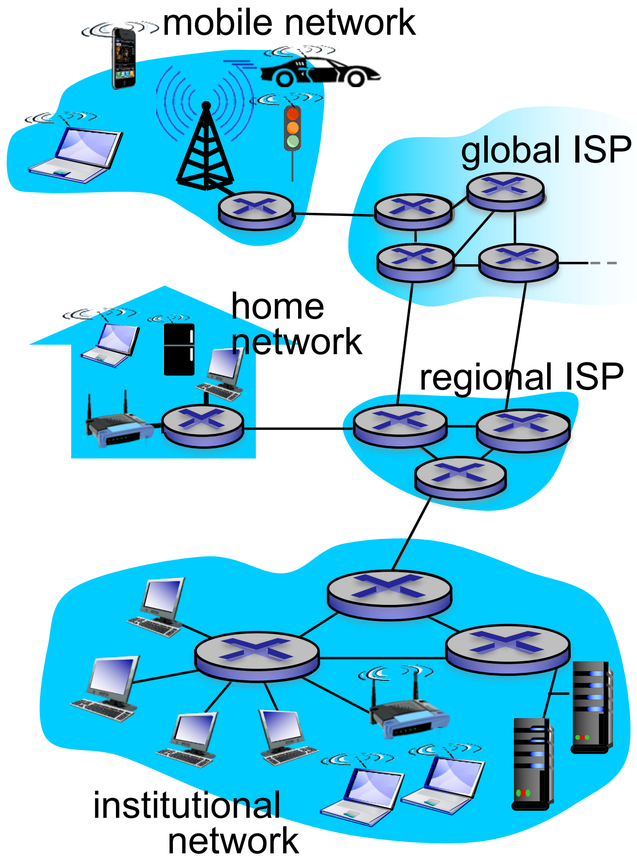
Computer Networks

What is the Internet?

- A bunch of computers hooked up

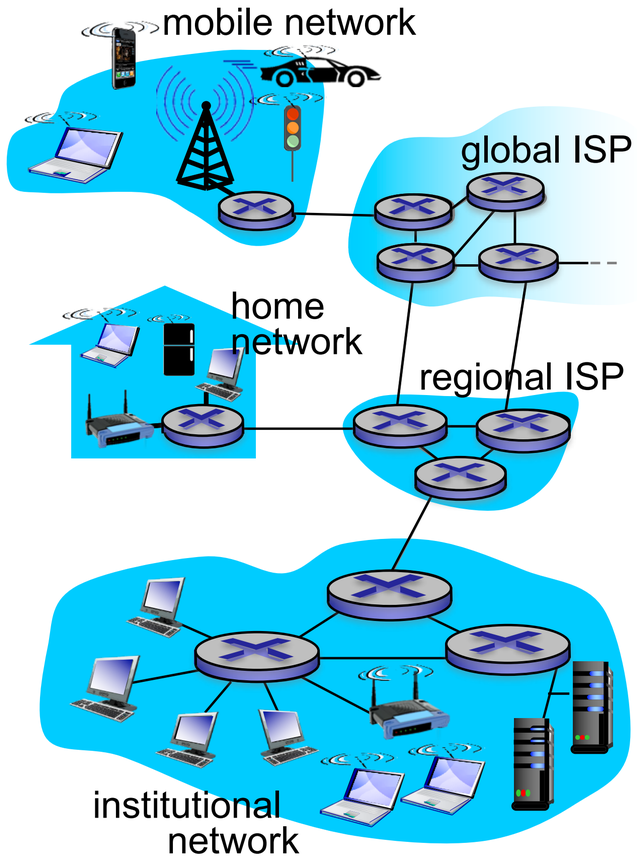
What is the Internet?

- A network of networks
- Hosts (PC, server, laptop, smartphone, sensor)
- Communication links (wireless, wired)



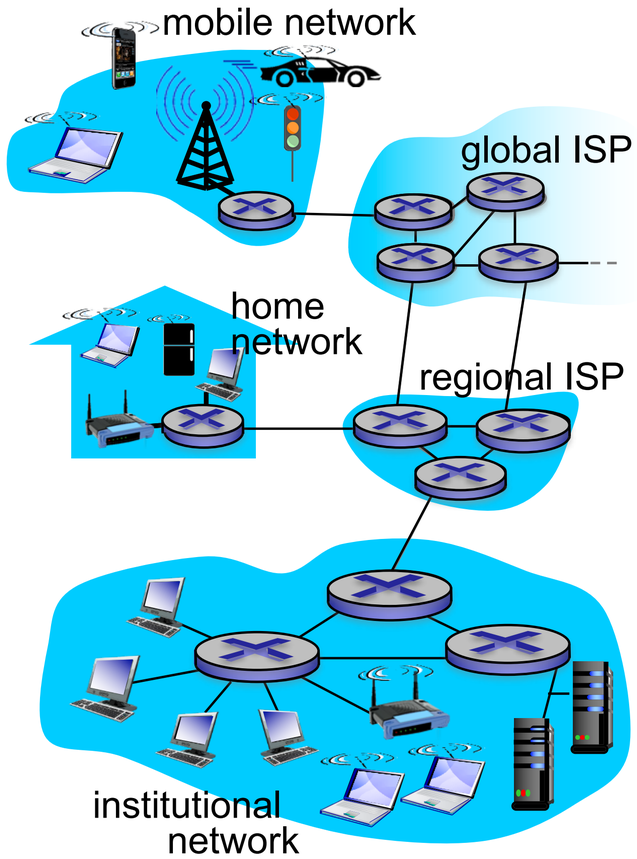
Network Structure

- Network edge – hosts
- Network core – interconnected routers

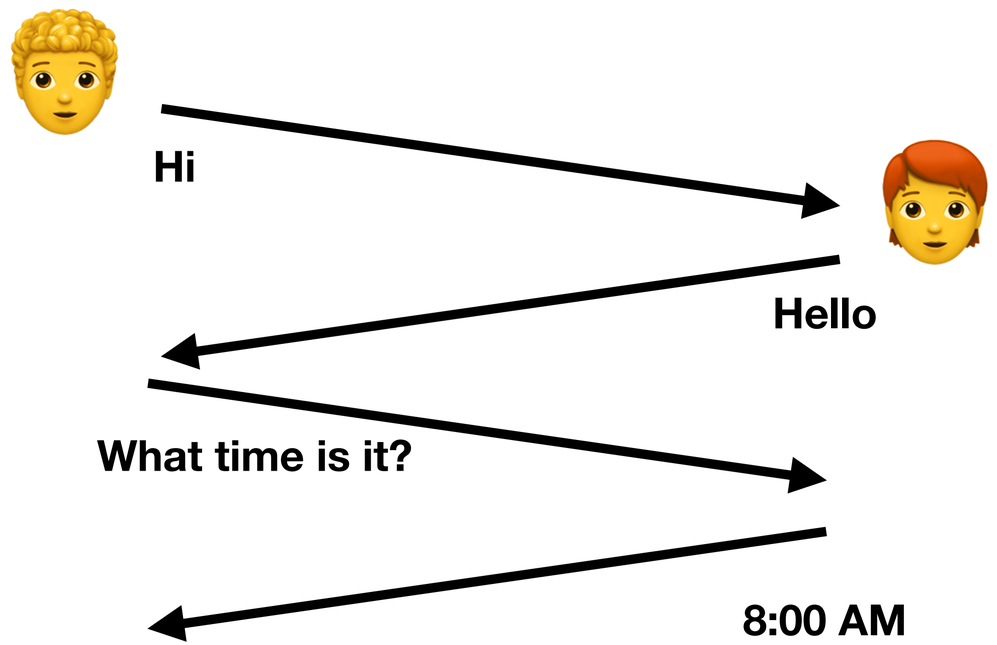


What is the Internet?

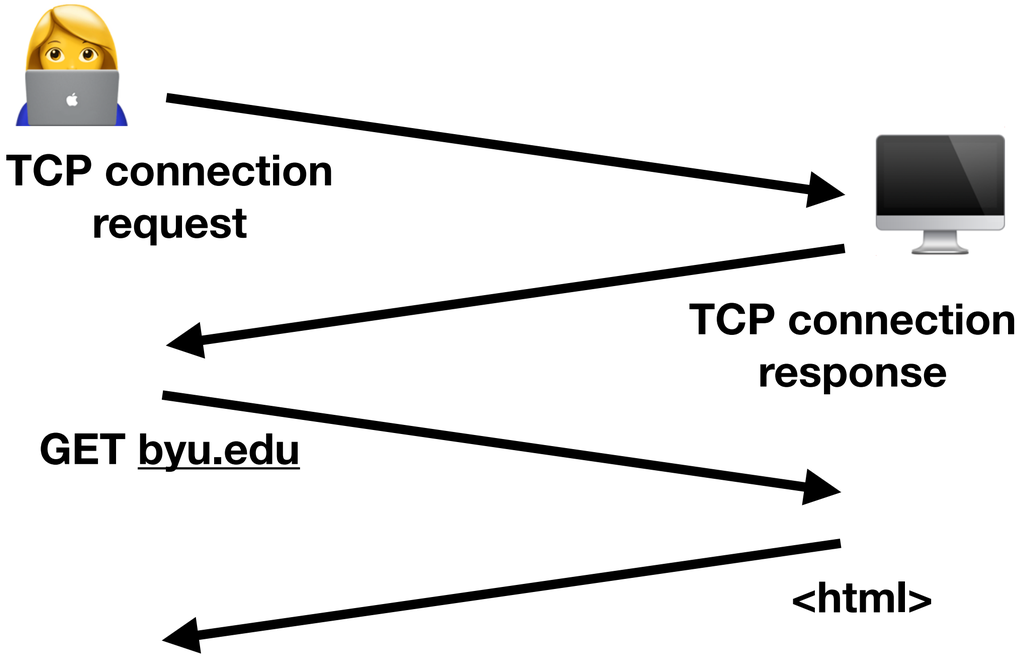
- How can they all talk to each other?
- Protocols!
- TCP, IP, HTTP, Skype, 802.11



Protocols



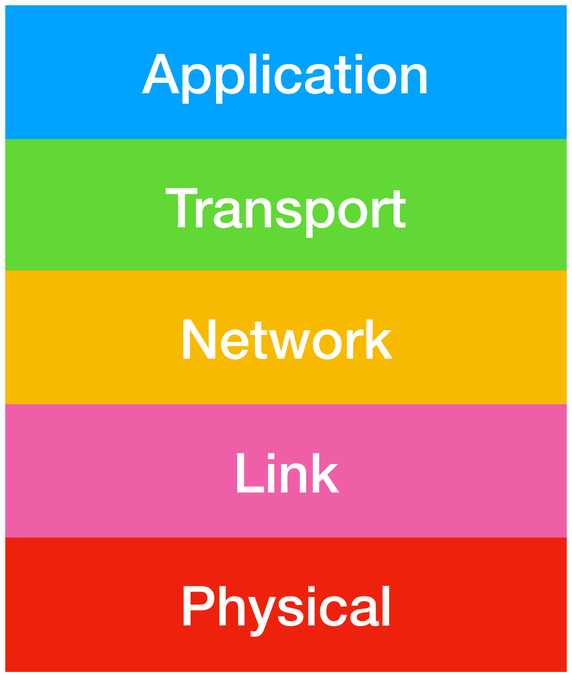
Protocols


TCP connection request
TCP connection response
GET byu.edu
<html>

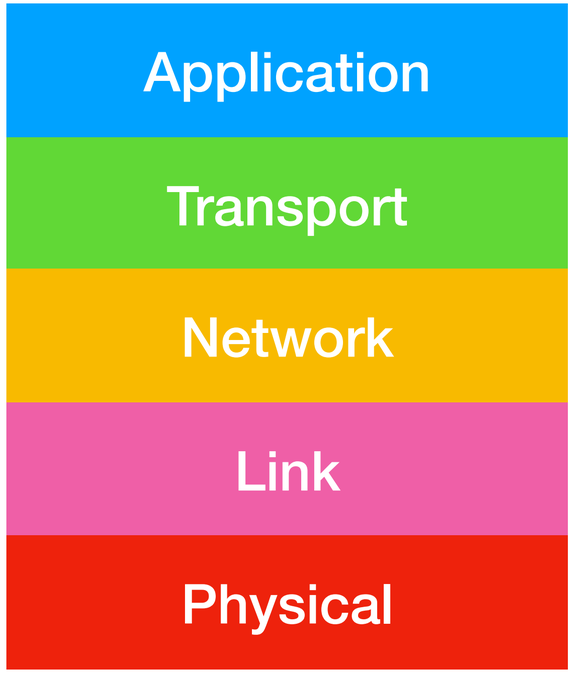
Protocols

- Reliability
- Security
- Privacy
- Fairness
- Routing

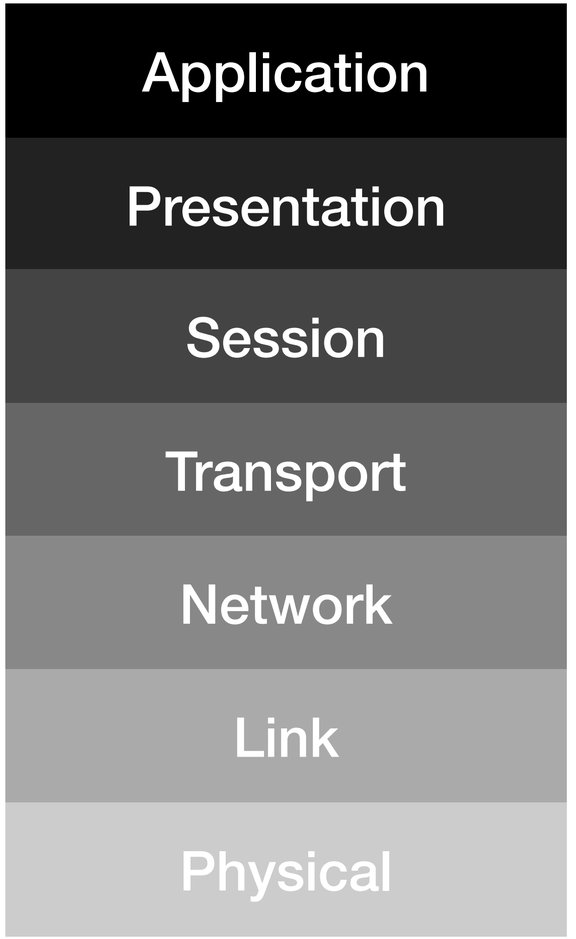
Internet Protocol Stack



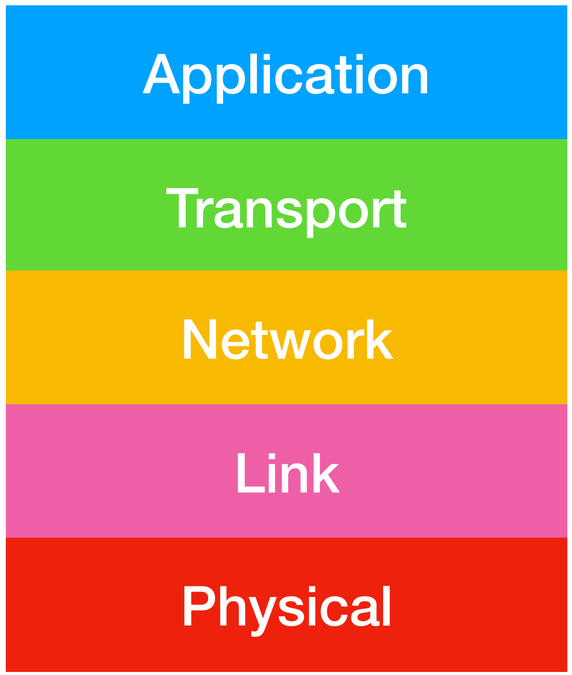
Internet Protocol Stack



OSI Model



Internet Protocol Stack



Application specific data

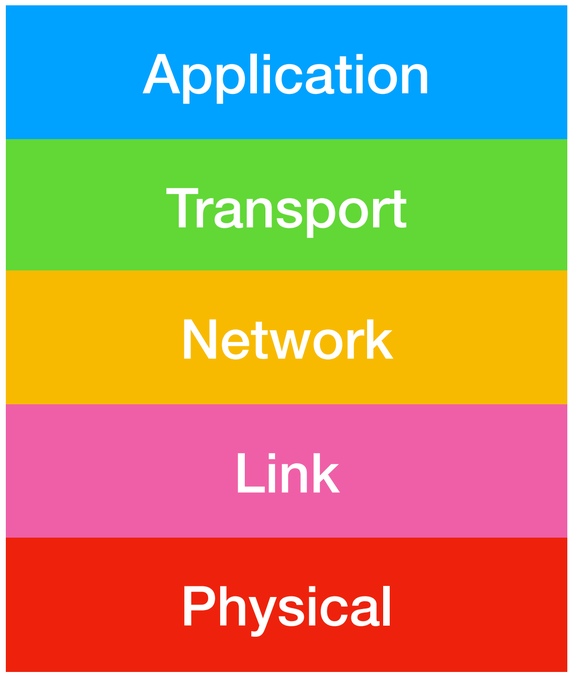
Program-to-program communication

Host-to-host communication

Hop-to-hop communication

Electricity

Internet Protocol Stack



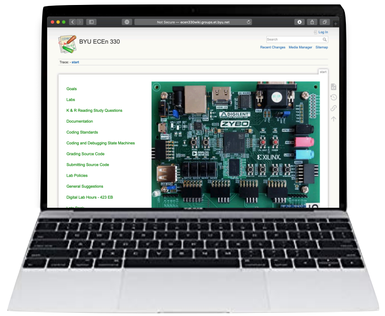
HTTP, SSH, FTP

TCP, UDP

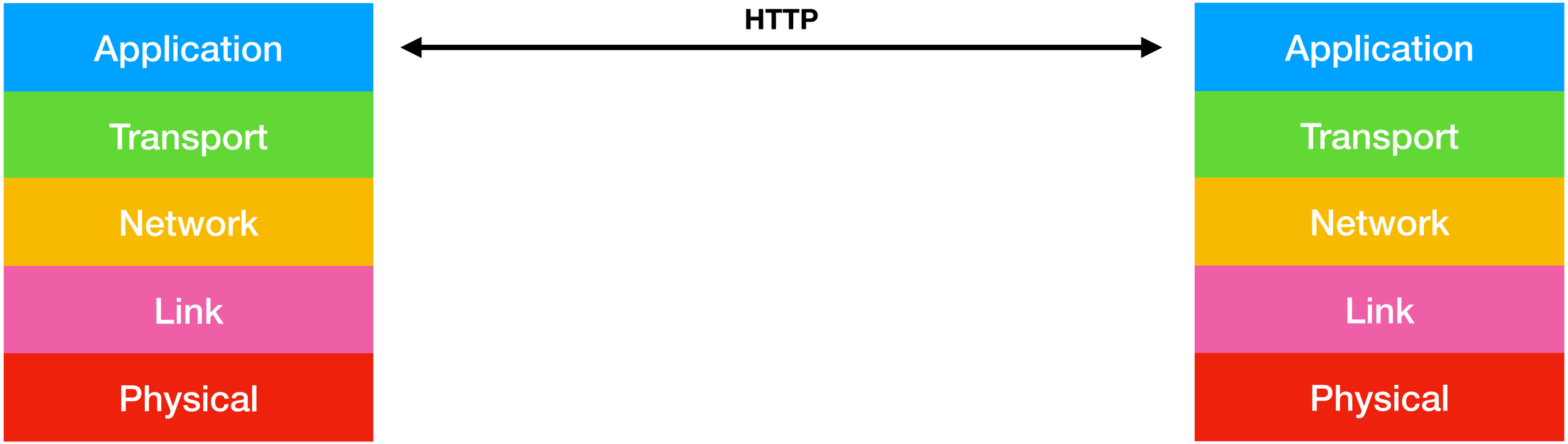
IP

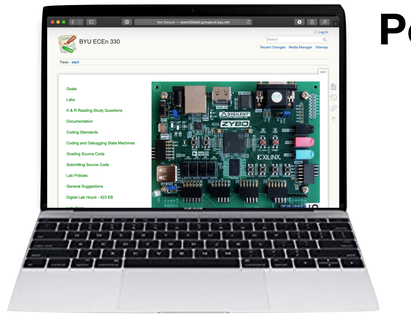
Ethernet, WiFi

Bits on a wire, wireless transmission (1000BASE-T, OFDM)


BYU ECEn 330
Goals
Labs
K & R Reading Study Questions
Documentation
Coding Standards
Coding and Debugging State Machines
Grading Source Code
Submitting Source Code
Lab Policies
General Suggestions
Digital Lab Hours - 423 EB
ZYBO
XILINX

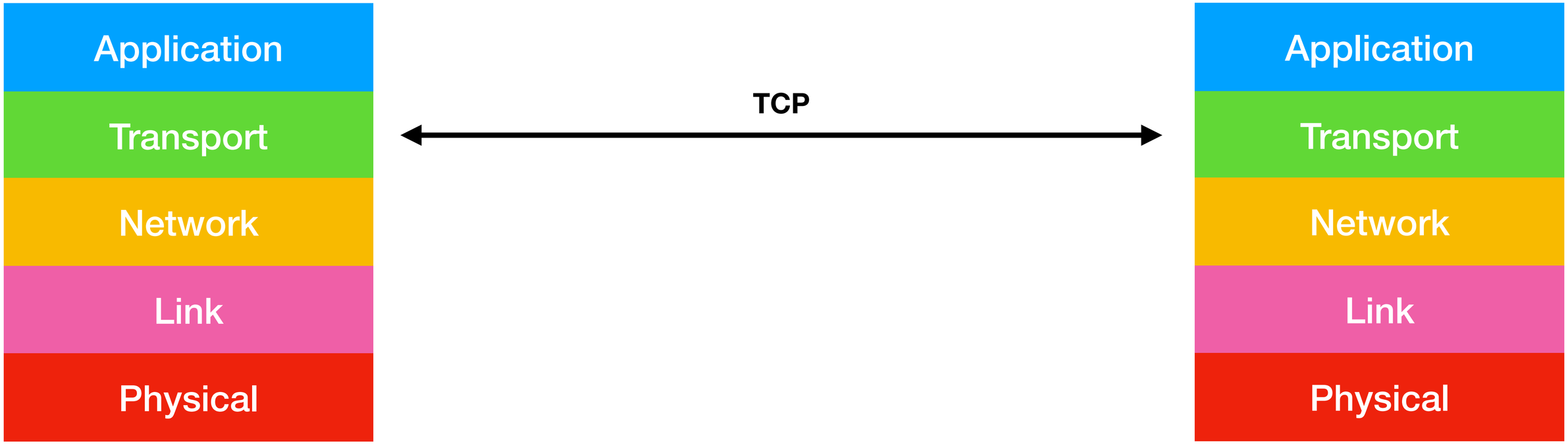

APACHE
HTTP SERVER PROJECT

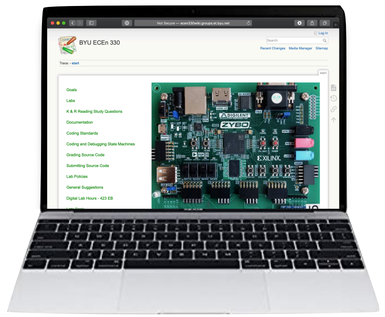

Application
Transport
Network
Link
Physical
HTTP
Application
Transport
Network
Link
Physical



Port: 34821

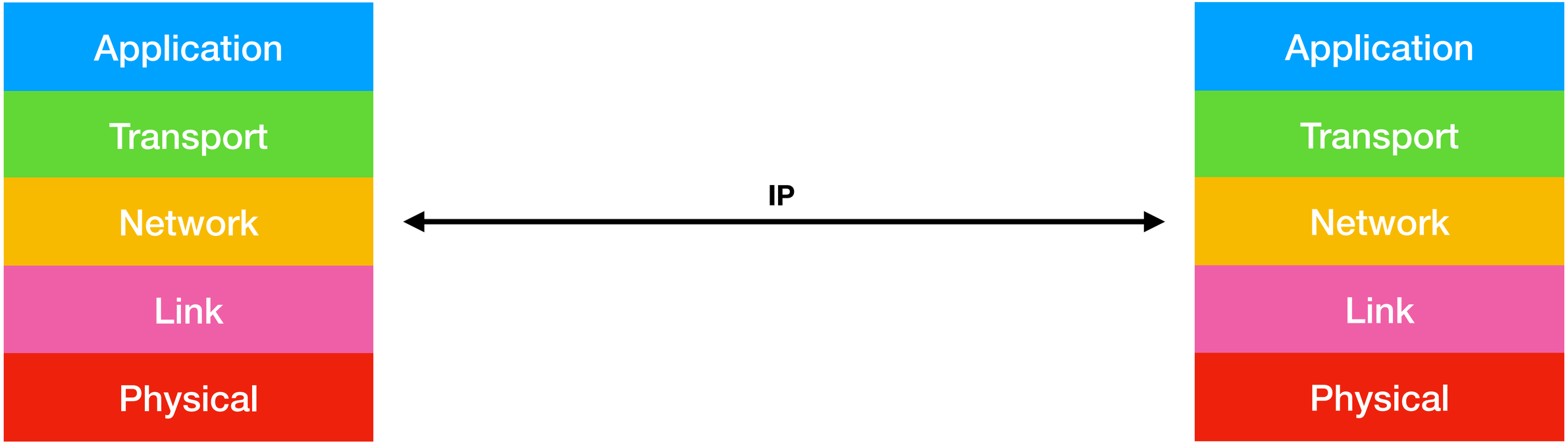
Port: 80

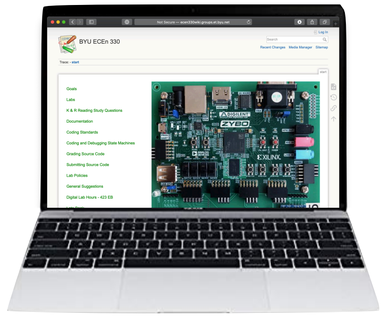




IP address: 10.0.1.45

IP address: 64.233.191.126





Application

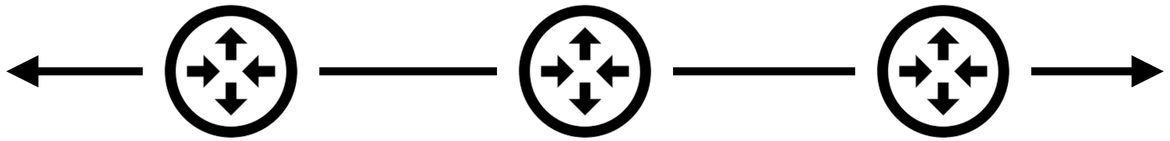
Transport

Network

Link

Physical

Ethernet / WiFi



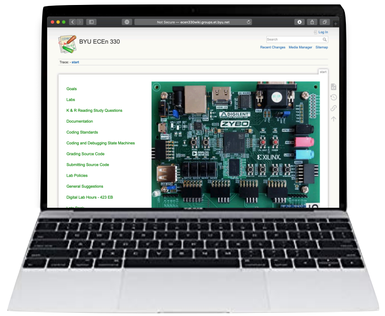
Application

Transport

Network

Link

Physical



Application

Transport

Network

Link

Physical

1000BASE-T, OFDM

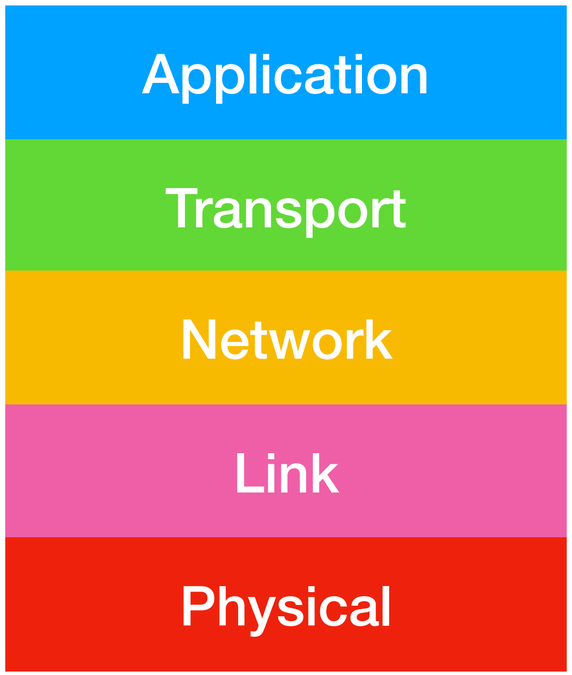
Application

Transport

Network

Link

Physical


Application
Transport
Network
Link
Physical

Application Layer Protocol

- Types of messages exchanged (request, response)
- Message syntax (format of bytes)
- Message semantics (meaning of information)
- Communication rules (sending & responding to messages)

Application Layer Protocol

- Data integrity
- Timing
- Security

HTTP

- Client/server model
- Client browser requests data (using HTTP) and displays web objects (such as HTML)
- Server sends (using HTTP) objects in response to requests

HTTP

- Two types of HTTP messages: request, response
- Use ASCII in message structure

HTTP Request

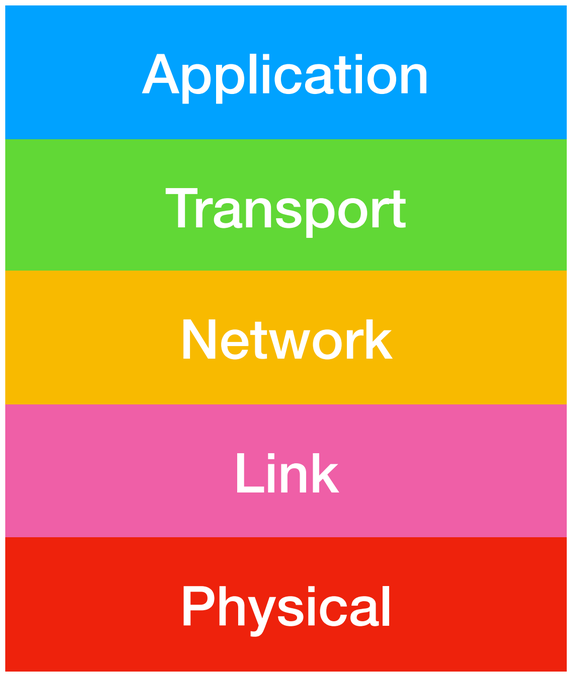
```
GET /index.html HTTP/1.1\r\n
Host: www.google.com\r\n
User-Agent: HTTPie/1.0.2\r\n
Accept: */*\r\n
Accept-Encoding: gzip, deflate\r\n
Connection: keep-alive\r\n
\r\n
```

HTTP Response

```
HTTP/1.1 200 OK\r\n
Cache-Control: private, max-age=0\r\n
Content-Encoding: gzip\r\n
Content-Length: 5191\r\n
Content-Type: text/html;\r\n
charset=ISO-8859-1\r\n
Date: Tue, 14 Jan 2020 14:30:54 GMT\r\n
\r\n
…data…
```

DNS: Domain Name System

- Every server has an IP address
- Names are easier to remember for humans
- DNS maps names to IP addresses


Application
Transport
Network
Link
Physical

Transport Services and Protocols

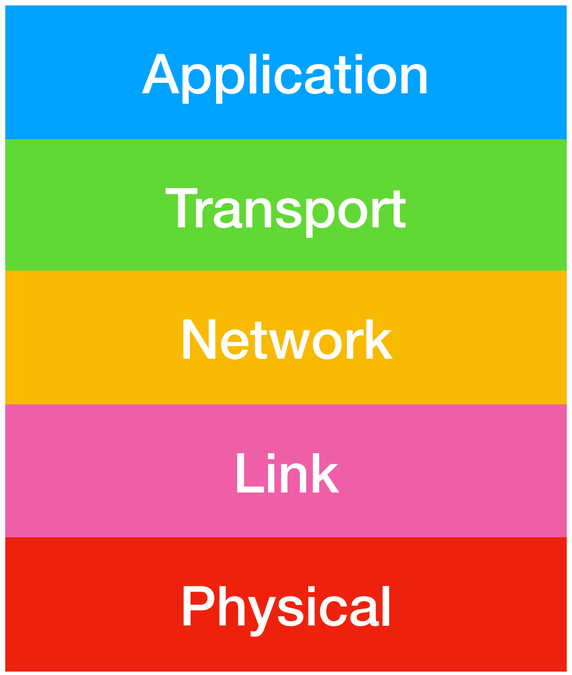
- Provide *logical communication* between app processes running on different hosts
- Transport protocols run in end systems
  - Send side: breaks app messages into segments, passes to network layer
  - Receive side: reassembles segments into messages, passes to app layer
- Internet: TCP and UDP

UDP

- Simple Internet transport protocol
- Data sent in segments
- Segments may be lost or delivered out-of-order (“best effort”)
- Connectionless — no handshaking between UDP sender and receiver

TCP Overview

- Point-to-point—one sender, one receiver
- Reliable, in-order byte stream—no message boundaries
- Pipelined—TCP congestion and flow control set window size
- Full duplex data
- Connection oriented
- Flow controlled—sender will not overwhelm receiver


Application
Transport
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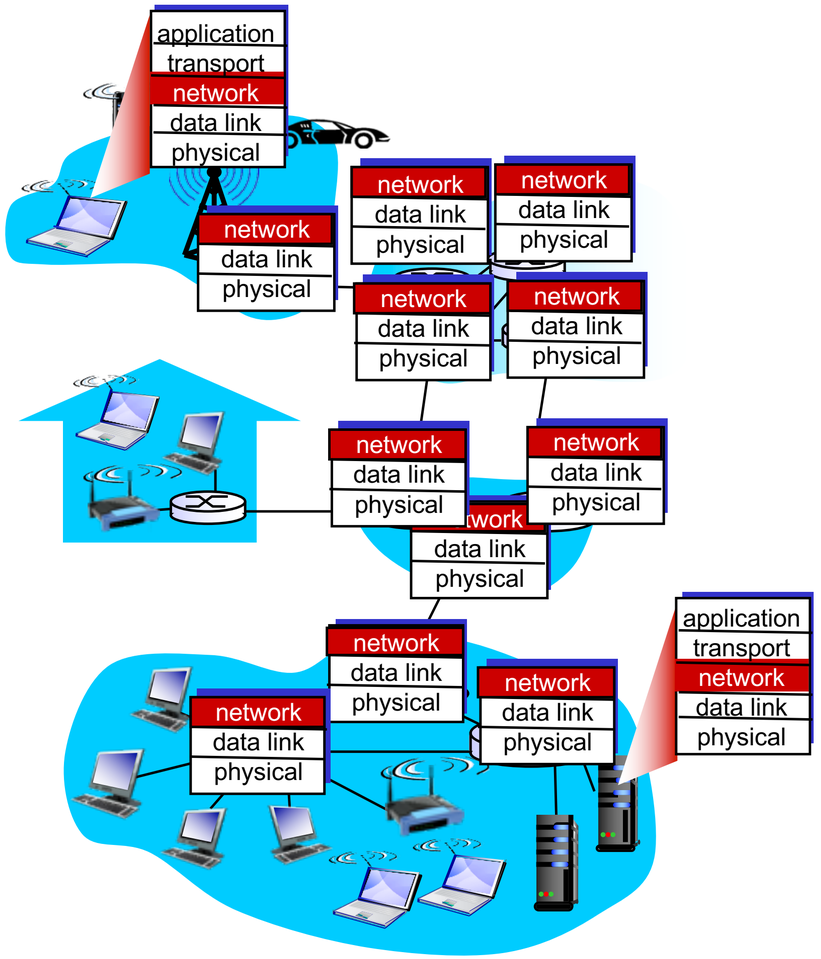
Link
Physical

Network Layer

- Transport segment from sending to receiving host
- Sender: encapsulates data into packets
- Receiver: delivers packets to transport layer
- Every host and router has network layer protocols
- Responsible for forwarding and routing data
- Router examines header fields in all IP datagrams



Data Plane and Control Plane

Data Plane

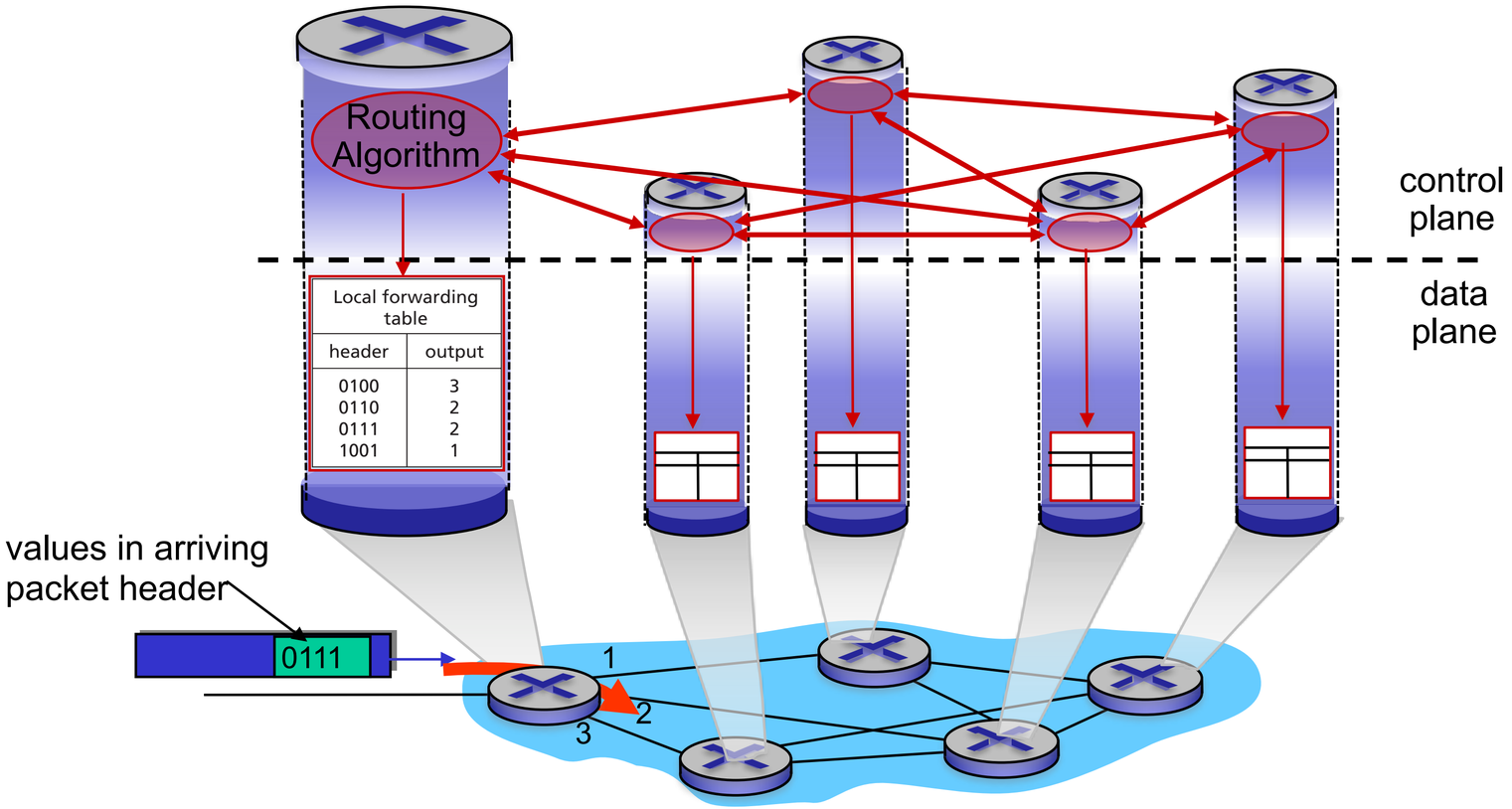
- Local, per-router function
- Determines how datagram arriving on router input port is forwarded to router output port (forwarding)

Control Plane

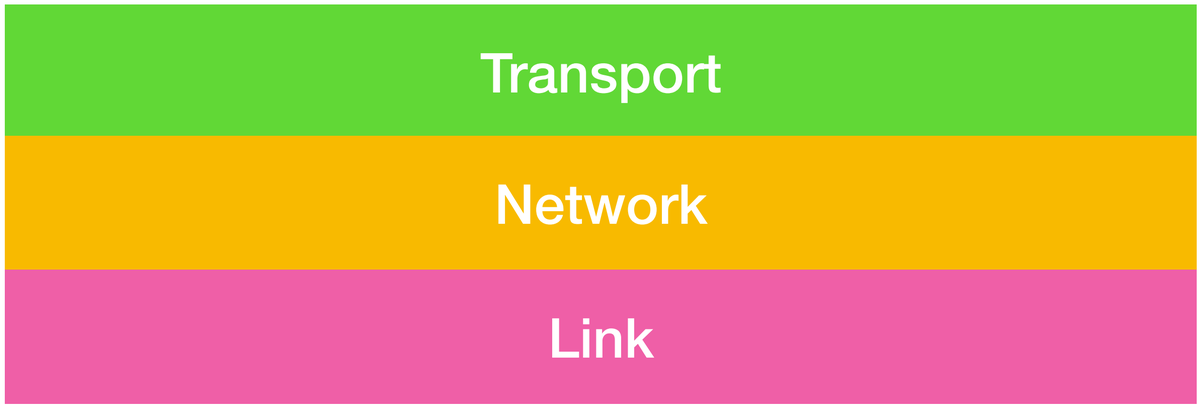
- Network-wide logic
- Determines how datagram is routed among routers along path from source host to destination host (routing)

Routing

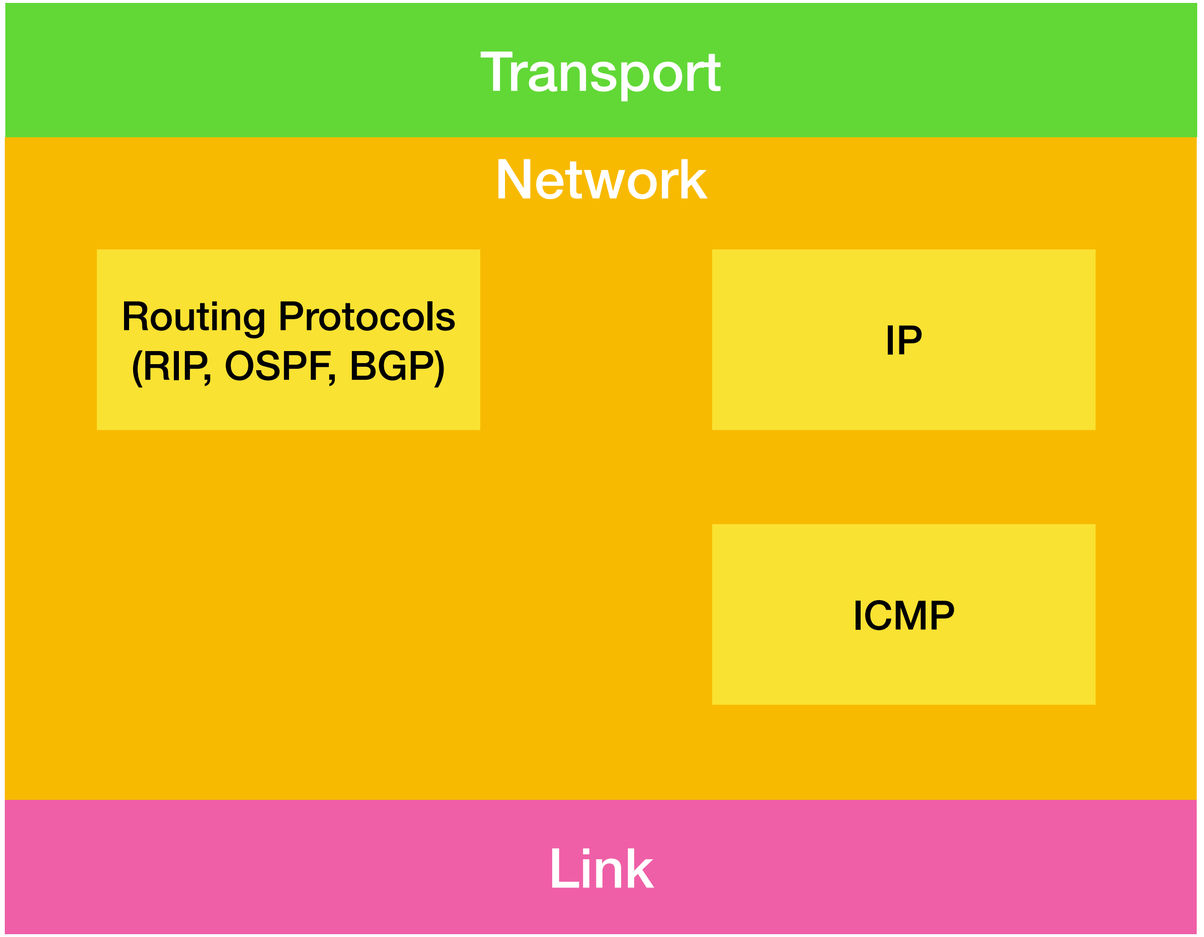
Individual routing algorithm components in each router interact with the control plane



Network Layer

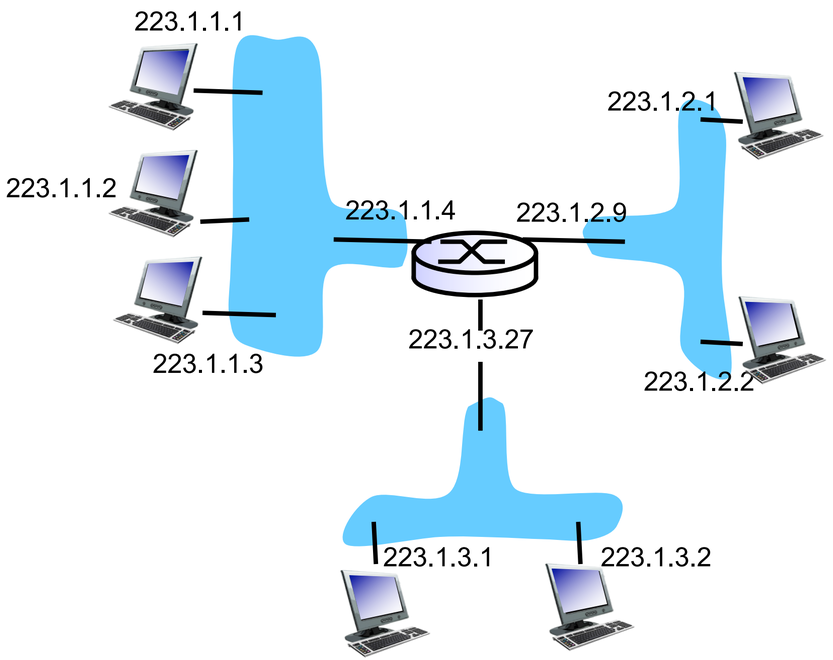


Network Layer



IP Addresses

- 32-bit identifier for host and router interface
- Use dotted-decimal notation
- Interface: connection between host/ router and physical link
- IP addresses associated with each interface

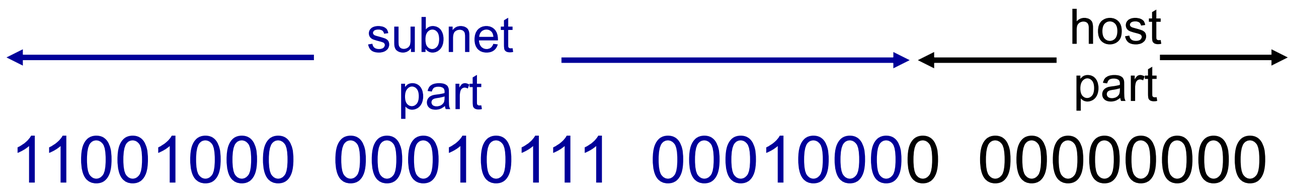


223.1.1.1 = 11011111 00000001 00000001 00000001

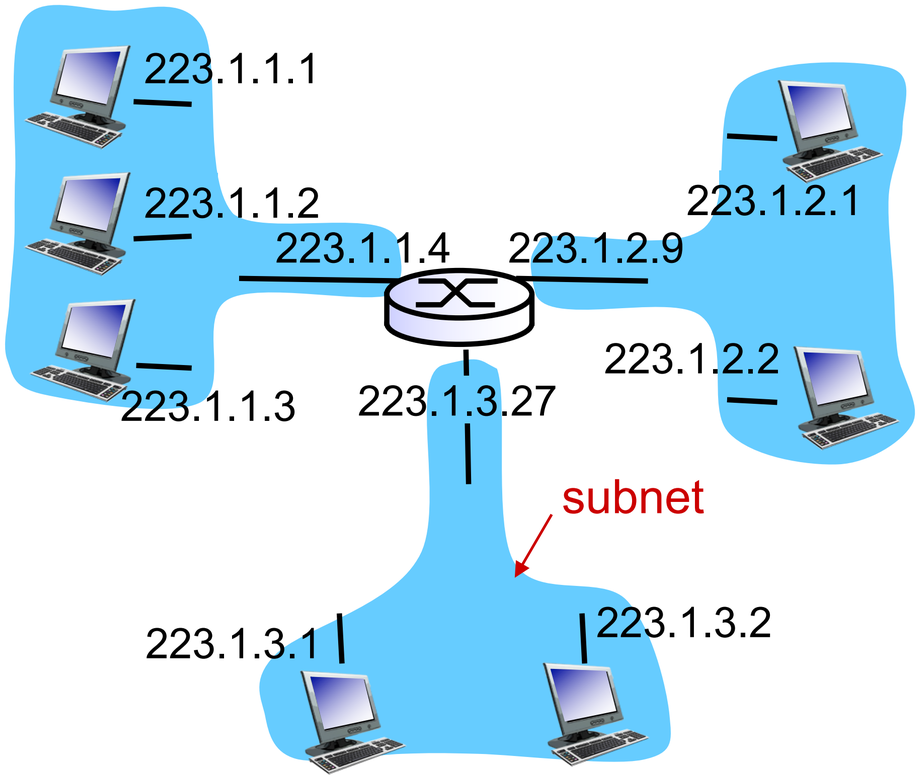
223 1 1 1

IP Addresses

- Two parts to an IP address
  - Subnet (higher order bits)
  - Host (low order bits)



Subnets


223.1.1.1
223.1.1.2
223.1.1.4
223.1.2.9
223.1.2.1
223.1.2.2
223.1.1.3
223.1.3.27
subnet
223.1.3.1
223.1.3.2

IP Addresses

- CIDR: Classless InterDomain Routing
- Subnet portion (or network prefix) of address of arbitrary length
- Address format: `a.b.c.d/x`, where `x` is # bits in subnet portion of address

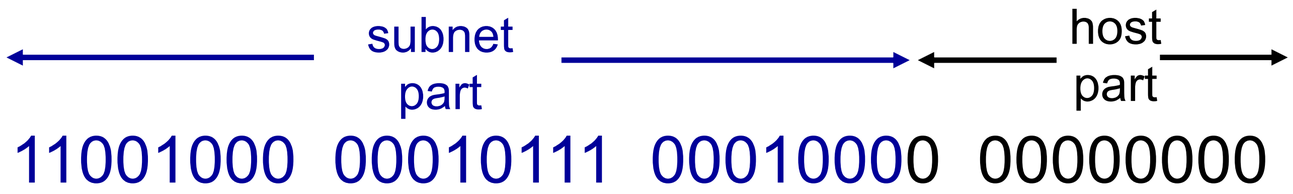
`200.23.16.0/23`

`11001000 00010111 00010000 00000000`

`/23 = 255.255.254.0`

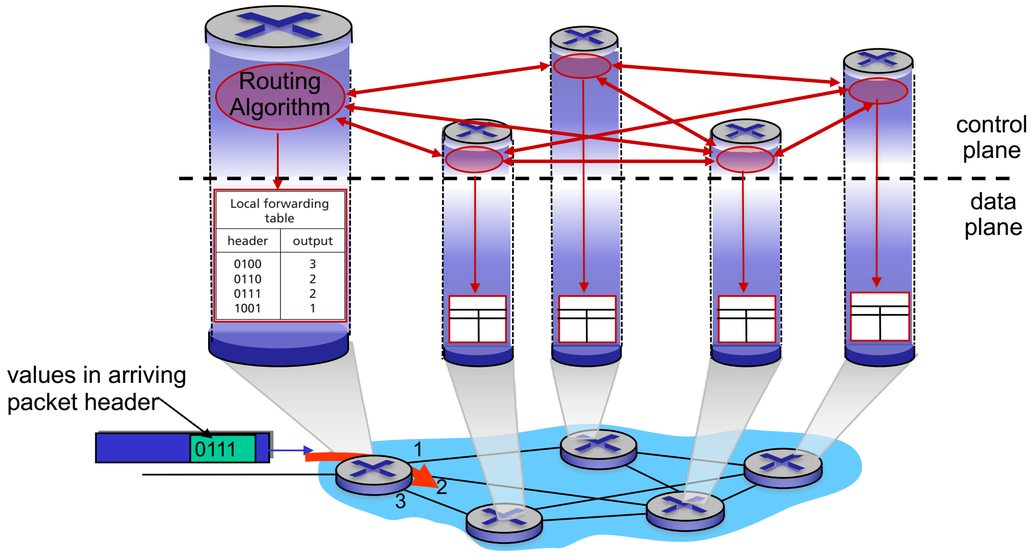
IP Addresses

- Used for identification



IP Addresses

- Used for location
  - Longest prefix matching



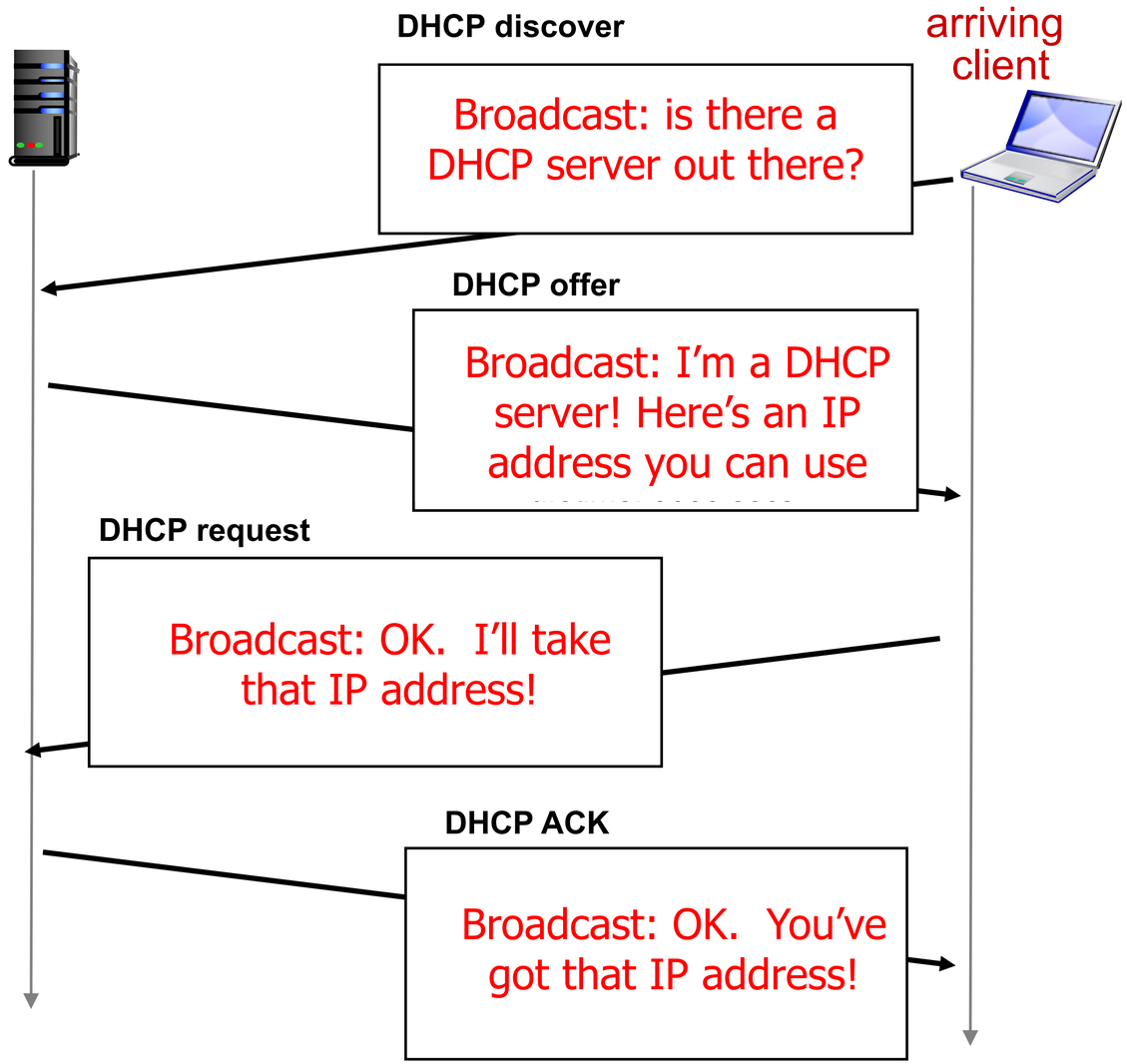
IP Addresses

- How does a host get an IP address?
  - Set a static IP address
  - DHCP

Dynamic Host Configuration Protocol (DHCP)

- Allow host to dynamically obtain an IP address from network server when it joins the network
- IP address get reserved (leased) for certain amount of time
- Can renew its lease on address its already using
- After lease expires, IP address can be used for another device

DHCP


DHCP discover
arriving client
Broadcast: is there a DHCP server out there?
DHCP offer
Broadcast: I'm a DHCP server! Here's an IP address you can use
DHCP request
Broadcast: OK. I'll take that IP address!
DHCP ACK
Broadcast: OK. You've got that IP address!

Special address blocks

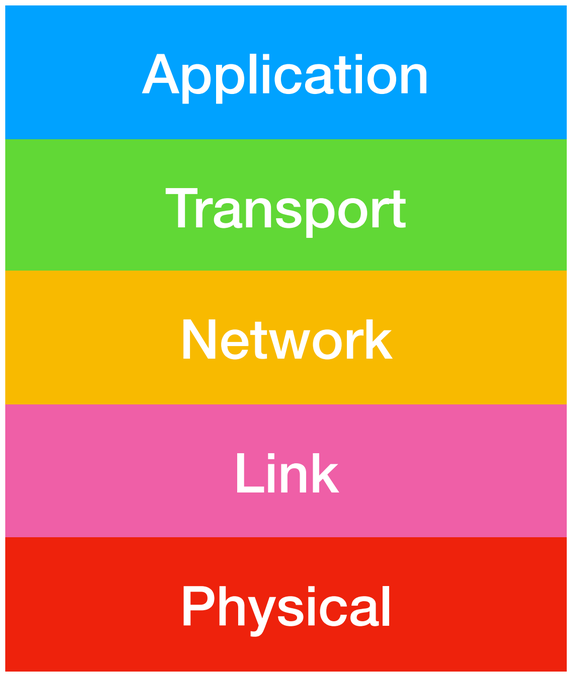
Address block	Address range	Number of addresses	Scope	Description
0.0.0.0/8	0.0.0.0–0.255.255.255	16 777 216	Software	Current network[1] (only valid as source address).
10.0.0.0/8	10.0.0.0–10.255.255.255	16 777 216	Private network	Used for local communications within a private network.[2]
100.64.0.0/10	100.64.0.0–100.127.255.255	4 194 304	Private network	Shared address space[3] for communications between a service provider and its subscribers when using a carrier-grade NAT.
127.0.0.0/8	127.0.0.0–127.255.255.255	16 777 216	Host	Used for loopback addresses to the local host.[1]
169.254.0.0/16	169.254.0.0–169.254.255.255	65 536	Subnet	Used for link-local addresses[4] between two hosts on a single link when no IP address is otherwise specified, such as would have normally been retrieved from a DHCP server.
172.16.0.0/12	172.16.0.0–172.31.255.255	1 048 576	Private network	Used for local communications within a private network.[2]
192.0.0.0/24	192.0.0.0–192.0.0.255	256	Private network	IETF Protocol Assignments.[1]
192.0.2.0/24	192.0.2.0–192.0.2.255	256	Documentation	Assigned as TEST-NET-1, documentation and examples.[5]
192.88.99.0/24	192.88.99.0–192.88.99.255	256	Internet	Reserved.[6] Formerly used for IPv6 to IPv4 relay[7] (included IPv6 address block 2002::/16).
192.168.0.0/16	192.168.0.0–192.168.255.255	65 536	Private network	Used for local communications within a private network.[2]
198.18.0.0/15	198.18.0.0–198.19.255.255	131 072	Private network	Used for benchmark testing of inter-network communications between two separate subnets.[8]
198.51.100.0/24	198.51.100.0–198.51.100.255	256	Documentation	Assigned as TEST-NET-2, documentation and examples.[5]
203.0.113.0/24	203.0.113.0–203.0.113.255	256	Documentation	Assigned as TEST-NET-3, documentation and examples.[5]
224.0.0.0/4	224.0.0.0–239.255.255.255	268 435 456	Internet	In use for IP multicast.[9] (Former Class D network).
240.0.0.0/4	240.0.0.0–255.255.255.254	268 435 456	Internet	Reserved for future use.[10] (Former Class E network).
255.255.255.255/32	255.255.255.255	1	Subnet	Reserved for the "limited broadcast" destination address.[1][11]

Case Study

Case Study

Case Study

Case Study


Application
Transport
Network
Link
Physical

Link Layer

- Takes care of transferring data from two physically adjacent devices (one hop)
- Data can transfer different link protocols (e.g., Ethernet, fiber, 802.11)
- Each link provides different services

Multiple Access Protocols

- Single shared broadcast channel
- Two or more simultaneous transmissions by nodes interfere
- Collision — if node receives two or more signals at the same time
- Multiple access protocols
  - Distributed algorithm that determines how nodes share channel
  - Communication about channel sharing must use channel itself

MAC Protocols

- Channel partitioning
- Random access
- Taking turns