NETWORKING FUNDAMENTALS

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Module 1
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UC San Diego

ATTRIBUTION

- These slides incorporate material from:
  - Alex C. Snoeren, UC San Diego
  - Michael Freedman and Kyle Jamieson, Princeton University
  - Internet Society
  - Computer Networking: A Top Down Approach

UC San Diego

Outline

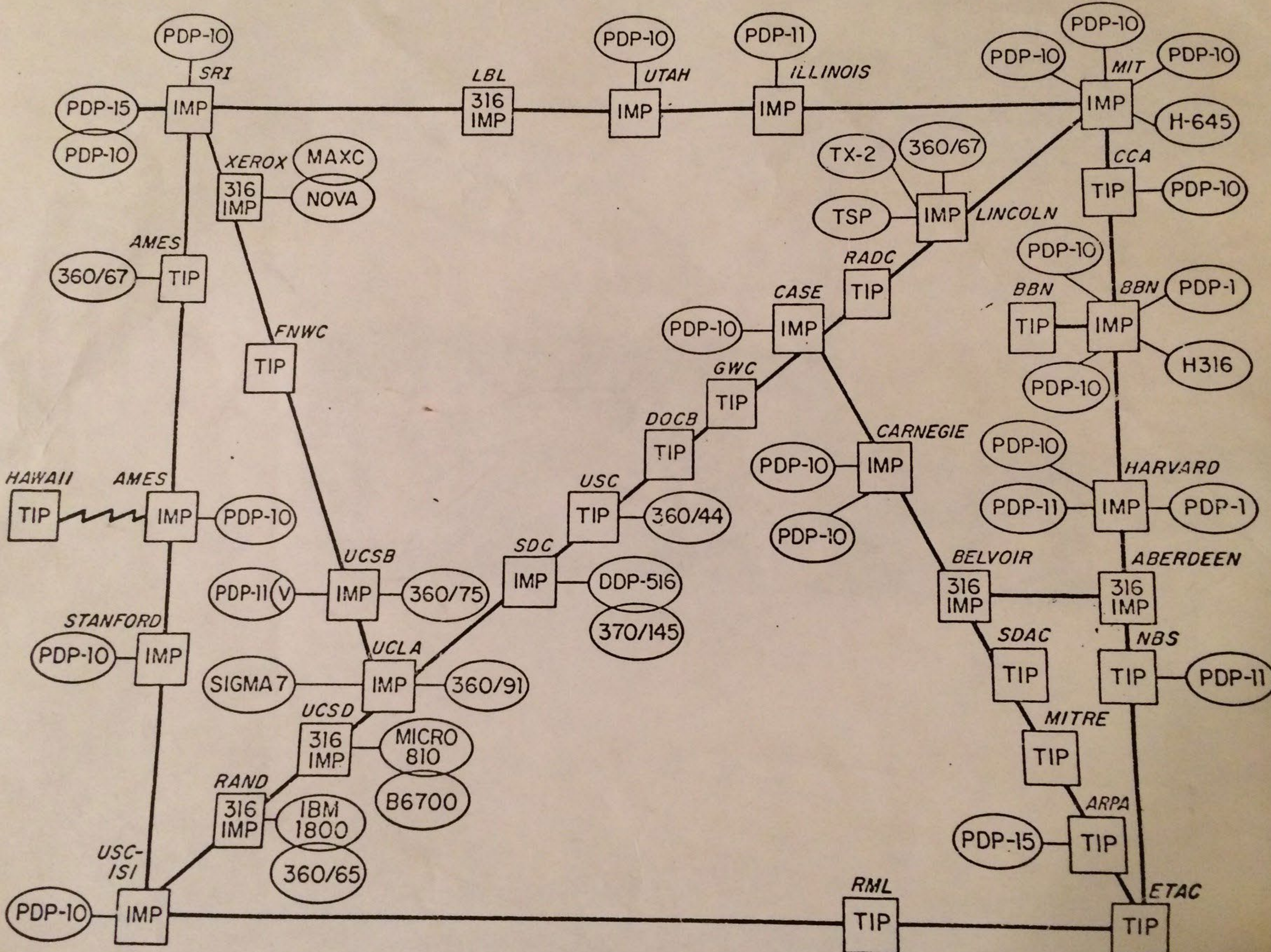
1. Packet switching
2. Addressing

BRIEF HISTORY OF THE INTERNET

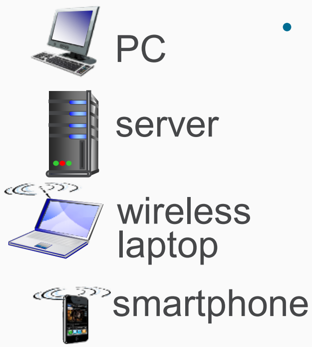
- 1968 - DARPA (Defense Advanced Research Projects Agency) contracts with BBN (Bolt, Beranek & Newman) to create ARPAnet
- 1970 - First five nodes:
  - UCLA
  - Stanford
  - UC Santa Barbara
  - U of Utah, and
  - BBN
- 1974 - TCP specification by Vint Cerf
- 1984 – On January 1, the Internet with its 1000 hosts converts en masse to using TCP/IP for its messaging

Data from the Internet Society

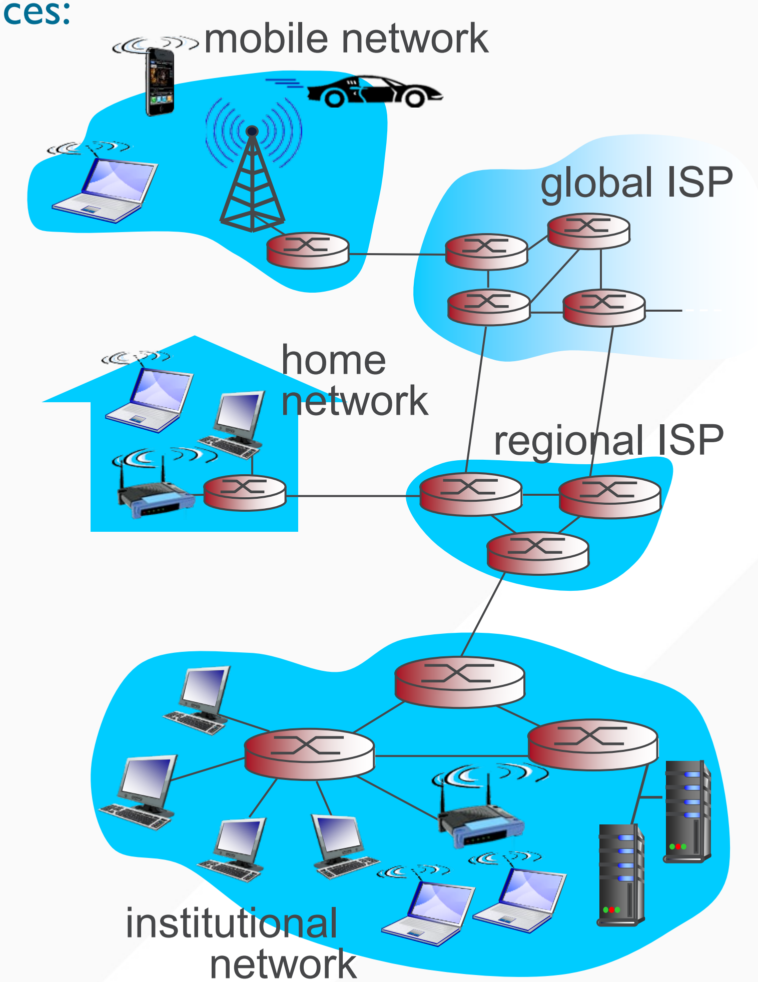
ARPA NETWORK, LOGICAL MAP, MAY 1973

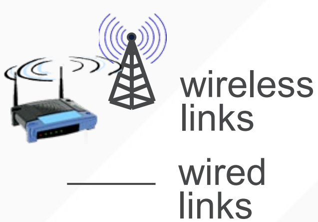


AN INTER-NETWORK

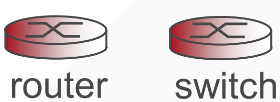


- billions of connected computing devices:
  - *hosts = end systems*
  - running *network apps*





- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: *bandwidth*

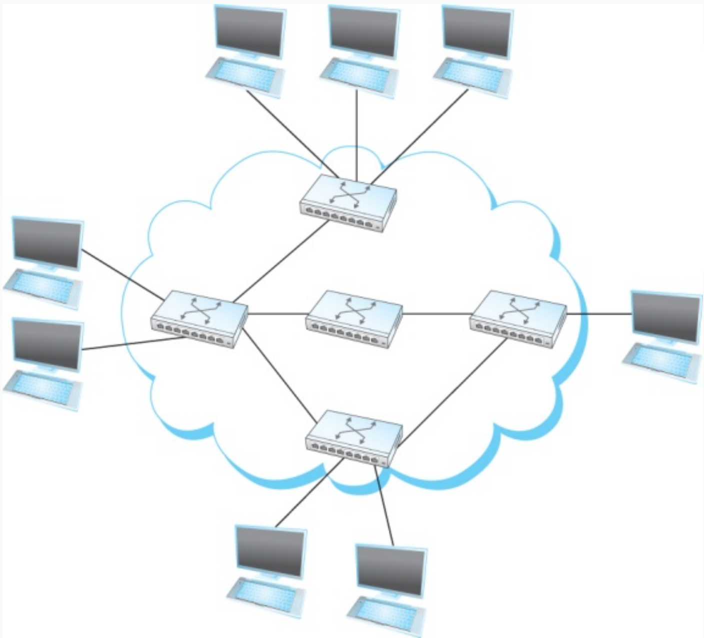


- *Packet switches:* forward packets (chunks of data)
  - *routers* and *switches*

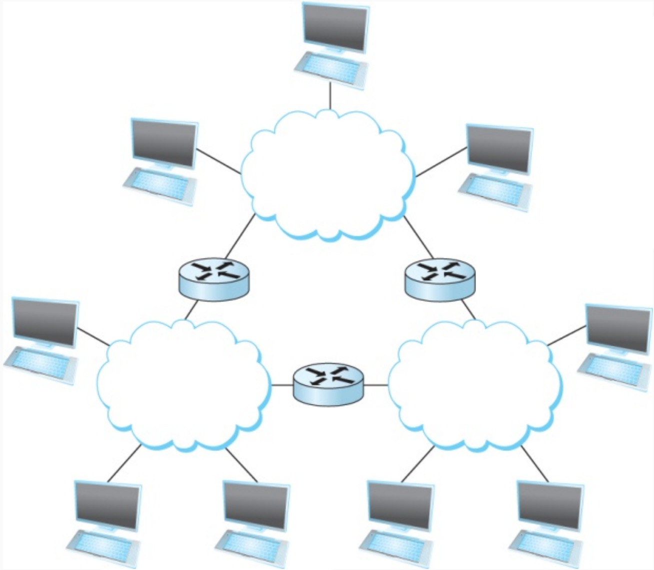
PACKET SWITCHING

- Data transmitted from source to destination in discrete *packets*
  - Variable size, usually a maximum transmission unit (MTU) of ~1500 bytes
  - 1 GB file is approx 715,000 packets
- Each packet routed independently
  - Has its own source and destination *address* used to find the route to the ultimate destination

NETWORK TERMINOLOGY

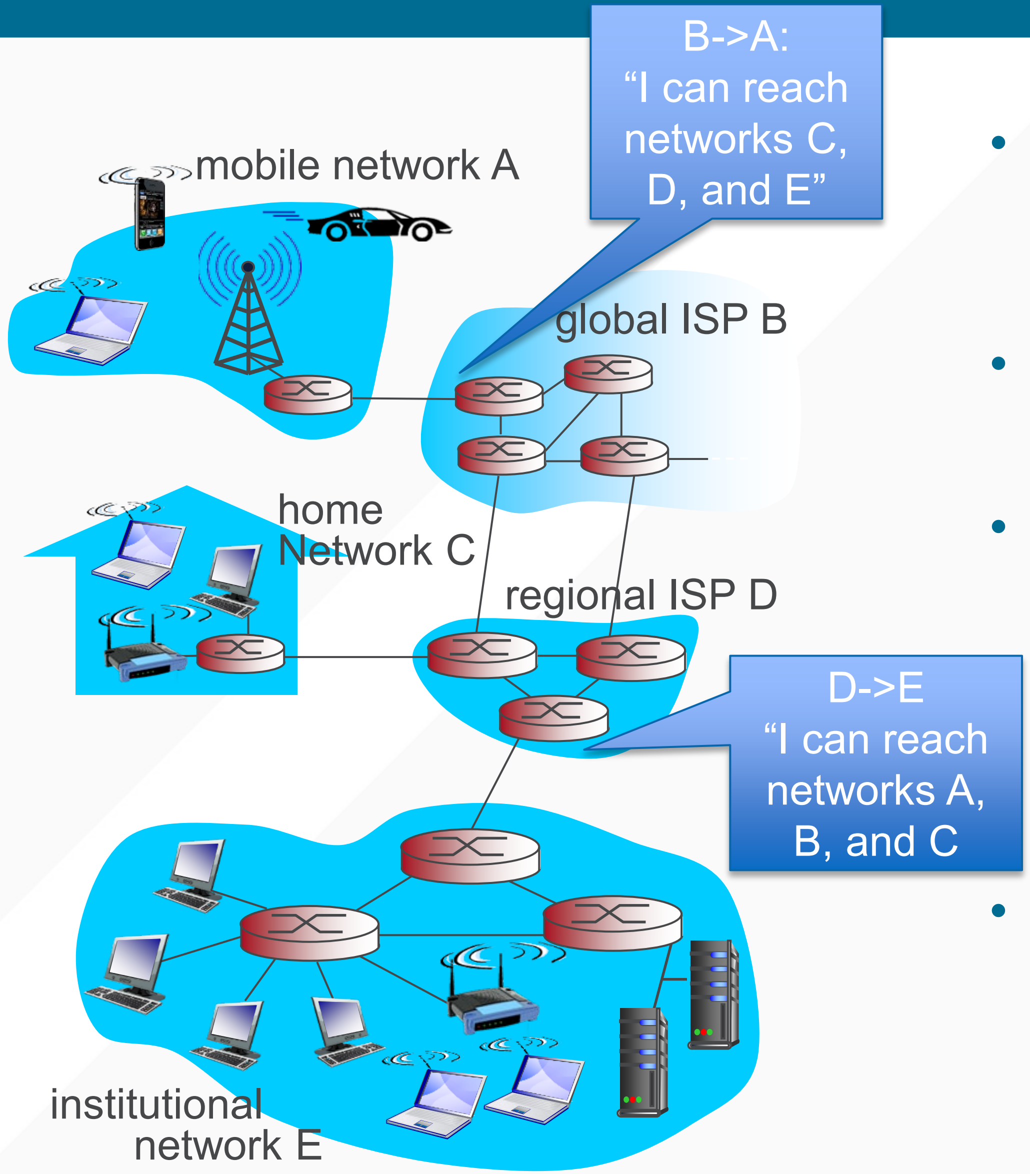


A single packet-switched network

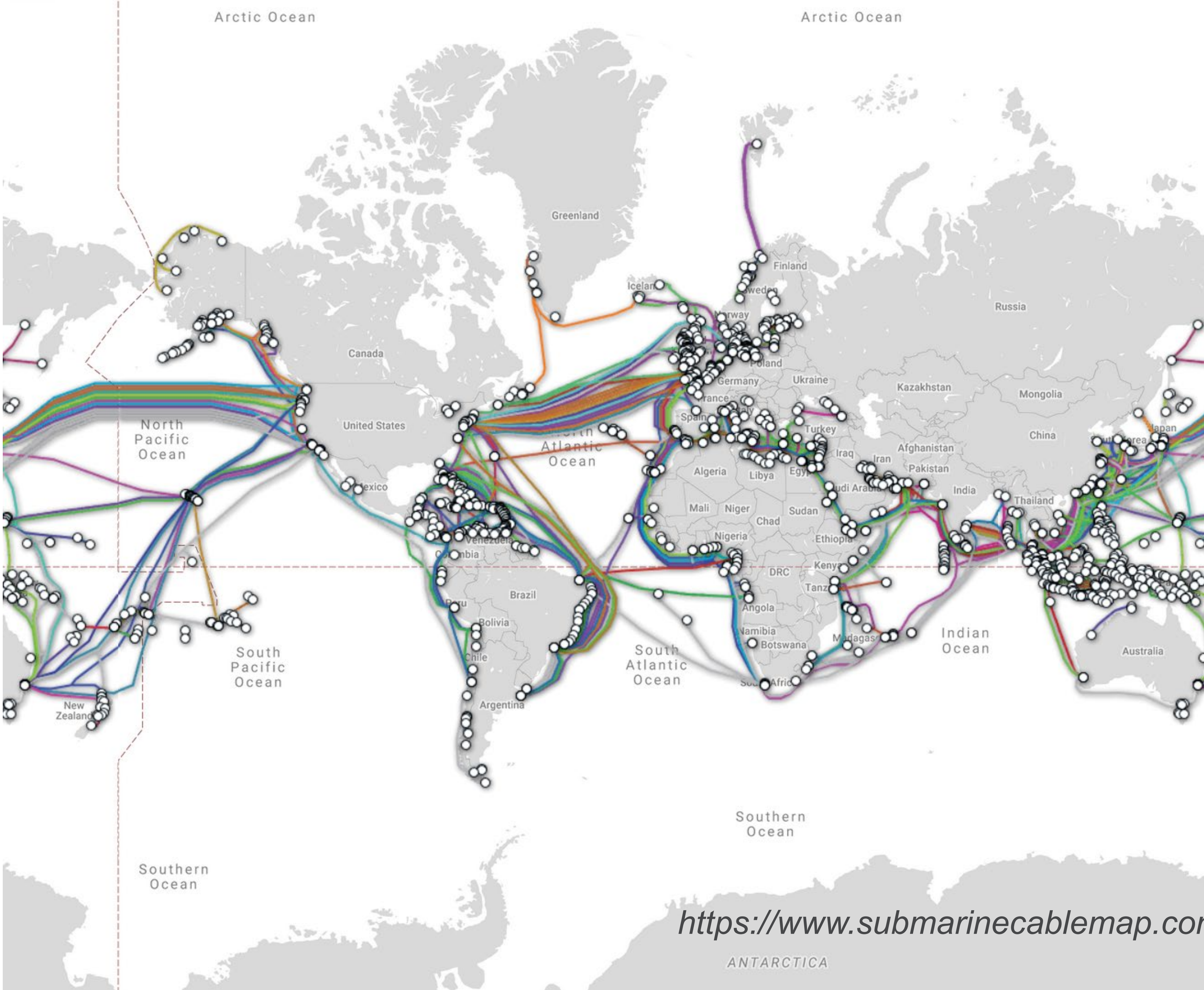


Interconnection of networks

ROUTING PACKETS BETWEEN NETWORKS



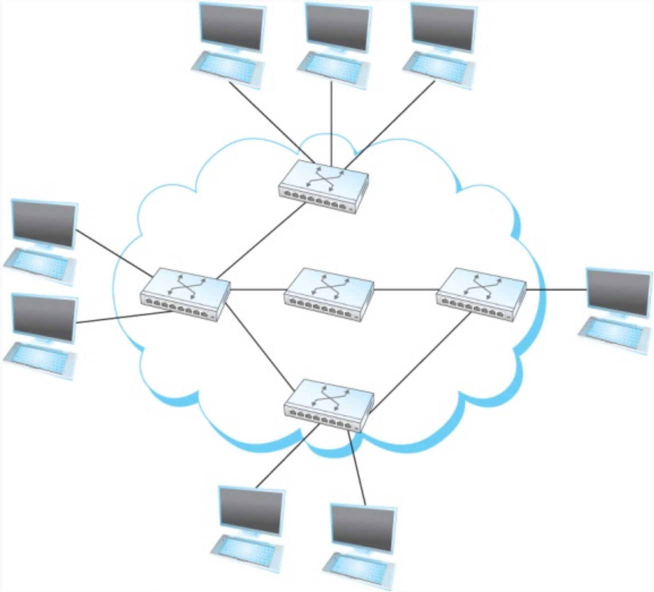
- Networks use *Border Gateway Protocol (BGP)* to announce reachability
- Each network talks just with its neighbors
- Goal is to get a packet to the destination network
  - It is up to that destination network to get individual packets to their ultimate destination
- Back-to-back packets from the same “connection” might take different paths!
  - Might arrive out of order too



https://www.submarinecablemap.com/

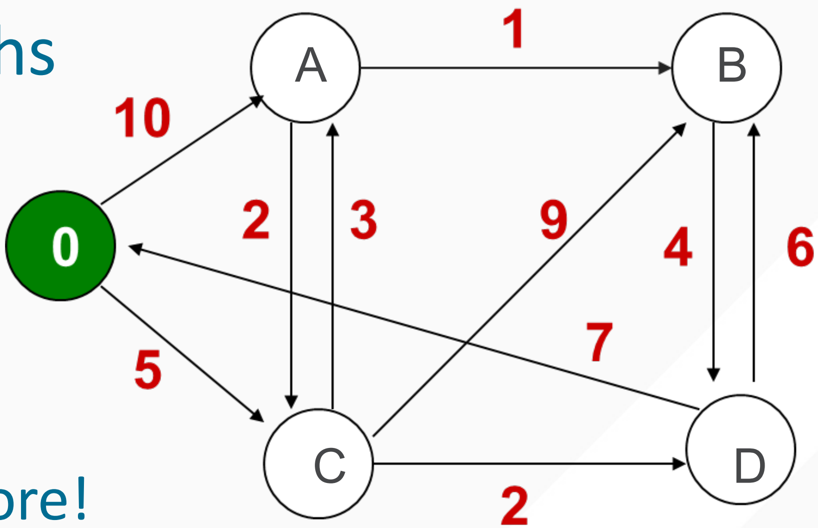
ROUTING PACKETS WITHIN A SINGLE NETWORK

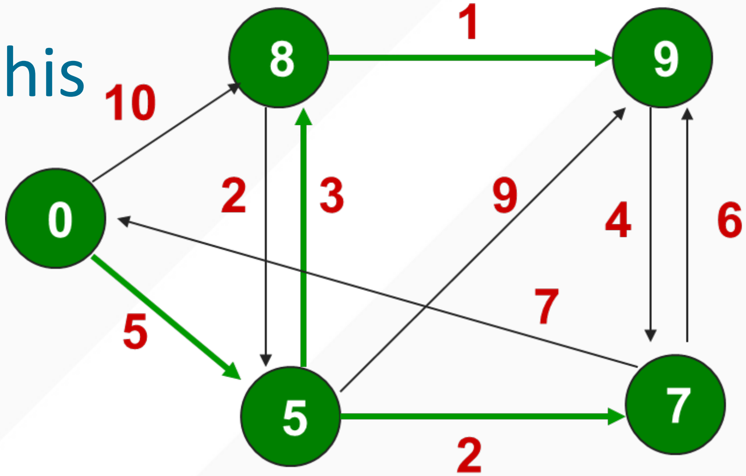
- E.g. UCSD, San Diego Comcast, a Google datacenter
- Packet switches communicate with each other using an *intra-domain* protocol called a Link-state protocol
  - Each packet switch sends a list of its neighbors to every other switch via a *broadcast*
  - As a result, each switch has the same "map" of what the network's *topology* looks like



ROUTING PACKETS WITHIN A SINGLE NETWORK

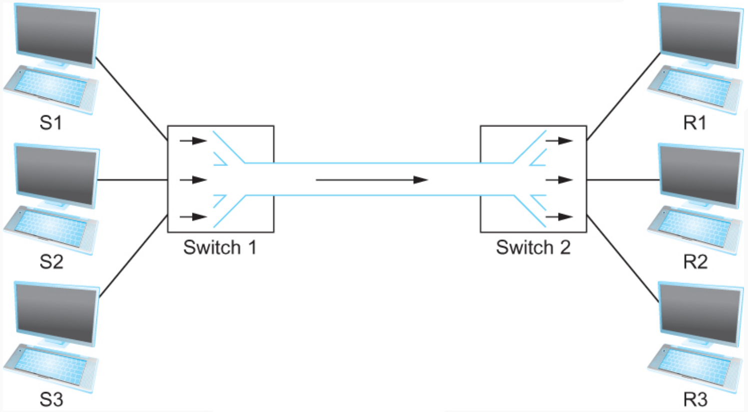
- Each packet switch uses its local topology map to choose paths to each destination
- Typically using Dijkstra's shortest path algorithm
    - Take CSE 123/222a to learn more!
- Packets are forwarded along this shortest path *tree*

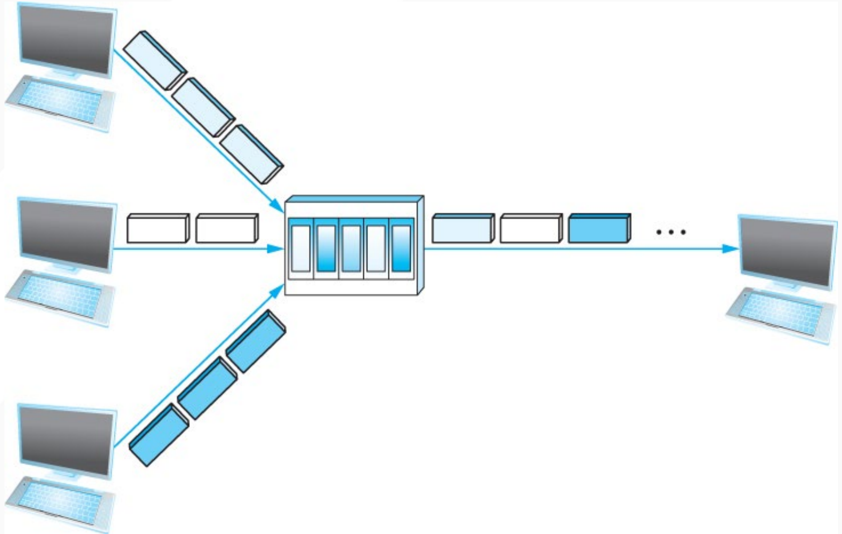




RESOURCE SHARING

Multiplexing multiple logical flows over a single physical link



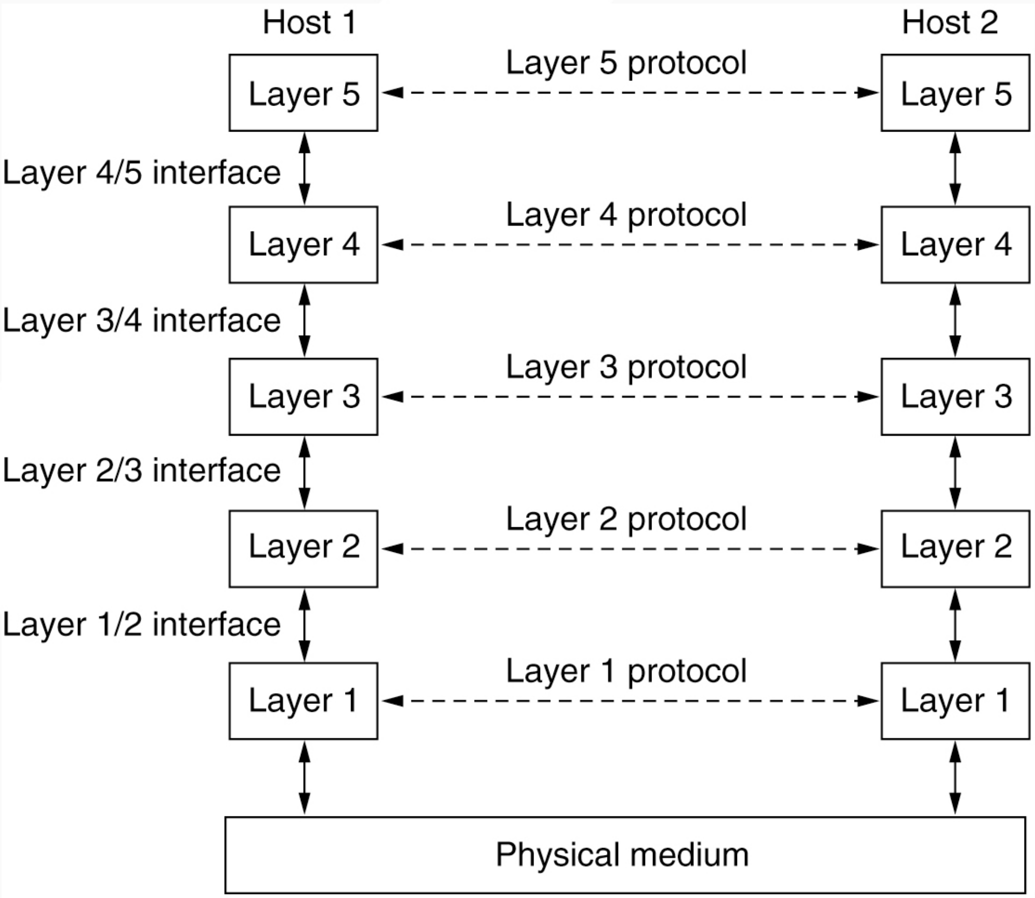


- Resource: links and nodes
- How to share a link?
  - Multiplexing
  - De-multiplexing
  - Queueing

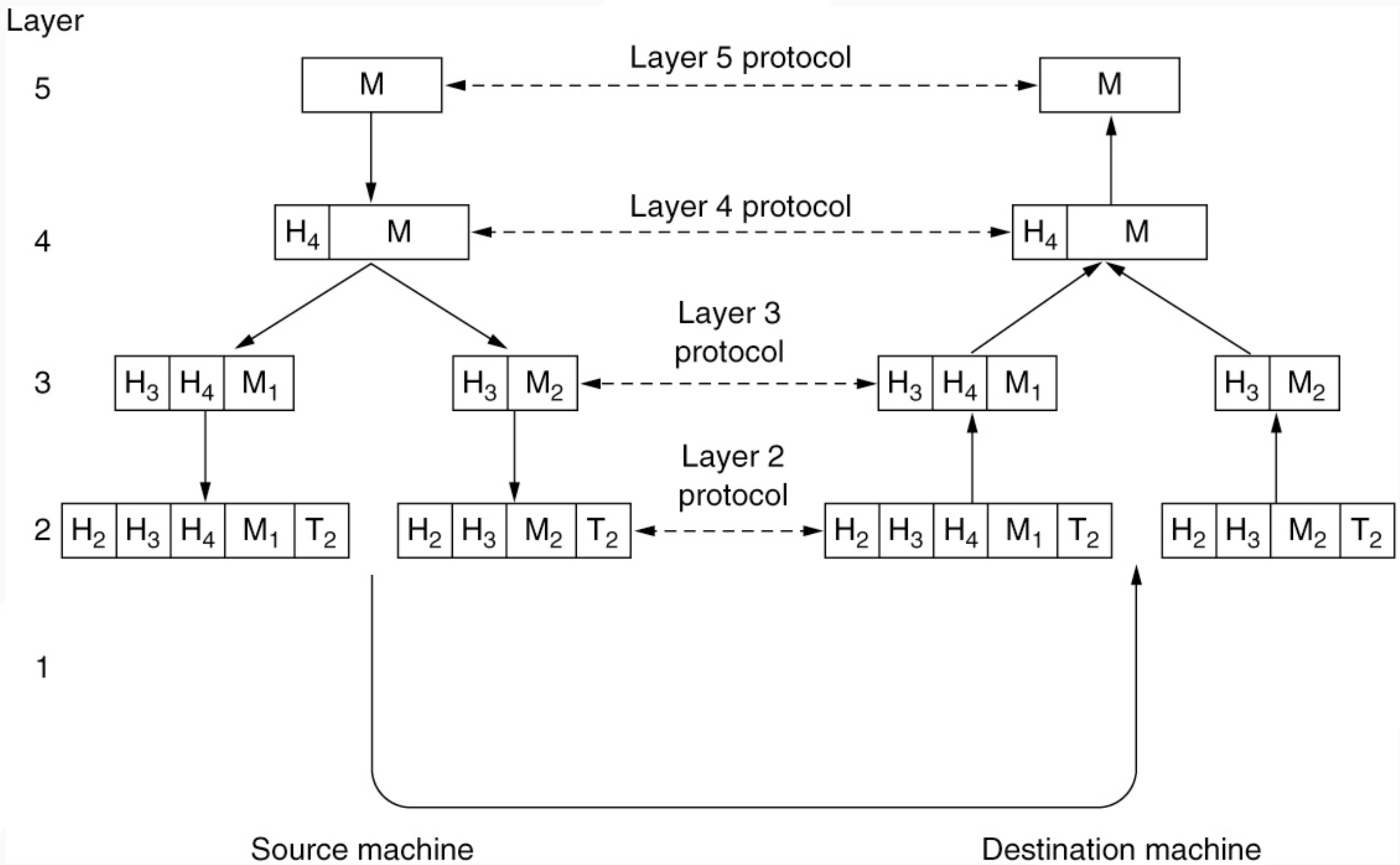
PROTOCOL LAYERING

- Networks organized as a stack of layers or levels
  - Each layer built upon the one below it
- Communication between corresponding layers
  - Use a common protocol referred to as a “layer n protocol”
  - Below layer 1 is the physical medium through which actual communication occurs
  - Interface lies between each pair of adjacent layers
- Network architecture: a set of layers and protocols
- Protocol stack: a list of the protocols used by a certain system, one protocol per layer

LAYERED PROTOCOL “STACK”



INFORMATION FLOW THROUGH LAYERS



Outline

1. Packet switching
2. Addressing

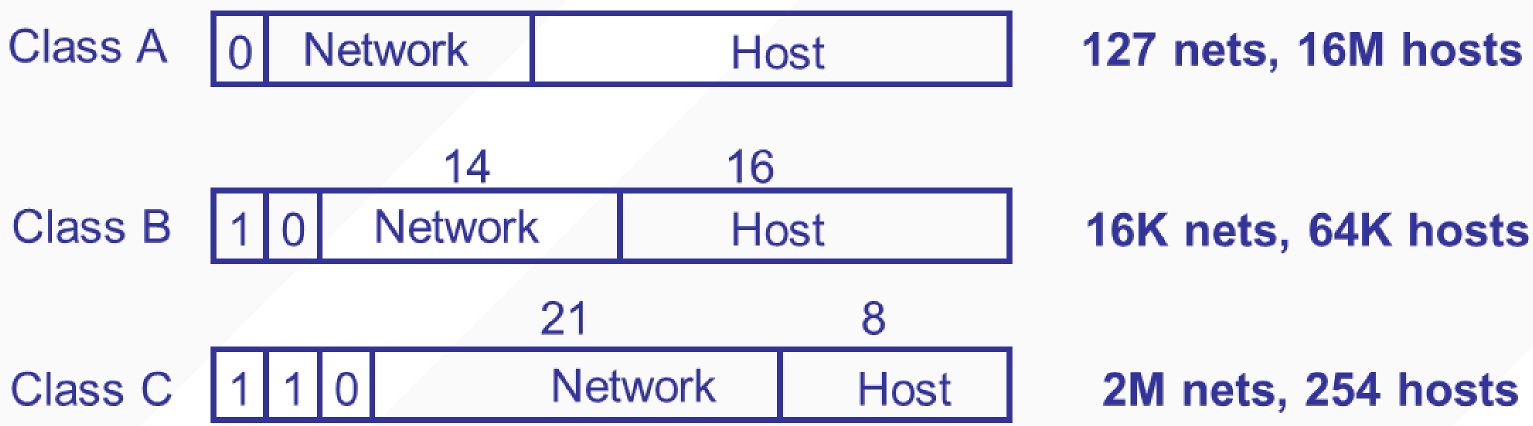
ADDRESSING CONSIDERATIONS

- Fixed length or variable length addresses?
- Issues:
  - Flexibility
  - Processing costs
  - Header size
- Engineering choice: IP uses fixed length addresses

- 32-bits in an IPv4 address
  - Dotted decimal format a.b.c.d
  - Each represent 8 bits of address
- Hierarchical: Network part and host part
  - E.g. IP address 128.54.70.238
  - 128.54 refers to the UCSD campus network
  - 70.238 refers to the host ieng6.ucsd.edu
- Which part is network *vs.* host?

CLASS-BASED ADDRESSING (NOT REALLY USED ANYMORE)

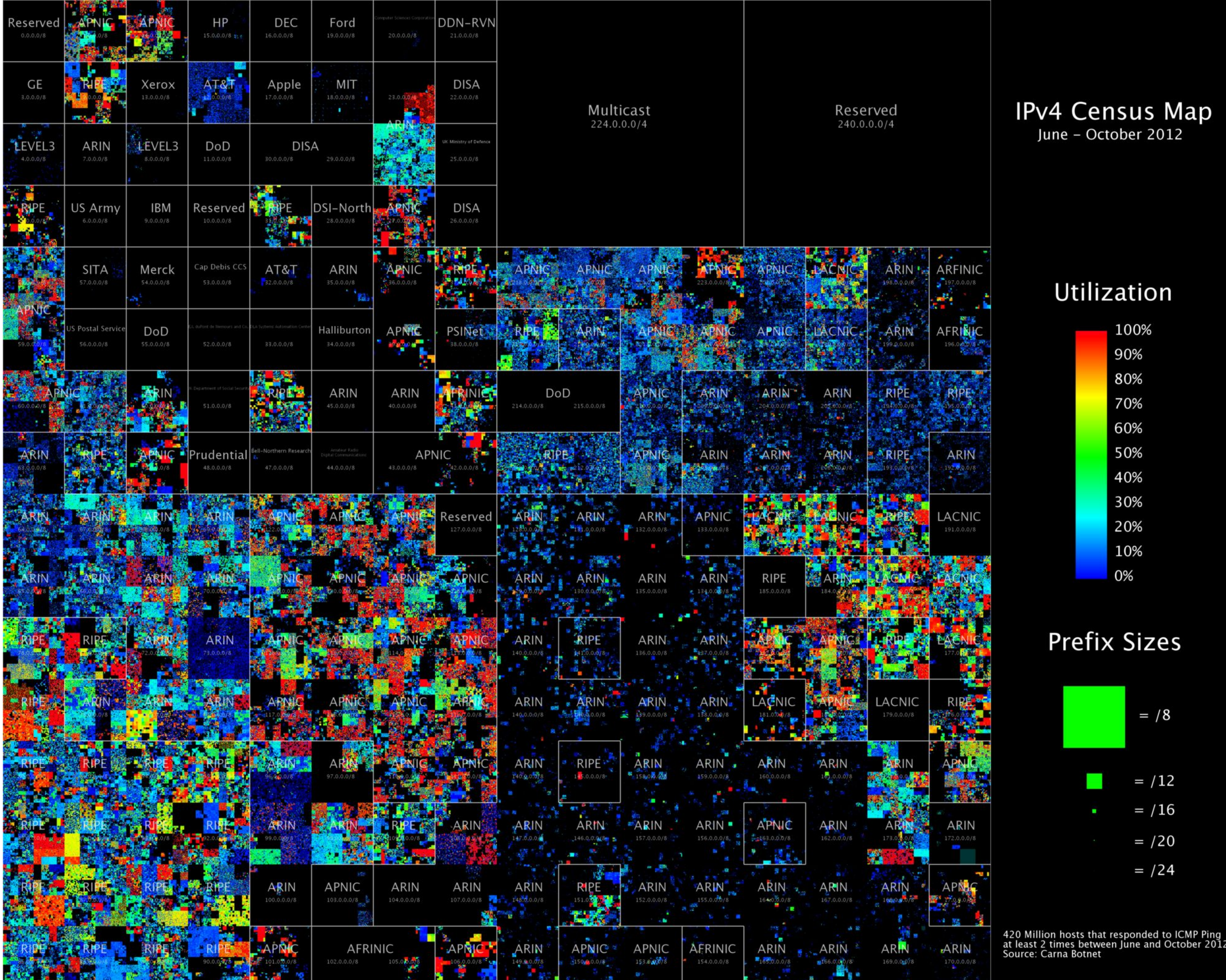
- Most significant bits determines “class” of address



- Special addresses
  - Class D (1110) for multicast, Class E (1111) experimental
  - 127.0.0.1: local host (a.k.a. the loopback address)
  - Host bits all set to 0: network address
  - Host bits all set to 1: broadcast address

IP ADDRESS PROBLEM (1991)

- Address space depletion
  - In danger of running out of classes A and B
- Why?
  - Class C too small for most organizations (only ~250 addresses)
  - Very few class A – very careful about giving them out (who has 16M hosts anyway?)
  - Class B – greatest problem



Reserved APNIC APNIC HP DEC Ford DDN-RVN
Multicast
224.0.0.0/4
Reserved
240.0.0.0/4
GE RIPE Xerox AT&T Apple MIT DISA
LEVEL3 ARIN LEVEL3 DoD DISA ARIN UK Ministry of Defence
RIPE US Army IBM Reserved RIPE DSI-North APNIC DISA
SITA Merck Cap Debis CCS AT&T ARIN APNIC RIPE APNIC APNIC APNIC APNIC APNIC LACNIC ARIN ARFINIC
APNIC US Postal Service DoD Halliburton APNIC PSINet RIPE ARIN APNIC APNIC APNIC LACNIC ARIN AFRINIC
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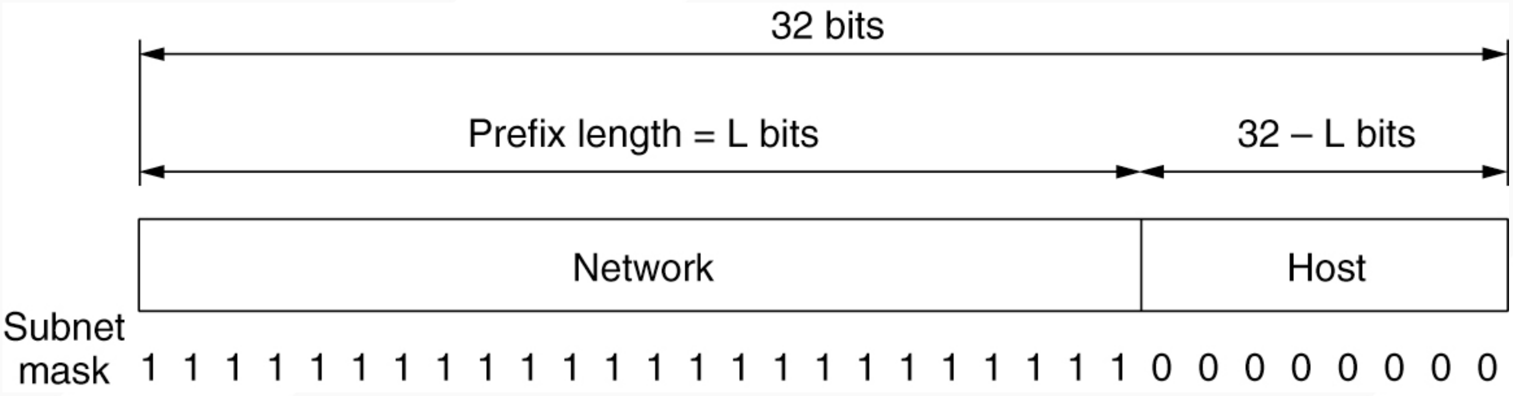
IPv4 Census Map
June – October 2012
Utilization
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Prefix Sizes
= /8
= /12
= /16
= /20
= /24
420 Million hosts that responded to ICMP Ping
at least 2 times between June and October 2012
Source: Carna Botnet

CIDR

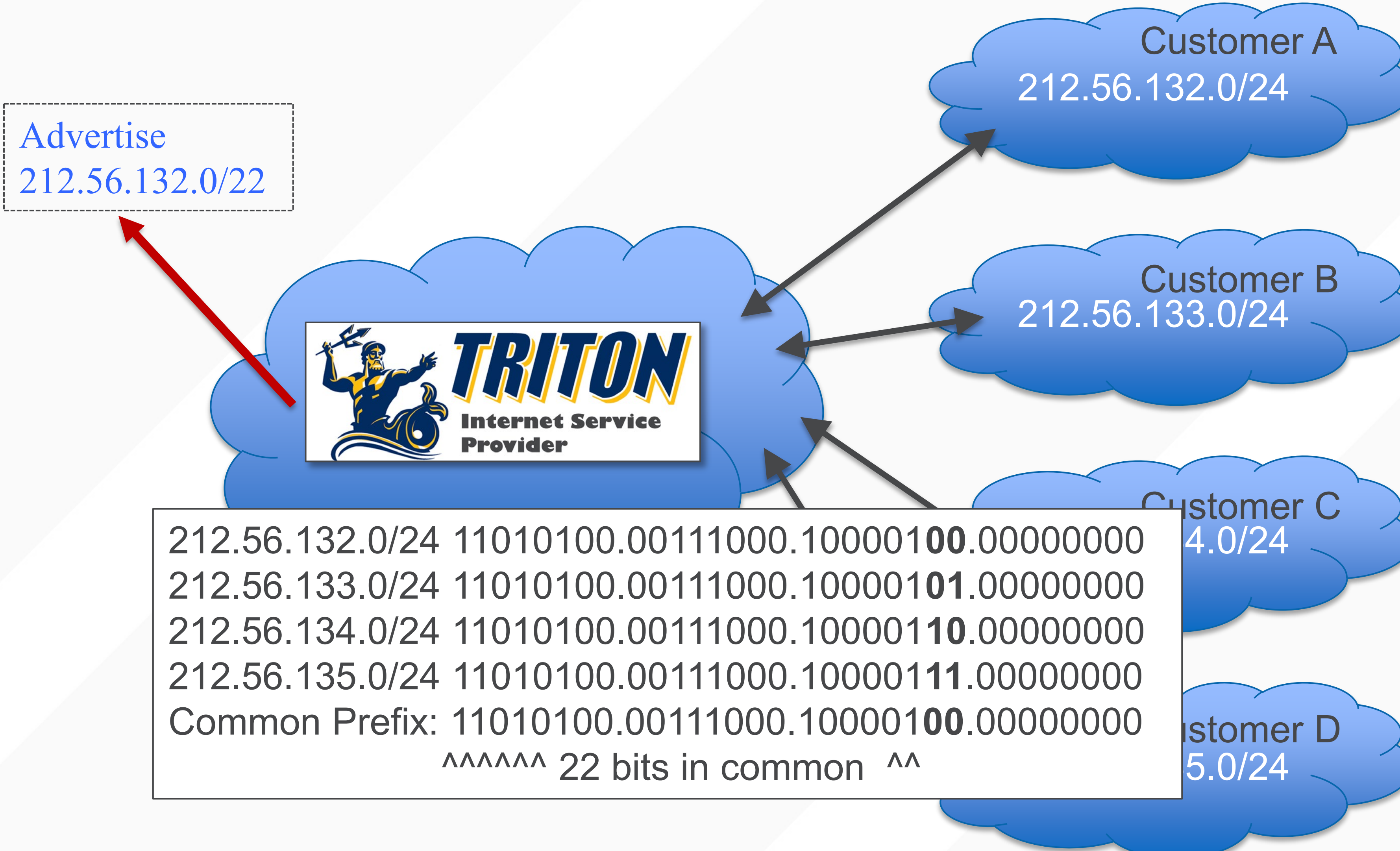
- Classless Inter-Domain Routing (1993)
  - Networks described by variable-length prefix and length
  - Allows arbitrary allocation between network and host address

  - e.g. 10.95.1.2 contained within 10.0.0.0/8:
    - 10.0.0.0 is network and remainder (95.1.2) is host
- Pro: Finer grained allocation; aggregation
- Con: More expensive lookup: longest prefix match

SUBNETS AND NETMASKS



ADDRESS AGGREGATION EXAMPLE



DIVIDING ADDRESSES WITHIN YOUR NETWORK

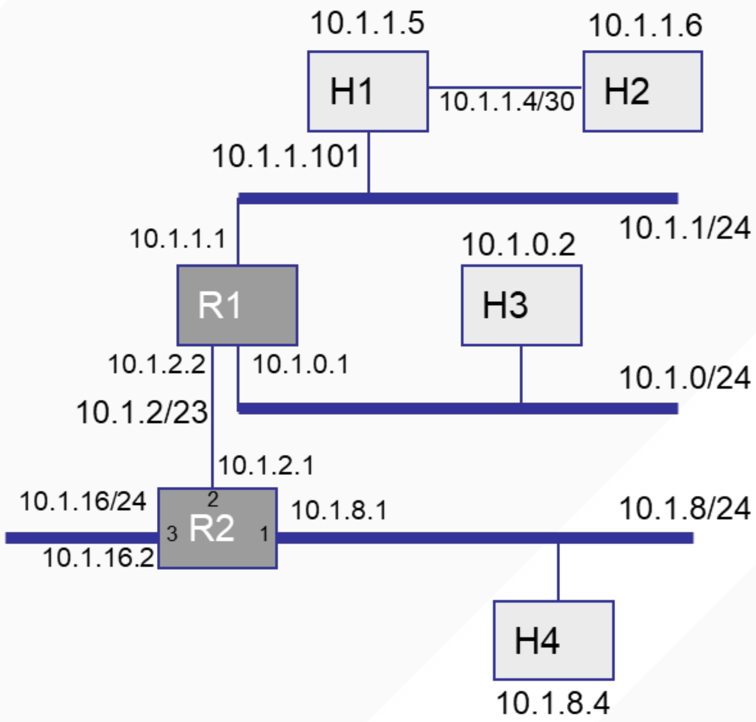
University	First address	Last address	How many	Prefix
Cambridge	194.24.0.0	194.24.7.255	2048	194.24.0.0/21
Edinburgh	194.24.8.0	194.24.11.255	1024	194.24.8.0/22
(Available)	194.24.12.0	194.24.15.255	1024	194.24.12.0/22
Oxford	194.24.16.0	194.24.31.255	4096	194.24.16.0/20

- Rule: **longest prefix matching**
  - Forward packets to the ***sub-network with the longest prefix***

FORWARDING TABLE EXAMPLE (R2)

- Packet to 10.1.1.6
- Matches 10.1.0.0/23

Destination	Next Hop
127.0.0.1	loopback
Default or 0/0	10.1.16.1
10.1.8.0/24	interface1
10.1.2.0/23	interface2
10.1.0.0/23	10.1.2.2
10.1.16.0/24	interface3

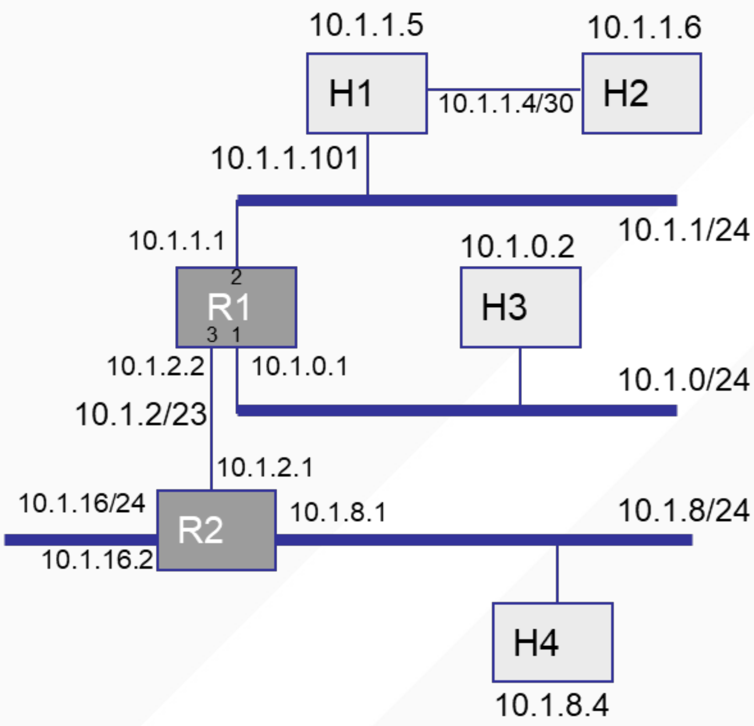


FORWARDING TABLE EXAMPLE 2 (R1)

- Packet to 10.1.1.6
- Matches 10.1.1.4/30
  - Longest prefix match

Routing table at R1

Destination	Next Hop
127.0.0.1	loopback
Default or 0/0	10.1.2.1
10.1.0.0/24	interface1
10.1.1.0/24	interface2
10.1.2.0/23	interface3
10.1.1.4/30	10.1.1.101

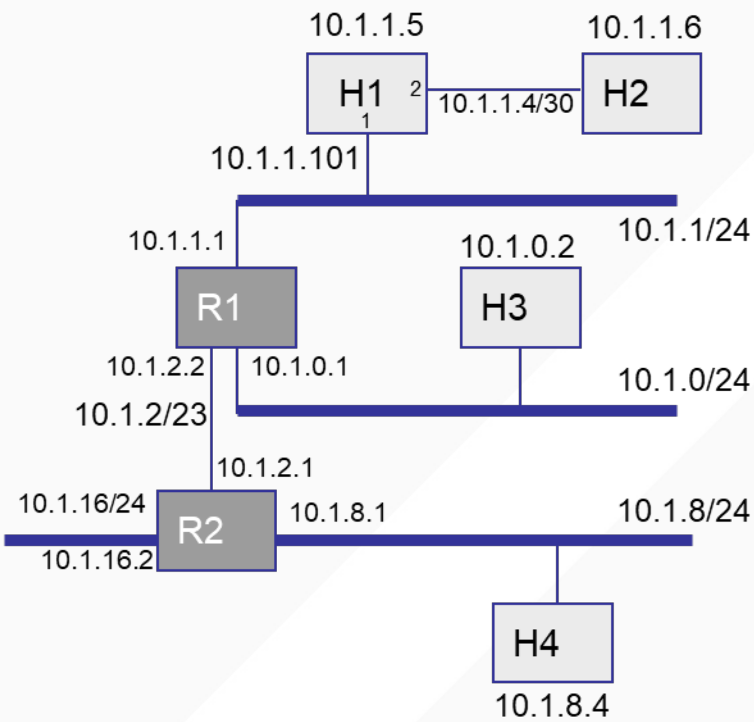


FORWARDING TABLE EXAMPLE 3 (H1)

- Packet to 10.1.1.6
- Direct route
  - Longest prefix match

Routing table at H1

Destination	Next Hop
127.0.0.1	loopback
Default or 0/0	10.1.1.1
10.1.1.0/24	interface1
10.1.1.4/30	interface2

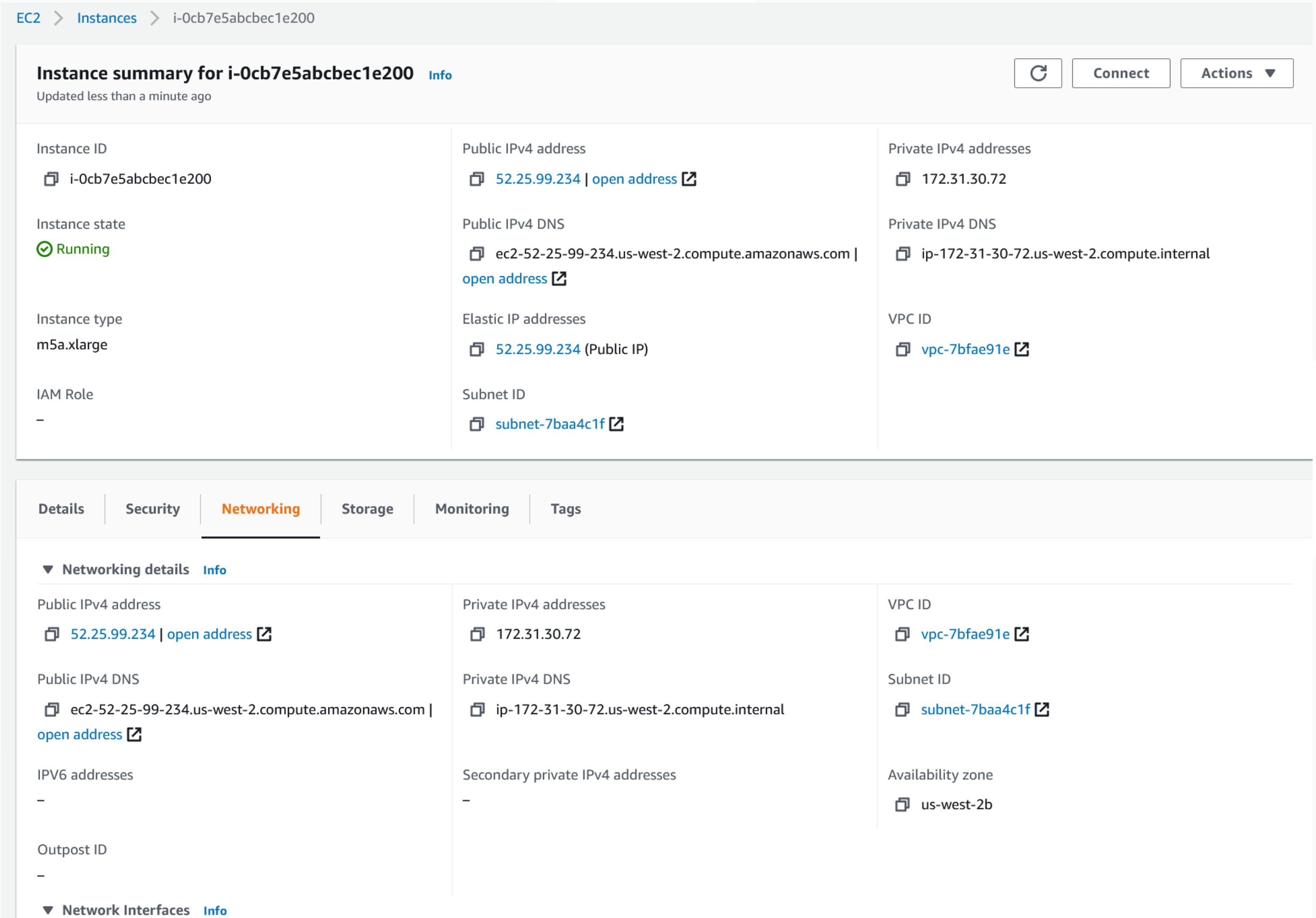


KEY TAKE-AWAY

```
       __|  __|_  )
       _|  (     /   Amazon Linux 2 AMI
      ___|\___|___|

https://aws.amazon.com/amazon-linux-2/
8 package(s) needed for security, out of 16 available
Run "sudo yum update" to apply all updates.
[ec2-user@ip-172-31-30-72 ~]$ ifconfig -a
eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 9001
        inet 172.31.30.72  netmask 255.255.240.0  broadcast 172.31.31.255
        inet6 fe80::65:43ff:fe81:f0  prefixlen 64  scopeid 0x20<link>
        ether 02:65:43:81:00:f0  txqueuelen 1000  (Ethernet)
        RX packets 67181  bytes 5406474 (5.1 MiB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 72005  bytes 5648089 (5.3 MiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

lo: flags=73<UP,LOOPBACK,RUNNING>  mtu 65536
        inet 127.0.0.1  netmask 255.0.0.0
        inet6 ::1  prefixlen 128  scopeid 0x10<host>
        loop  txqueuelen 1000  (Local Loopback)
        RX packets 0  bytes 0 (0.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 0  bytes 0 (0.0 B)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

[ec2-user@ip-172-31-30-72 ~]$
```

- To reach a computer, you need:
  - Its IP address
- But to configure that server, you need:
  - Its IP address
  - It’s netmask
  - The “default” gateway address

AMAZON EC2 VIRTUAL MACHINE VIEW

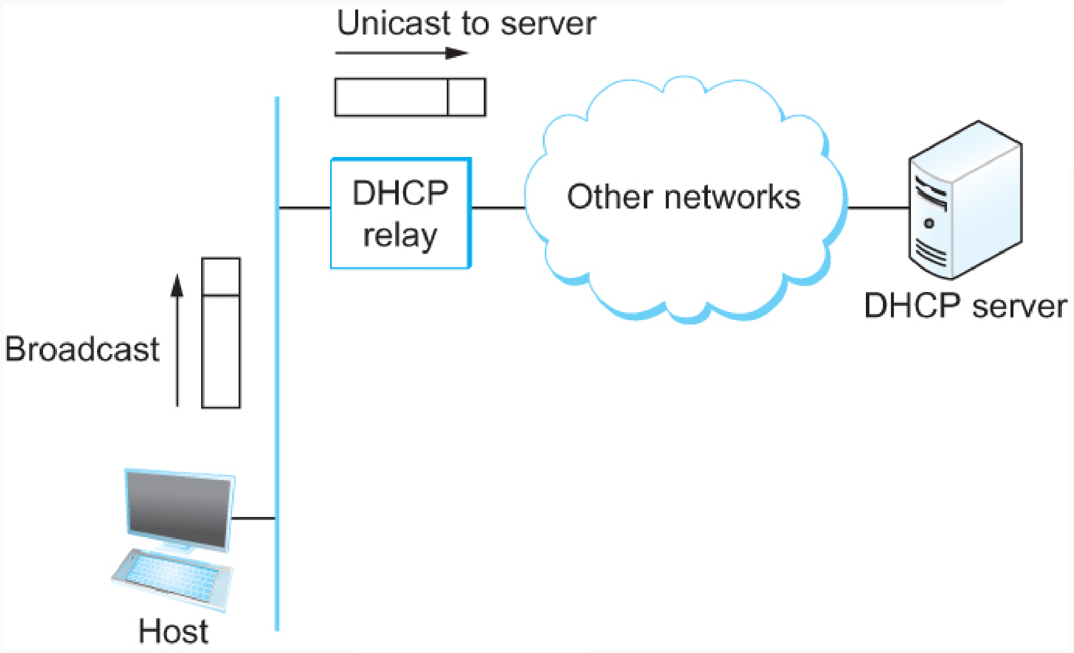


ASSIGNING ADDRESSES VIA DHCP

- DHCP server is responsible for providing configuration information to hosts
- There is at least one DHCP server for an administrative domain
- DHCP server maintains a pool of available addresses

DHCP IN ACTION

- Newly booted or attached host sends DHCPDISCOVER message to a special IP address (255.255.255.255)
- DHCP relay agent unicasts the message to DHCP server and waits for the response



DNS HOSTNAME VERSUS IP ADDRESS

- **DNS host name** (e.g. www.cs.ucsd.edu)
  - **Mnemonic** name appreciated by humans
  - **Variable length**, full alphabet of characters
  - Provides **little** (if any) information about **location**
- **IP address** (e.g. 128.112.136.35)
  - Numerical address appreciated by **routers**
  - **Fixed length**, decimal number
  - **Hierarchical** address space, related to host **location**

MAPPING NAMES TO ADDRESSES

```
GETADDRINFO(3)            Linux Programmer's Manual            GETADDRINFO(3)

NAME
       getaddrinfo,  freeaddrinfo,  gai_strerror - network address and service
       translation

SYNOPSIS
       #include <sys/types.h>
       #include <sys/socket.h>
       #include <netdb.h>

       int getaddrinfo(const char *node, const char *service,
                       const struct addrinfo *hints,
                       struct addrinfo **res);

       void freeaddrinfo(struct addrinfo *res);

       const char *gai_strerror(int errcode);
```

A FACT ABOUT NAME→ADDRESS MAPPINGS

```
struct addrinfo {
    int              ai_flags;
    int              ai_family;
    int              ai_socktype;
    int              ai_protocol;
    socklen_t        ai_addrlen;
    struct sockaddr *ai_addr;
    char            *ai_canonname;
    struct addrinfo *ai_next;
};
```

- Looking up a name results in a *linked list* of results. Why?
  - Support for newer "IPv6 (128-bit)" and classic "IPv4 (32-bit)"
  - A name can map to many IP addresses. E.g. google.com