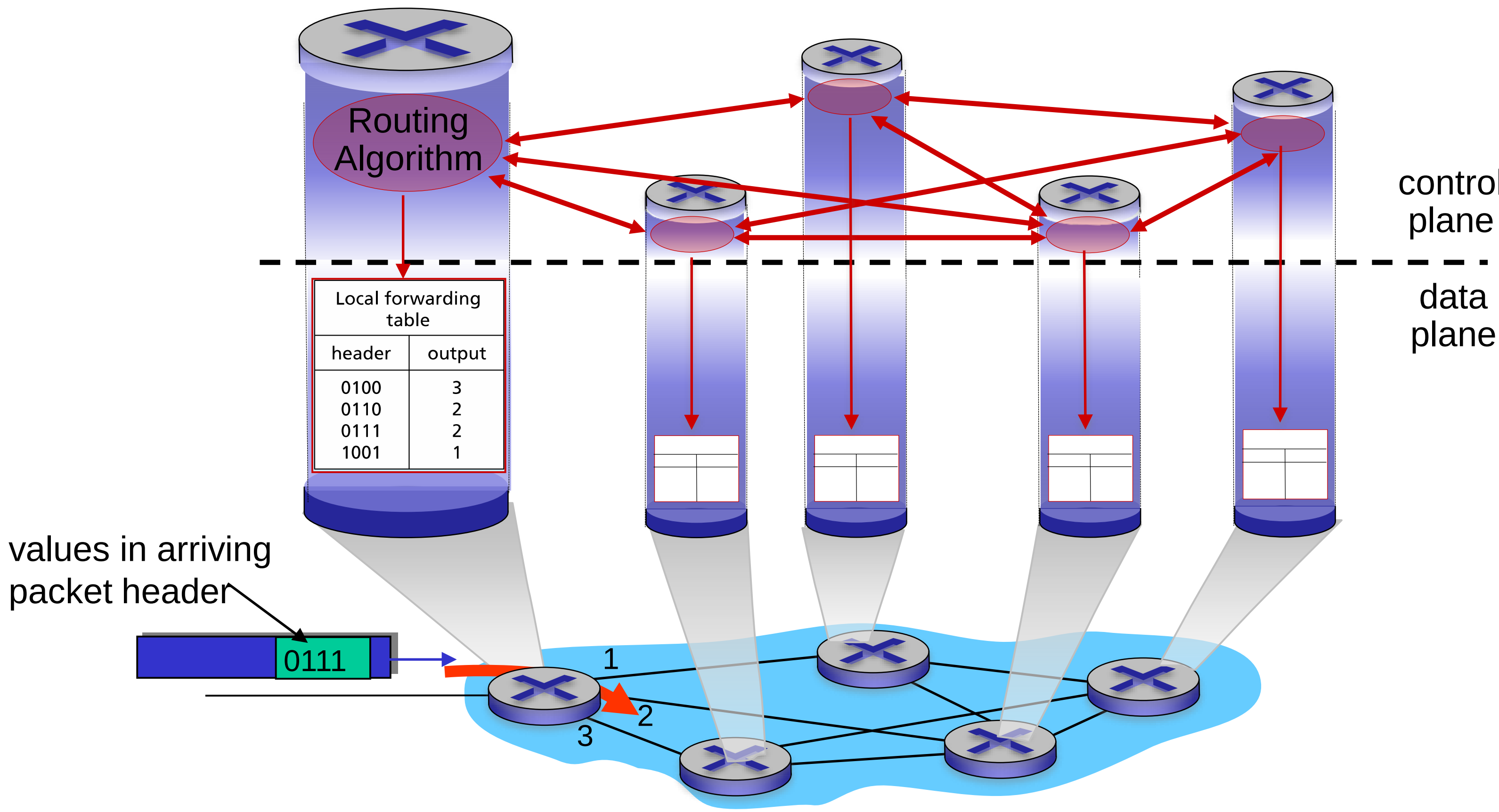


Control plane

- network-wide logic
- determines how datagram is routed among routers along end-end path from source host to destination host
- two control-plane approaches:
  - *traditional routing algorithms:* implemented in routers
  - *software-defined networking (SDN)*: implemented in (remote) servers

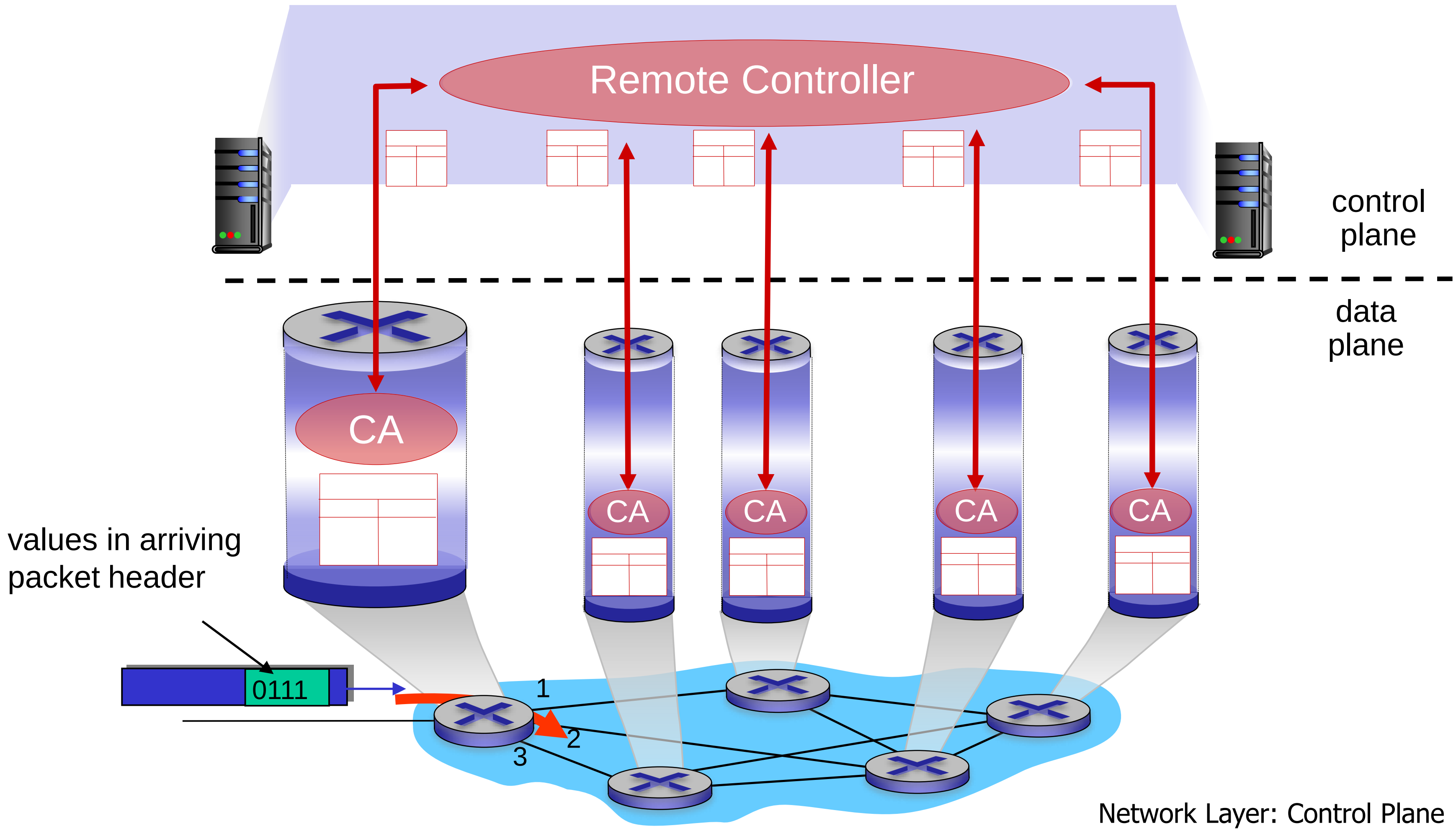
Per-router control plane

Individual routing algorithm components *in each and every router* interact in the control plane

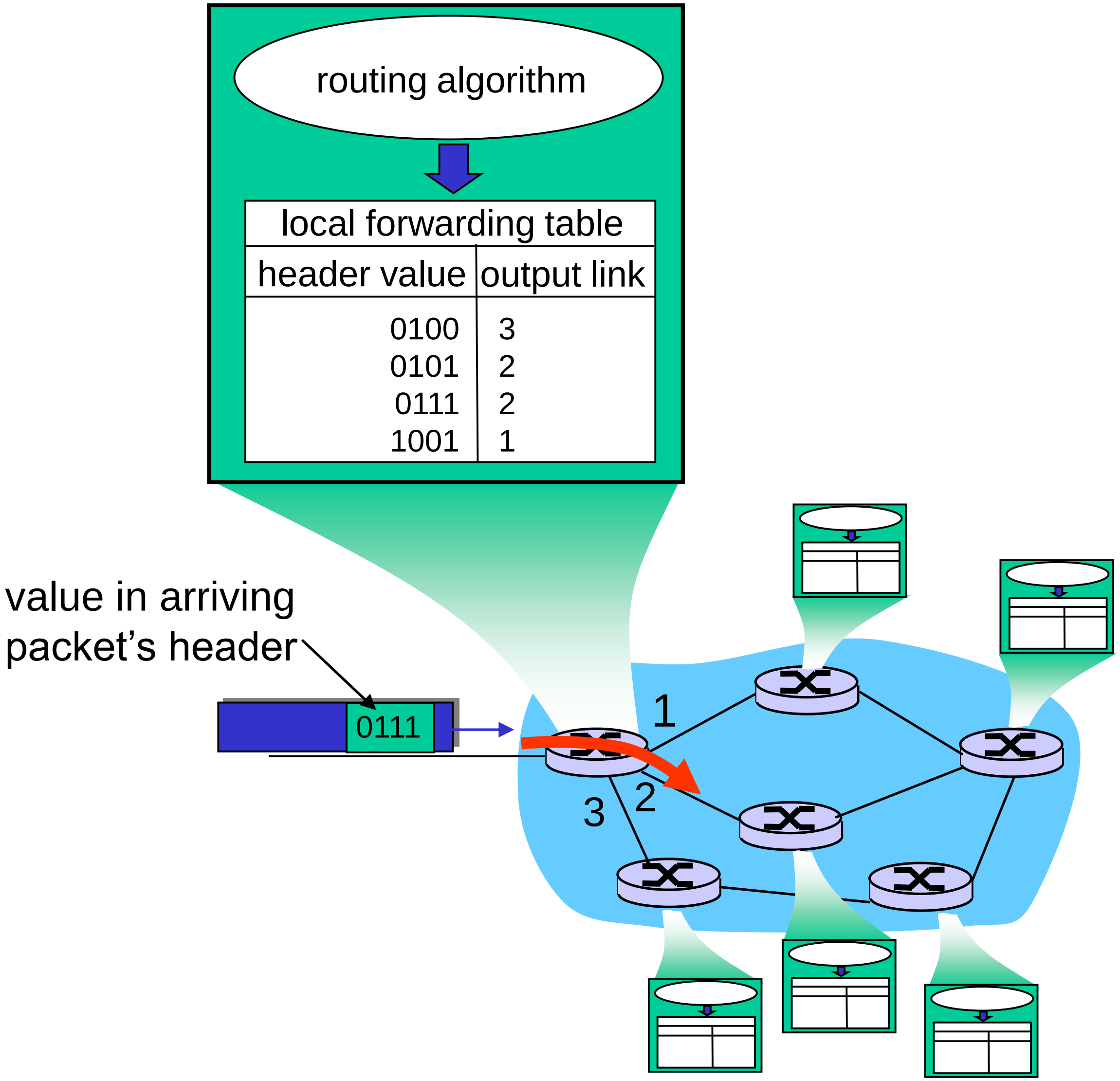


Logically centralized control plane

A distinct (typically remote) controller interacts with local control agents (CAs)

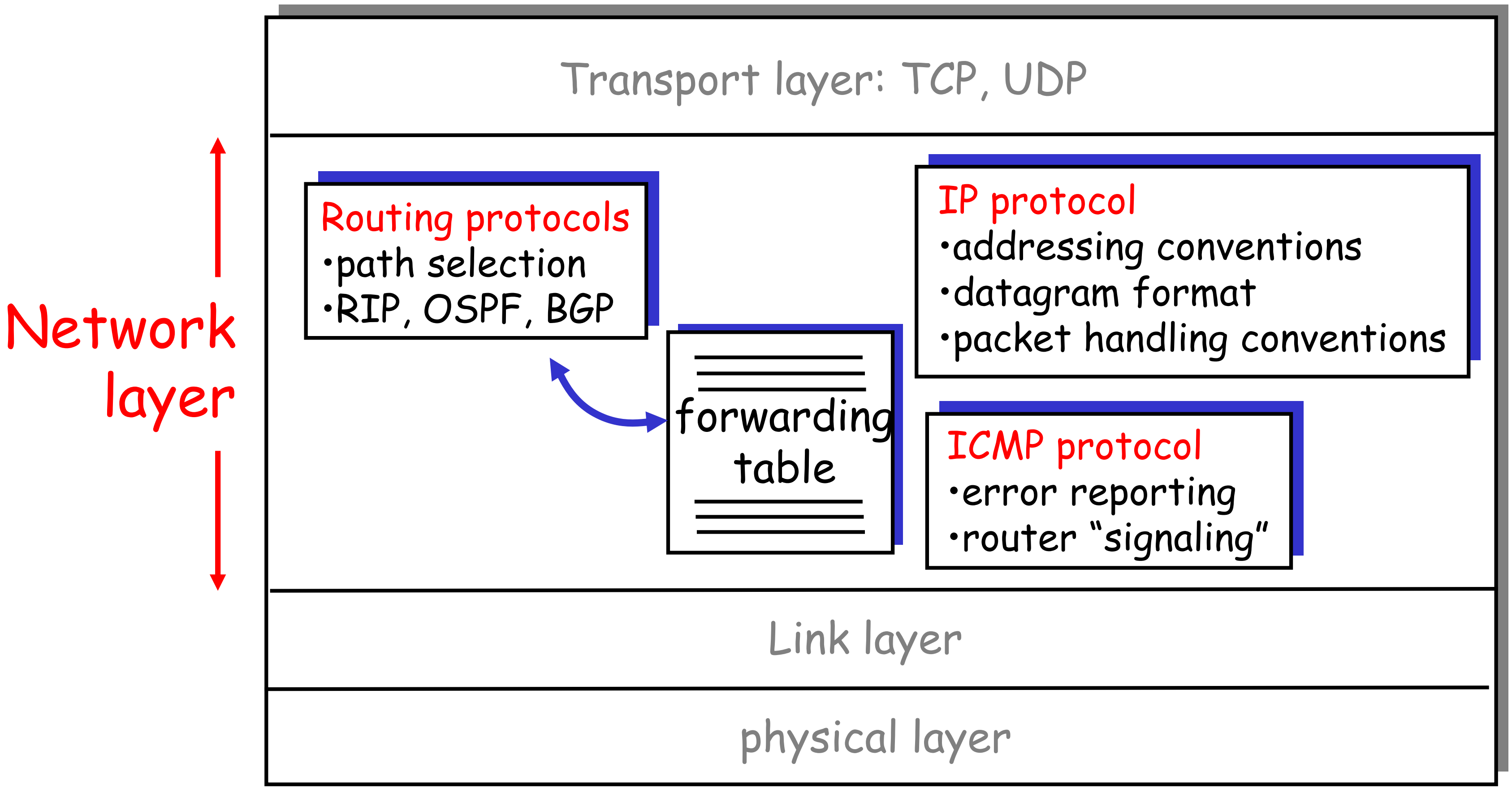


Interplay between routing and forwarding



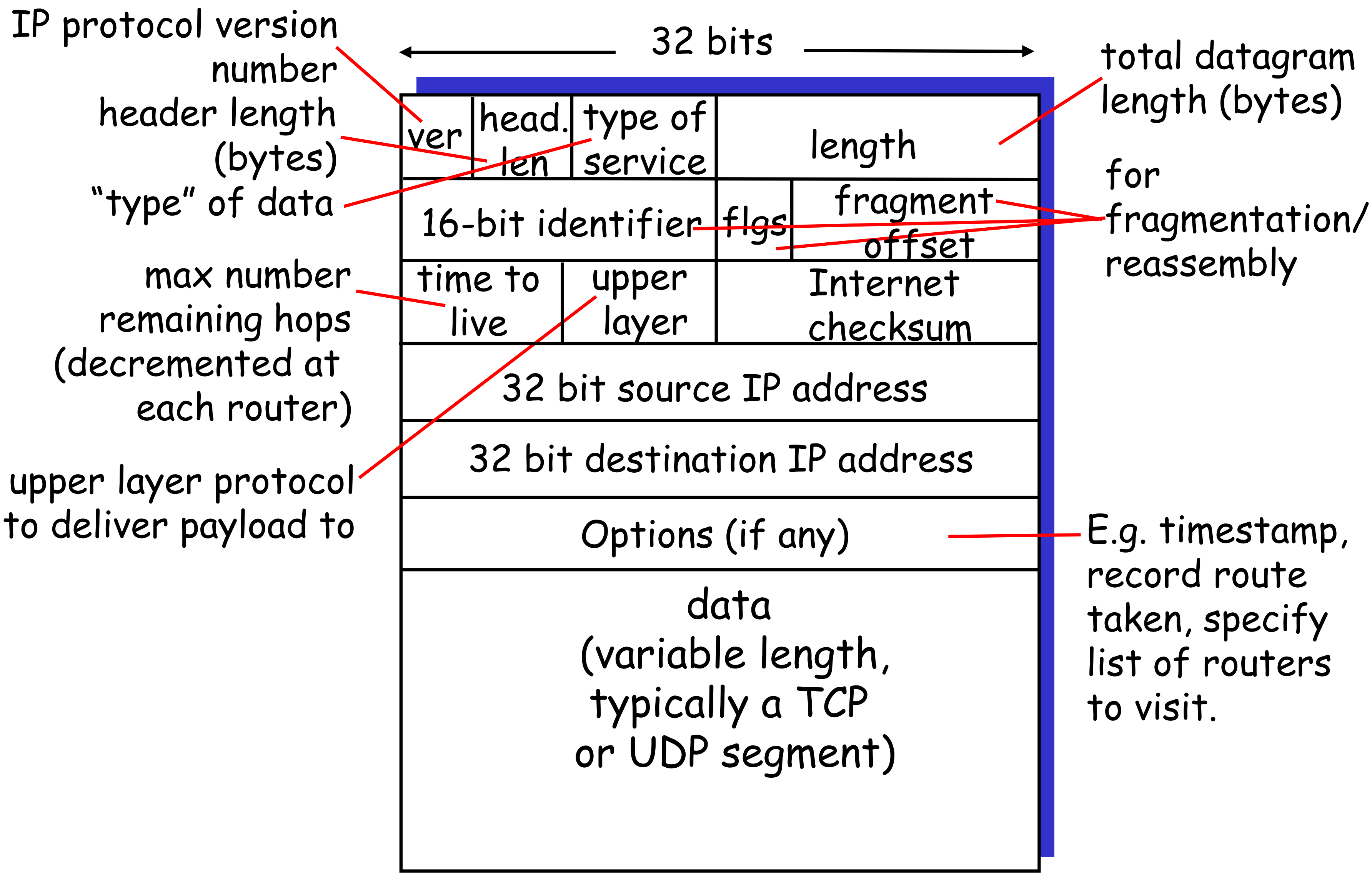
What does the Network layer consist of?

Host, router network layer functions:



The Internet Protocol (IP)

IP datagram format (IPv4)



IP datagram format (IPv4)

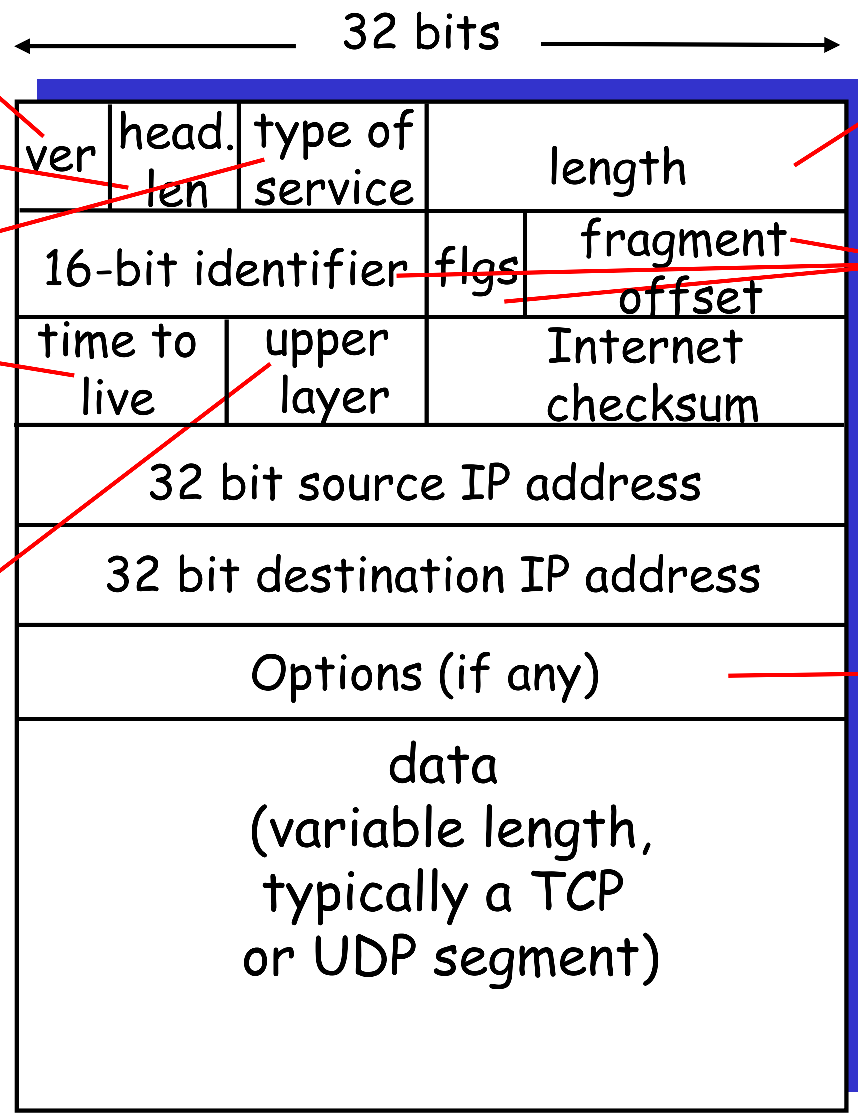
IP protocol version number

header length (bytes)

"type" of data

max number remaining hops (decremented at each router)

upper layer protocol to deliver payload to



total datagram length (bytes)

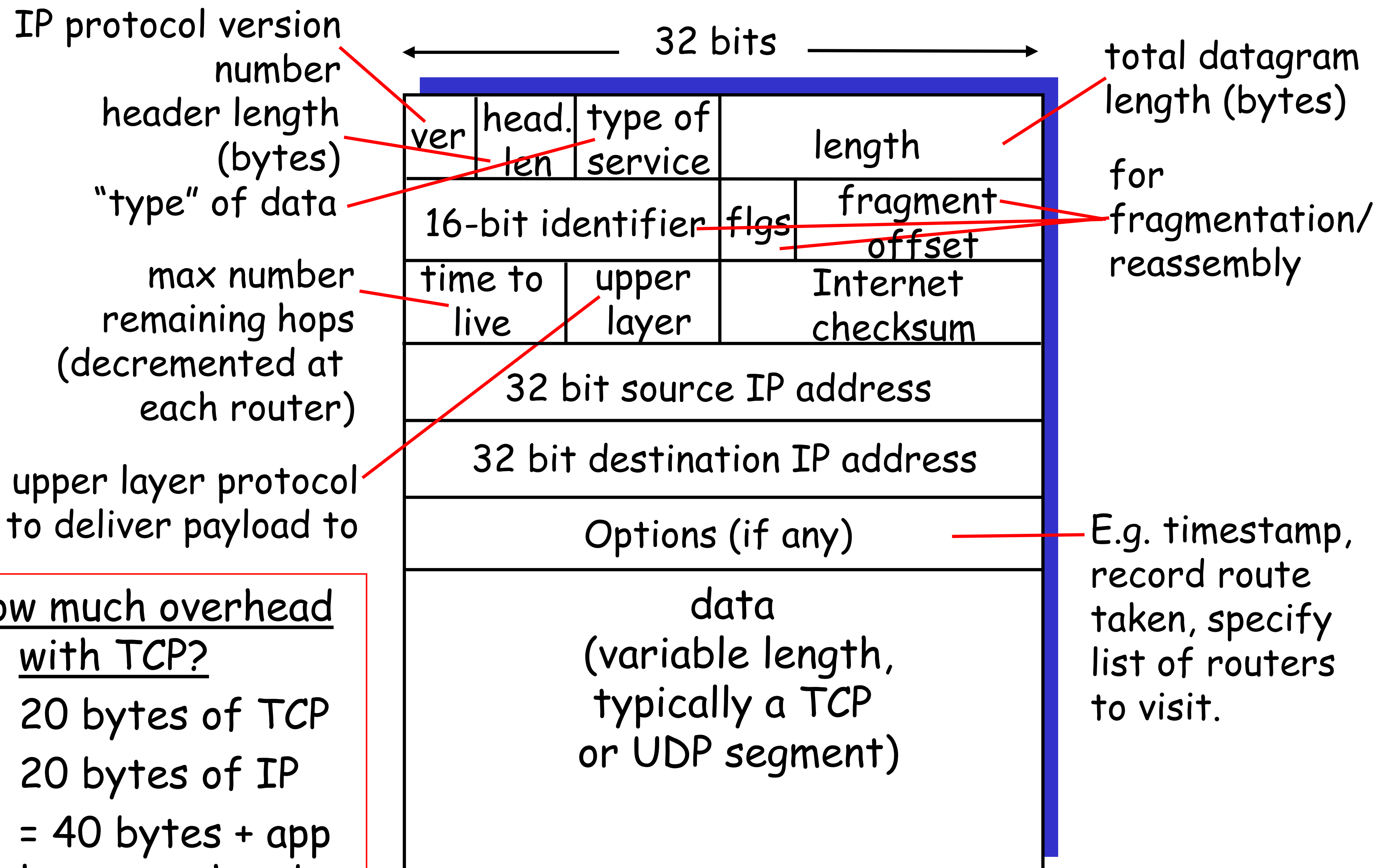
for fragmentation/ reassembly

E.g. timestamp, record route taken, specify list of routers to visit.

<u>how much overhead with TCP?</u>

- ?? bytes of TCP
- ?? bytes of IP

IP datagram format (IPv4)

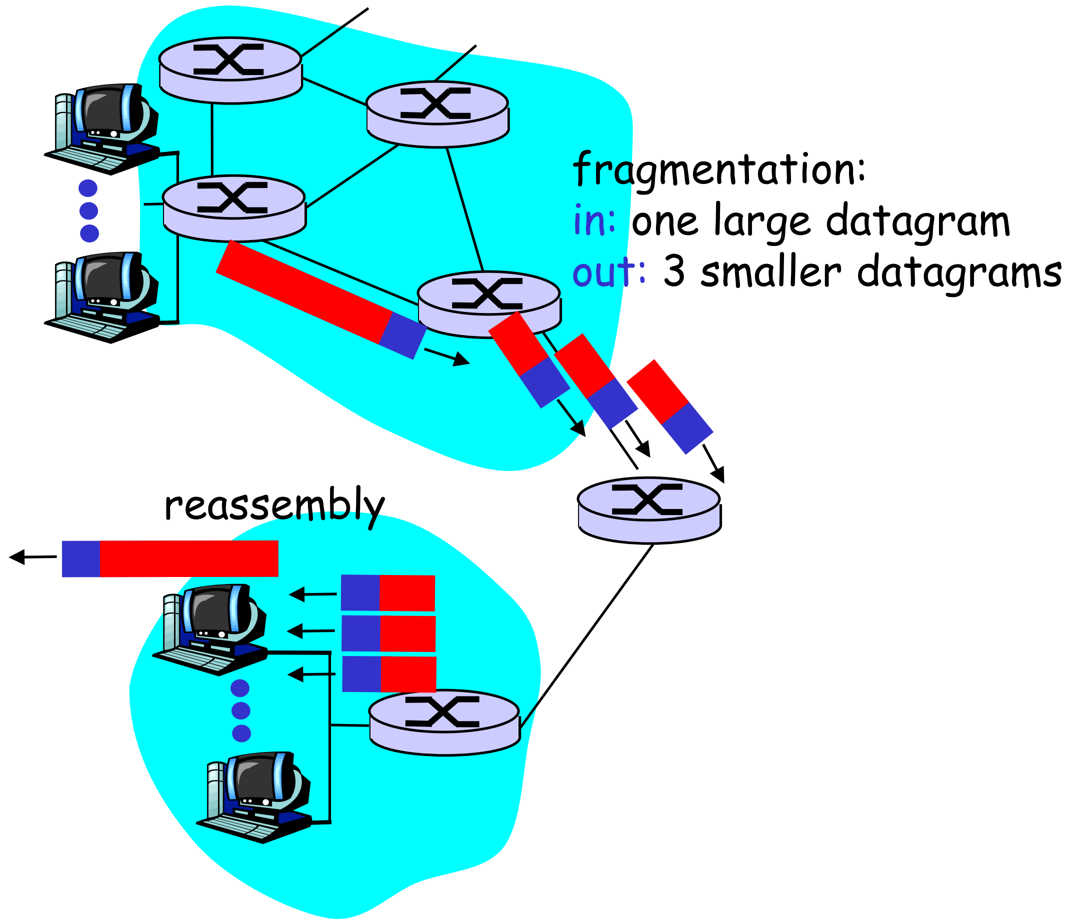


<u>how much overhead with TCP?</u>

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

IP Fragmentation & Reassembly

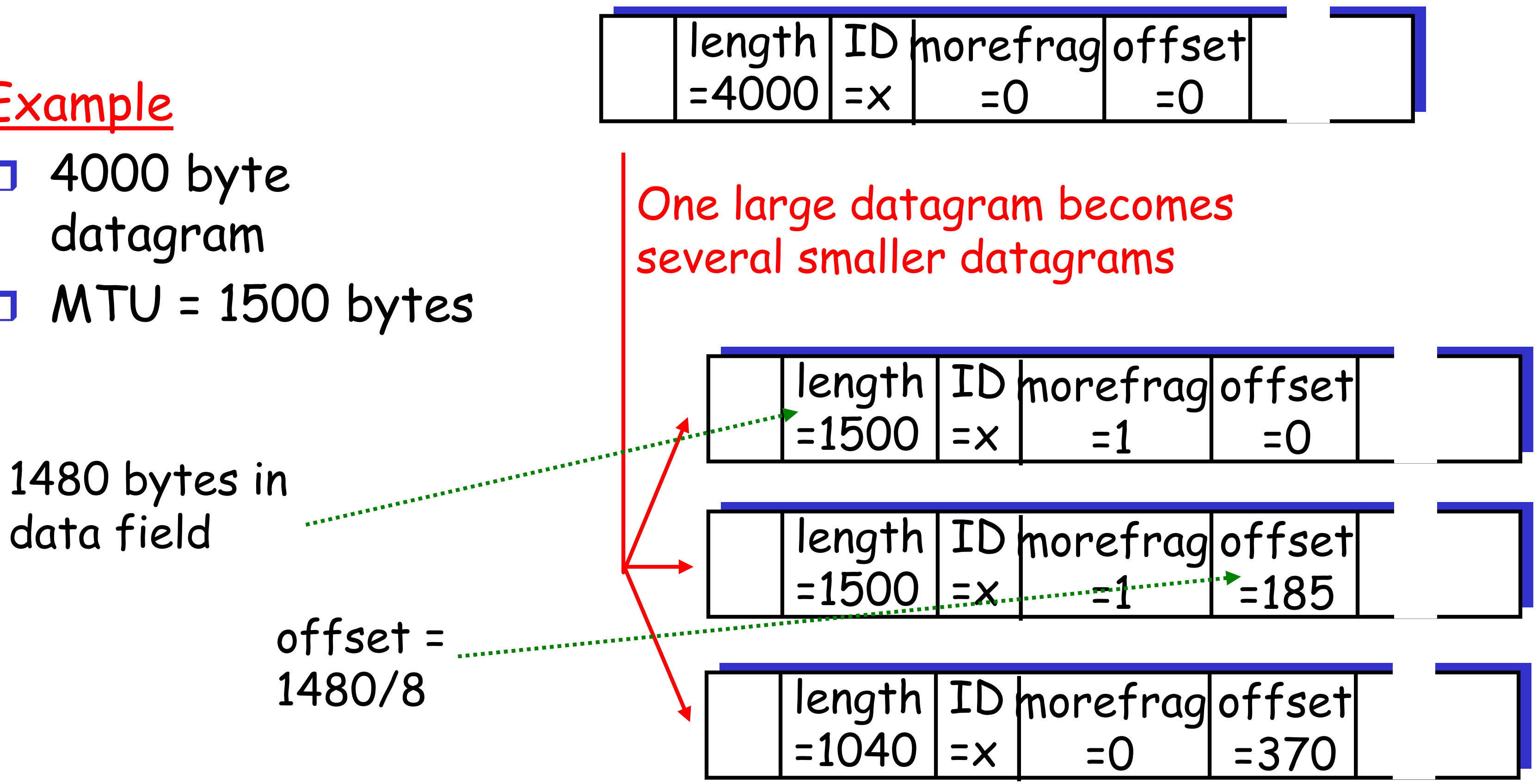
- network links have a limit on the largest possible link-level frame size permitted.
  - MTU: Maximum Transmission Unit
  - different link types, different MTUs
- large IP datagram can be divided ("fragmented") within the network (internetworking)
  - one datagram becomes several datagrams
  - "reassembled" only at final destination
  - IP header bits used to identify, order related fragments



IP Fragmentation and Reassembly

Example

- 4000 byte datagram
- MTU = 1500 bytes



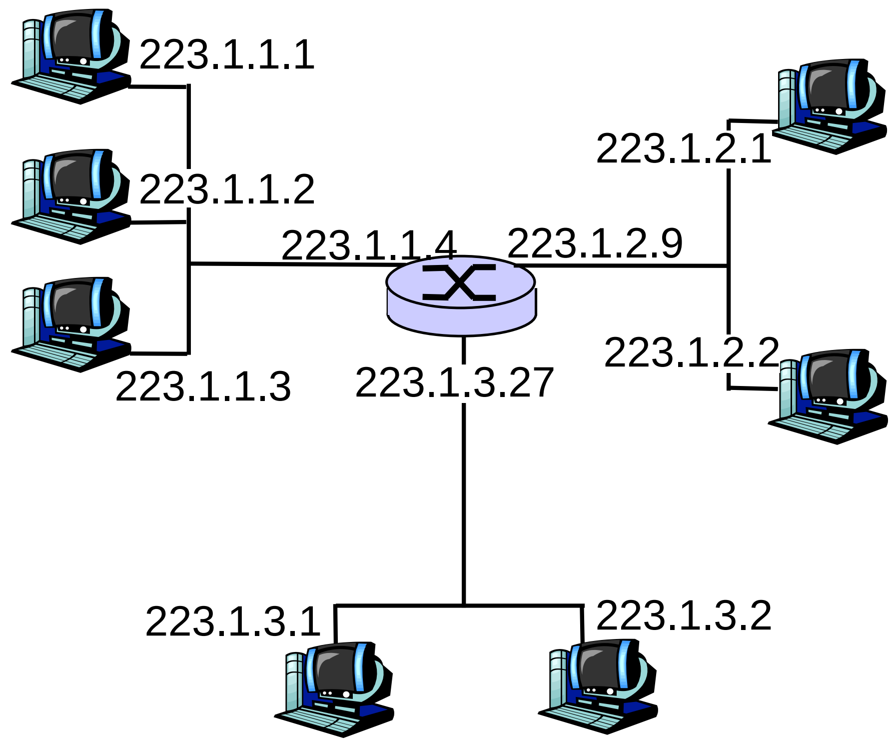
ICMP: Internet Control Message Protocol

- used by hosts & routers to communicate network-level information
  - error reporting: unreachable host, network, port, protocol
  - echo request/reply (used by ping)
- network-layer "above" IP:
  - ICMP msgs carried in IP datagrams
- ICMP message: type, code plus first 8 bytes of IP datagram causing error

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

IPv4 Addressing

- IP address: 32-bit identifier for host, router *interface*
- *interface:* connection between host/router and physical link
  - routers typically have multiple interfaces
  - hosts usually have one, but may have multiple interfaces (multi-homed)
  - IP addresses are associated with each interface



$223.1.1.1 = \underbrace{11011111}_{223}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}$

Class-based Addressing

- IP addresses consist of:
  - Network part
  - Host part
- IP addresses are divided into five classes: A, B, C, D, and E.
- Problems ??

0	Network (7 bits)	Host (24 bits)

Class A

1	0	Network (14 bits)	Host (16 bits)

Class B

110	Network (21 bits)	Host (8 bits)

Class C

1110	Multicast address

Class D

1111	Future use addresses

Class E

Subnets: Motivation

- The "classful" addressing scheme proposes that the network portion of a IP address uniquely identifies one physical network.
  - Any network with more than 255 hosts needs a class B address. Class B addresses can get exhausted before we have 4 billion hosts!

- Take bits from the host number part to create a "subnet" number ("right sizing").

Addressing in the Internet

CIDR: Classless InterDomain Routing

- subnet portion of address of arbitrary length
- address format: a.b.c.d/x, where x is # bits in subnet portion of address
- Before CIDR, Internet used a class-based addressing scheme where x could be 8, 16, or 24 bits. These corrsp to classes A, B, and C resp.

subnet part | host part

11001000 00010111 00010000 00000000

200.23.16.0/23

IP addresses: how to get one?

Q: How does *host* get IP address?

- hard-coded by system admin in a file
  - Wintel: control-panel->network->configuration->tcp/ip->properties
  - UNIX: /etc/rc.config
- DHCP: Dynamic Host Configuration Protocol: dynamically get address from a server
  - this is becoming very popular

IP addresses: how to get one?

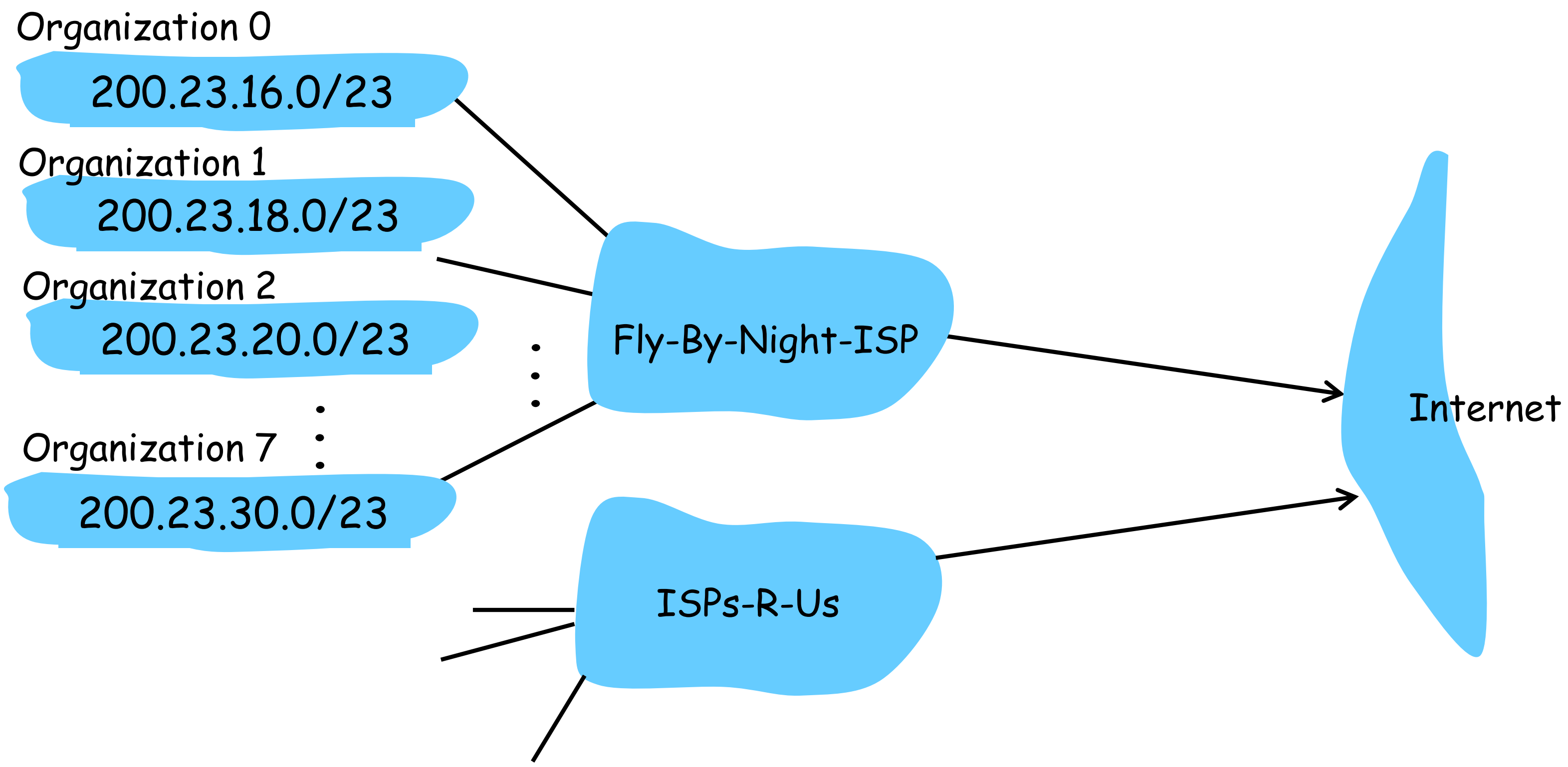
Q: How does *network* get subnet part of IP addr?

A: gets allocated portion of its provider ISP's address space

ISP's block	11001000	00010111	00010000	00000000		200.23.16.0/20
Organization 0	11001000	00010111	00010000	00000000		200.23.16.0/23
Organization 1	11001000	00010111	00010010	00000000		200.23.18.0/23
Organization 2	11001000	00010111	00010100	00000000		200.23.20.0/23
...		…..		….		….
Organization 7	11001000	00010111	00011110	00000000		200.23.30.0/23

Hierarchical addressing: route aggregation

ISP has an address block; it can further divide this block into sub blocks and assign them to subscriber organizations.



IP addressing: the last word...

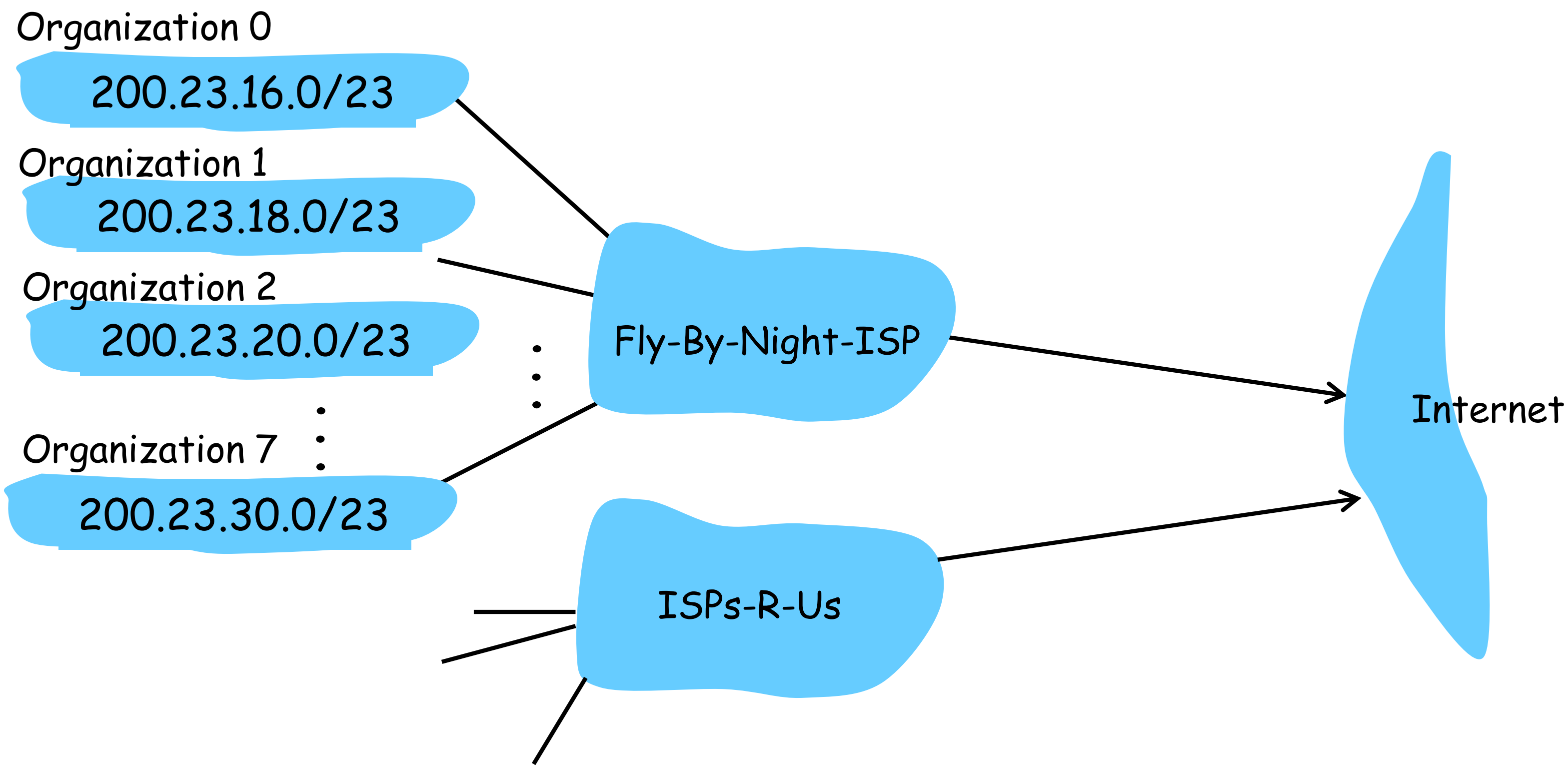
Q: How does an ISP get block of addresses?

A: ICANN: Internet Corporation for Assigned Names and Numbers

- allocates addresses
- manages DNS
- assigns domain names, resolves disputes

Hierarchical addressing: route aggregation

ISP has an address block; it can further divide this block into sub blocks and assign them to subscriber organizations.



Hierarchical addressing: route aggregation

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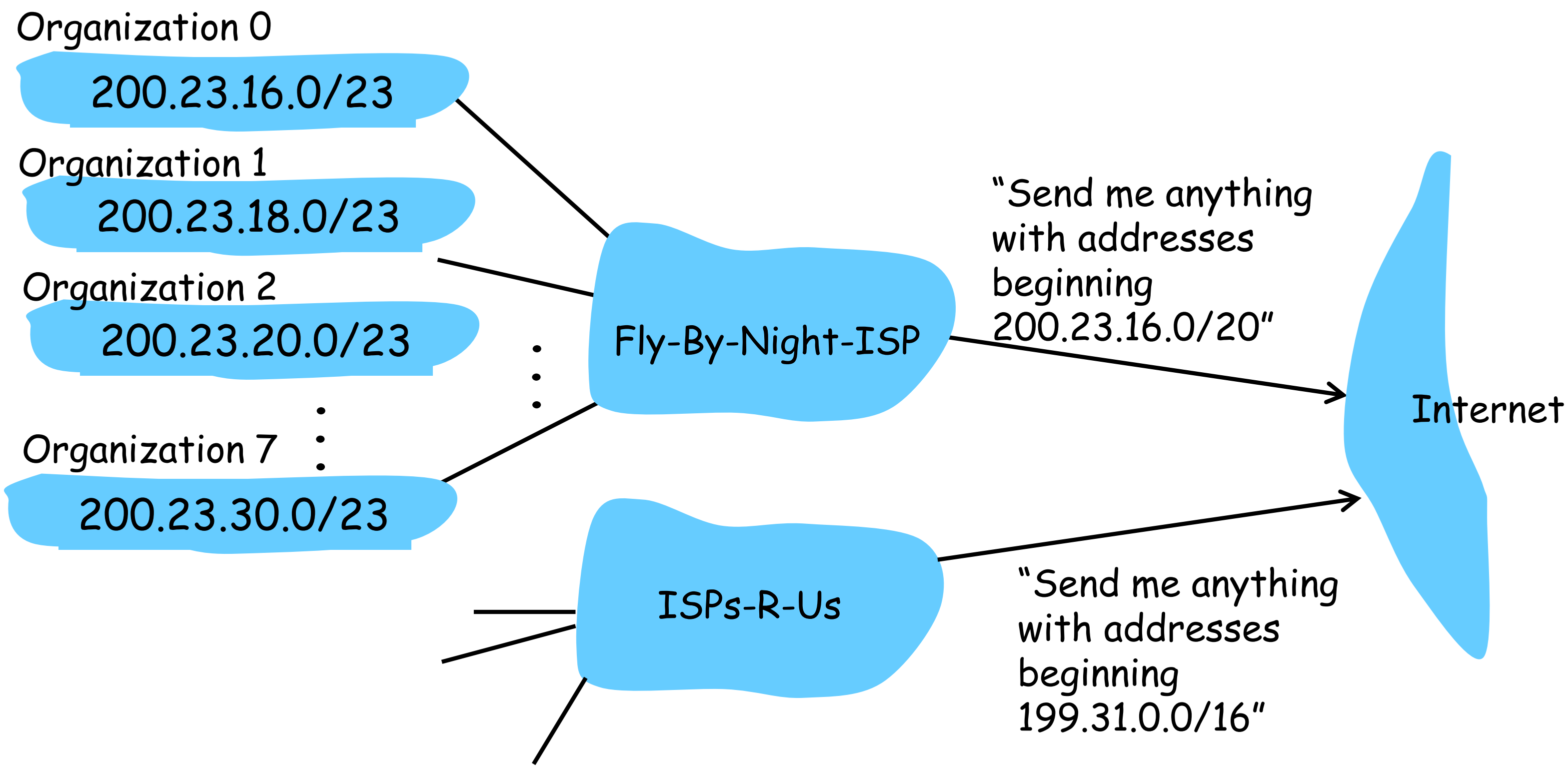


Forwarding: Longest prefix matching

Prefix	Link Interface
200.23.16.0/21	0
200.23.24.0/23	1
200.23.24.0/21	2
otherwise	3

Examples

Dest IP: 200.23.22.161 Which interface?

Dest IP: 200.23.24.172 Which interface?

Forwarding: Longest prefix matching

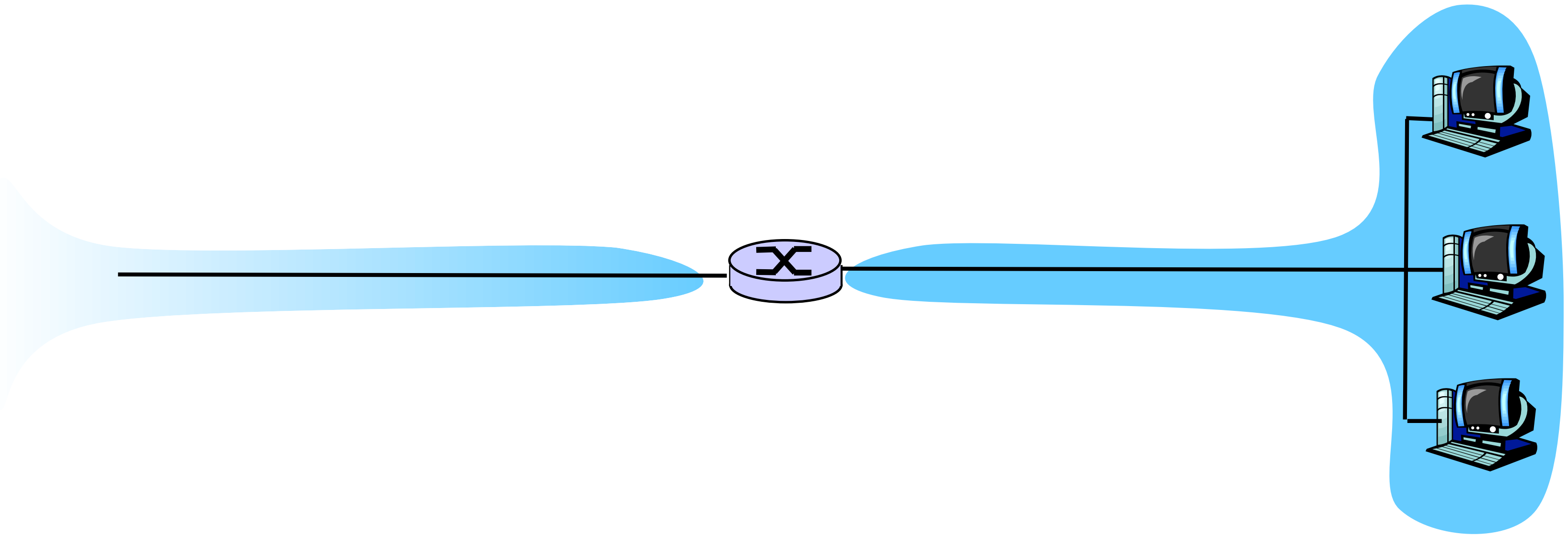
Prefix Match	Link Interface
11001000 00010111 00010	0
11001000 00010111 0001100	1
11001000 00010111 00011	2
otherwise	3

Examples

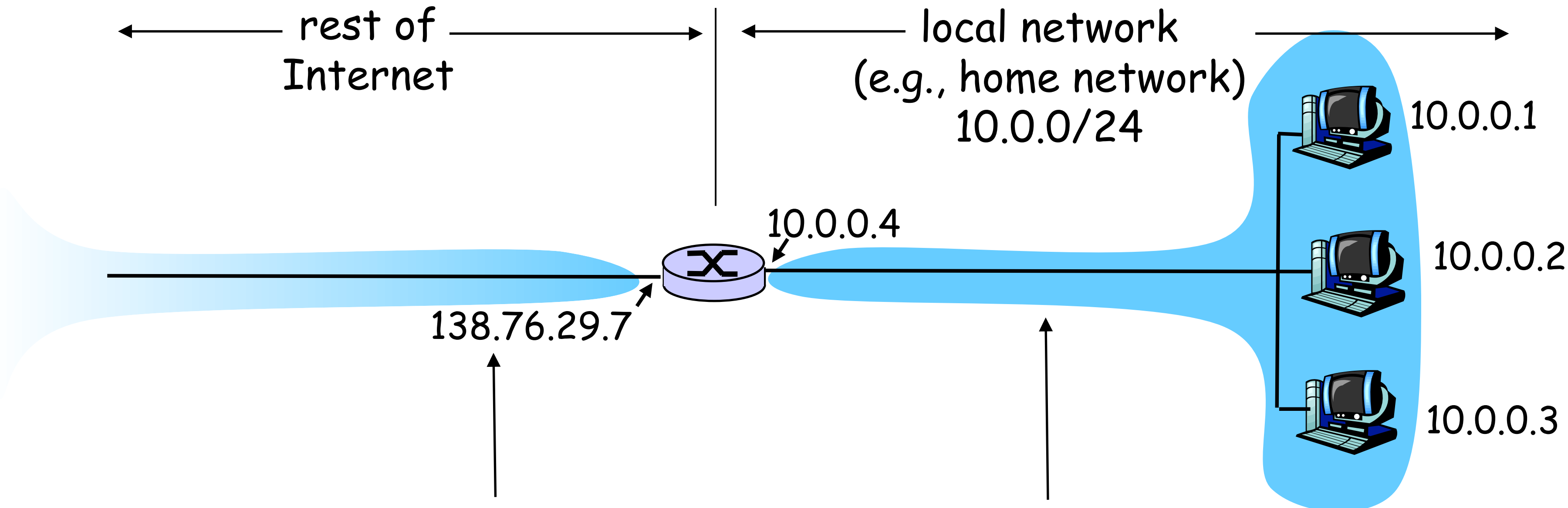
Dest IP: 11001000 00010111 00010110 10100001 Which interface?

Dest IP: 11001000 00010111 00011000 10101010 Which interface?

NAT: Network Address Translation



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 (as usual)

NAT: Network Address Translation

- Motivation: local network uses just one IP address as far as outside word is concerned:
  - no need to be allocated range of addresses from ISP: - just one IP address is used 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 net not explicitly addressable, visible by outside world (a security plus).

NAT: Network Address Translation

- NAT is controversial:
  - routers should only process up to layer 3
  - violates end-to-end argument
    - NAT possibility must be taken into account by app designers, eg, P2P applications
  - address shortage should instead be solved by IPv6

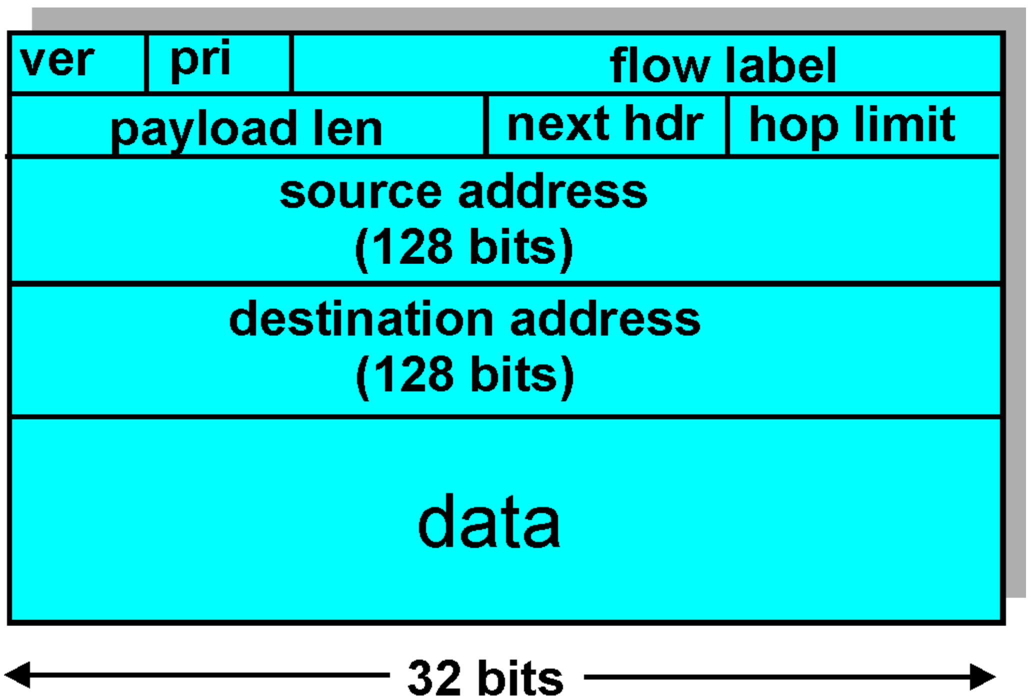
IPv6

- Initial motivation: 32-bit address space soon to be completely allocated.
- 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 (Cont)

Priority: identify priority among datagrams in flow
Flow Label: identify datagrams in same "flow."
(concept of "flow" not well defined).
Next header: identify upper layer protocol for data



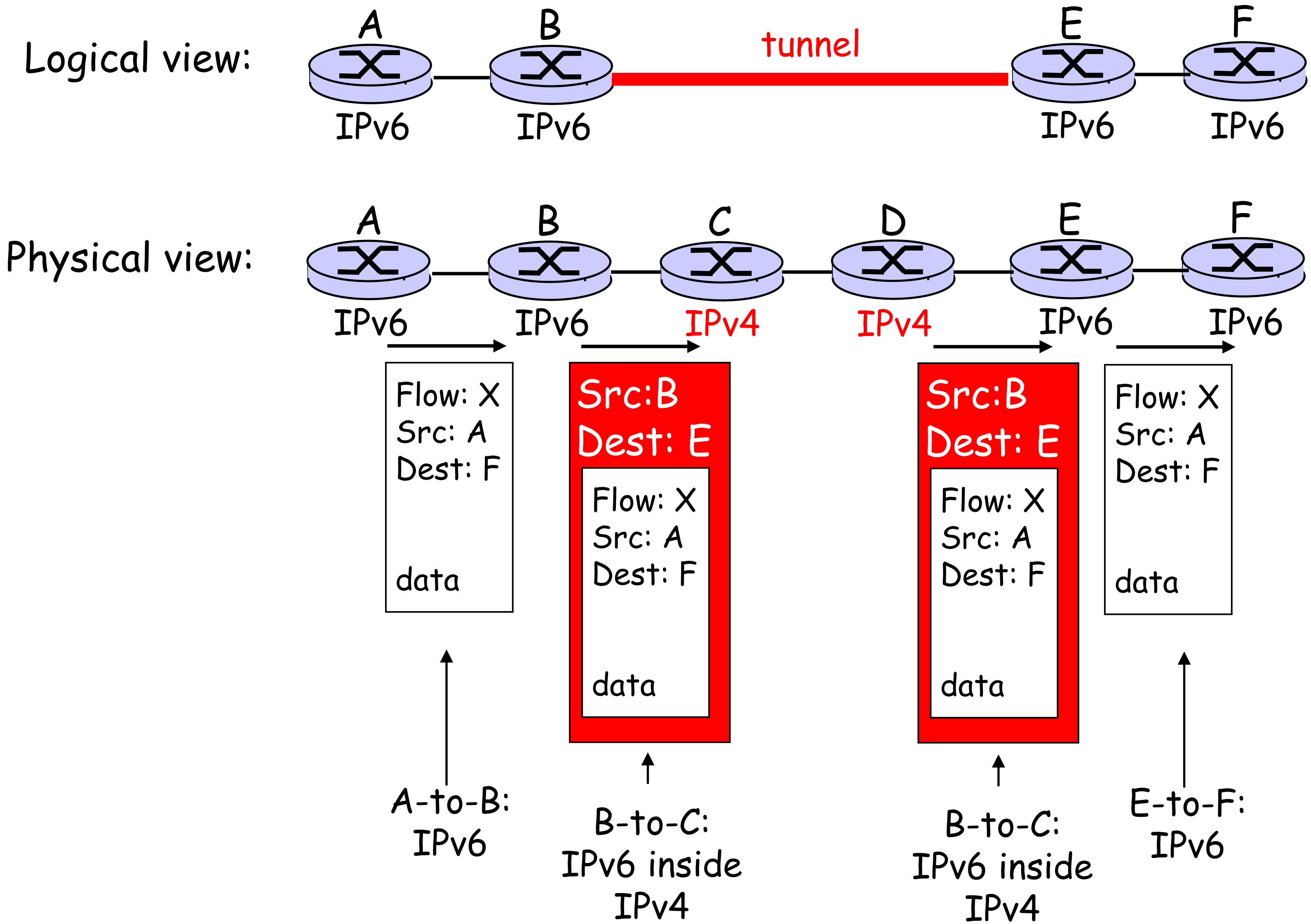
Other Changes from IPv4

- *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

Transition From IPv4 To IPv6

- Not all routers can be upgraded simultaneous
  - no "flag days"
  - How will the network operate with mixed IPv4 and IPv6 routers?
- *Tunneling:* IPv6 carried as payload in IPv4 datagram among IPv4 routers

Tunneling

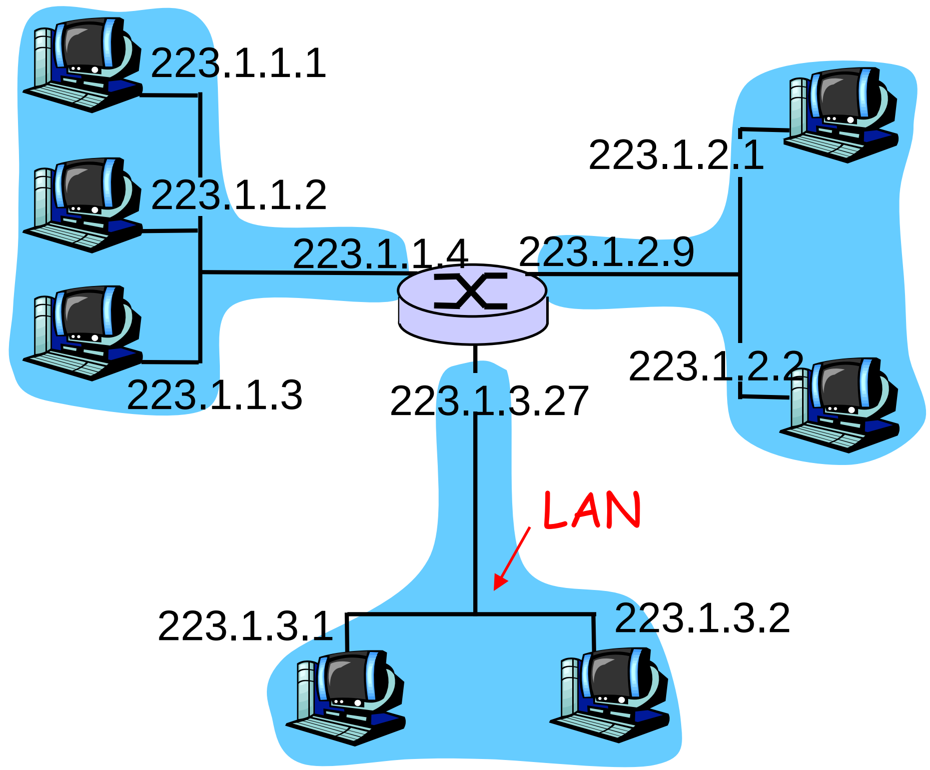


Logical view:
A
B
E
F
tunnel
IPv6
IPv6
IPv6
IPv6
Physical view:
A
B
C
D
E
F
IPv6
IPv6
IPv4
IPv4
IPv6
IPv6
Flow: X
Src: A
Dest: F
data
Src:B
Dest: E
Flow: X
Src: A
Dest: F
data
Src:B
Dest: E
Flow: X
Src: A
Dest: F
data
Flow: X
Src: A
Dest: F
data
A-to-B:
IPv6
B-to-C:
IPv6 inside
IPv4
B-to-C:
IPv6 inside
IPv4
E-to-F:
IPv6

More slides …

Subnets

- IP address:
  - subnet part (high order bits)
  - host part (low order bits)
- *What's a subnet ?*
  - device interfaces with same subnet part of IP address
  - can physically reach each other without intervening router



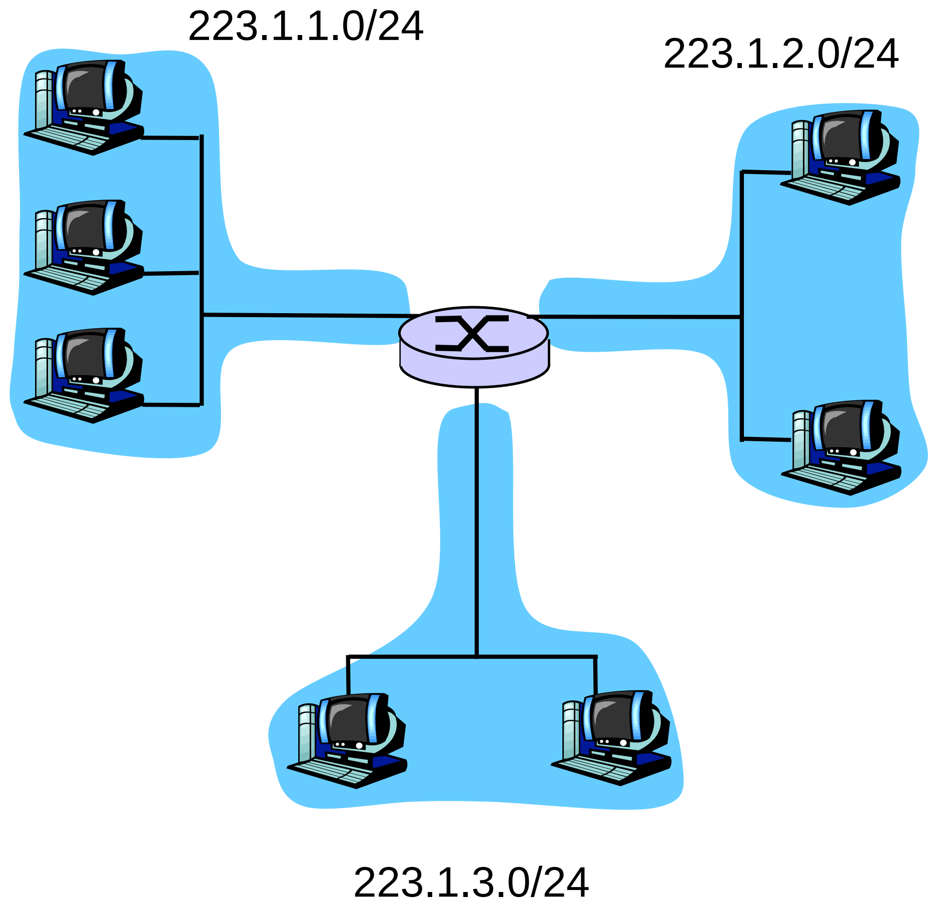
network consisting of 3 subnets

Subnets

Recipe

To determine the subnets:

- Detach each interface from its host or router, creating islands of isolated networks.
- Each isolated network is called a subnet.



Subnet mask: /24

Subnets

How many?