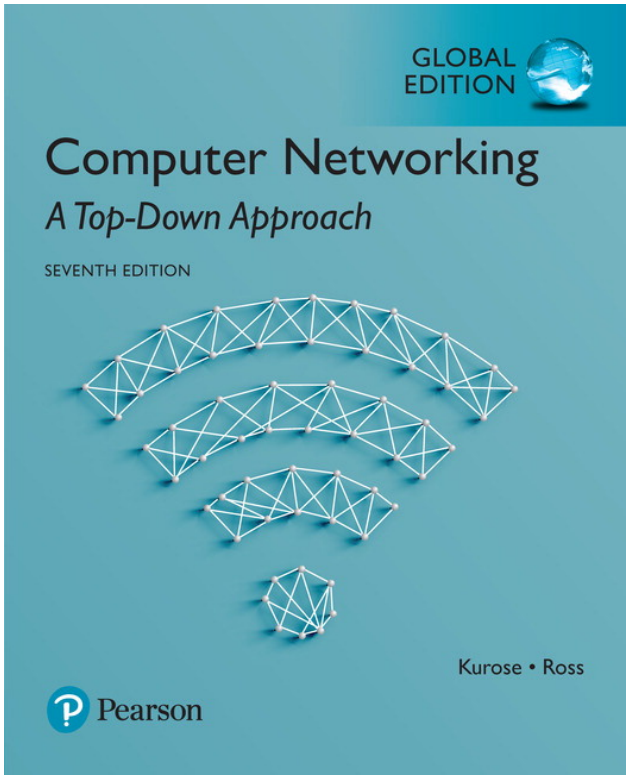
Chapter 1
Introduction



Computer Networking: A Top Down Approach, Global Edition, 7/E. Jim Kurose, Keith Ross. Pearson, Nov 2016.

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Thanks and enjoy! JFK/KWR

Chapter 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

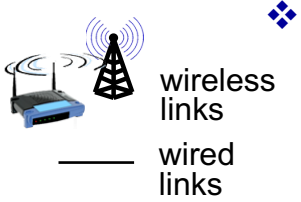
1.5 protocol layers, service models

1.6 networks under attack: security

1.7 history

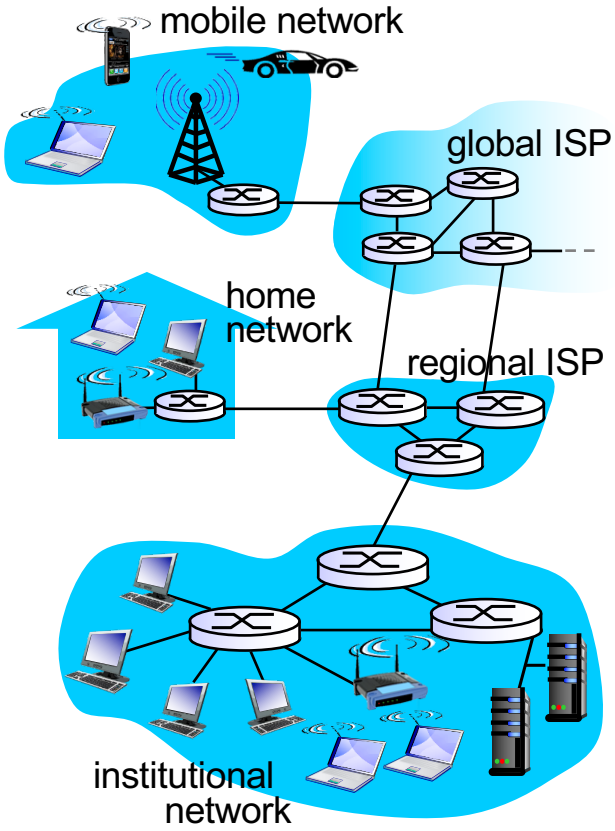
What's the Internet: "nuts and bolts" view

- millions/billions of connected computing devices:
  - *hosts* = *end systems*
  - running *network applications*



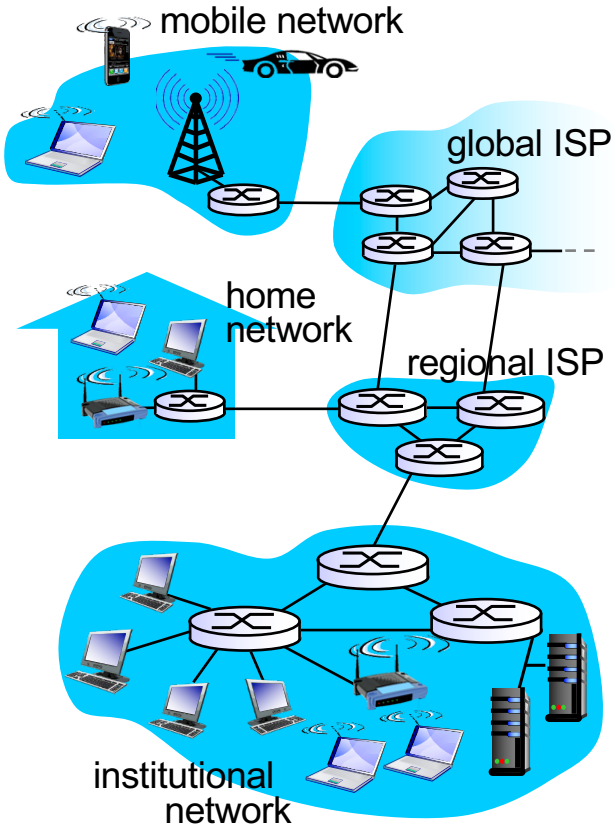
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: *bandwidth*

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



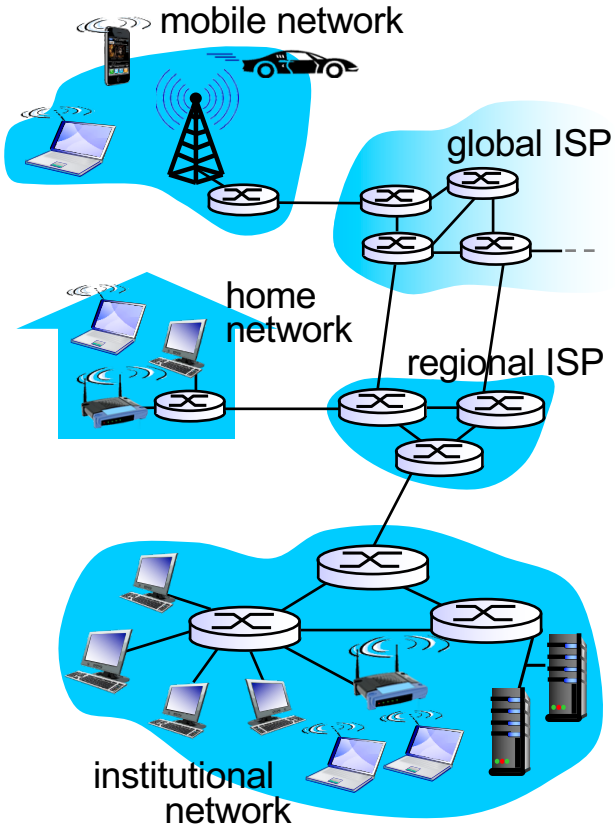
What's the Internet: "nuts and bolts" view II

- *Internet:* "network of networks"
  - Interconnected ISPs
    - Internet Service Providers
- *protocols* control sending and receiving of messages
  - e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet: a service view

- *Infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social networks, streaming audio and video, …
- *provides programming interface to applications*
  - hooks that allow sending and receiving application programs to "connect" to Internet
  - provides service options, analogous to postal service



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

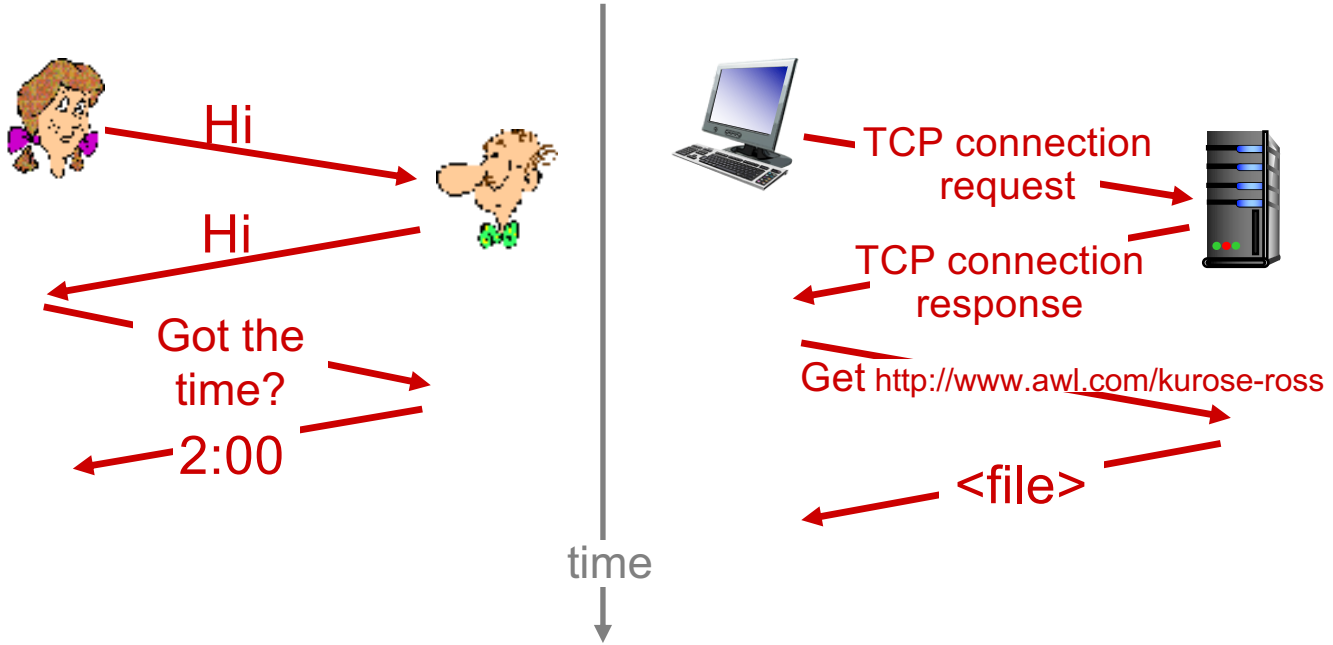
network protocols:

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

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

What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

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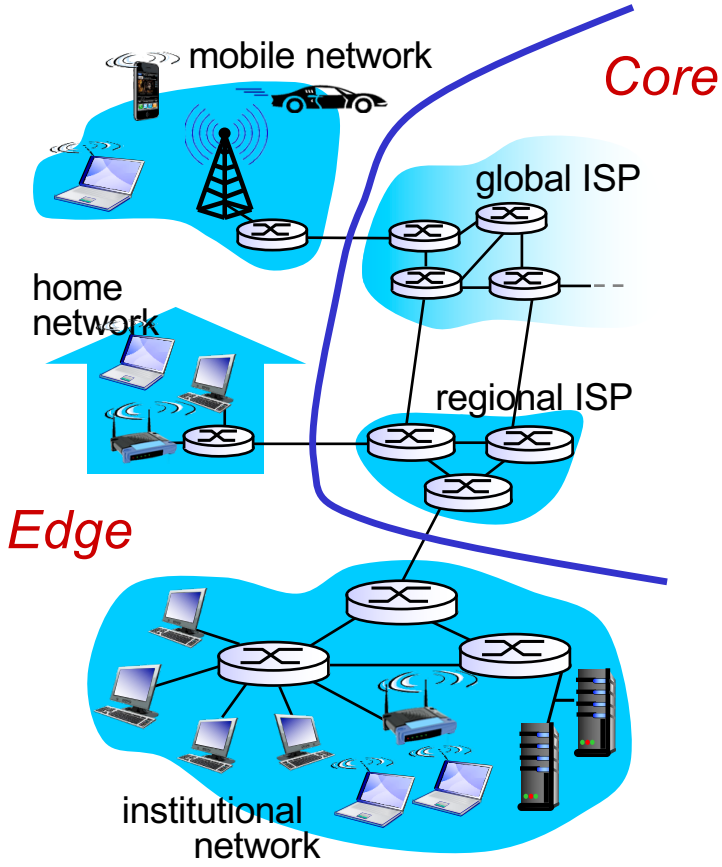
A closer look at network structure:

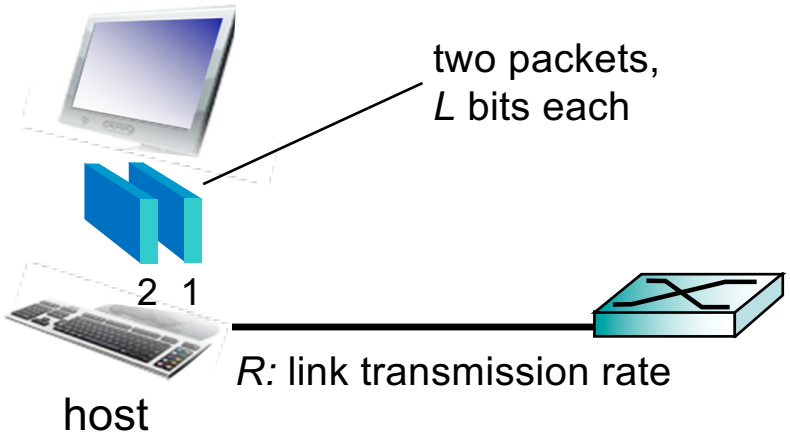
- *network edge:*
  - hosts: clients and servers
  - servers often in data centers
- *access networks, physical media:* wired or wireless communication links
- *network core:*
  - interconnected routers
  - network of networks



Host: sends *packets* of data

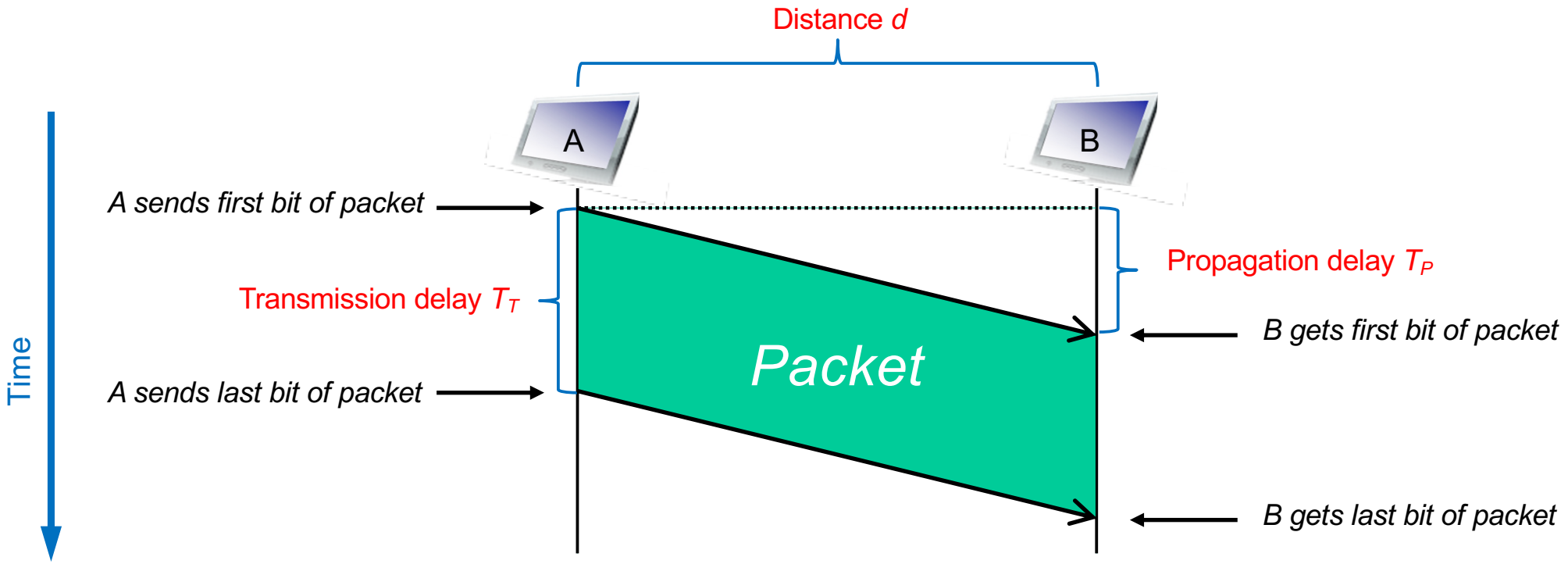
host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length *L* bits
- transmits packet on *link* into access network
- Links are *serial*
  - packets transmitted one bit at a time, at a certain rate *R*
  - link *transmission rate,* link *capacity,* or link *bandwidth*



$$\text{packet transmission delay} = \text{time needed to transmit a packet with } L \text{ bits into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Transmission and Propagation Delay



Time from A starts sending until B has received entire packet:

$$T = T_T + T_P = \frac{L}{r} + \frac{d}{s}$$

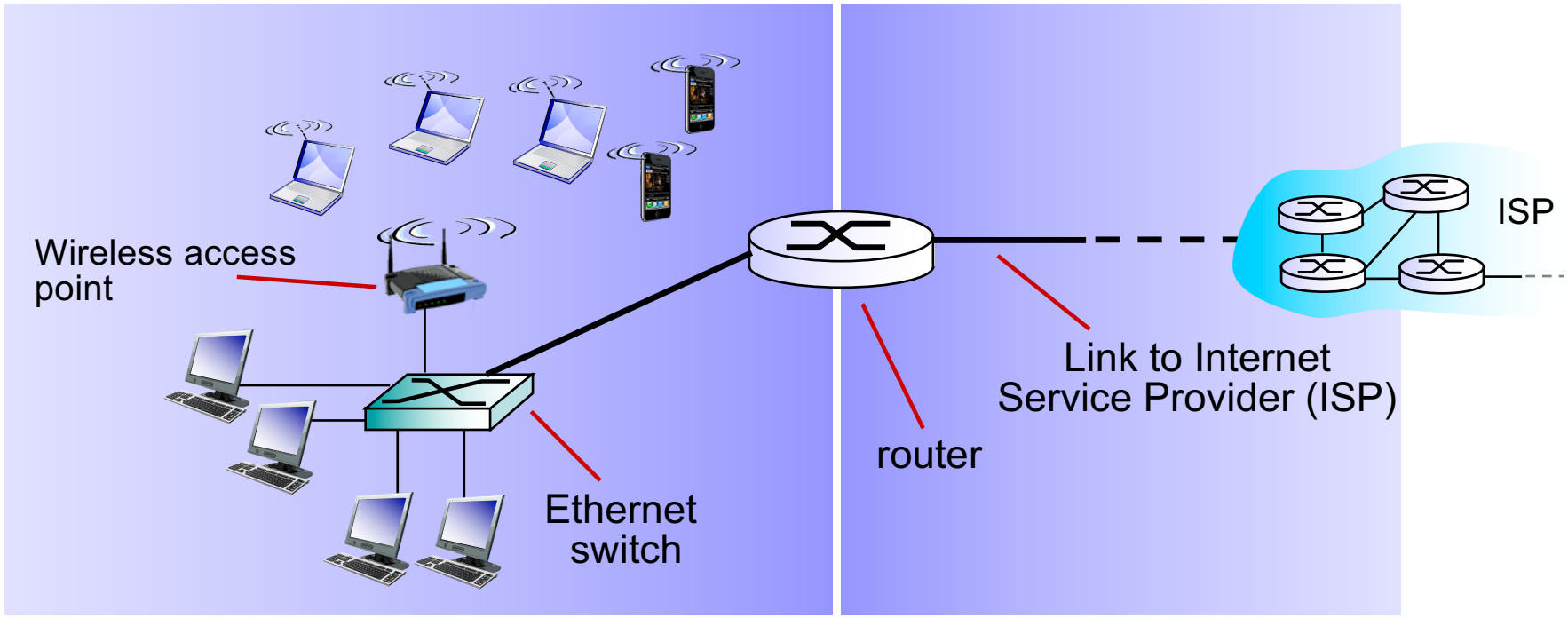
L packet size (bit)
r link rate (bit/s)
s propagation speed (m/s)
d distance (m)

A Note on Data Rates

- Bit rate, bandwidth and capacity
  - Used interchangeably in networking
  - Different concepts, but closely related
- Qualified as bits per second
- Abbreviated as "bit/s"
- SI prefixes
  - kilobit per second, "kbit/s" (10^3)
  - megabit per second, "Mbit/s" (10^6)
  - gigabit per second, "Gbit/s" (10^9)
  - terabit per second, "Tbit/s" (10^{12})
  - petabit per second, "Pbit/s" (10^{15})
  - exabit per second, "Ebit/s" (10^{18})
  - …
- Less formally, also "bps" or "b/s"
  - Textbook uses "bps"

- Some confusion in the computing business
- For instance, in storage, "giga" or "G" sometimes also mean 2^{30} (1,073,741,824)
  - as in "4 GB of memory" (GB means "gigabyte")
  - "mega" or "M" could mean 220 (1,048,576), "kilo" or "k" could mean 2^{10} (1,024), etc.
  - In this course, we never use prefixes this way!
- The prefixes "kibi" ("Ki"), "mebi" ("Mi"), "gibi" ("Gi"), etc, have been introduced to resolve the ambiguity
  - "Binary prefixes" – power of two
  - kibi is 2^{10}, mibi is 2^{20}, gibi is 2^{30}, tibi is 2^{40}, etc
  - yet to be adopted by industry

Access networks



Local Access

- Home, office, school, hotspots, …
- Wireless Local Area Network (WiFi)
  - IEEE 802.11
    - IEEE 802.11b, IEEE 802.11g, IEEE 802.11n, IEEE 802.11ac, etc.
  - Up to 11, 54, 300, 433, … Mbps
- Ethernet (Wired LAN)
  - IEEE 802.3
  - Copper cable, optical fiber
  - 10/100 Mbps, 1/10/40/100 Gbps

Internet Service Provider Access

- How we connect to the ISP
- xDSL (Digital Subscriber Line)
  - ADSL, ADSL2, ADSL2+, VDSL, …
  - Existing telephone lines
  - 1 – 100 Mbps
- Optical Fiber
  - 10 Mbps – 100 Gbps
- DOCSIS (Data Over Cable Service Interface Specification)
  - DOCSIS/Euro-DOCSIS 1.0/2.0/3.0
  - Internet access over cable TV networks
  - 1 – 200 Mbps
- Wireless broadband
  - 3G, 4G (LTE)
  - Internet access over mobile phone networks
  - 1 Mbps – 1 Gbps

Actual data rates depend on many factors. Reported rates can be considerably lower.

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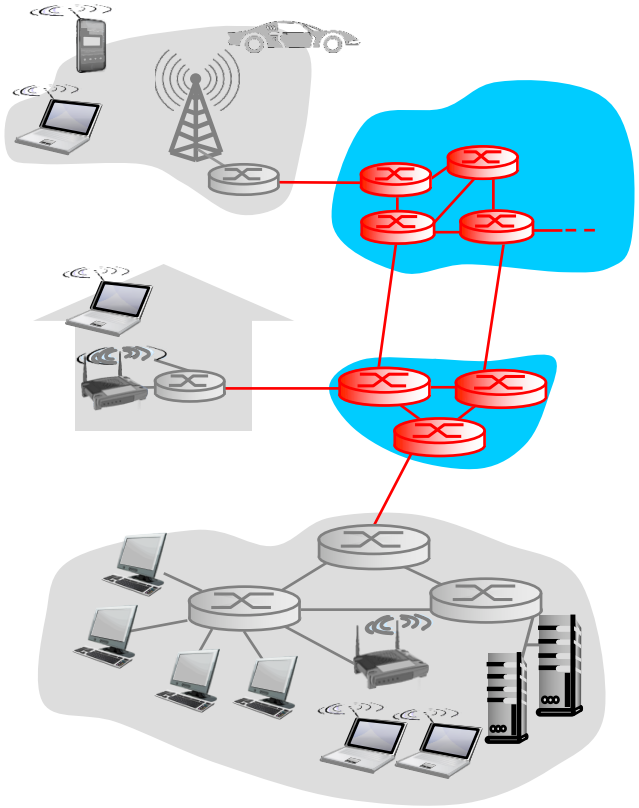
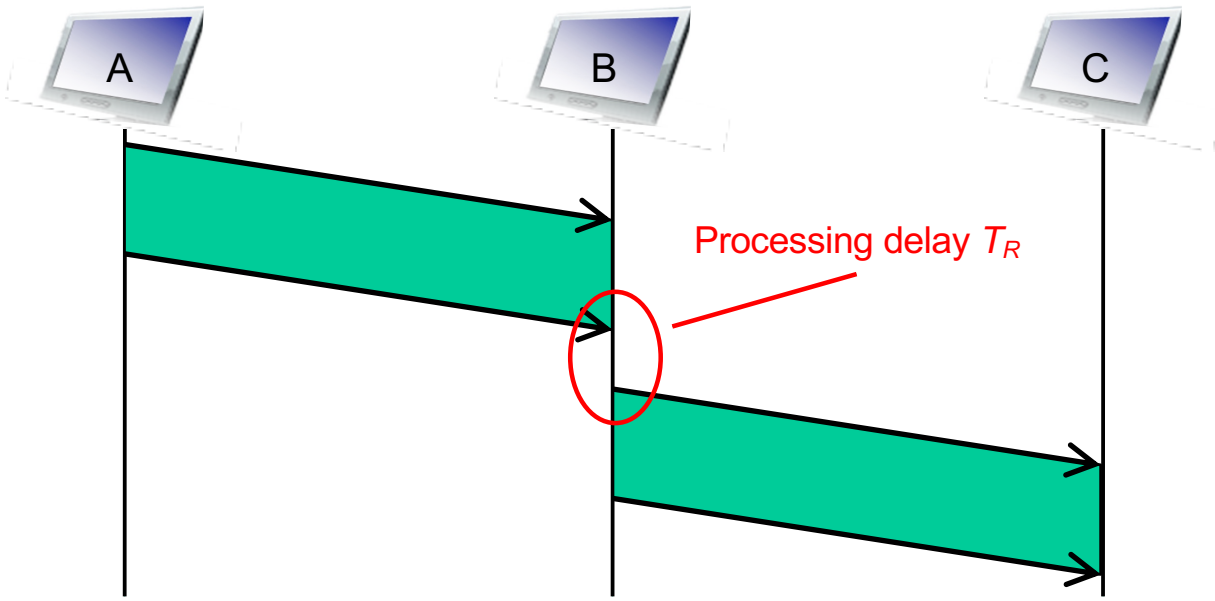
The network core

- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into *packets*
  - forward packets from one router to the next, across links on path from source to destination
  - each packet transmitted at full link capacity



Packet Switching: store-and-forward

- Store-and-forward: entire packet must arrive at a router before it can be transmitted on next link
- Processing delay: it takes some time for router to process packet before transmitting on next link
  - Check and verify packet
  - Decide what to do with it
  - Third delay component: T_R



Time from A starts sending until C has received entire packet (assuming both links have same speed and length):

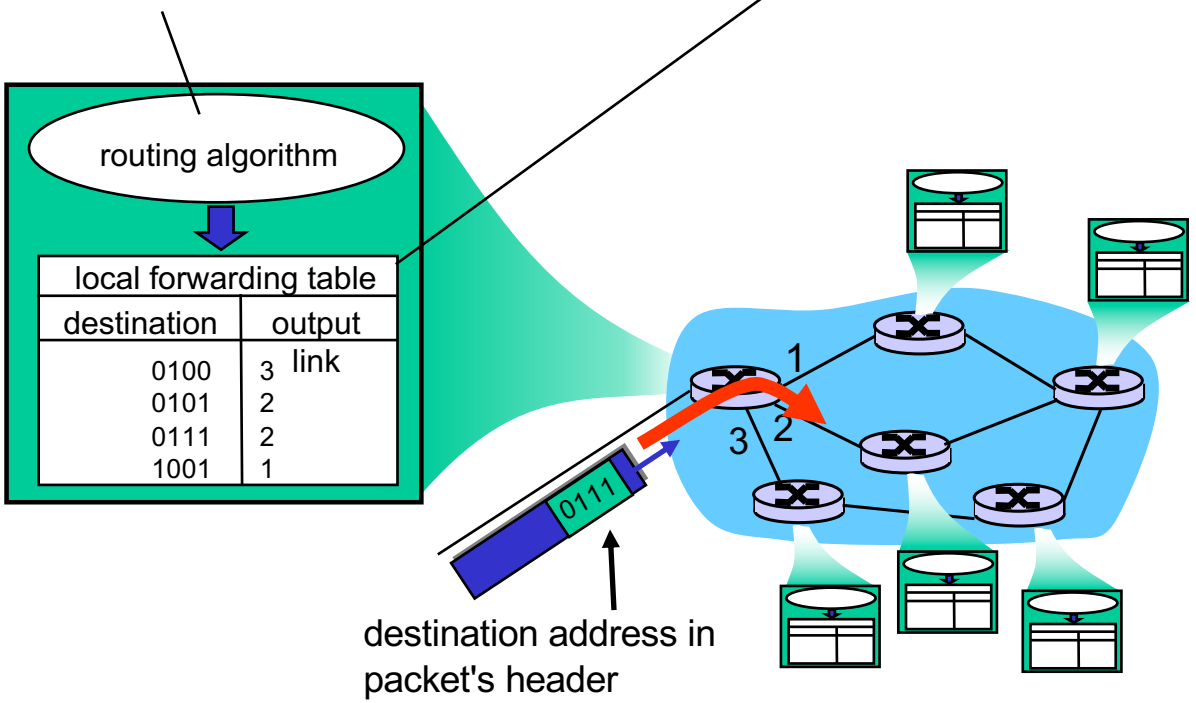
$$T = 2T_T + 2T_P + T_R$$

Two key network-core functions

routing: determines source-destination route taken by packets

- *routing algorithms*

forwarding: move packets from router's input to appropriate output link

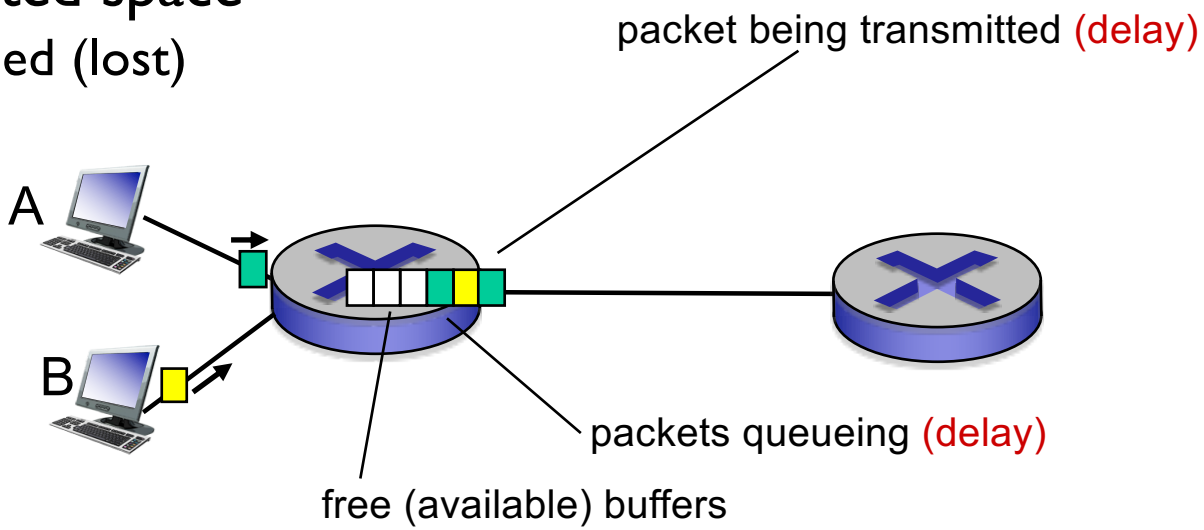


Queuing delay and packet loss

- Only one packet can be sent at a time on a link
- Other packets have to wait in a queue in the router
  - Fourth delay component: queuing delay T_Q
- Packet loss: queues have limited space
  - If queue is full, packet is dropped (lost)

The four delay components

T_T transmission delay
T_P propagation delay
T_R processing delay
T_Q queuing delay

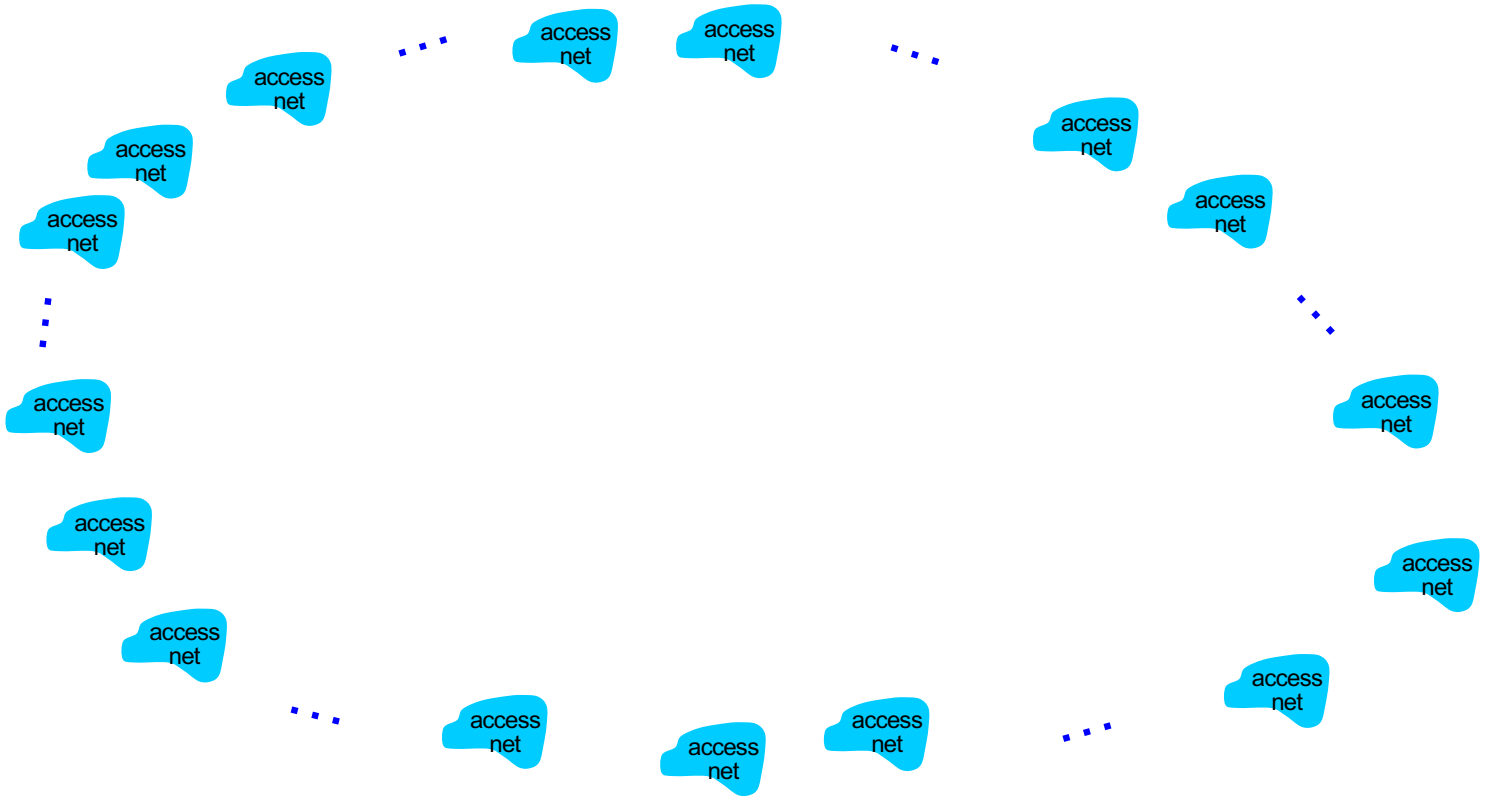


Internet structure: network of networks

- End systems connect to Internet via access ISPs (Internet Service Providers)
  - Residential, company and university ISPs
- Access ISPs in turn must be interconnected.
  - So that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - Evolution was driven by economics and national policies
- Let's take a stepwise approach to describe current Internet structure

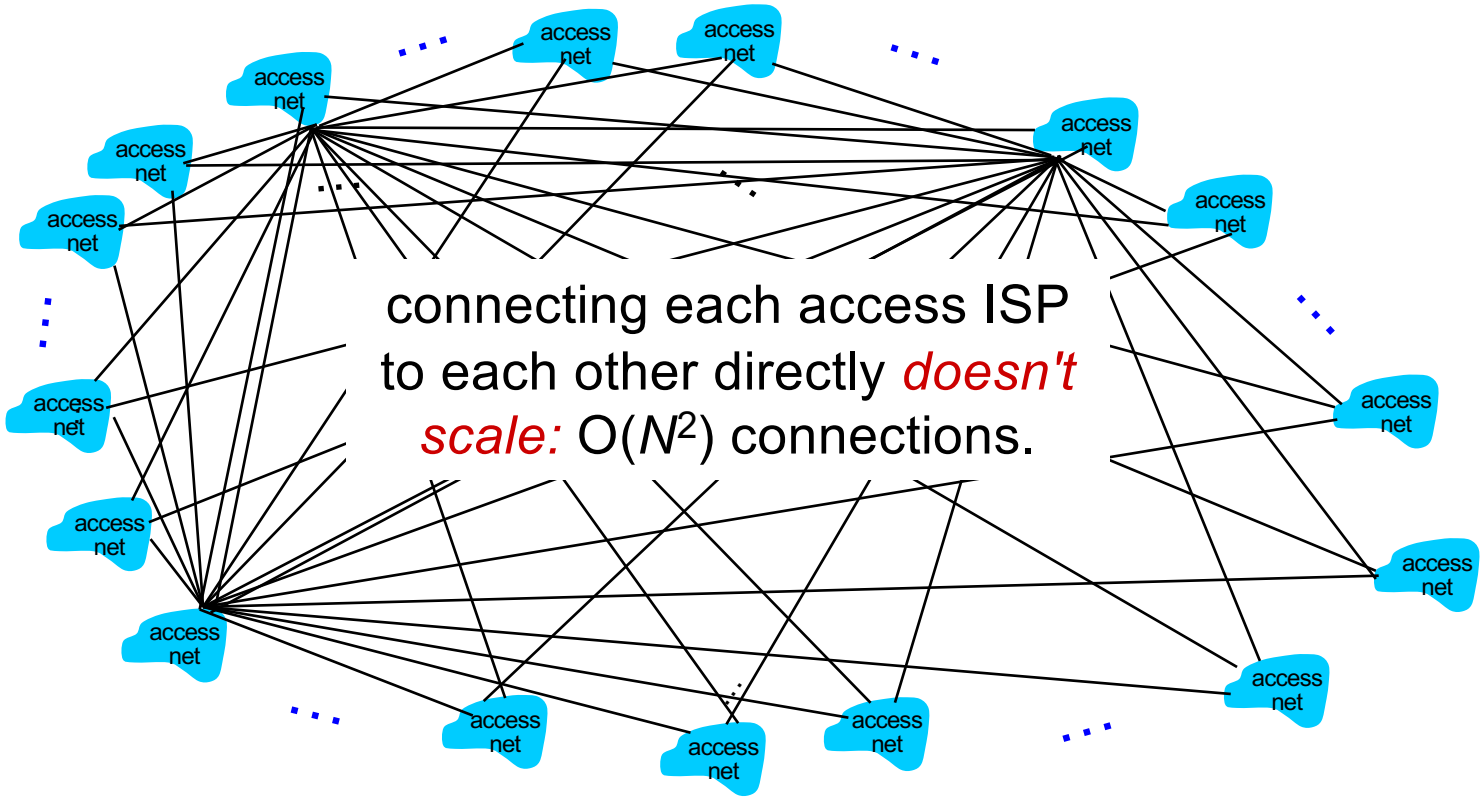
Internet structure: network of networks

Question: given *millions* of access ISPs, how to connect them together?



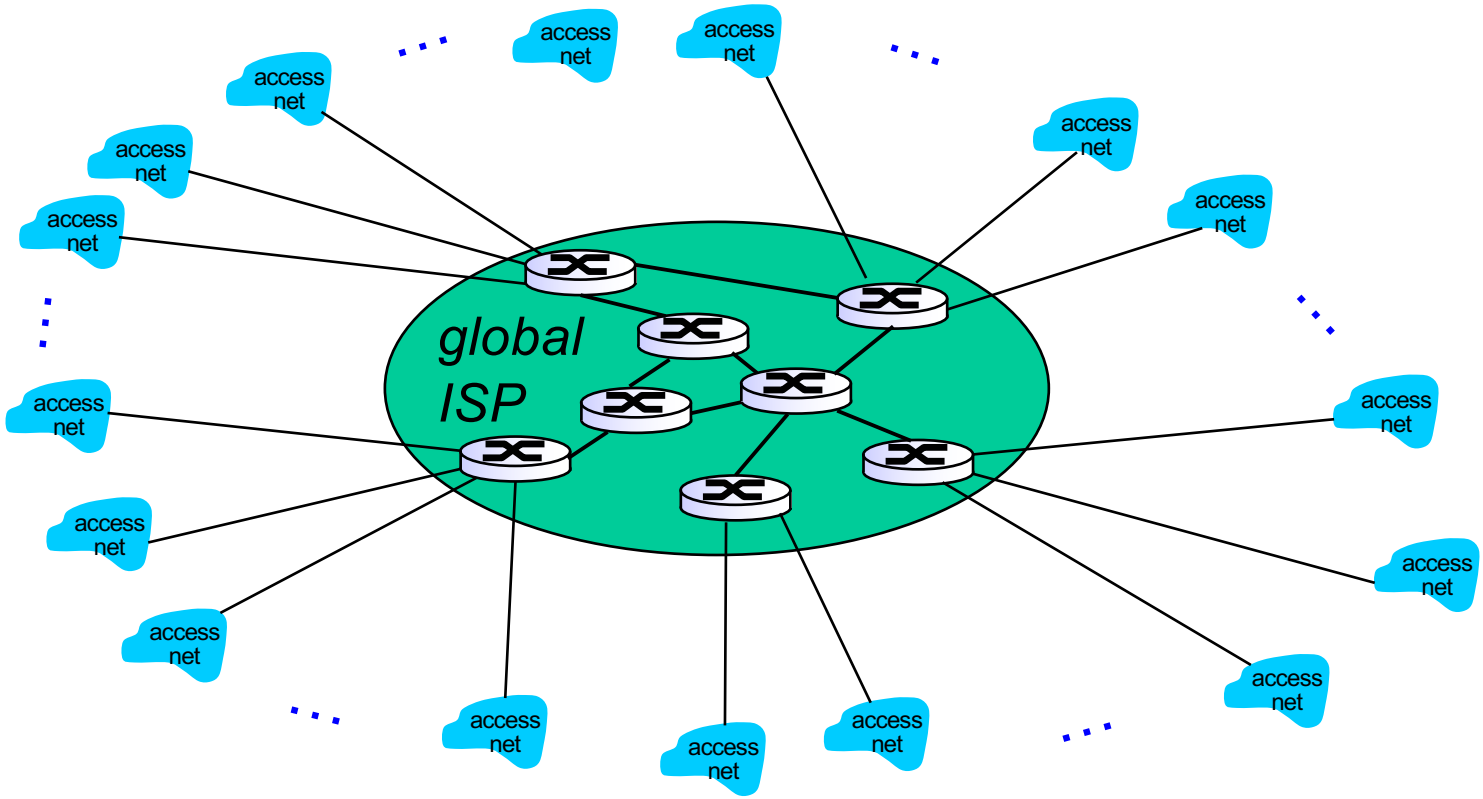
Internet structure: network of networks

Option: connect each access ISP to every other access ISP?



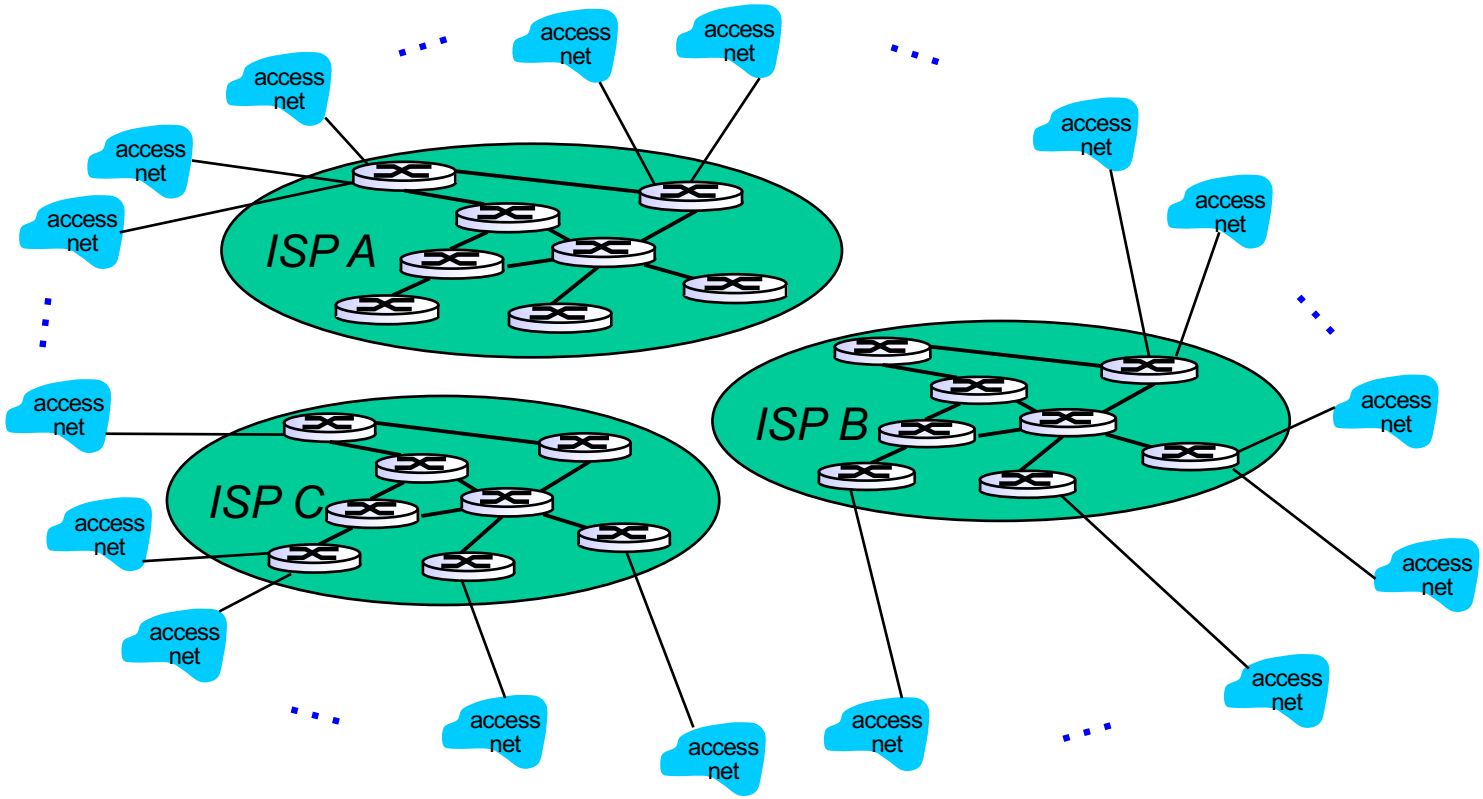
Internet structure: network of networks

Option: connect each access ISP to a global ISP for transit?
Customer and provider ISPs have economic agreement.



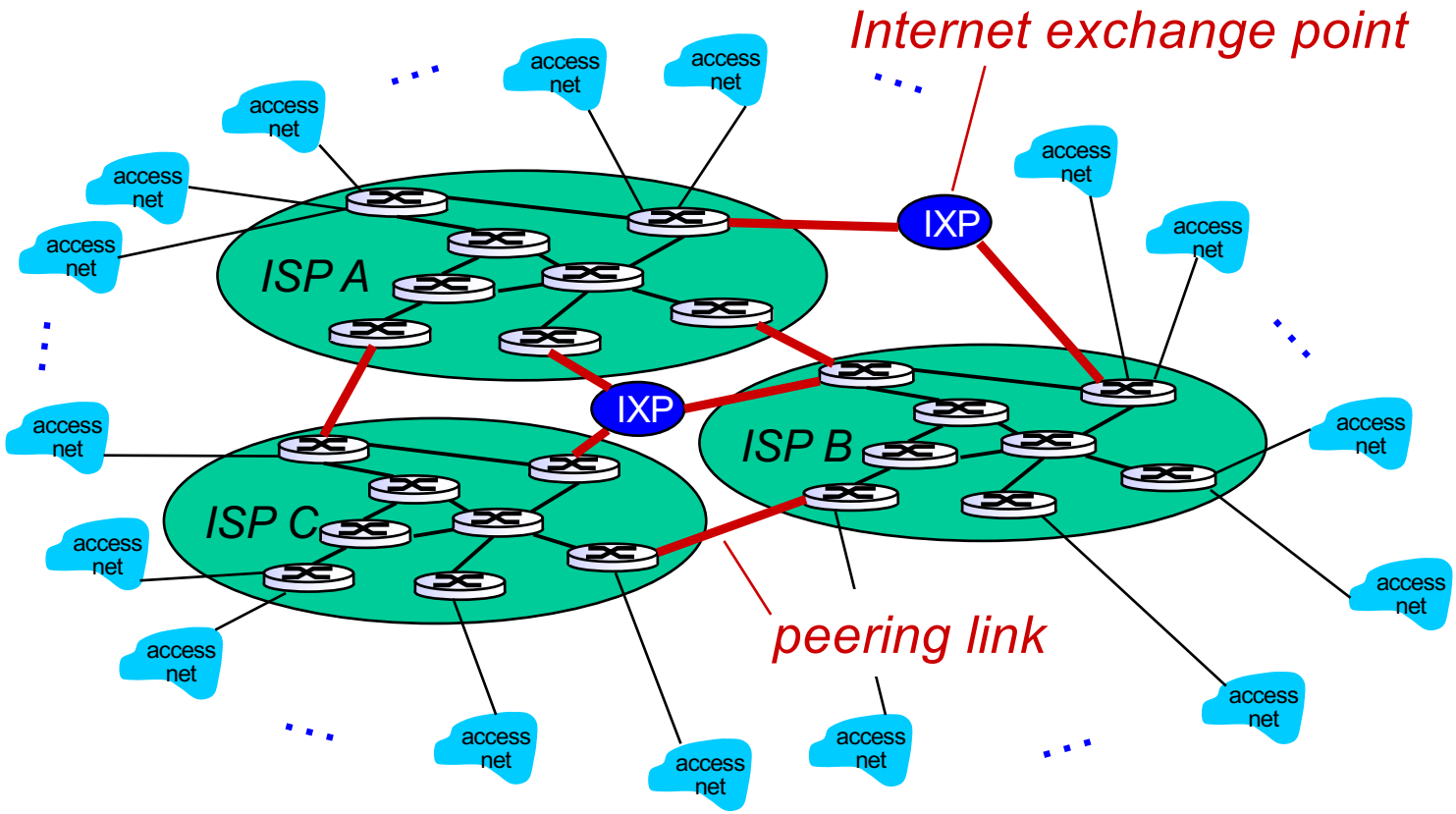
Internet structure: network of networks

But if one global ISP is viable business, there will be competitors ….



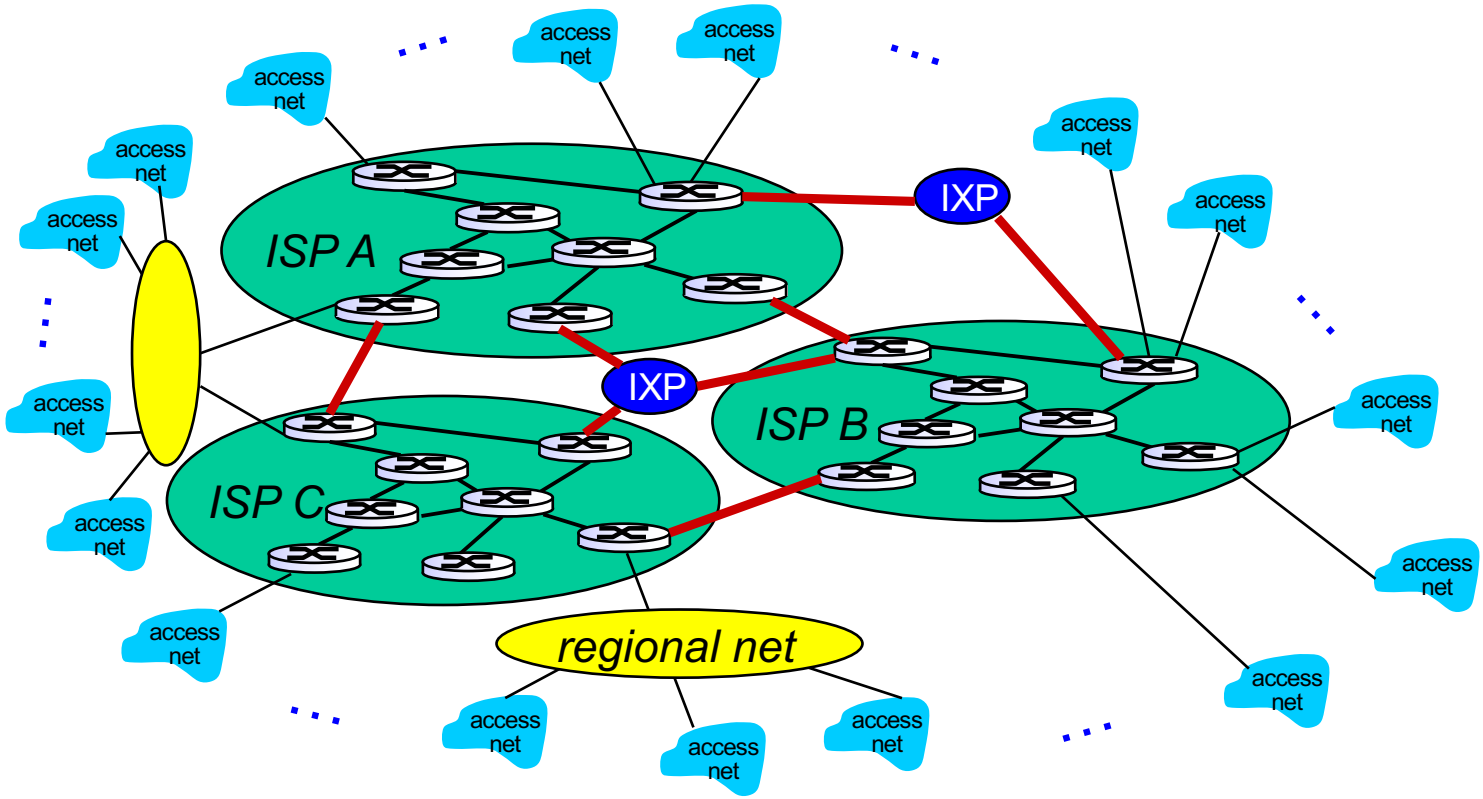
Internet structure: network of networks

But if one global ISP is viable business, there will be competitors …. which must be interconnected



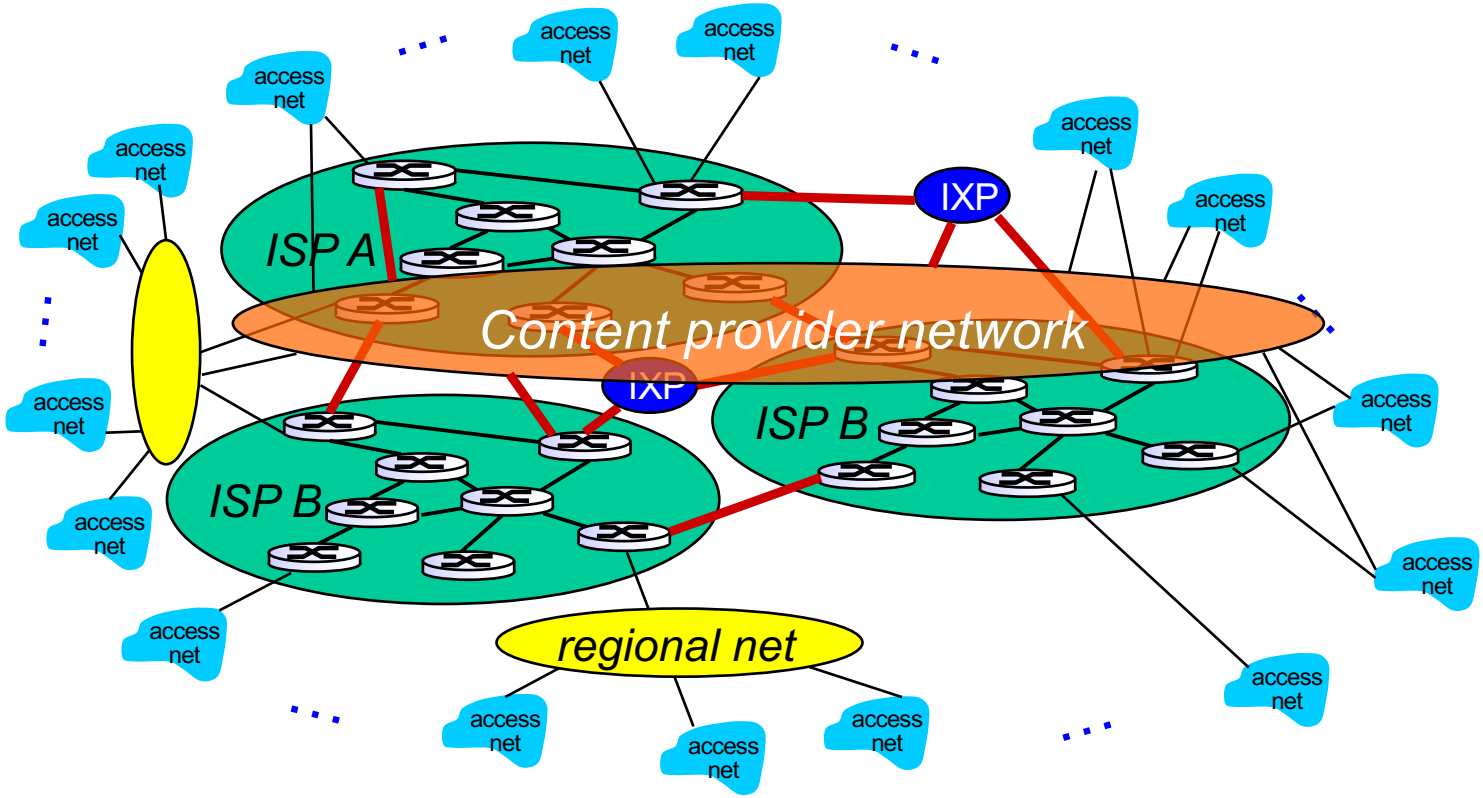
Internet structure: network of networks

… and regional networks may arise to connect access nets to ISPS

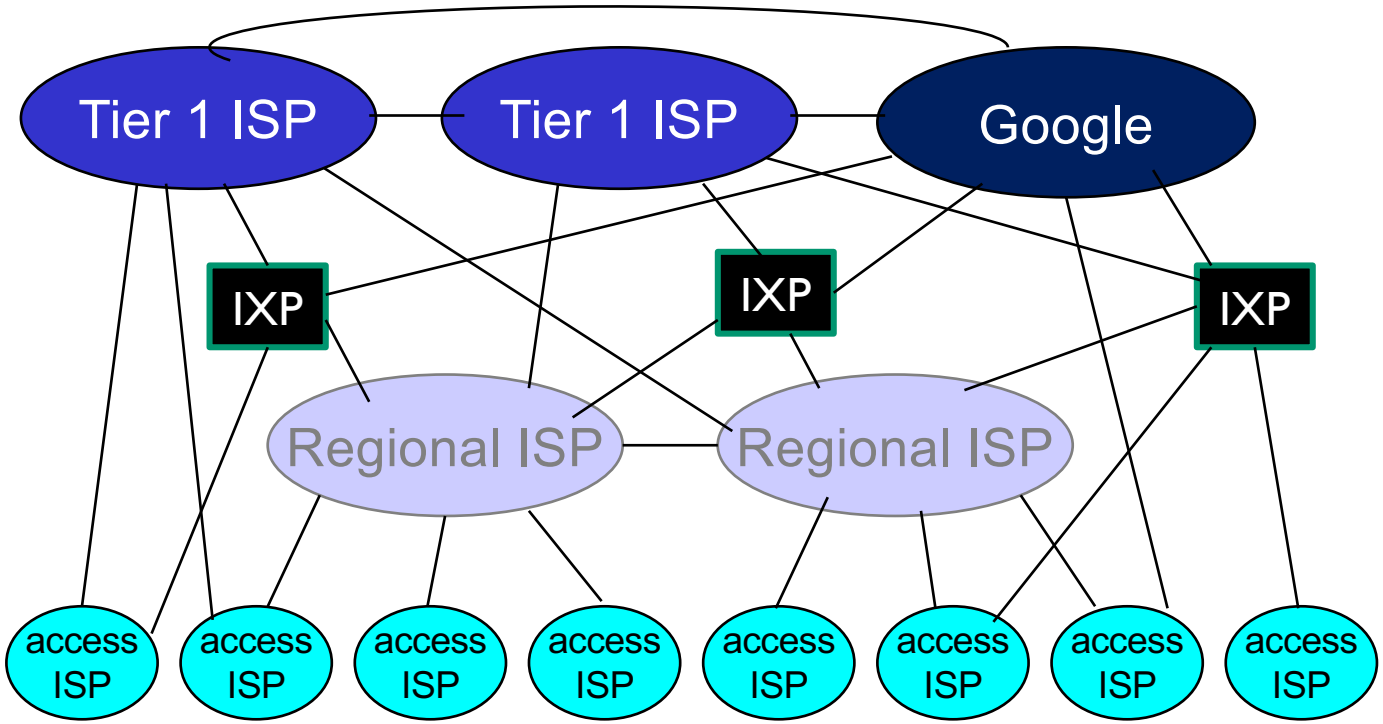


Internet structure: network of networks

… and content providers (e.g., Google, Microsoft, Akamai) may run their own networks, to bring services and content close to end users



Internet structure: network of networks



- at the center: small number of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT, Telia Carrier), national and international coverage
  - content provider network (e.g, Google): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs

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Protocol layers

Networks are complex, with many "pieces":

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

is there any hope of *organizing* structure of networks?

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…. or at least our discussion of networks?

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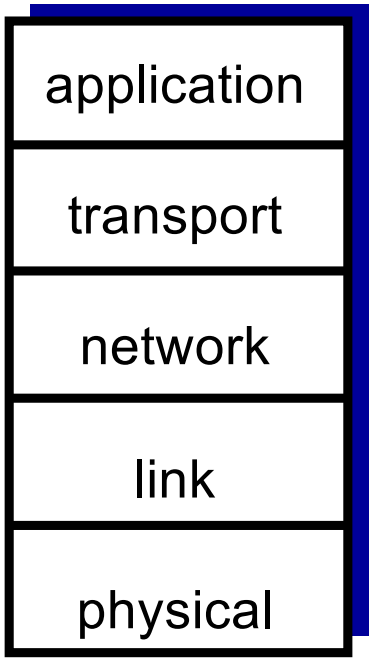
Why layering?

dealing with complex systems:

- explicit structure allows identification and relationship of the different pieces
  - layered *reference model* for discussion
- modularization eases maintenance and updating of system
  - change of implementation of layer's service transparent to rest of system
  - For example, a change in gate procedure doesn't affect rest of system
- layering considered harmful?

Internet protocol stack

- *application:* supporting network applications
  - FTP, SMTP, HTTP
- *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"

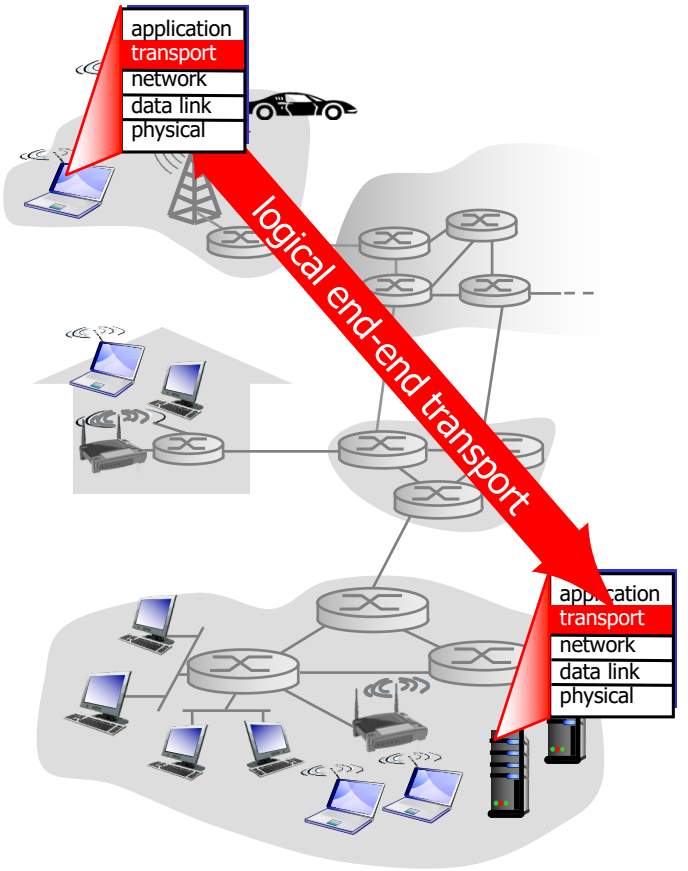


Application Layer

- Mail
  - SMTP
    - Simple Mail Transfer Protocol
  - POP
    - Post Office Protocol
  - IMAP
    - Internet Message Access Protocol
- Web
  - HTTP
    - Hypertext Transfer Protocol
  - TLS
    - Transport Layer Security
- File Sharing
  - BitTorrent
- IP Telephony
  - SIP
    - Session Initiation Protocol
  - Skype
- Directory Services
  - DNS
    - Domain Name System

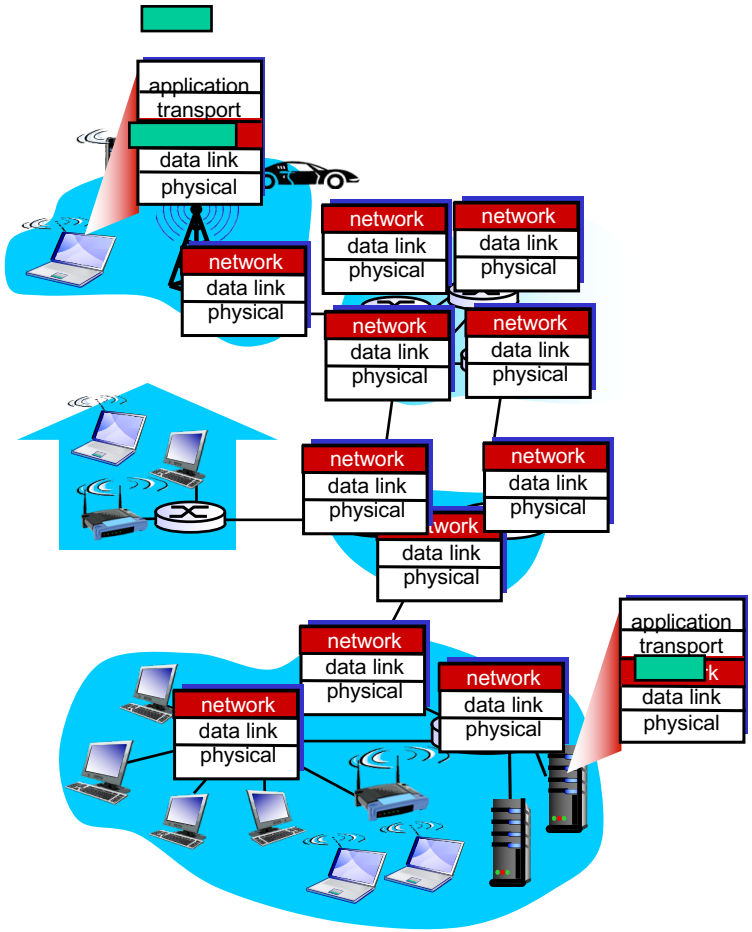
Transport Layer

- Provide communication between application processes on different hosts
- "End-to-end" communication
  - Between web browser on laptop and web server on enterprise server, for instance
- TCP
  - Transmission Control Protocol
  - Reliable delivery of a stream of data (ordered and confirmed)
- UDP
  - User Datagram Protocol
  - Delivery of individual datagrams (packets)



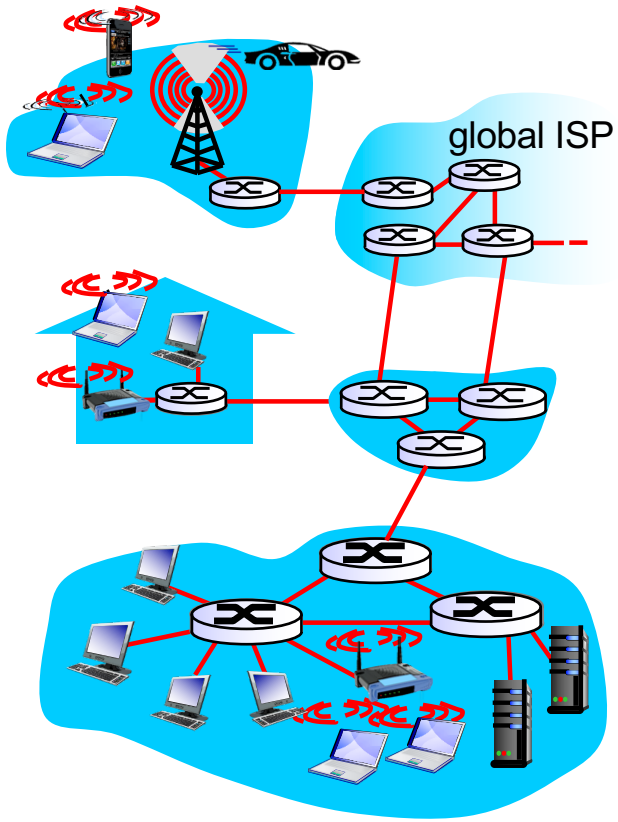
Network layer

- Deliver individual packets from sending to receiving host
- Network layer protocols in every host and router
- Router examines header fields in all IP datagrams passing through it
  - *Router* – network layer switch
  - Routing decision
    - Where packet should go next



Link layer

- Transfer *datagrams* between physically adjacent nodes over a *link*
  - "One step"
- IEEE 802.11 Wireless LAN
- Ethernet
- Bluetooth
- IEEE 802.15 Wireless PAN
- 3G, 4G, 5G
- …



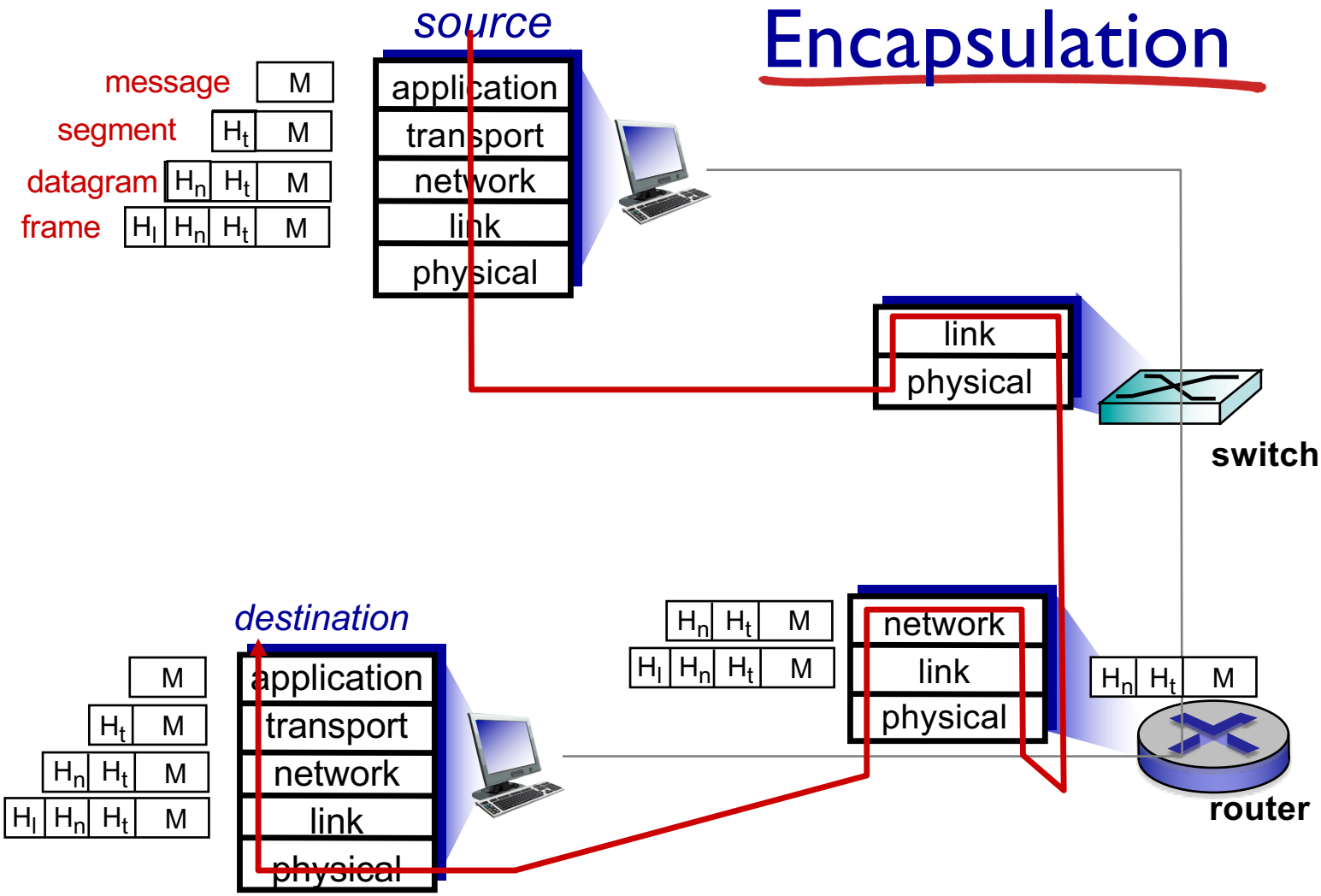
Physical layer

- physical, electrical, etc., properties
- bit: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

twisted pair (TP)

- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gpbs Ethernet
  - Category 6: 10Gbps
  - Category 7, 8: 40 Gb/s, 100 Gb/s

Encapsulation



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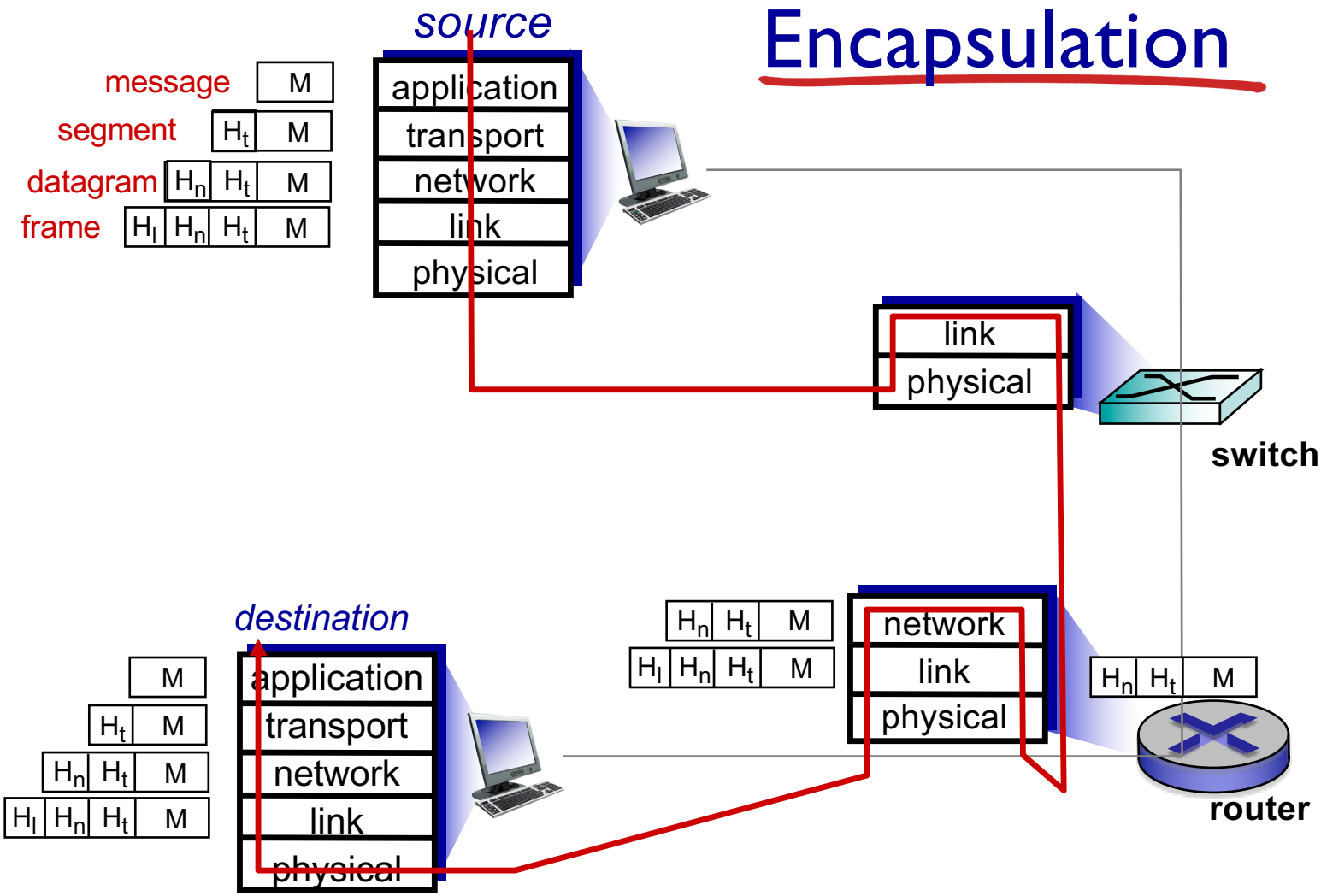

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Introduction: summary

covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access network
  - ~~packet-switching versus circuit-switching~~
  - Internet structure
- ~~performance: loss, delay, throughput~~
- layering, service models
- ~~security~~
- ~~history~~

you now have:

- context, overview, "feel" of networking
- more depth, detail *to follow!*

Next Lectures

- Application Layer
  - Lecture 2, 3 and 4
- Transport Layer
  - Lecture 5 and 6
- Network Layer
  - Lecture 7 and 8
- Data Link Layer
  - Lecture 9 and 10