THE NETWORK LAYER & IP ADDRESSING

COMP 30650: NETWORKS AND INTERNET SYSTEMS

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RECAP

Switched Ethernet

- Hubs
- Switches
- Backwards Learning
  - Lookup table
- Spanning Trees
  - Circular reference problem
- Motivation for Network Layer

TODAY'S PLAN

The Network Layer

- Routing V Forwarding

Store and Forward

- Datagram Service
- Internet Protocol
- Virtual Packet Switching
- Internetworking
- IP Address format

GOALS OF NETWORK LAYER

We want the network layer to:

- Scale to large networks
  - Using addresses with hierarchy
- Support diverse technologies
  - Internetworking with IP
- Use link bandwidth well
  - Lowest-cost routing

What kind of service does the Network Layer provide to the Transport layer?

- How is it implemented at routers?
  - Routers are the devices that operate at the Network Layer – they join networks together.

ROUTING VS. FORWARDING

Routing is the process of deciding in which direction to send traffic

- Network wide (global) and expensive

Forwarding is the process of sending a packet on its way

- Node process (local) and fast

TOPIC

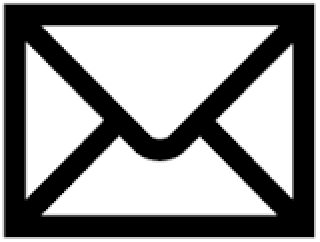
What kind of service does the Network Layer provide to the Transport layer?

- How is it implemented at routers?

TWO NETWORK SERVICE MODELS

Datagrams, or connectionless service

- Like postal letters
- (This one is IP)



Virtual circuits, or connection-oriented service

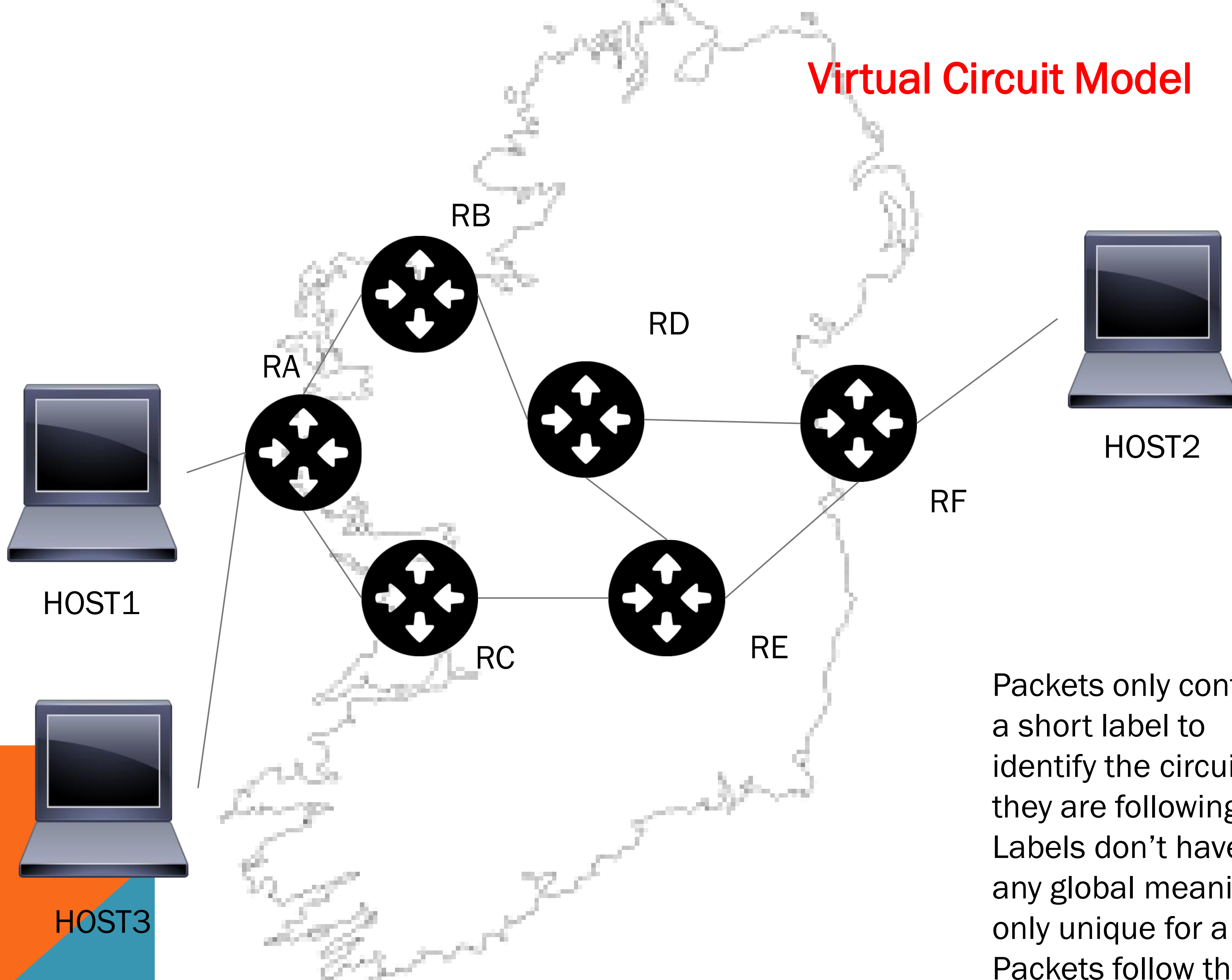
- Like a telephone call

STORE-AND-FORWARD PACKET SWITCHING

Both models are implemented with store-and-forward packet switching

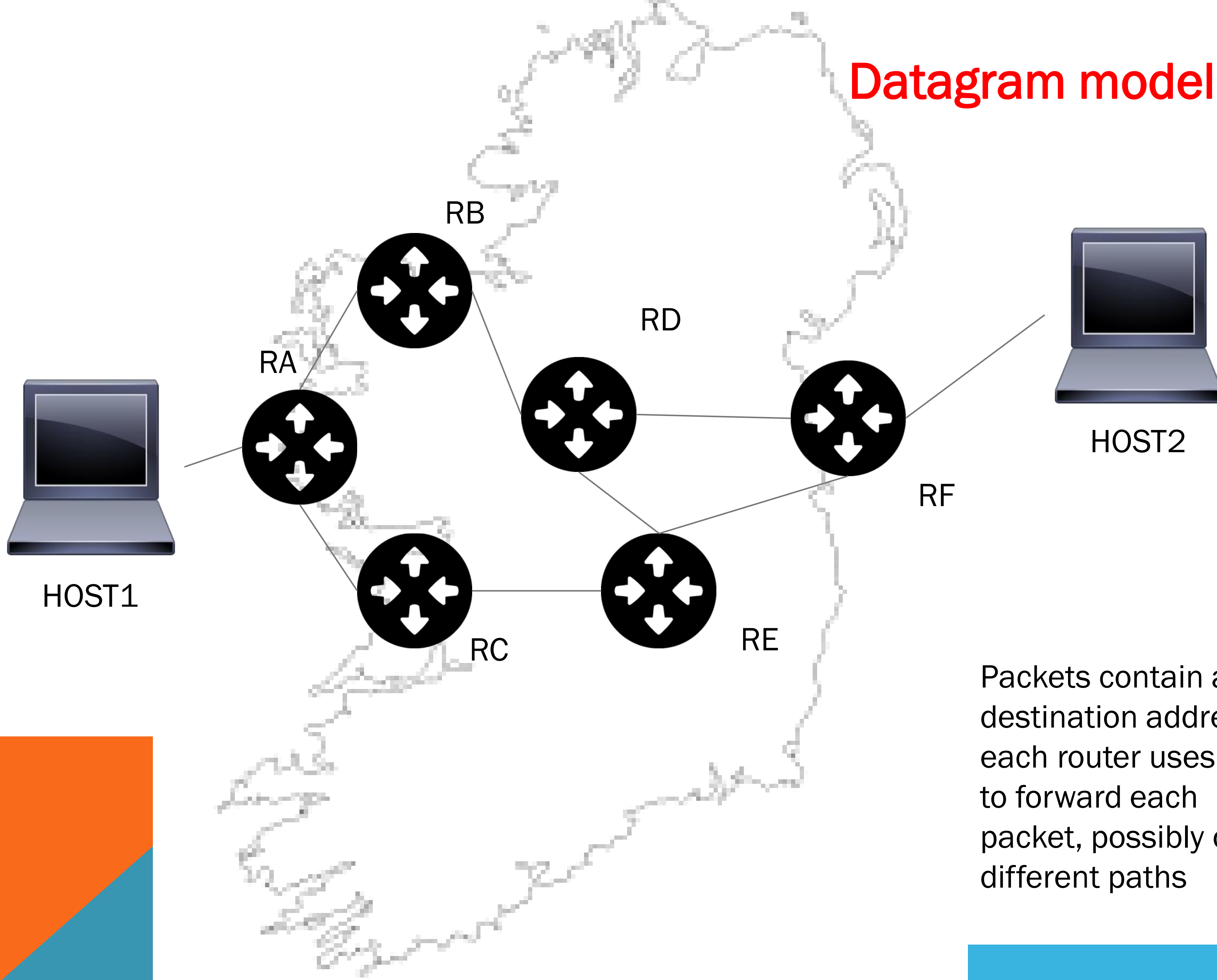
- Routers receive a complete packet, storing it temporarily if necessary before forwarding it onwards

Virtual Circuit Model



Packets only contain a short label to identify the circuit they are following
Labels don't have any global meaning, only unique for a link
Packets follow the same route

Datagram model



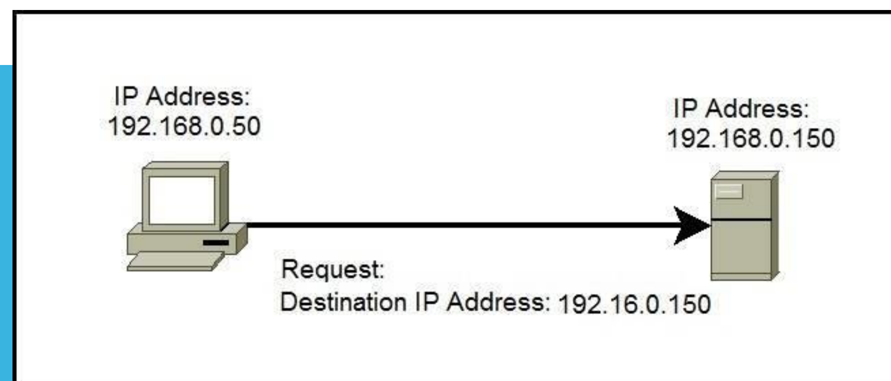
Packets contain a destination address; each router uses it to forward each packet, possibly on different paths

DATAGRAM MODEL

Each router has a forwarding table keyed by destination

Gives next hop for each destination address; may change

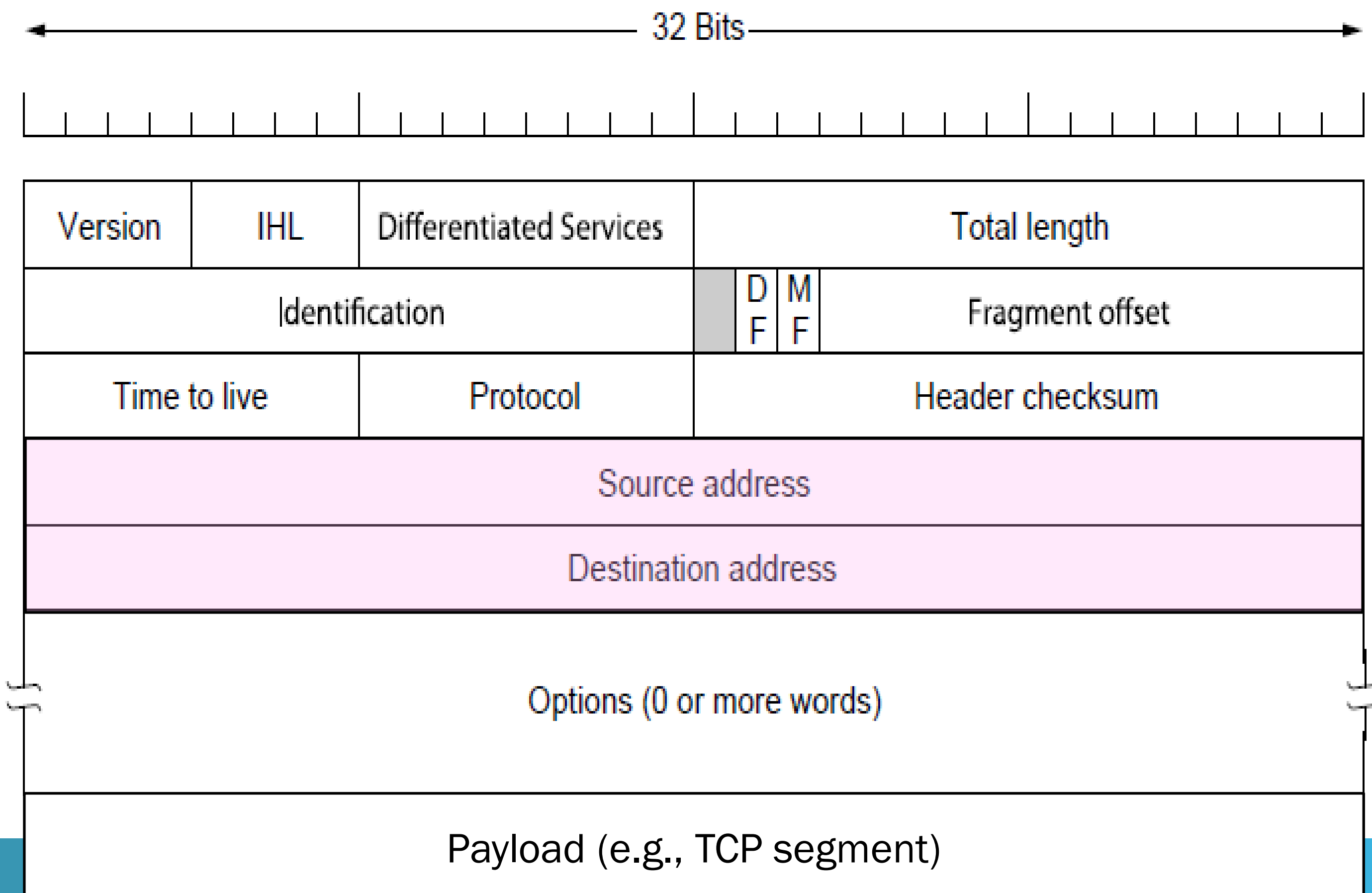
Dest.	A's table (initially) Line	A's table (later) Line	C's Table Line	E's Table Line
A			A	C
B	B	B	A	D
C	C	C		C
D	B	B	E	D
E	C	D	E	
F	C	D	E	F



IP (INTERNET PROTOCOL)

Network layer of the Internet, uses datagrams

- IPv4 carries 32 bit addresses on each packet (often 1.5 KB)



INTERNETWORKING

How do we connect different networks together?

- This is called internetworking.
- We’ll look at how IP (Internet Protocol) achieves it.

How are networks different?

- Service model (Datagrams, VCs)
- Addressing (what kind)
- Quality Of Service (priorities, no priorities)
- Packet sizes
- Security (whether encrypted)

Internetworking hides the differences with a common protocol.

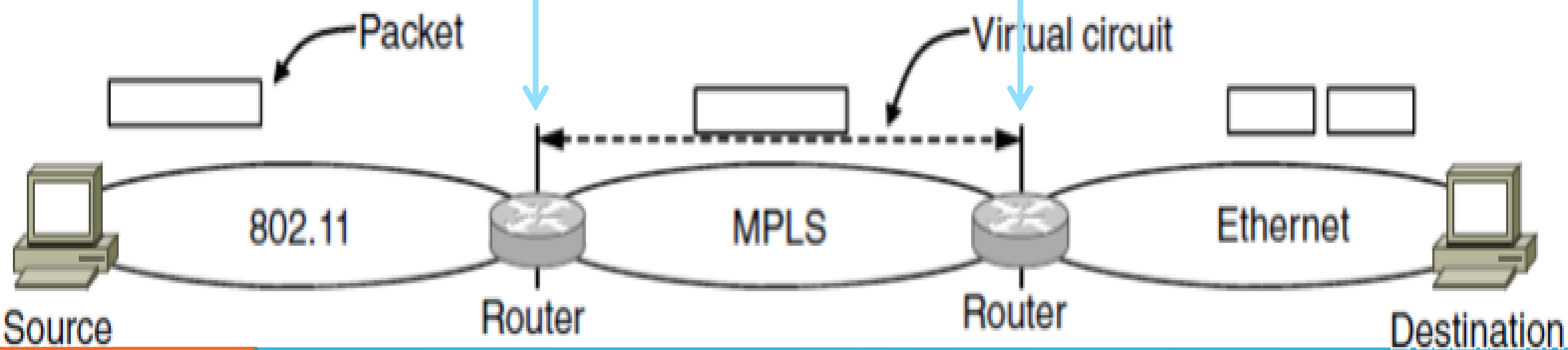
CONNECTING DATAGRAM AND VC NETWORKS

An example to show that it's not so easy

- Need to map destination address to a VC and vice-versa
- A bit of a "road bump", e.g., might have to set up a VC

Complexity!

Complexity!



Datagram Network

Virtual circuit

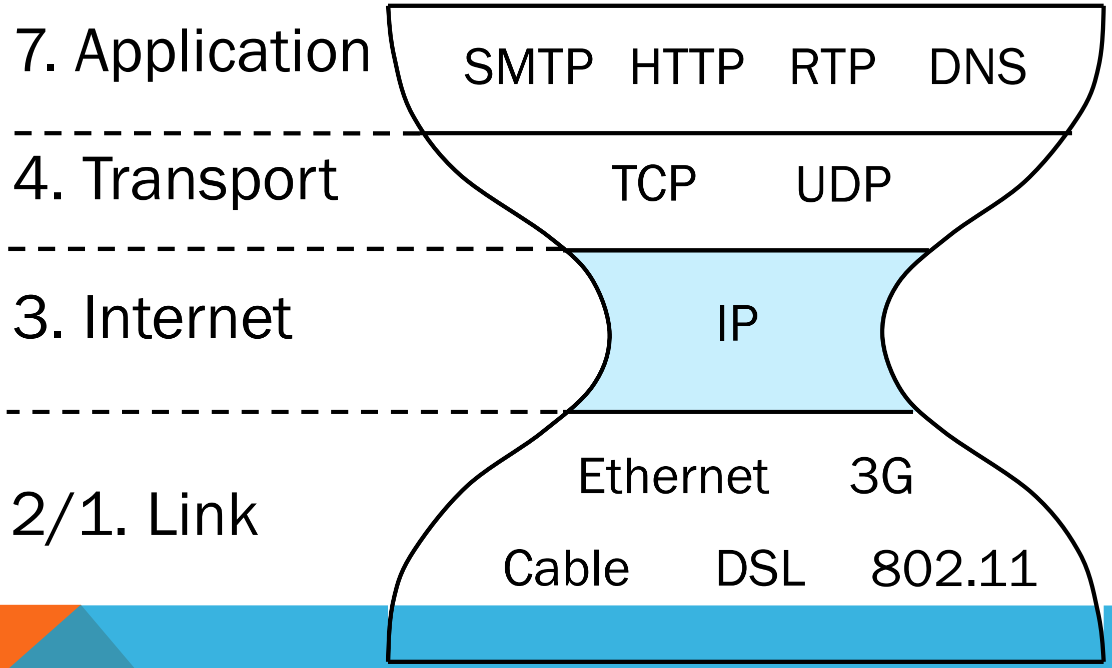
Multiprotocol Label Switching

Datagram Network

INTERNET REFERENCE MODEL

IP is the “narrow waist” of the Internet

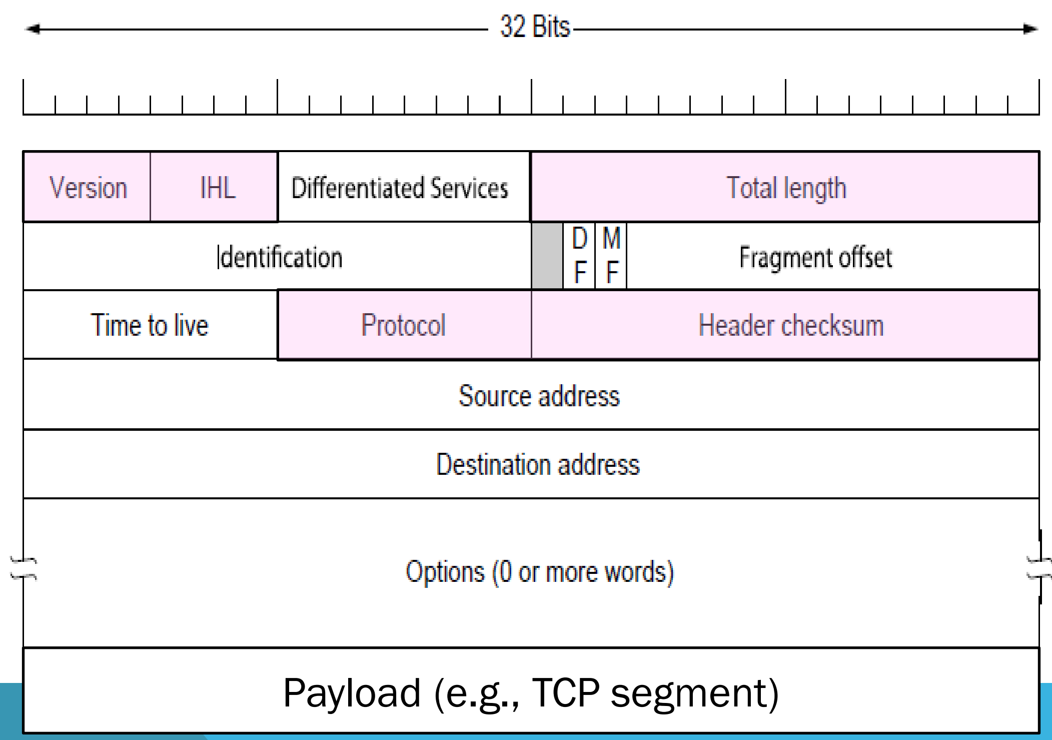
- Supports many different links below and apps above



IPV4 (INTERNET PROTOCOL)

Various fields to meet straightforward needs

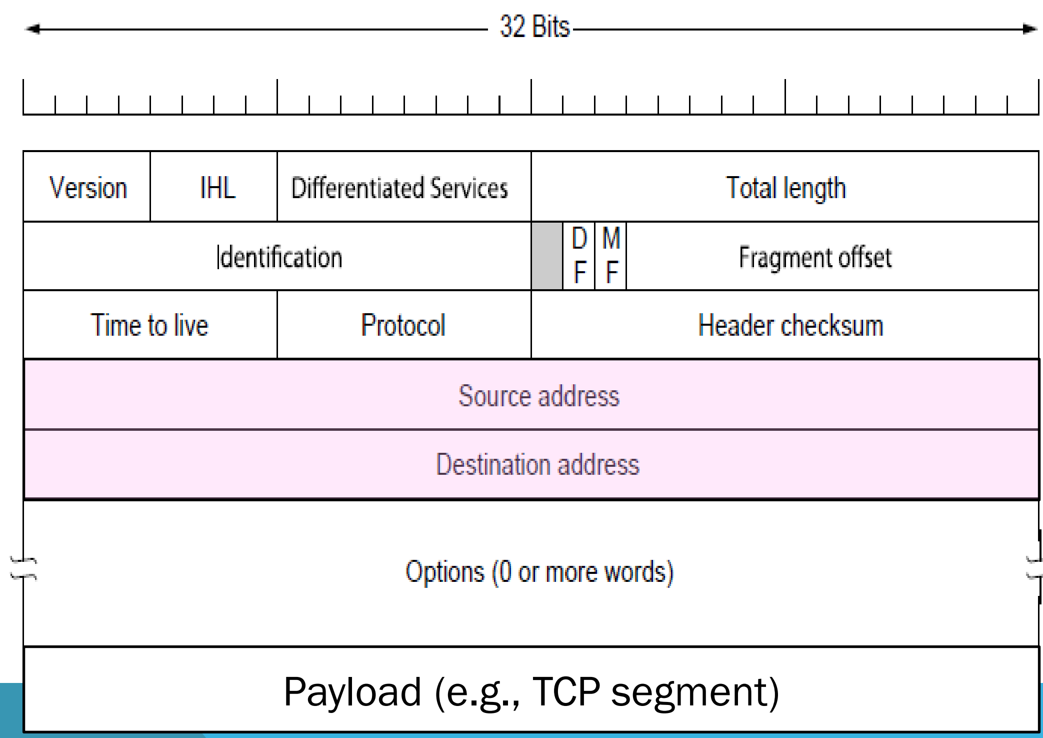
- Version, Header (IHL) and Total length, Protocol (of payload), and Header Checksum to protect header data against corruption/errors



IPV4

Network layer of the Internet, uses datagrams

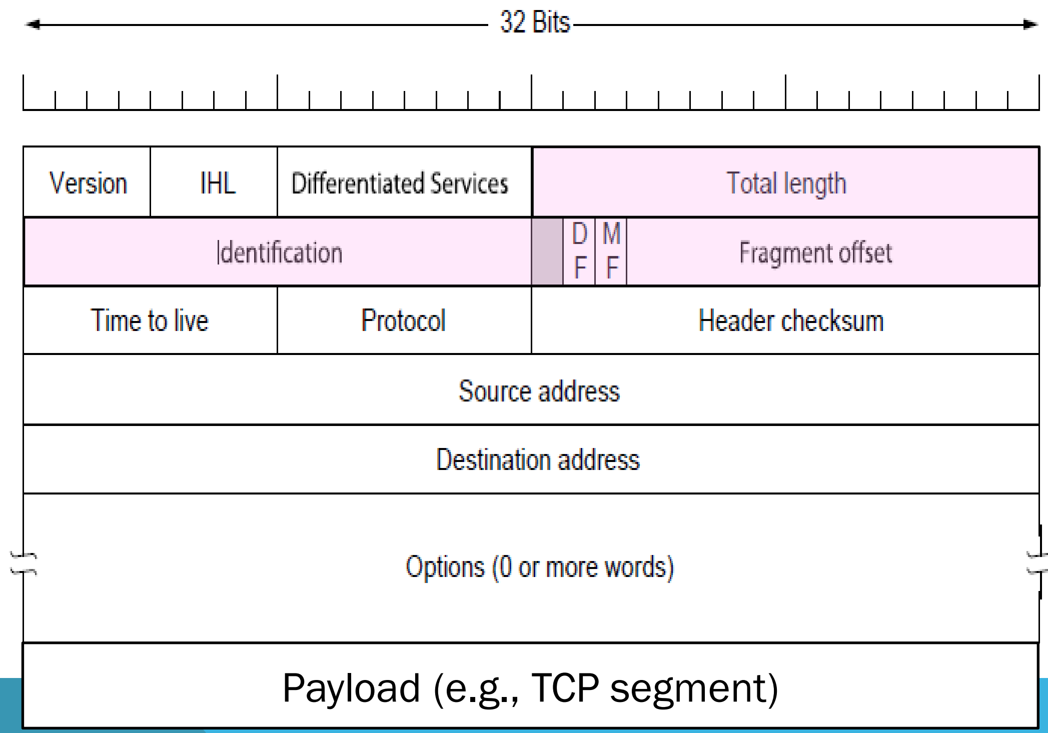
- Provides a layer of addressing above link addresses
  - IP Address



IPV4

Some fields to handle packet size differences

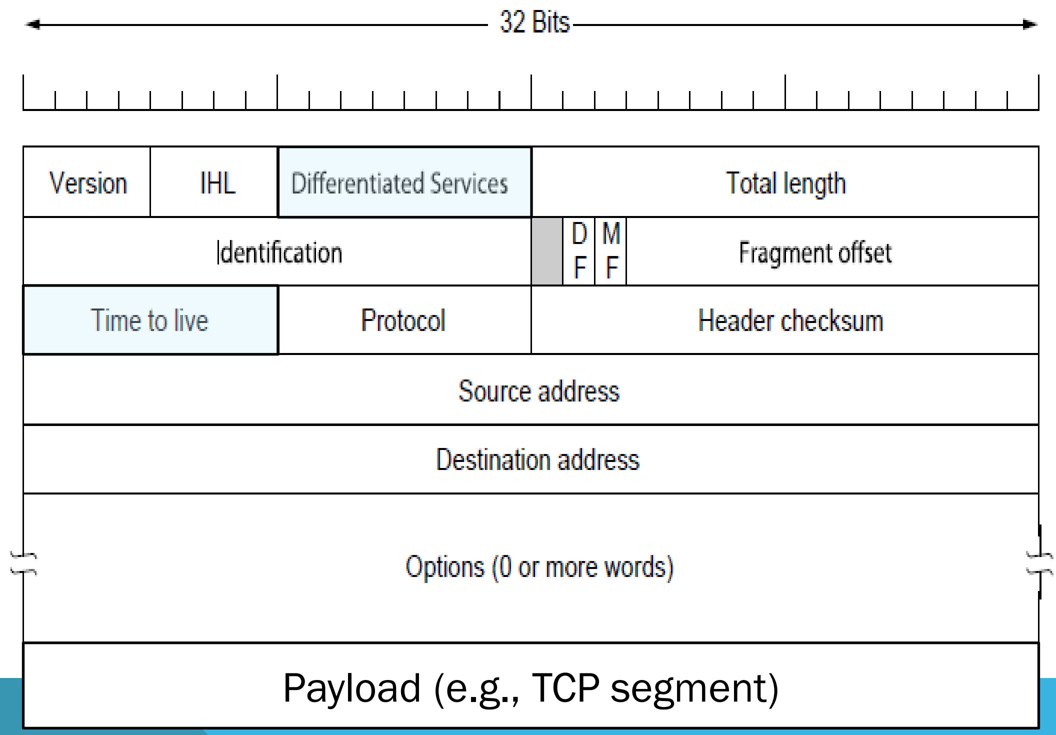
- Identification, Fragment offset, Fragment control bits



IPV4

Other fields to meet other needs

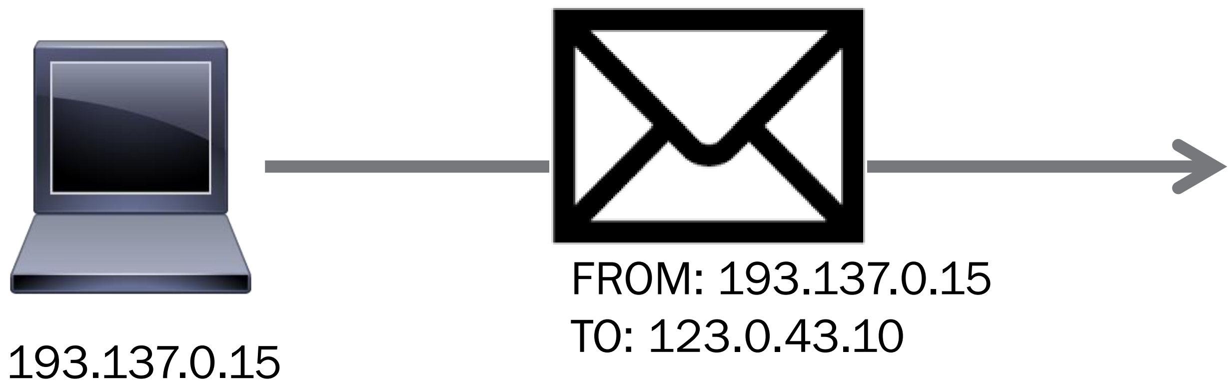
- Differentiated Services, Time to live (TTL)



ADDRESSING AT NETWORK LAYER

What do IP addresses look like?

- And IP prefixes, or blocks of addresses



IP ADDRESSES

IPv4 uses 32-bit addresses

- IPv6 - uses 128-bit addresses – see this soon

Written in “dotted quad” notation

- Four 8-bit numbers separated by dots

$$\overbrace{\texttt{aaaaaaaa}}^{\text{8 bits}}\overbrace{\texttt{bbbbbbbb}}^{\text{8 bits}}\overbrace{\texttt{cccccccc}}^{\text{8 bits}}\overbrace{\texttt{dddddddd}}^{\text{8 bits}} \leftrightarrow \texttt{A.B.C.D}$$

00010010 | 00011111 | 00000000 | 00000001 ↔

IP ADDRESSES

IPv4 uses 32-bit addresses

- IPv6 uses 128-bit addresses

Written in "dotted quad" notation

- Four 8-bit numbers separated by dots

8 bits 8 bits 8 bits 8 bits

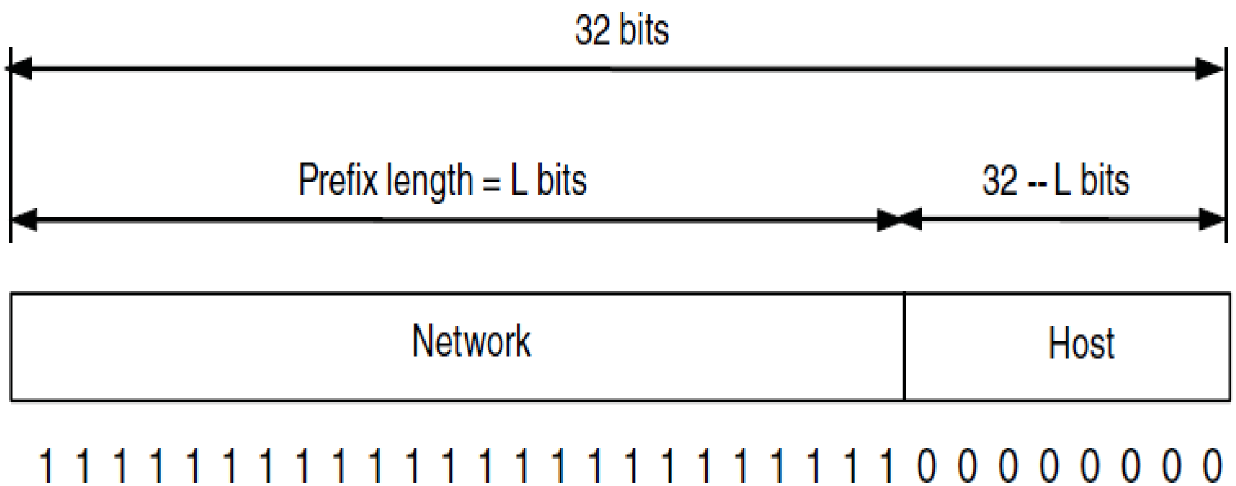
`aaaaaaaabbbbbbbbccccccccdddddddd` ↔ `A.B.C.D`

`00010010|00011111|00000000|00000001` ↔ 18.31.0.1

IP PREFIXES

Addresses are allocated in blocks called <u>prefixes</u>

- Addresses in an L-bit prefix have the same top L bits
- There are 2^{32-L} addresses aligned on 2^{32-L} boundary



IP PREFIXES

Written in “IP address/length” notation

- Address is lowest address in the prefix, length is prefix bits
- E.g., 128.13.0.0/16 is 128.13.0.0 to 128.13.255.255
- So a /24 (“slash 24”) is 256 addresses, and a /32 is one address

00010010000111110000000xxxxxxxx

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`00010010|00011111|00000000|xxxxxxxx` ↔ **18.31.0.0/24**

`| | |` ↔ `128.13.0.0/16`

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`00010010 | 00011111 | 00000000 | xxxxxxxx` ↔ **18.31.0.0/24**

`10000000 | 00001101 | xxxxxxxx | xxxxxxxx` ↔ `128.13.0.0/16`

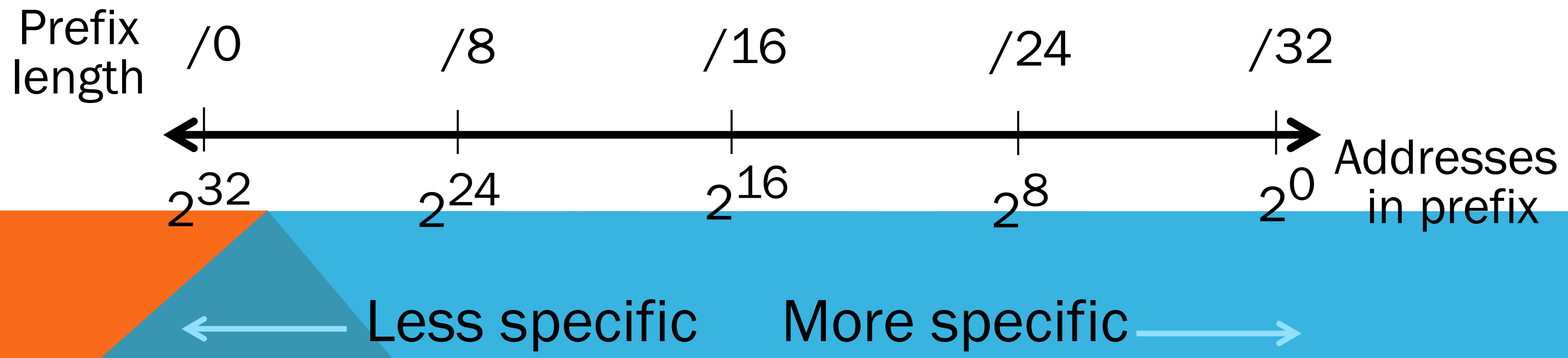
IP PREFIXES

More specific prefix

- Has longer prefix, hence a smaller number of IP addresses

Less specific prefix

- Has shorter prefix, hence a larger number of IP addresses



SUBNET MASKS

A subnet mask is a number that defines a range of IP addresses available within a network. A single subnet mask limits the number of valid IPs for a specific network

Ip Address 18.31.0.0 **Subnet Mask** 255.255.255.0

- In the example above, the first three sections are full (255 out of 255), meaning the IP addresses of devices within the subnet mask must be identical in the first three sections
- Allows 256 unique IP addresses in the network

255.255.**0.0**. allows up to 65,536 (256 X 256) addresses

PUBLIC / PRIVATE IP ADDRESSES

Public IP addresses, e.g., 18.31.0.1

- Valid destination on the global Internet
- Must be allocated to you before use
- Mostly exhausted …so we are using IPv6

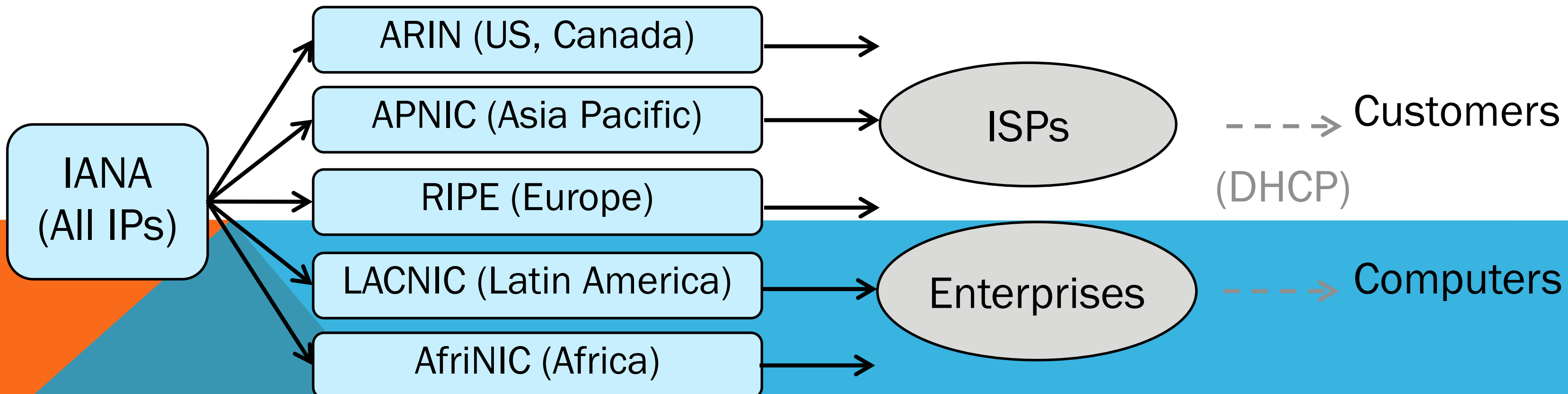
Private IP addresses

- Can be used freely within private networks (home, small company)
  - 10.0.0.0/8, 172.16.0.0/12, 192.168.0.0/16
  - Need public IP address(es) and NAT to connect to global Internet
    - Network Address Translation

ALLOCATING PUBLIC IP ADDRESSES

Follows a hierarchical process

- IANA delegates to regional bodies (RIRs)
  - Internet Assigned Numbers Authority (IANA)
- RIRs delegate to companies in their region
  - Regional Internet Registries
- Companies assign to their customers/computers (later, DHCP)



IP FORWARDING

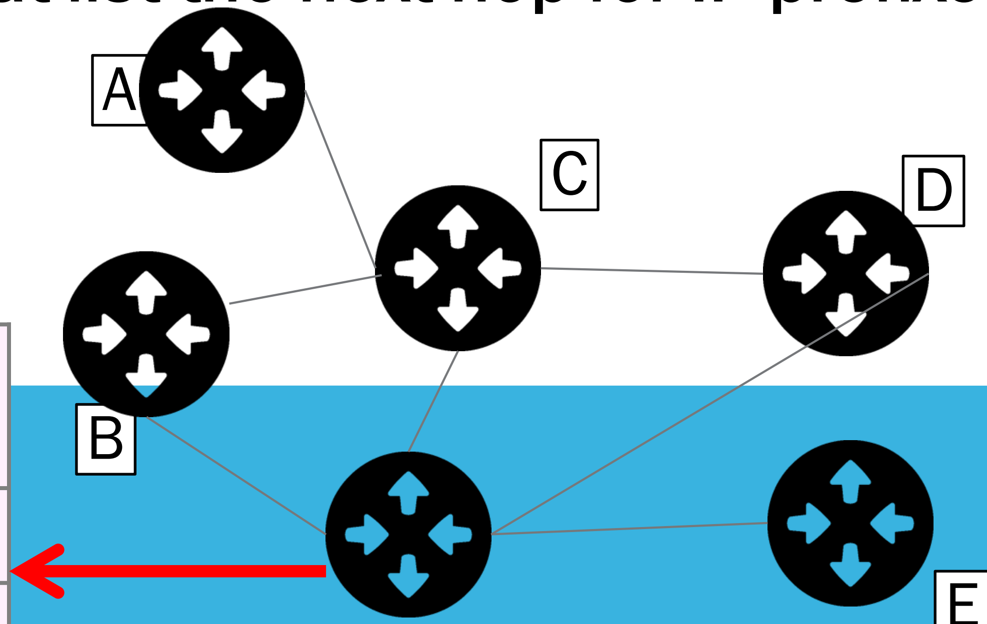
<u>Forwarding</u> is the process of sending a packet on its way

IP addresses on one network belong to the same prefix

- Forwarding table has one entry for whole prefix

Nodes use tables that list the next hop for IP prefixes

Prefix	Next Hop
192.24.0.0/18	D
192.24.12.0/22	B



LONGEST MATCHING PREFIX

Prefixes in the table might overlap!

- Combines hierarchy with flexibility

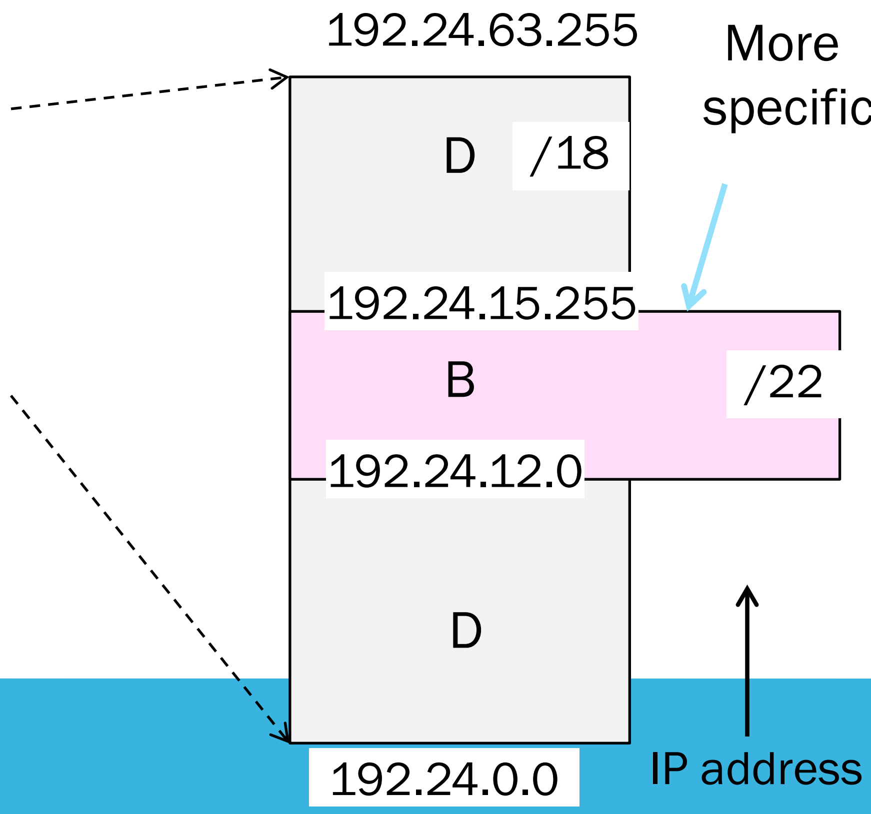
<u>Longest matching prefix</u> forwarding rule:

- For each packet, find the longest prefix that contains the destination address, i.e., the most specific entry
- Forward the packet to the next hop router for that prefix

LONGEST MATCHING PREFIX

Prefix	Next Hop
192.24.0.0/18	D
192.24.12.0/22	B

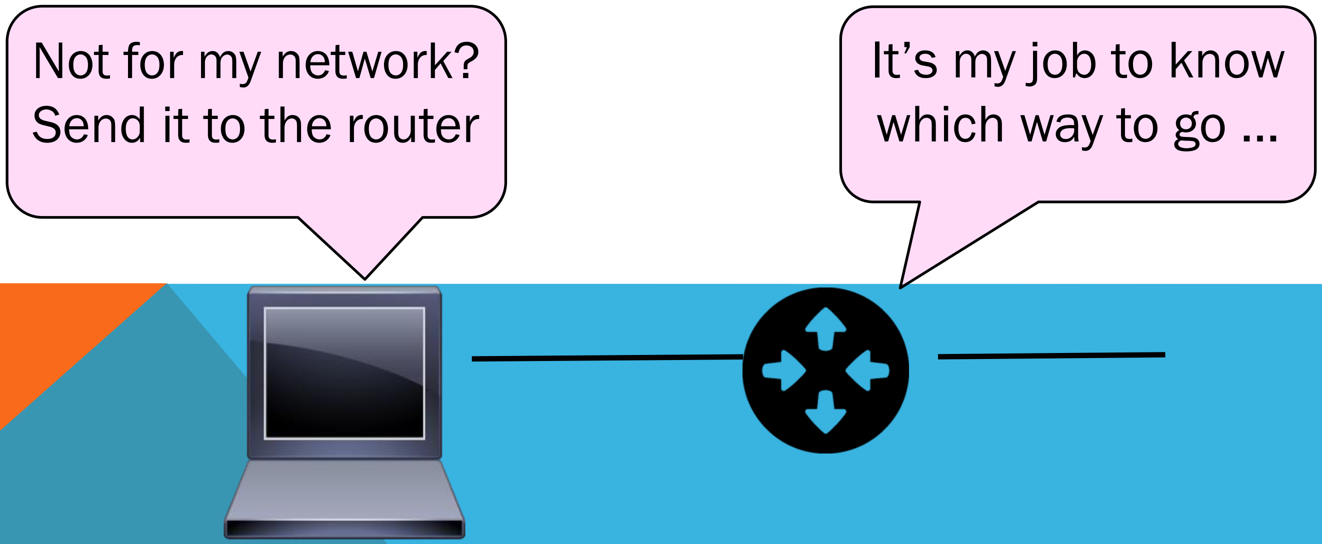
192.24.6.0 →
192.24.14.32 →
192.24.54.0 →



HOST/ROUTER DISTINCTION

In the Internet:

- Routers do the routing, know which way to all destinations
- Hosts send remote traffic (out of prefix) to nearest router



HOST FORWARDING TABLE

Give using longest matching prefix

- 0.0.0.0/0 is a default route that catches all IP addresses

Prefix	Next Hop
My network prefix	Send direct to that IP
0.0.0.0/0	Send to my router

FLEXIBILITY OF LONGEST MATCHING PREFIX

Can provide default behavior, with less specific prefixes

- To send traffic going outside an organization to a border router

Can have special case behavior, with more specific prefixes

- For performance, economics, security, …

PERFORMANCE OF LONGEST MATCHING PREFIX

Uses hierarchy for a compact table

- Benefits from less specific prefixes

Lookup more complex than table

- Was a concern for slow routers, but not an issue in practice these days