Internet Architecture Overview

These slides have been adapted from the Pearson slides. S. Thomson 01/2017.

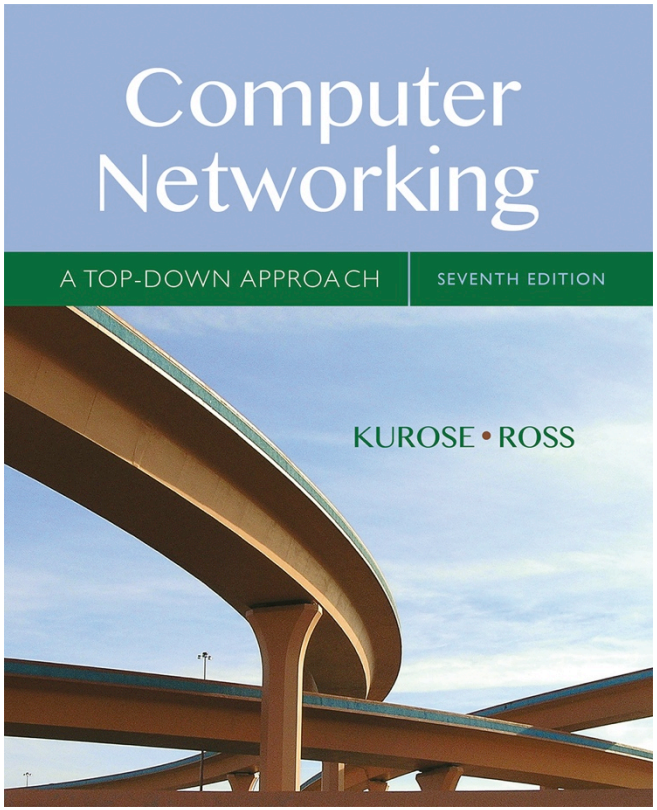
A note on the use of these Powerpoint slides:

We're making these slides freely available to all (faculty, students, readers). They're in PowerPoint form so you see the animations; and can add, modify, and delete slides (including this one) and slide content to suit your needs. They obviously represent a *lot* of work on our part. In return for use, we only ask the following:

- If you use these slides (e.g., in a class) that you mention their source (after all, we'd like people to use our book!)
- If you post any slides on a www site, that you note that they are adapted from (or perhaps identical to) our slides, and note our copyright of this material.

Thanks and enjoy! JFK/KWR

©All material copyright 1996-2016
J.F Kurose and K.W. Ross, All Rights Reserved



Computer Networking: A Top Down Approach

7th edition
Jim Kurose, Keith Ross
Pearson/Addison Wesley
April 2016

Goal of Course

How the Internet works,

and

Why it works that way

Course Outcomes

- Explain how the Internet works
  - Internet architecture
  - Protocol layering and modularity
  - Naming and addressing
  - Management, Control and Data planes
- Network Programming
  - Socket API
  - Protocol design
  - Protocol implementation
- Key concepts
  - Design principles
  - Best current practices

Outline

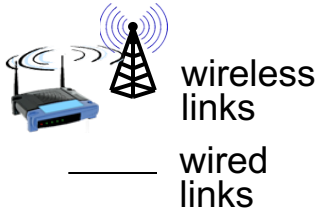
- What is the Internet?
  - A Topology View
  - A Services View
  - A Protocol View
- What is a protocol?
- Internet Architecture
  - Original Goals
  - Packet switching
  - Protocol Stack
  - Naming and addressing
- Internet History

What is the Internet?

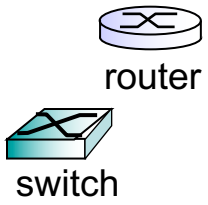
- What do you think of when you hear the term Internet?

What is the Internet: Topology View

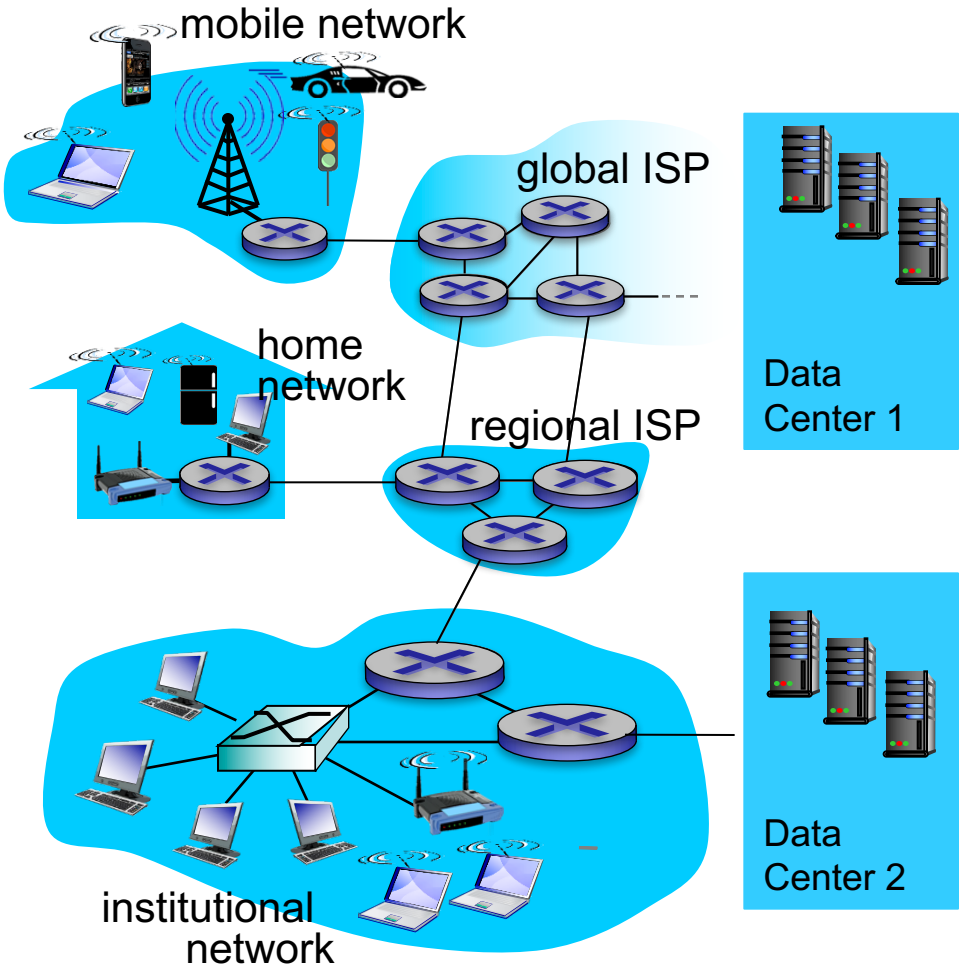
- billions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*



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

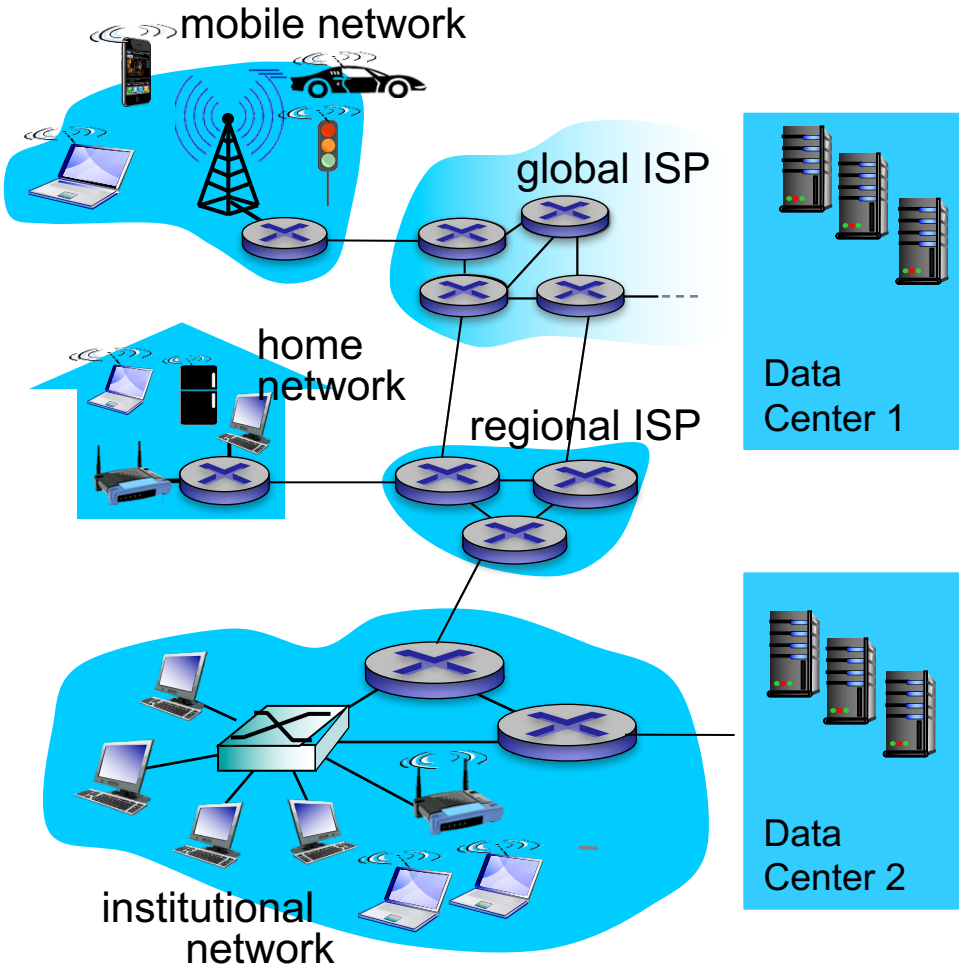


- *packet switches:* forward packets (chunks of data)
  - *routers* and *switches*



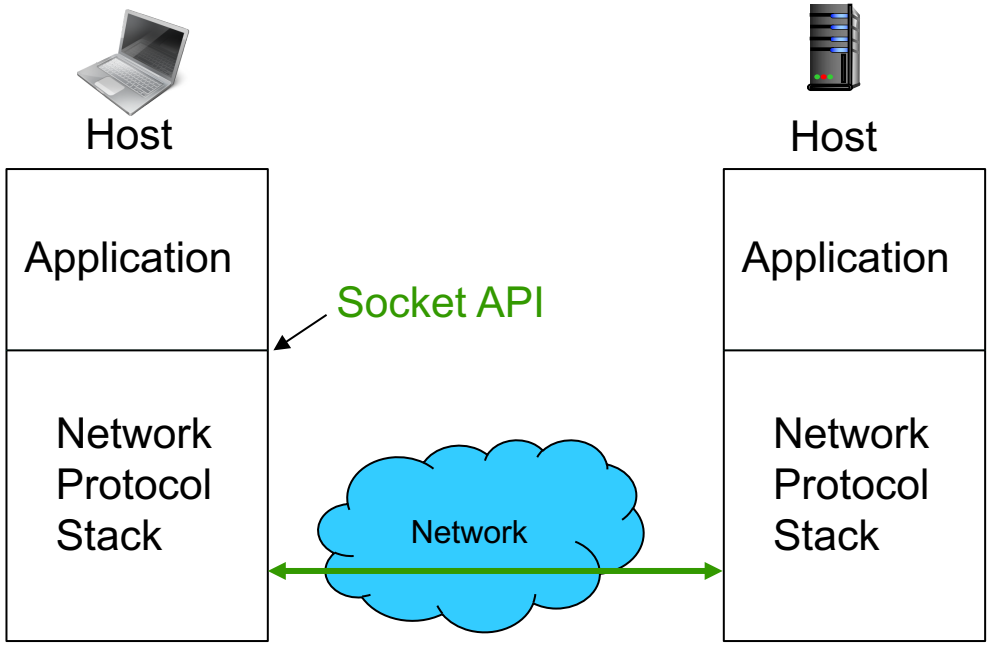
What is the Internet: Topology View

- *Network:*
  - Supports communication between interconnected hosts
  - LAN, MAN, WAN
- *Internet:* "network of networks"
  - Interconnected ISPs



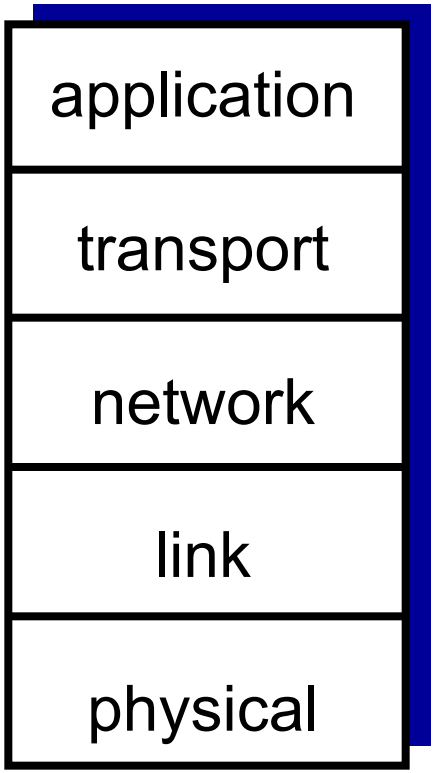
What is the Internet: Services View

- *infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social media, …
- *provides programming interface to apps*
  - hooks that allow sending and receiving app programs to "connect" to Internet
  - provides service options, analogous to postal service



What is the Internet: Protocol View

- *protocols* control sending, receiving of messages
  - e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's a protocol?

human protocols:

- "what's the time?"
- "I have a question"
- introductions

… specific messages sent

… specific actions taken when messages received, or other events

network protocols:

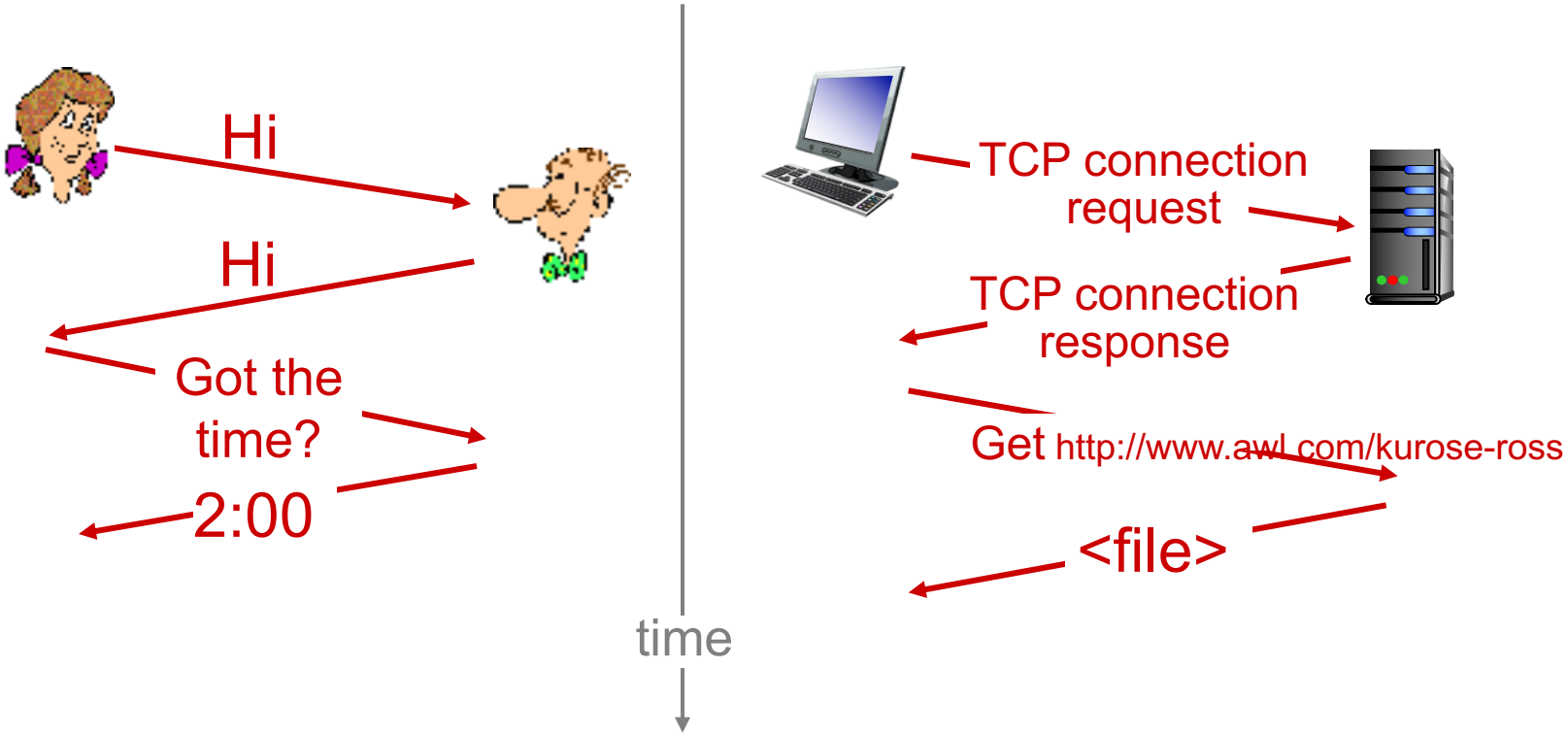
- machines rather than humans
- all communication activity in Internet governed by protocols

protocols define format, order of messages sent and received among network entities, and actions taken on message transmission, receipt

i.e. syntax and semantics

What's a protocol?

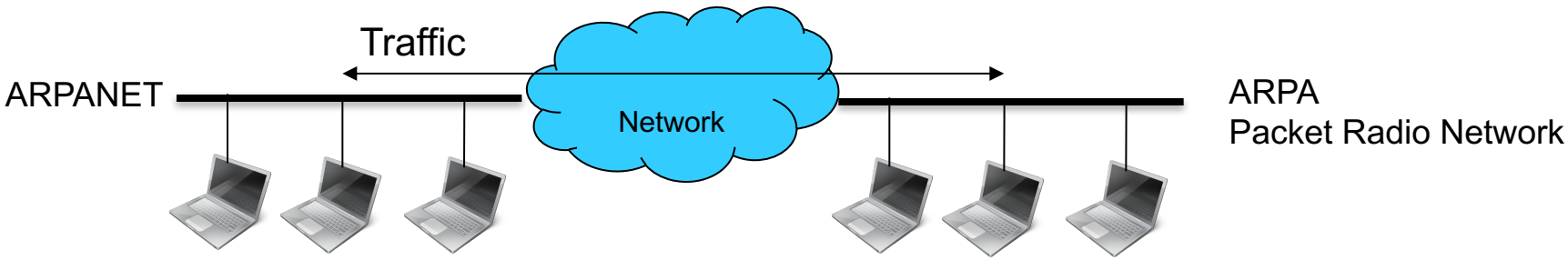
a human protocol and a computer network protocol:



Q: other human protocols?

Internet Architecture: Original Motivation

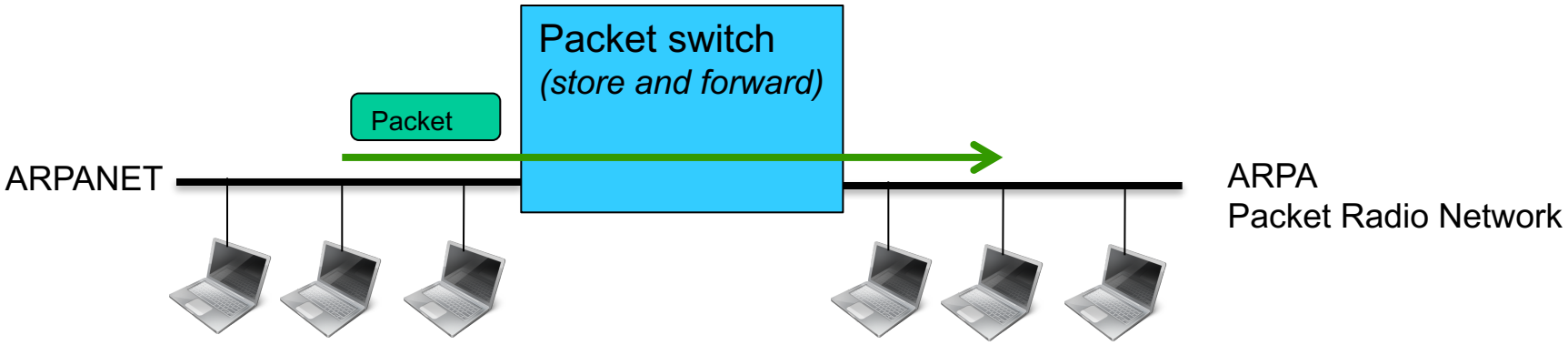
- Clue is in the name: *Inter*-net
- "Multiplexed utilization of existing interconnected networks"



Internet Architecture: Packet Switching

Achieving the goal of multiplexing (sharing)

- One technique for multiplexing is Packet Switching:
  - Application data is broken up into packets of some maximum size
  - No connection set-up; forwarding based on destination IP address
  - "Best-effort" service

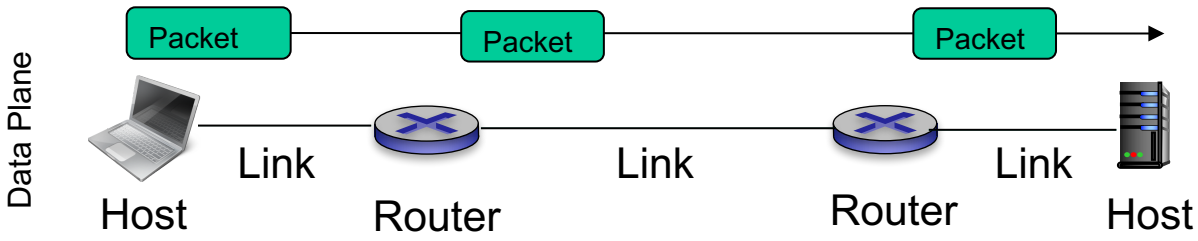


Internet Architecture: Packet Switching

Achieving the goal of multiplexing (sharing)

- Components:
  - Hosts: Transmit and receive application packets of length L
  - Routers: Store and forward packets
  - Links: Propagate packets

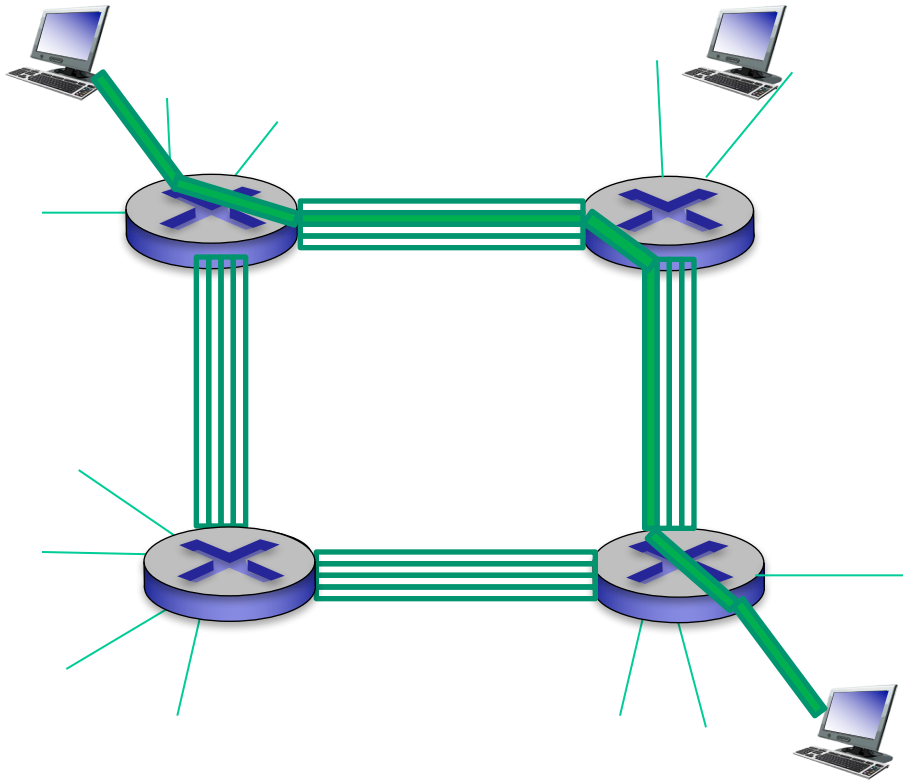
- Note:
  - A router may also act as a host e.g. management



Alternative Architecture: circuit switching

end-end resources allocated to, reserved for "call" between source & dest:

- in diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- commonly used in traditional telephone networks

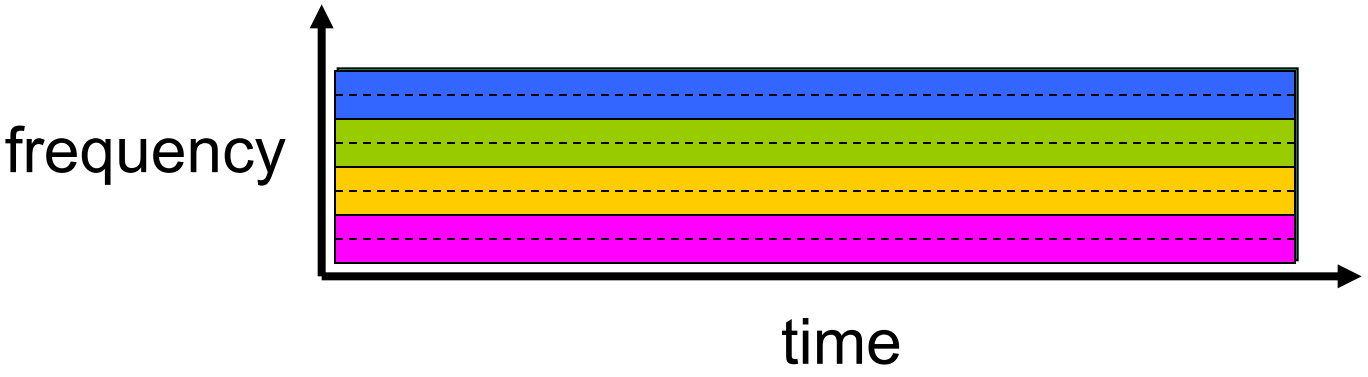


Circuit switching: FDM versus TDM

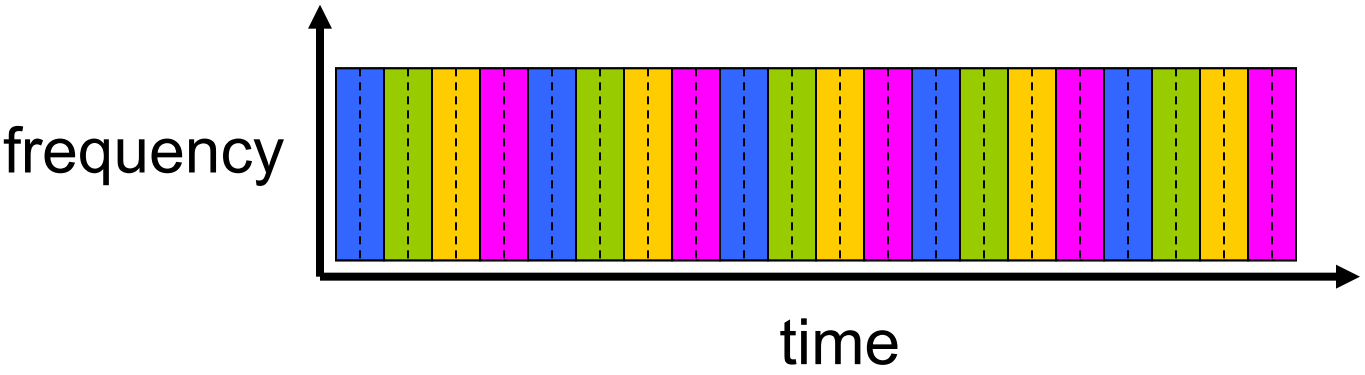
Example:

4 users

FDM



TDM



Packet switching versus circuit switching

is packet switching a "slam dunk winner?"

- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- *Q:* How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 7)

Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

Internet Architecture: Secondary Goals

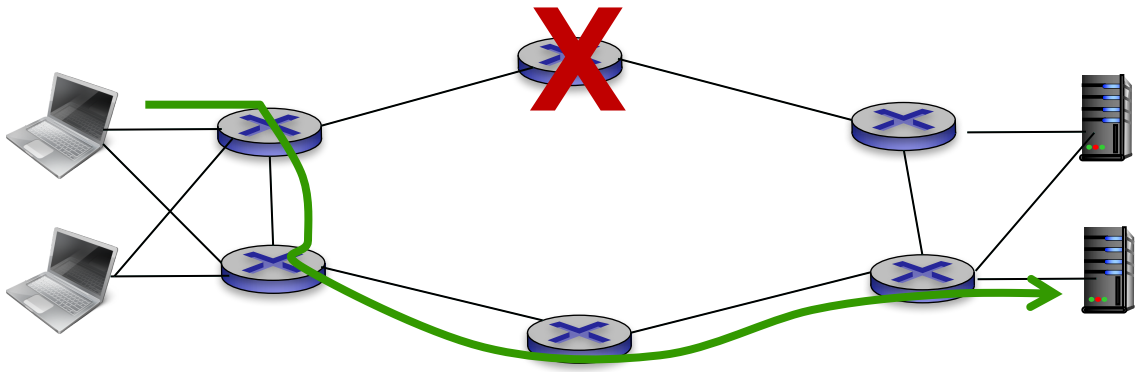
To achieve effective inter-connection

1. Communication must continue despite loss of networks or routers
2. Must support multiple services to accommodate applications with different network requirements
3. Must support a variety of link technologies
4. Must support distributed management
5. Must be cost-effective
6. Must allow host attachment with low-level of effort
7. Resources must be accountable

Different goals, priorities would have resulted in a different architecture.
Lesson: Clearly define problem statement and requirements

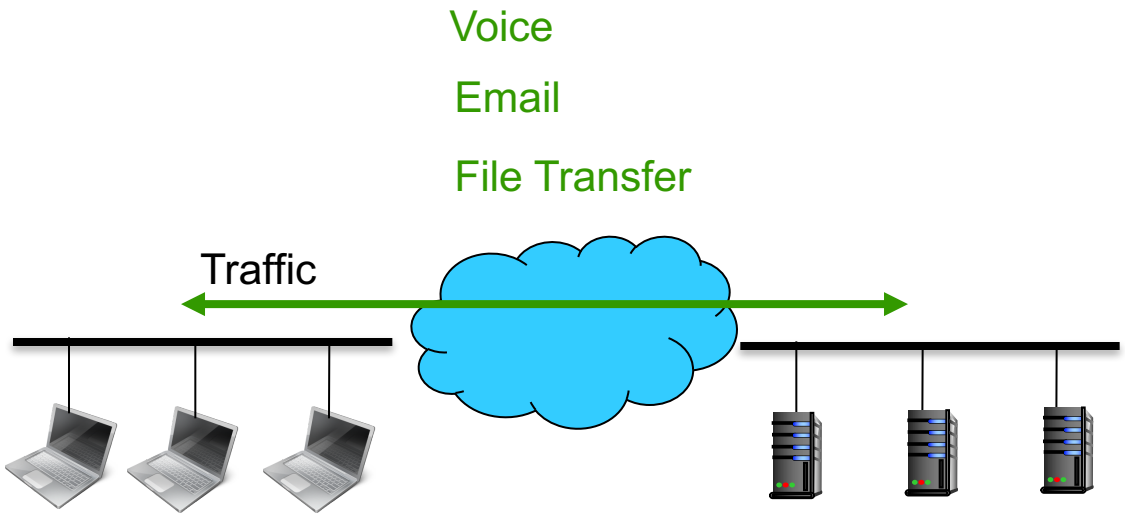
Internet Architecture: Secondary Goals

- Goal 1
- Communication continuity in face of network failures



Internet Architecture: Secondary Goals

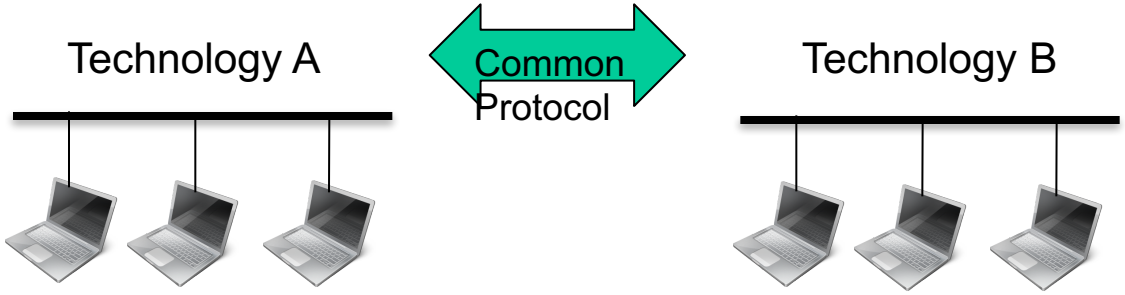
- Goal 2
- Support multiple applications with varying network requirements



Internet Architecture: Secondary Goals

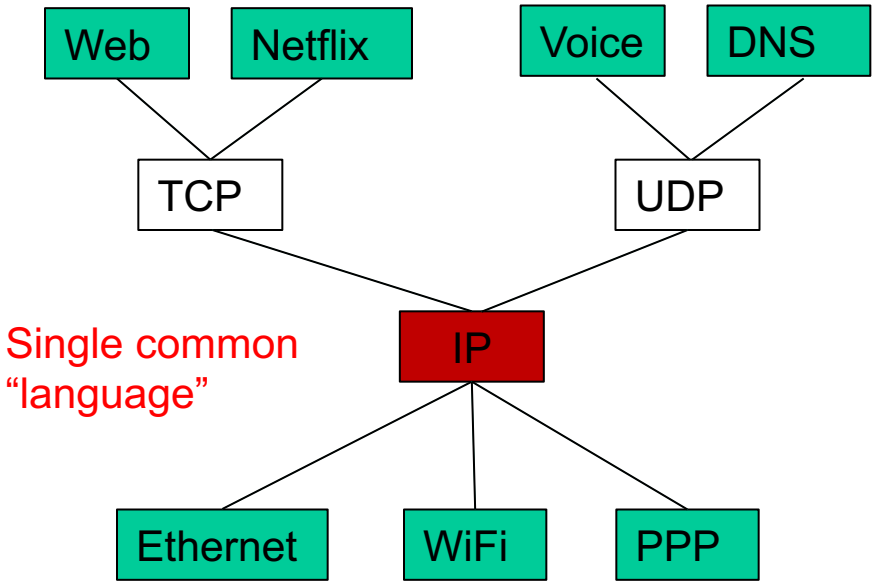
- Goal 3

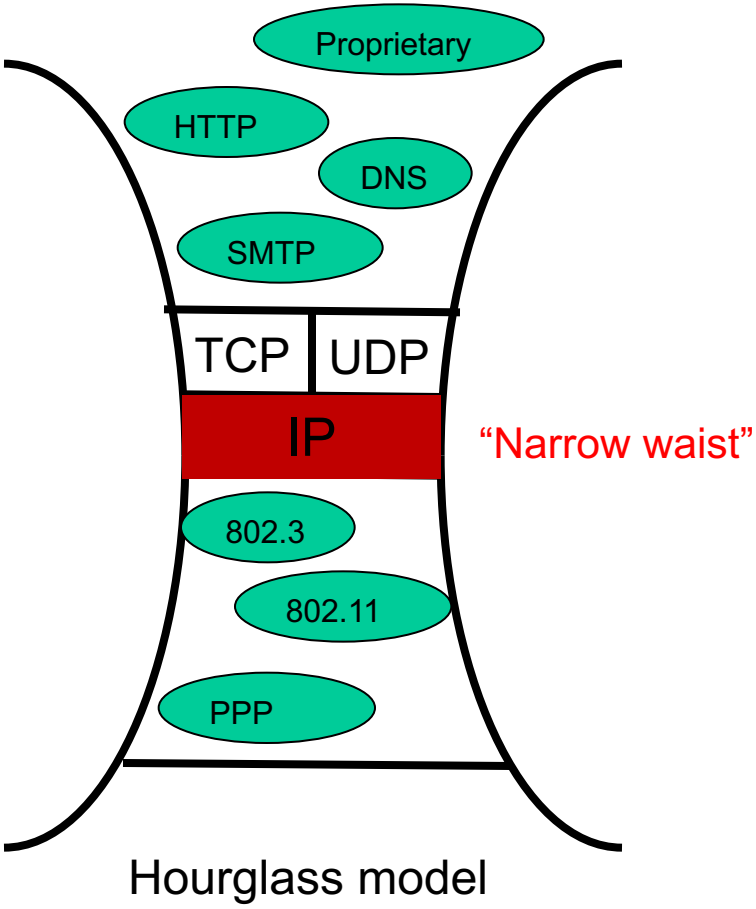
- Enable networks using different link technologies to communicate with each other (without translation)



Internet Architecture: Hour-glass model

Achieving the goal of inter-connection



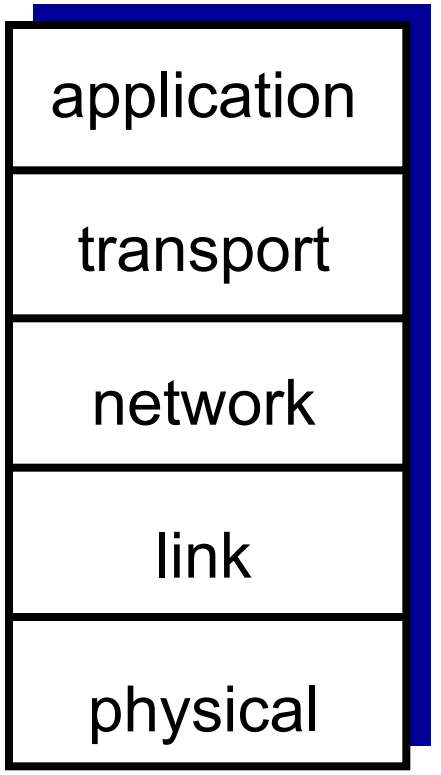


Hourglass model

Highly successful at accomplishing goals, *but* transport and IP Layer have proved hard to evolve

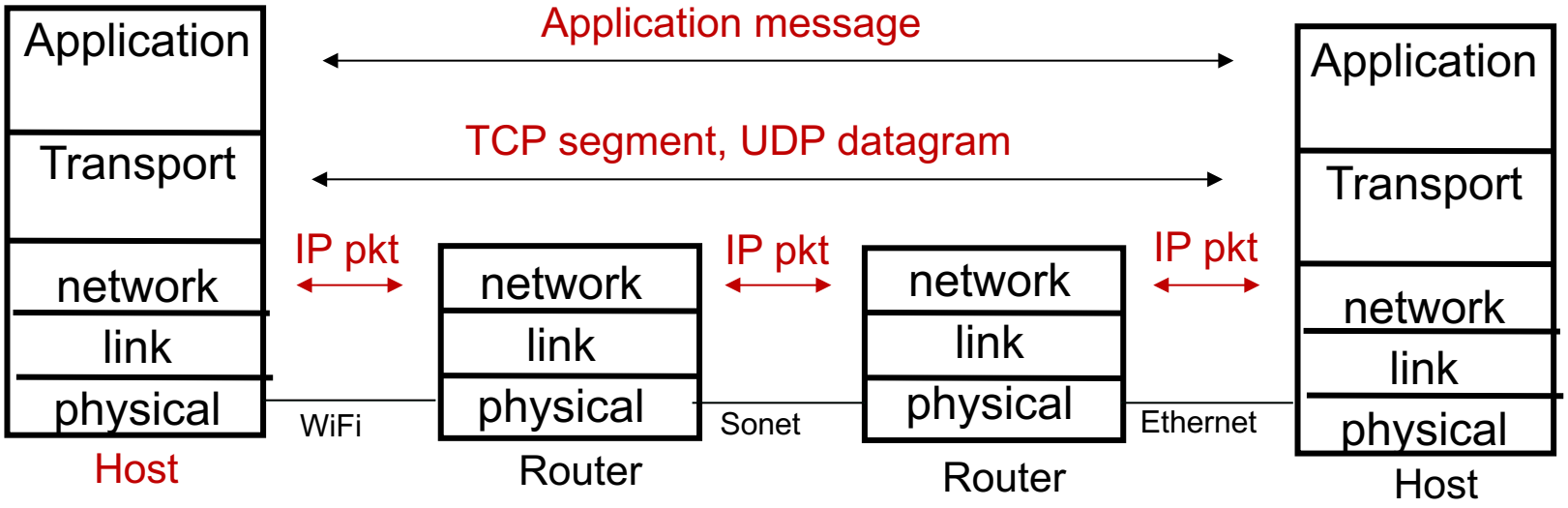
Internet Architecture: Protocol Stack

- *application:* supporting network applications
  - SMTP, HTTP, VoIP
- *transport:* process-process data transfer
  - TCP, UDP
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP
- *physical:* bits "on the wire"

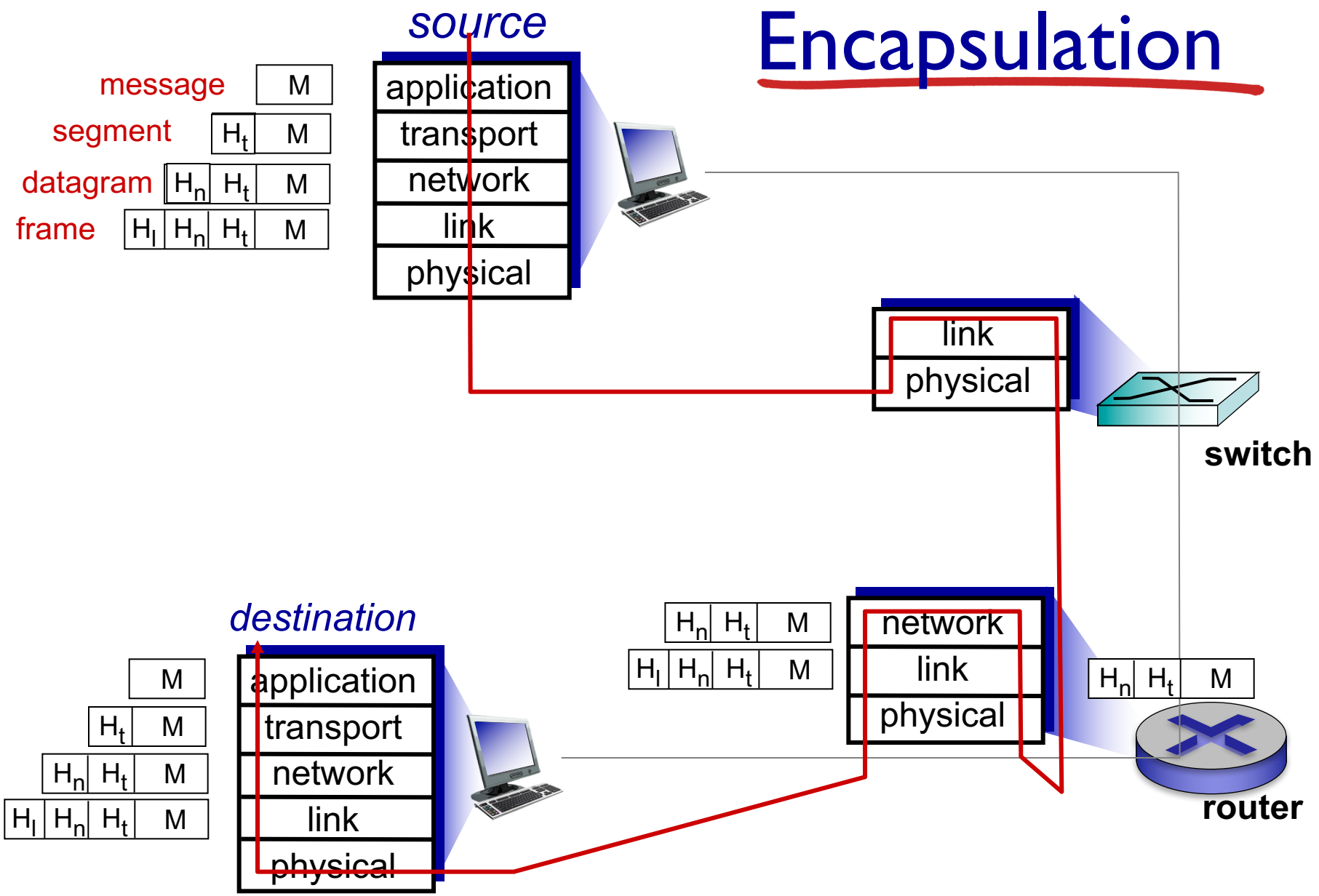


Internet Architecture: Protocol Stack Hosts vs Routers

- Hosts run all 5 layers of protocol stack; routers only 3 layers
- Hosts responsible for applications and transport.
- Routers run network layer only



Encapsulation



Internet Architecture: Inter-connection
Achieving Secondary Goals

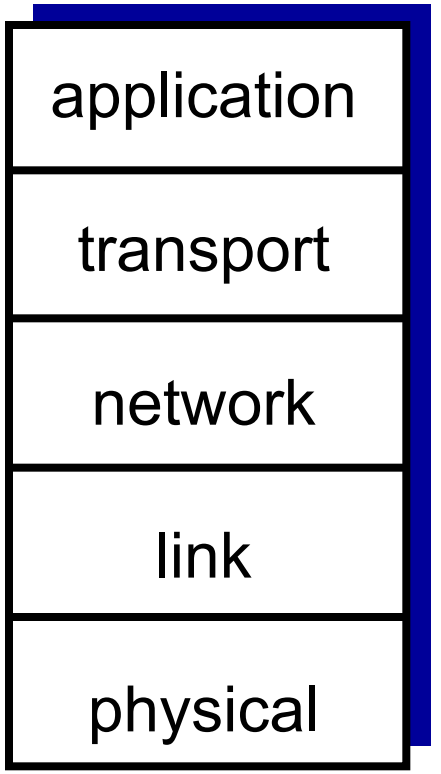
- Goal 1: Application and Transport Intelligence (state) in hosts, not network
  - When network failures occur, hosts can continue communicating as long as there is an available route (fate sharing)
    - Alternative: state maintained reliably in network (complex)

- Goal 2: Two Transport services offered (TCP and UDP), Reliable vs Unreliable service

- Goal 3: Minimal requirements from link-layer means IP can run over many link technologies

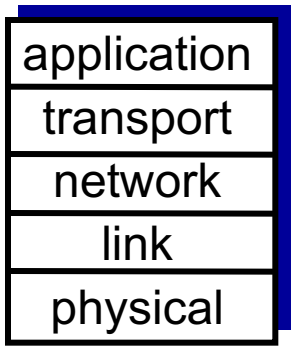
Protocol Stack: Why layering?

- Modularity
  - Export services to layers above
  - Use services from layers below
- Interfaces
  - Hide implementation details
  - Implementation may evolve without impacting other layers



Design Consideration: Duplication of functions at multiple layers e.g. error detection and correction.

Internet Architecture: Naming and Addressing

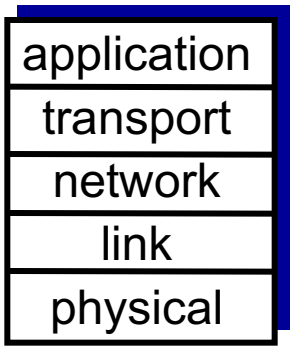


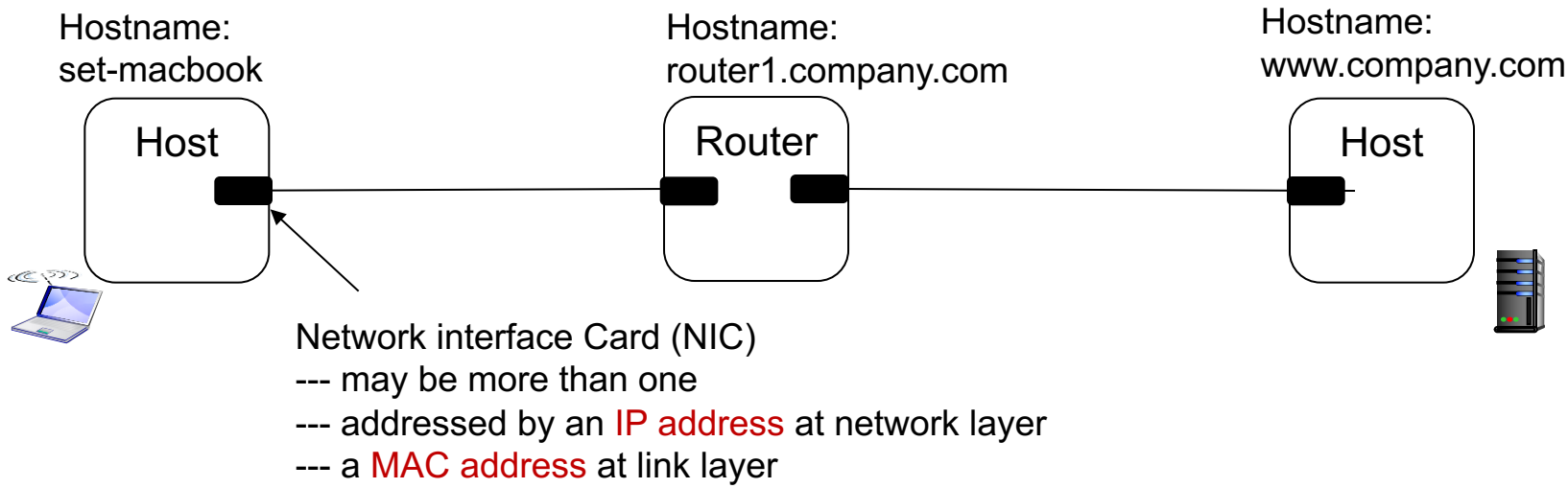
Application-dependent
e.g. web URL, Skype name, Email address
A fundamental name for any host is DNS FQDN

IP address, port

IP address

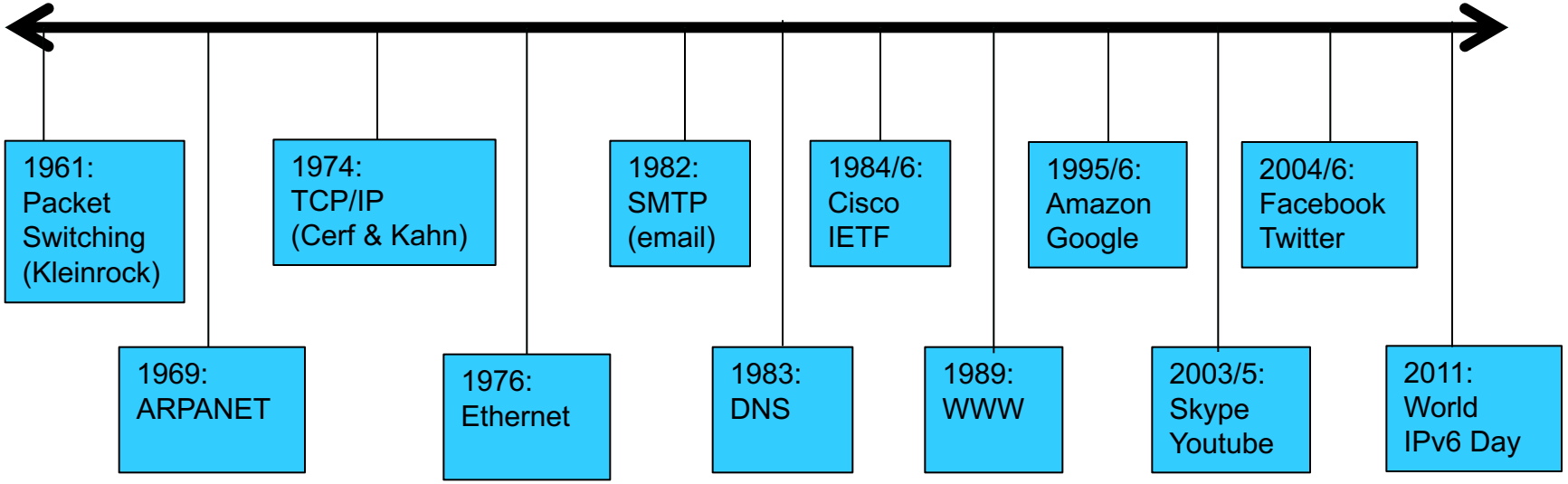
MAC address (802 networks)



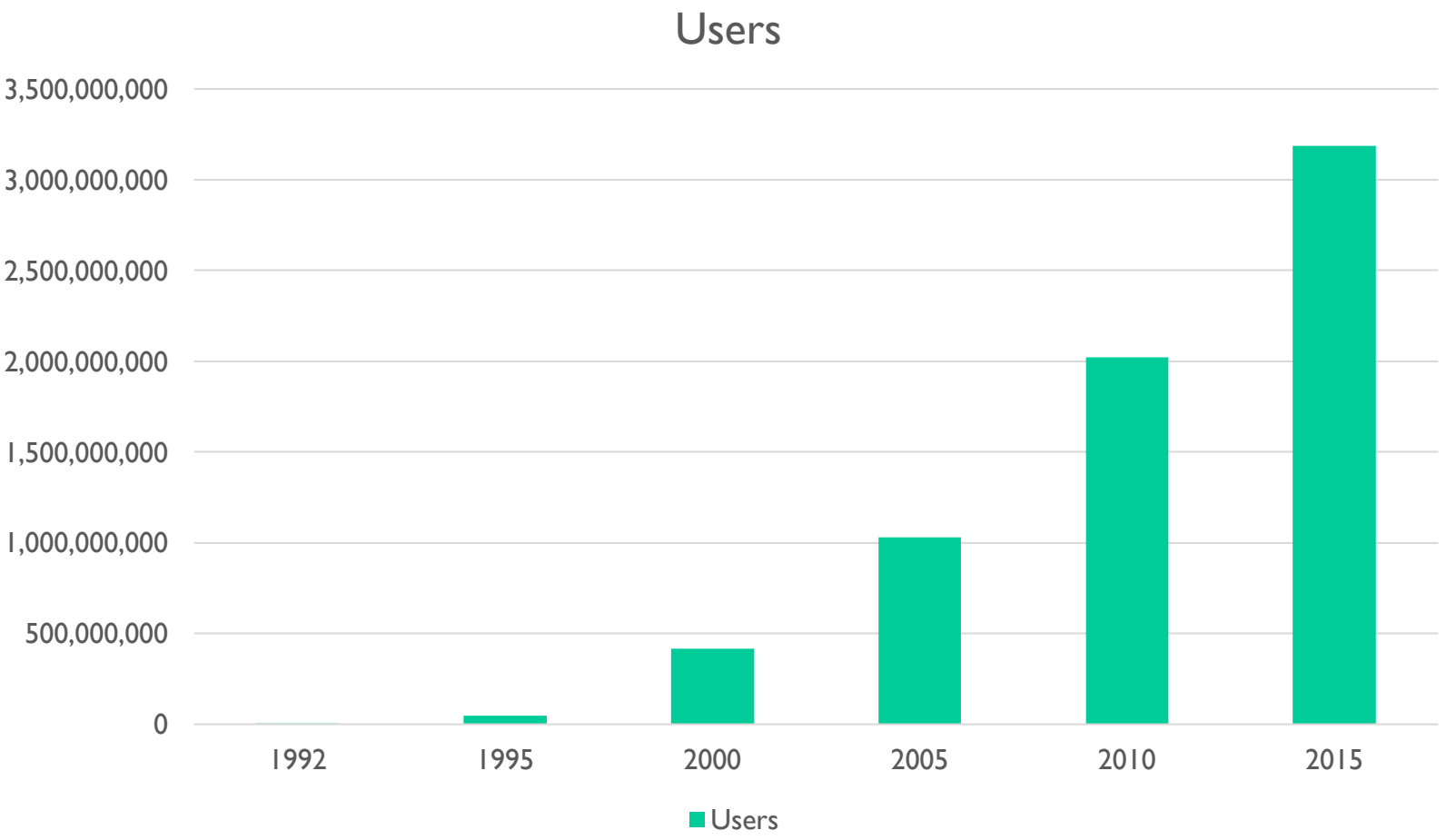


Network interface Card (NIC)
--- may be more than one
--- addressed by an IP address at network layer
--- a MAC address at link layer

Internet History
A selected timeline



Internet Growth



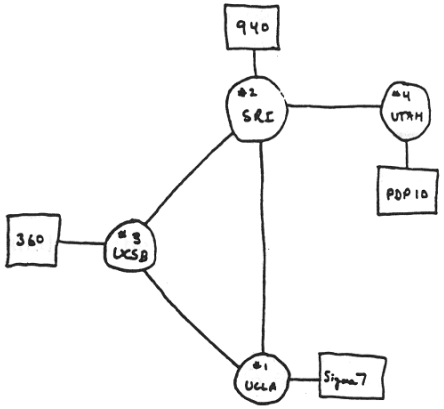
(*) Number of Internet-connected devices is 2-3 times higher in 2015

Internet history

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational

- 1972:
  - ARPAnet public demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



THE ARPA NETWORK

Internet history

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

Internet history

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control

- new national networks: CSnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet history

1990, 2000's: commercialization, the Web, new apps

- early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

late 1990's – 2000's:

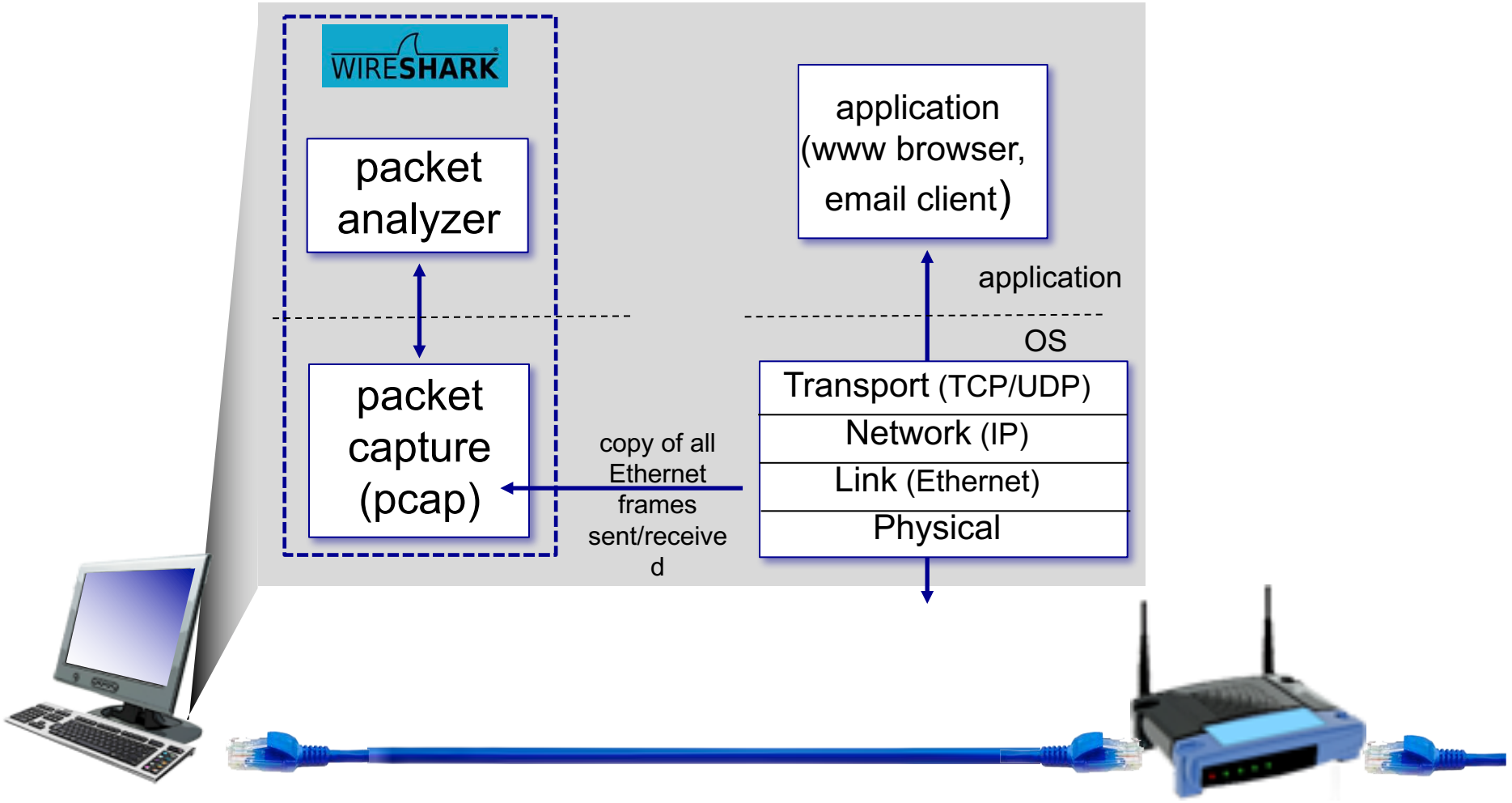
- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Internet history

2005-present

- ~5B devices attached to Internet (2016)
  - smartphones and tablets
- aggressive deployment of broadband access
- increasing ubiquity of high-speed wireless access
- emergence of online social networks:
  - Facebook: ~ one billion users
- service providers (Google, Microsoft) create their own networks
  - bypass Internet, providing "instantaneous" access to search, video content, email, etc.
- e-commerce, universities, enterprises running their services in "cloud" (e.g., Amazon EC2)

Chapter 1
Additional Slides


WIRESHARK
packet analyzer
packet capture (pcap)
application (www browser, email client)
application
OS
Transport (TCP/UDP)
Network (IP)
Link (Ethernet)
Physical
copy of all Ethernet frames sent/received