Computer networking (TDDE25): Part 1 …

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Kick starting science ...

What do you have in the future?

What do you have in the future?

How does it keep going?

… well, cable into wall …

What happens there?

What happens there?

Or maybe more realistically …

- Work at company …

How do we build services that are …

Efficient

Secure

Reliable

Important problem faced every day by many companies, including …

Almost everything that can be connected is becoming connected and services are increasingly relying on the Internet …

End hosts increasingly diverse …

IP picture frame
http://www.ceiva.com/

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

Internet
refrigerator

Slingbox: watch,
control cable TV remotely

Internet phones

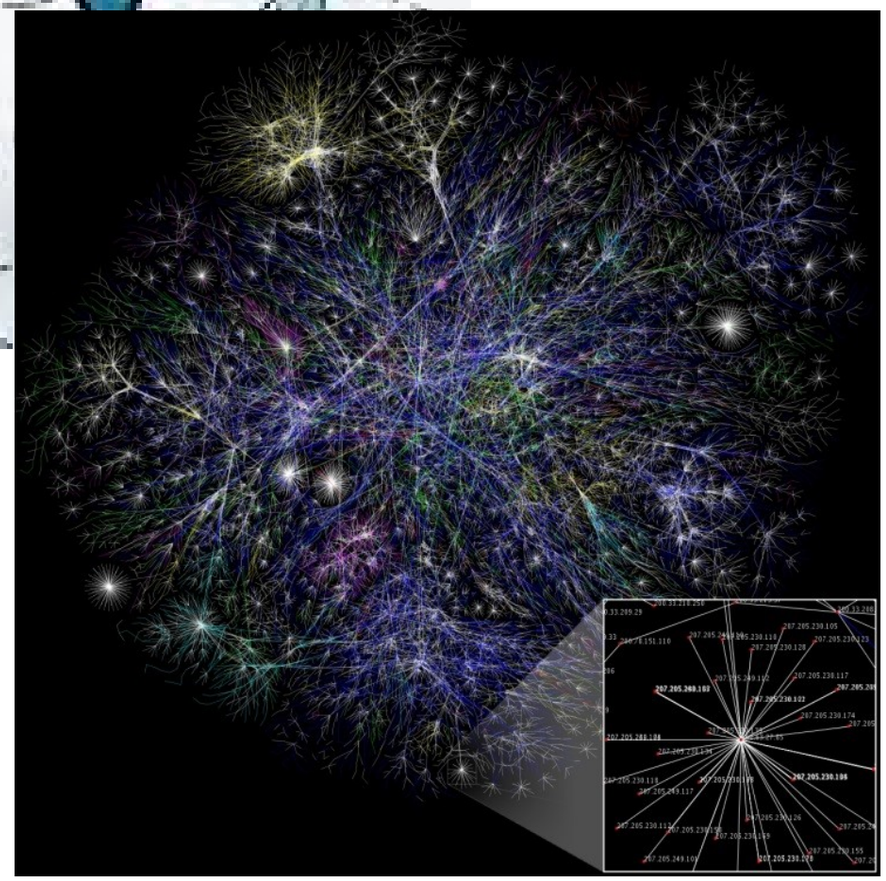
… and the future has more! …

Here, we try to give an initial glimpse into things such as …

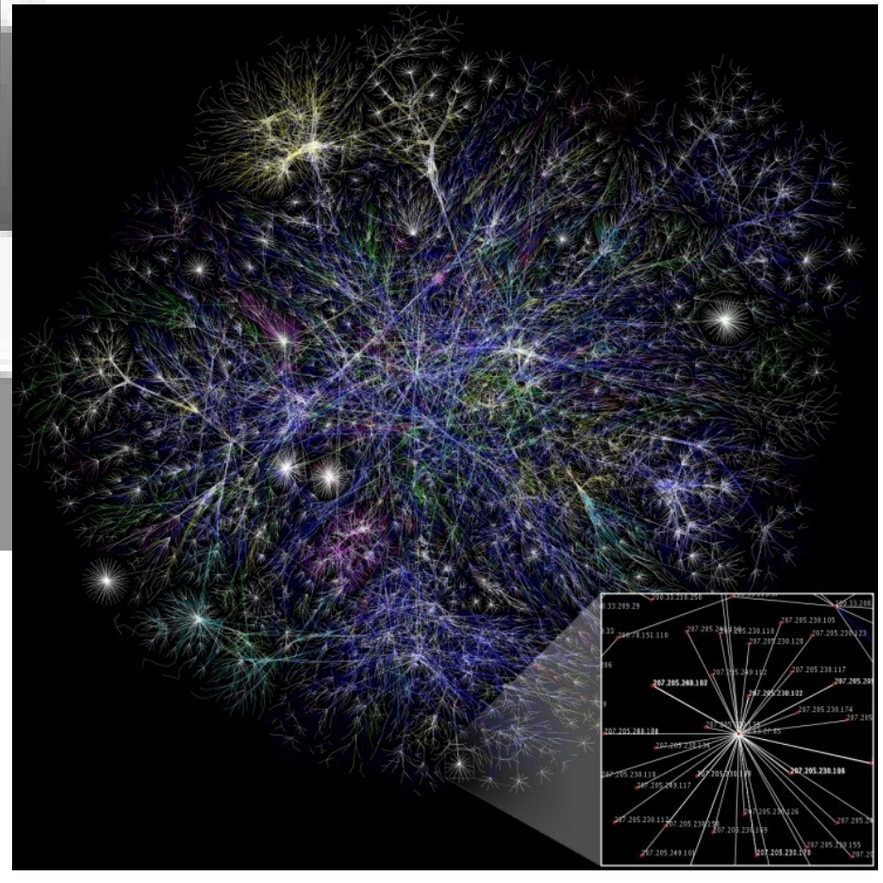
How do we build scalable, efficient, secure, and reliable services?

How do we communicate with a machine across the world?

How do we find out who to talk to?



How do we find a path?



How do we **avoid sending too much** for the receiver and network to handle?

What happens at our machine? Inside the network? Along the path?

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So let’s start the lecture …

Roadmap

- What is the Internet?
- Network Edge
  - End systems, access networks, links
- Network Core
  - Packet switching, network structure
- Protocol Layers, service models
- Network Security
- History

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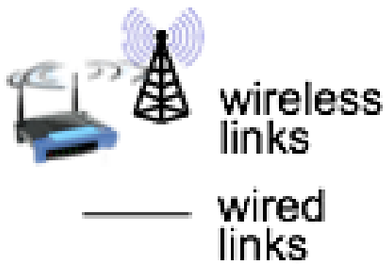
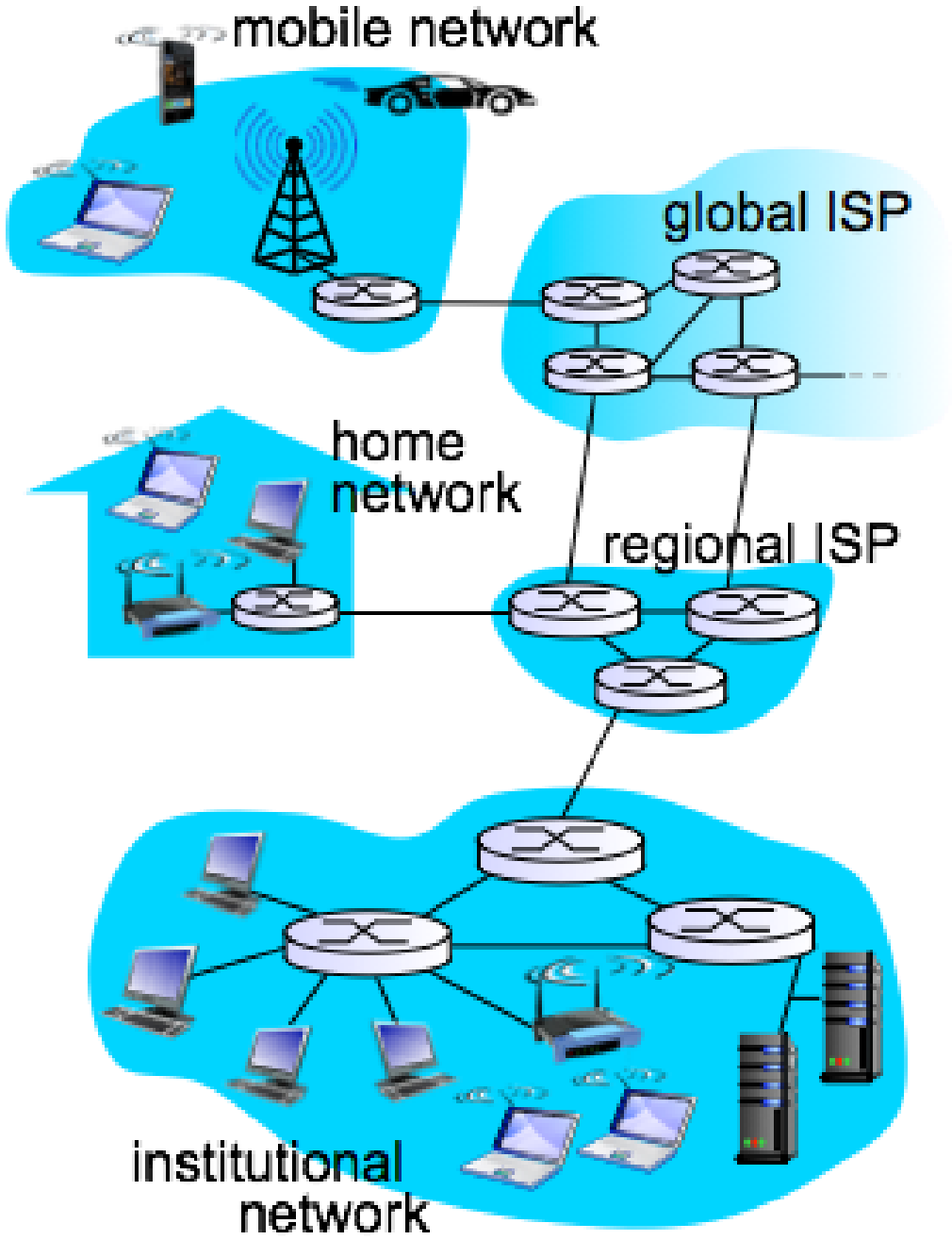
What's the Internet: "Nuts and Bolts View"

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



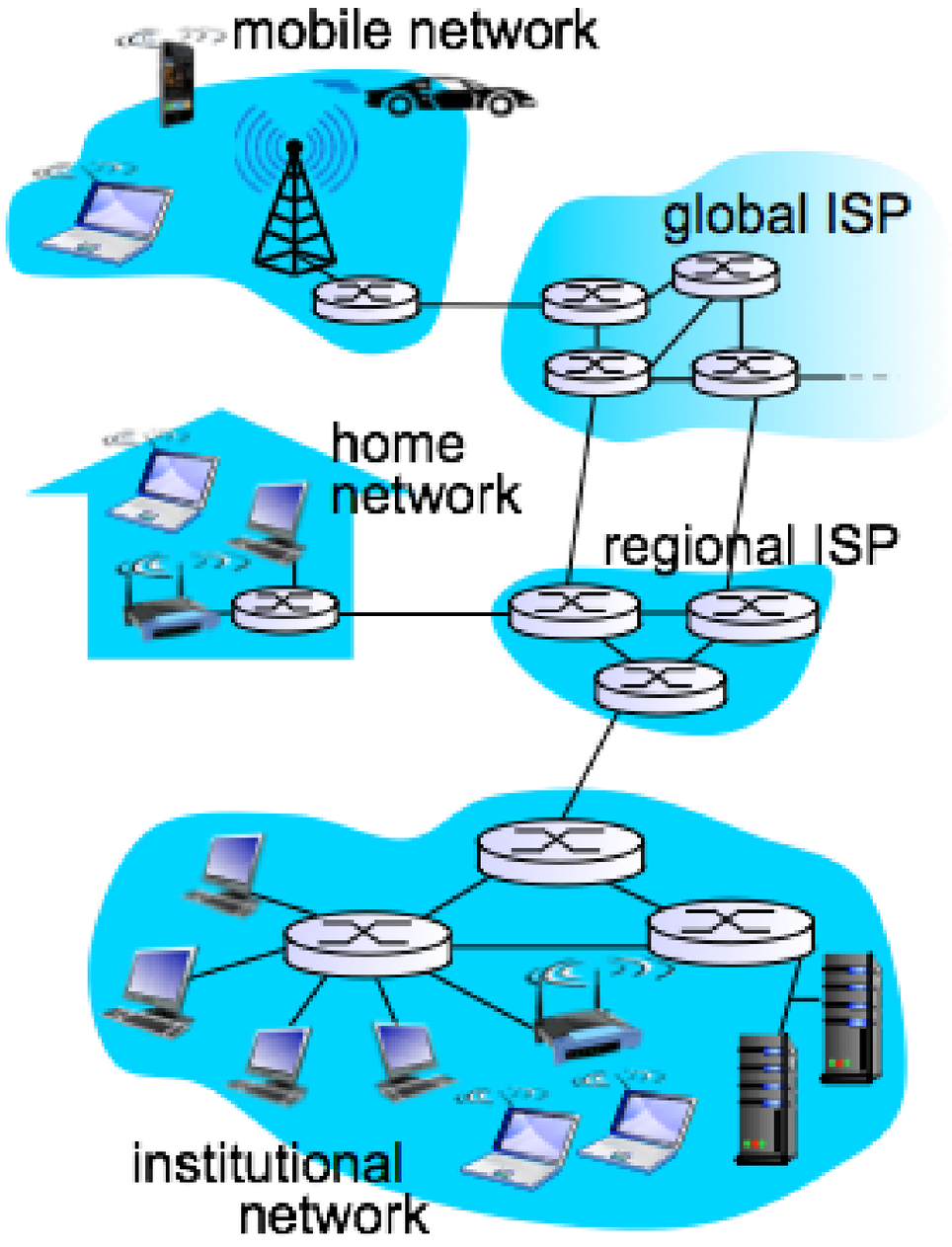
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: *bandwidth*

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



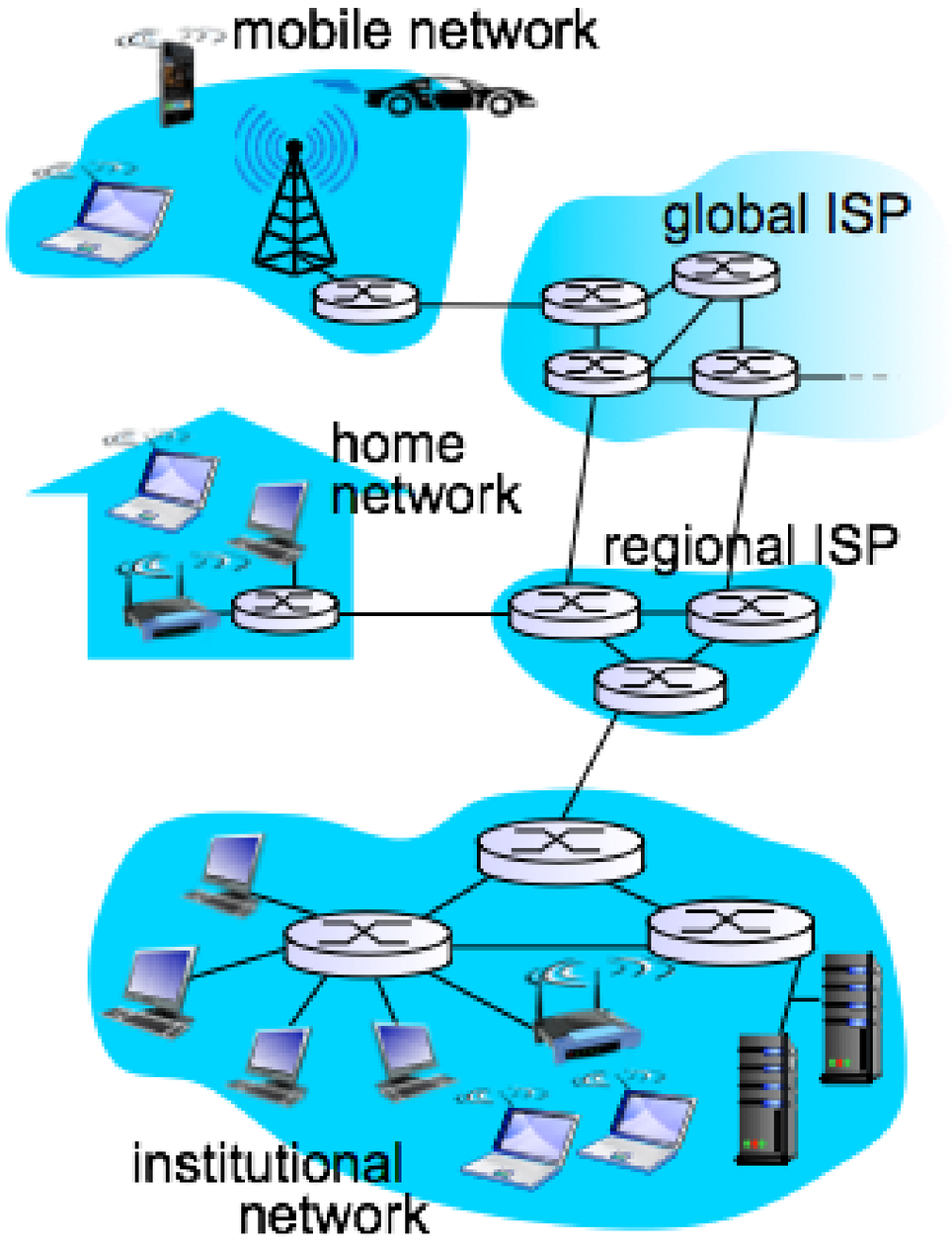
What's the Internet: "Nuts and Bolts View"

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



What's the Internet: "Service View"

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



Today's service/company landscape include …

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Equipment manufacturers
(also sell services and help
Operate networks)

Today's service/company landscape include …

Network operators

Equipment manufacturers
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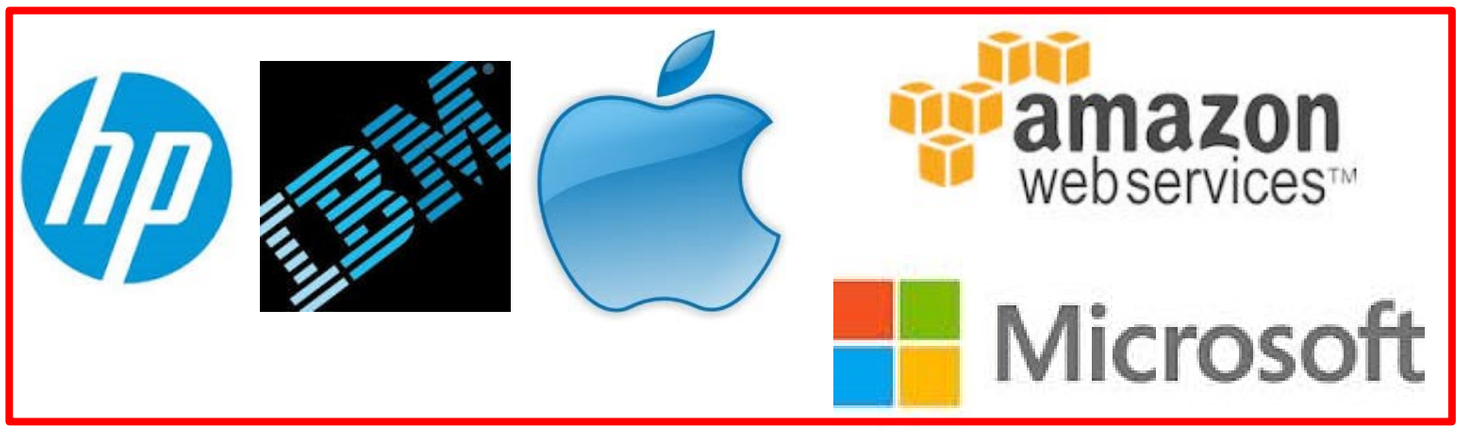
Operate networks)

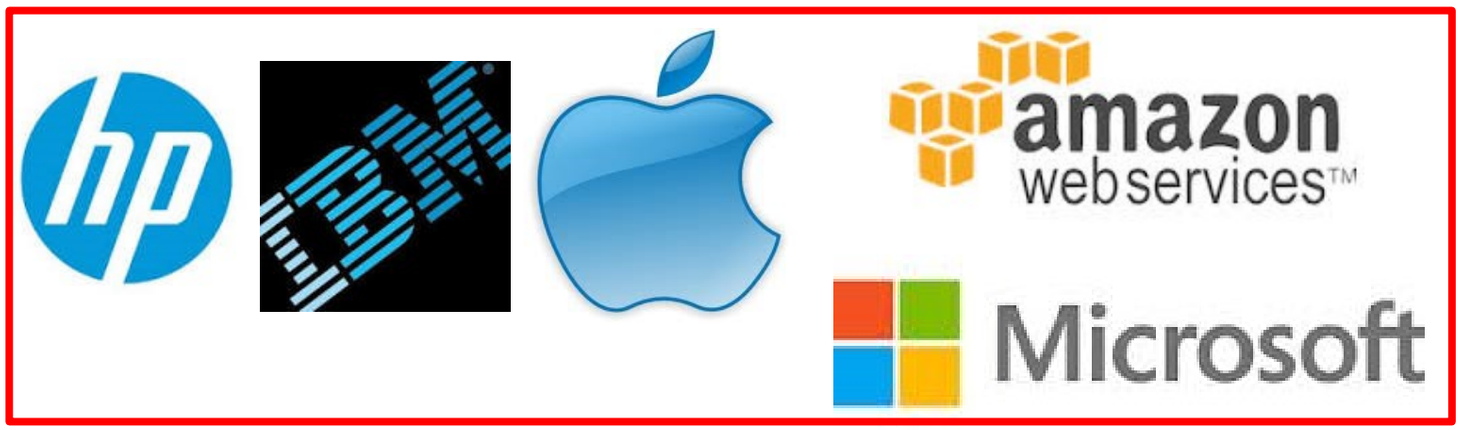
Today’s service/company landscape include …



Enterprise solutions and network service (e.g., data center solutions and cloud providers)

Today's service/company landscape include …

Content delivery networks



Enterprise solutions and network service (e.g., data center solutions and cloud providers)

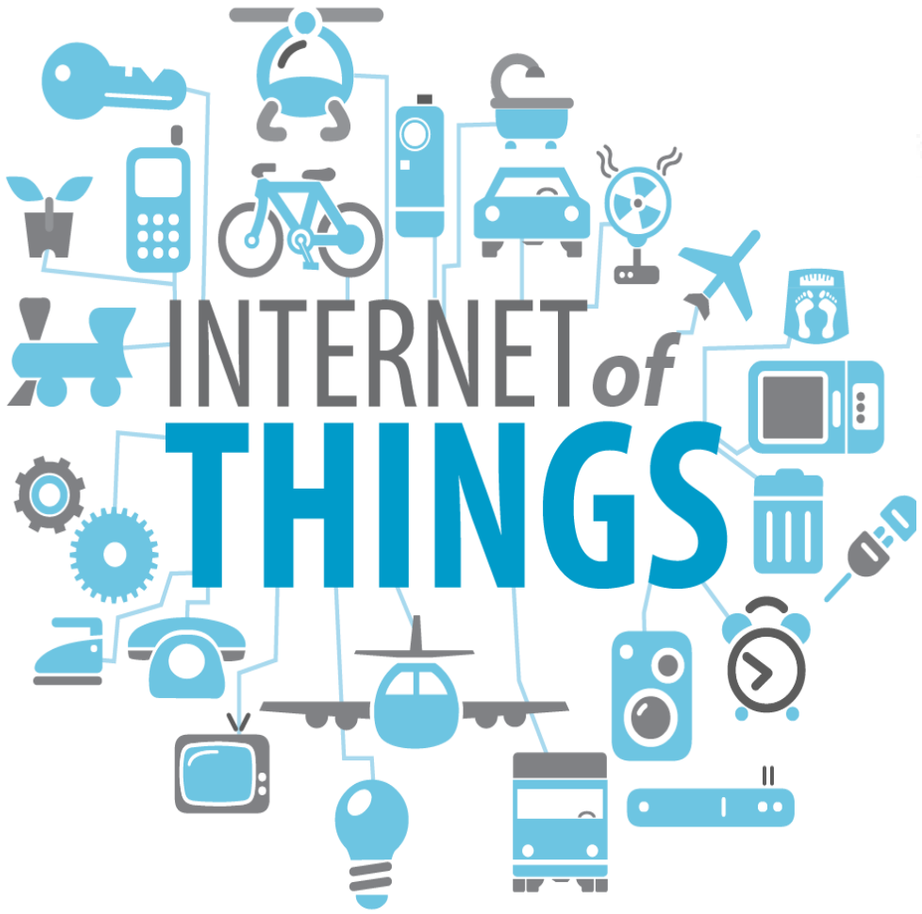
Today's service/company landscape include …

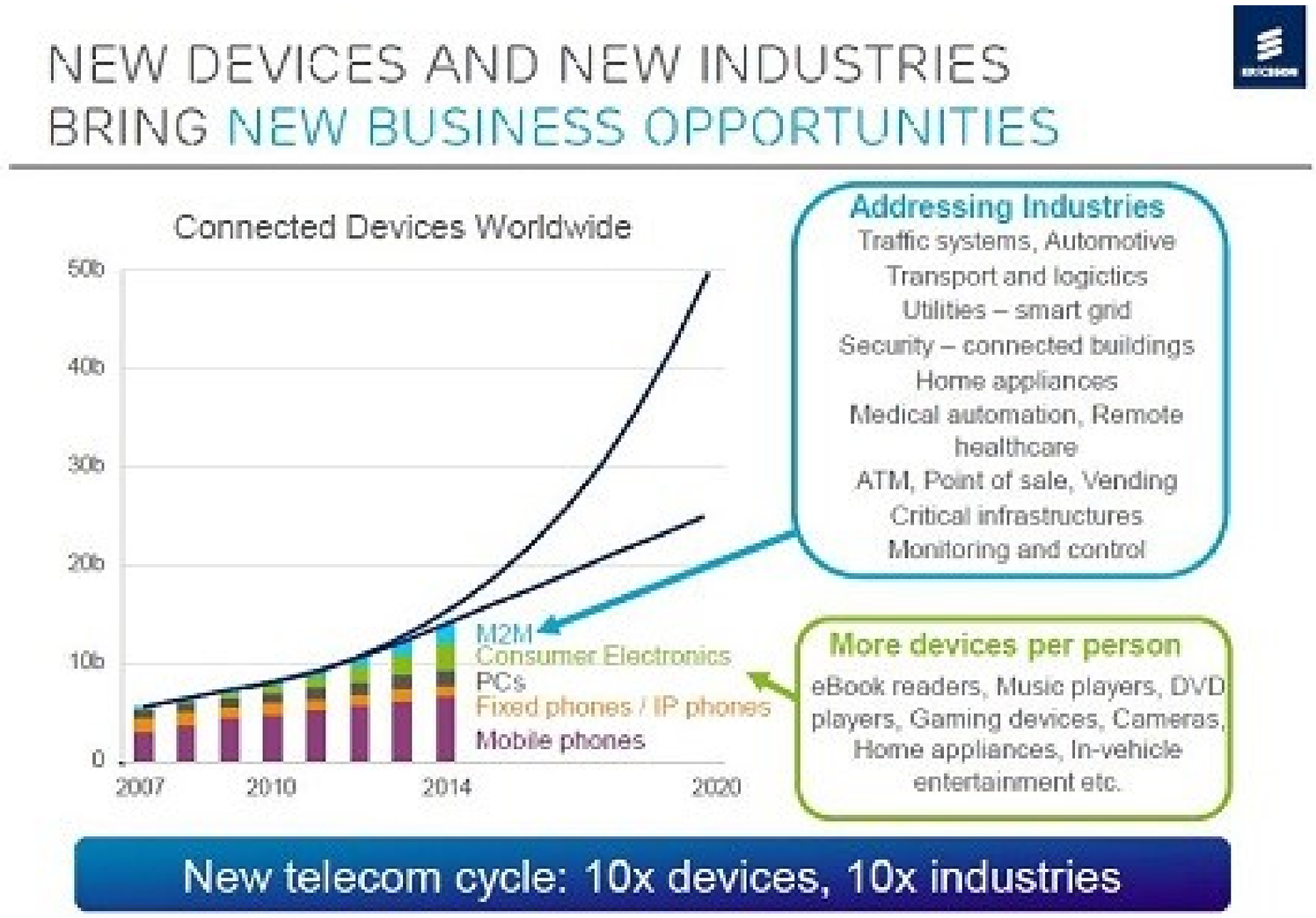
End user services (e.g., web-based social networks, search, communication, and streaming)

Some common applications today …

- World Wide Web (WWW)
- Remote login (telnet, rlogin, ssh)
- File transfer
- Peer-to-peer file sharing
- Cloud computing/services
- Instant messaging (chat, text messaging, etc.)
- Live and video-on-demand streaming
- Internet phone (Voice-Over-IP)
- Distributed games
- …

… and tomorrow





The 2020 vision

- Everything that can be connected will be connected
  - 50B devices (perhaps more like 500B …)
- IoT and smart cities
  - Machine-to-machine
- High-definition 3D streaming to heterogeneous clients

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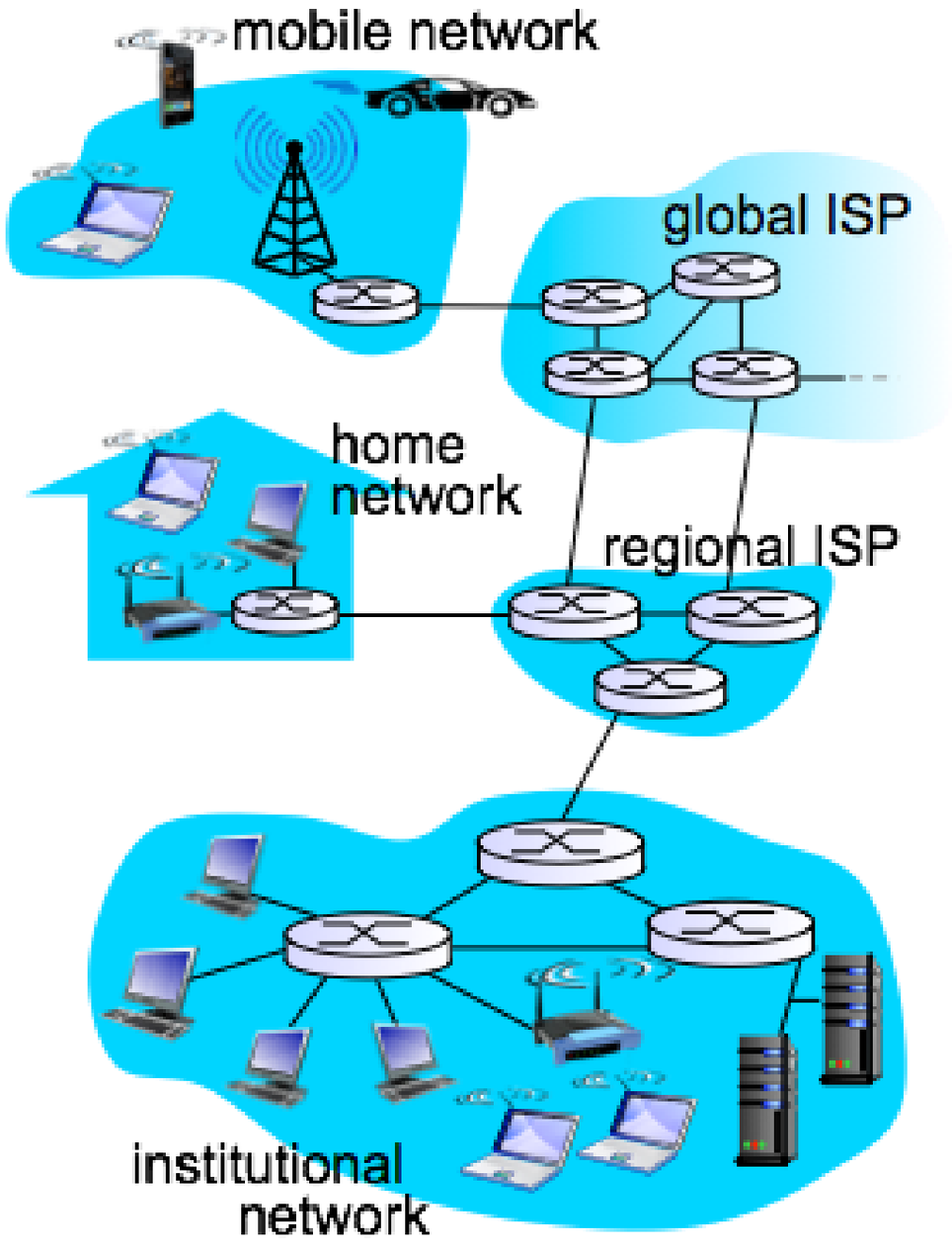
A Closer Look at Network Structure

- *network edge:*
  - hosts: clients and servers
  - servers often in data centers

- *access networks, physical media:* wired, wireless communication links

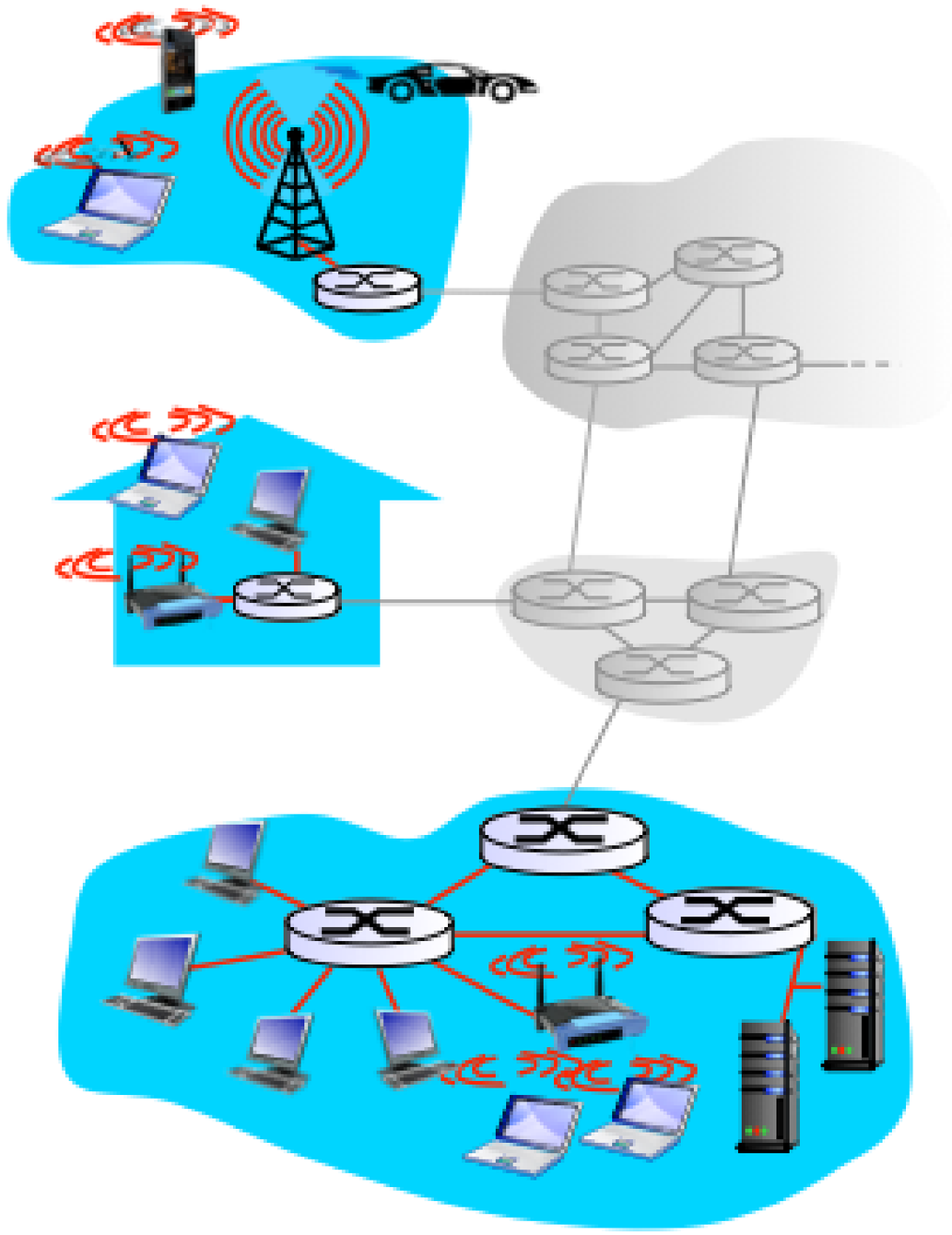
- *network core:*
  - interconnected routers
  - network of networks



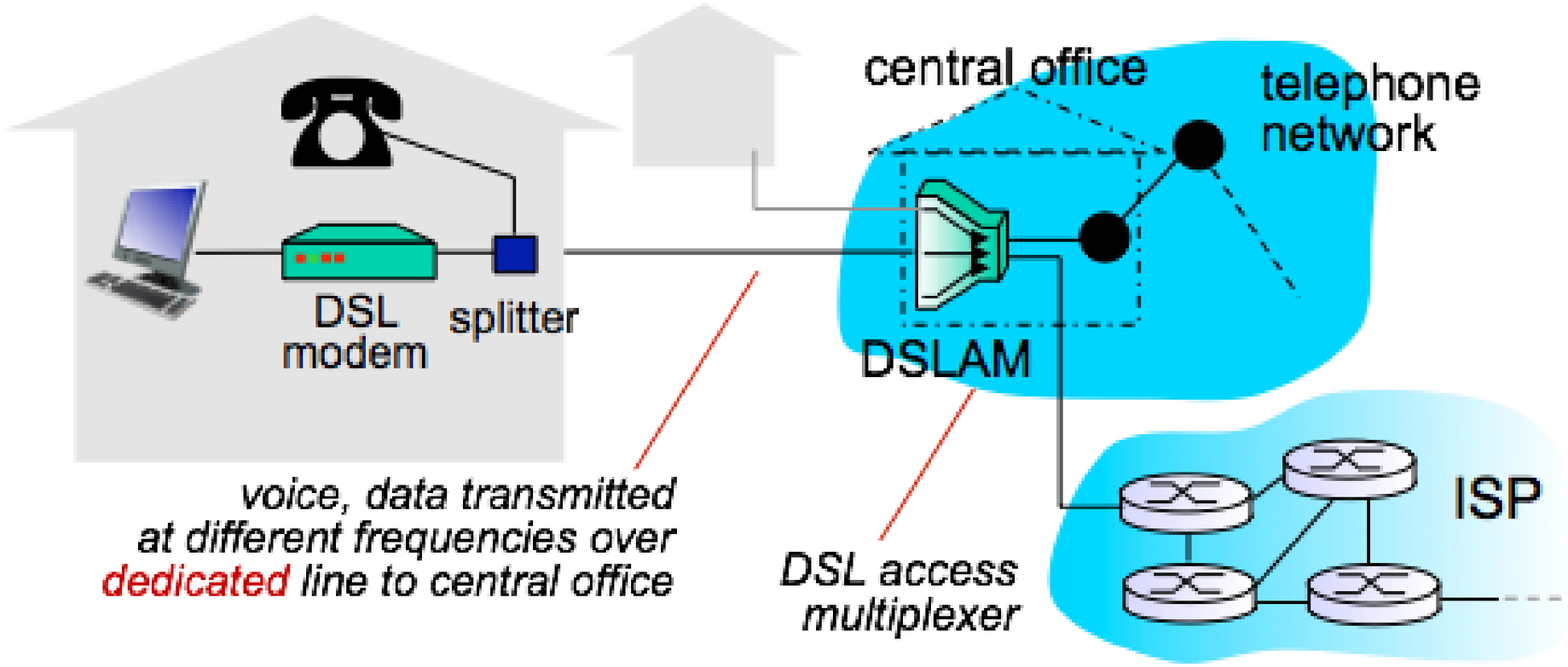
Access Networks and Physical Media

Q: How to connect end systems to edge router?

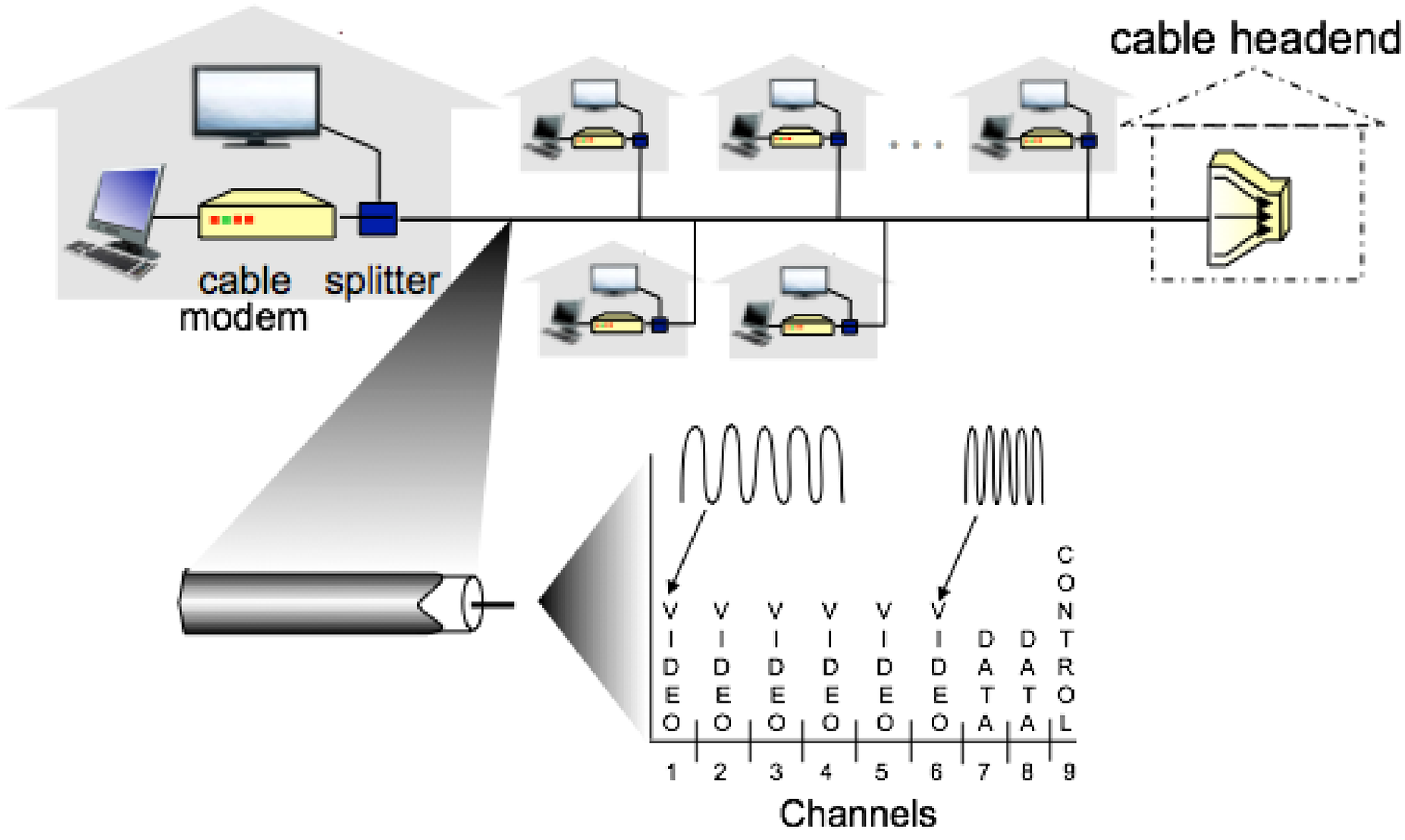
- residential access nets
- institutional access networks (school, company)
- mobile access networks



Access Net: Digital Subscriber Line (DSL)

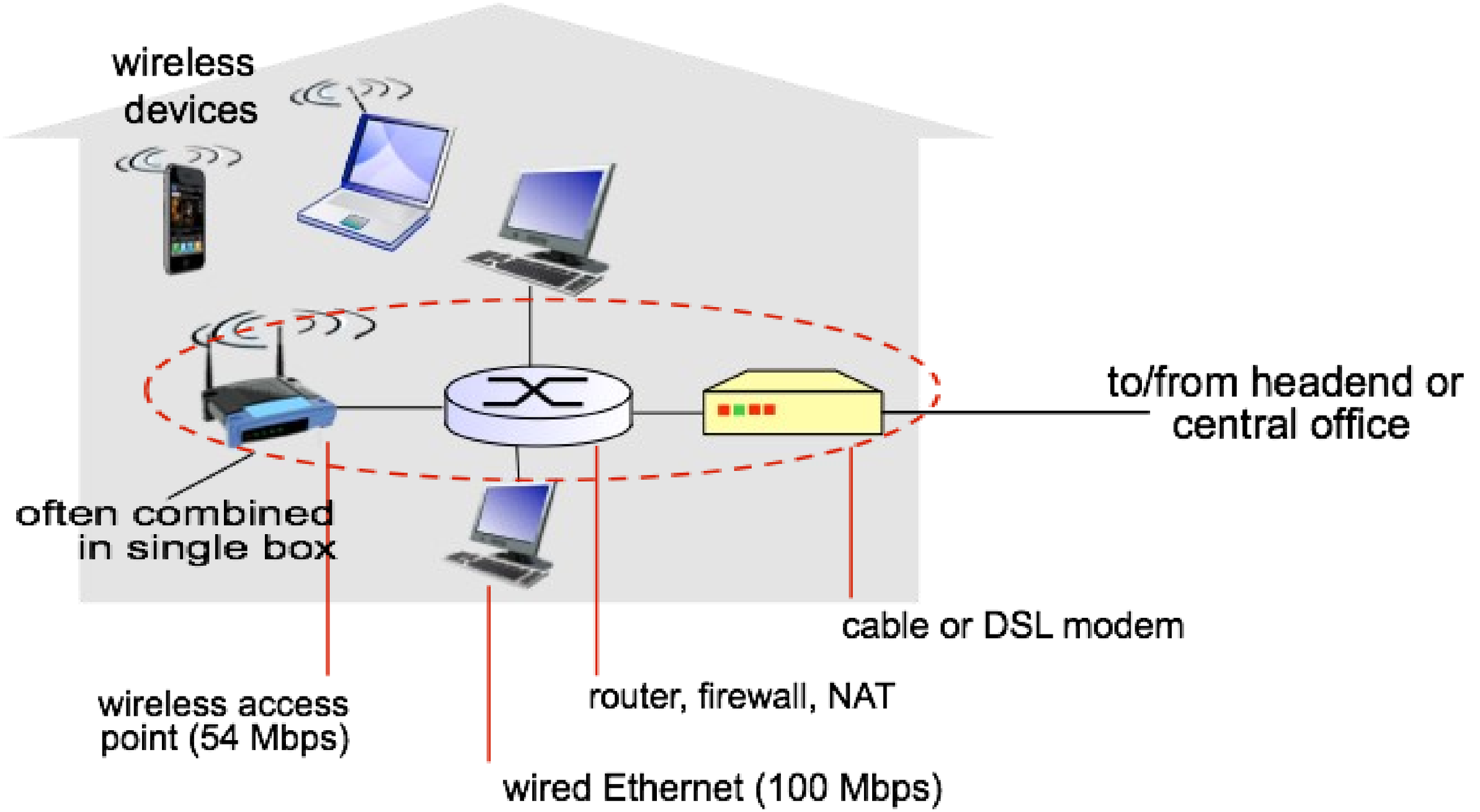


Access Net: Cable Network

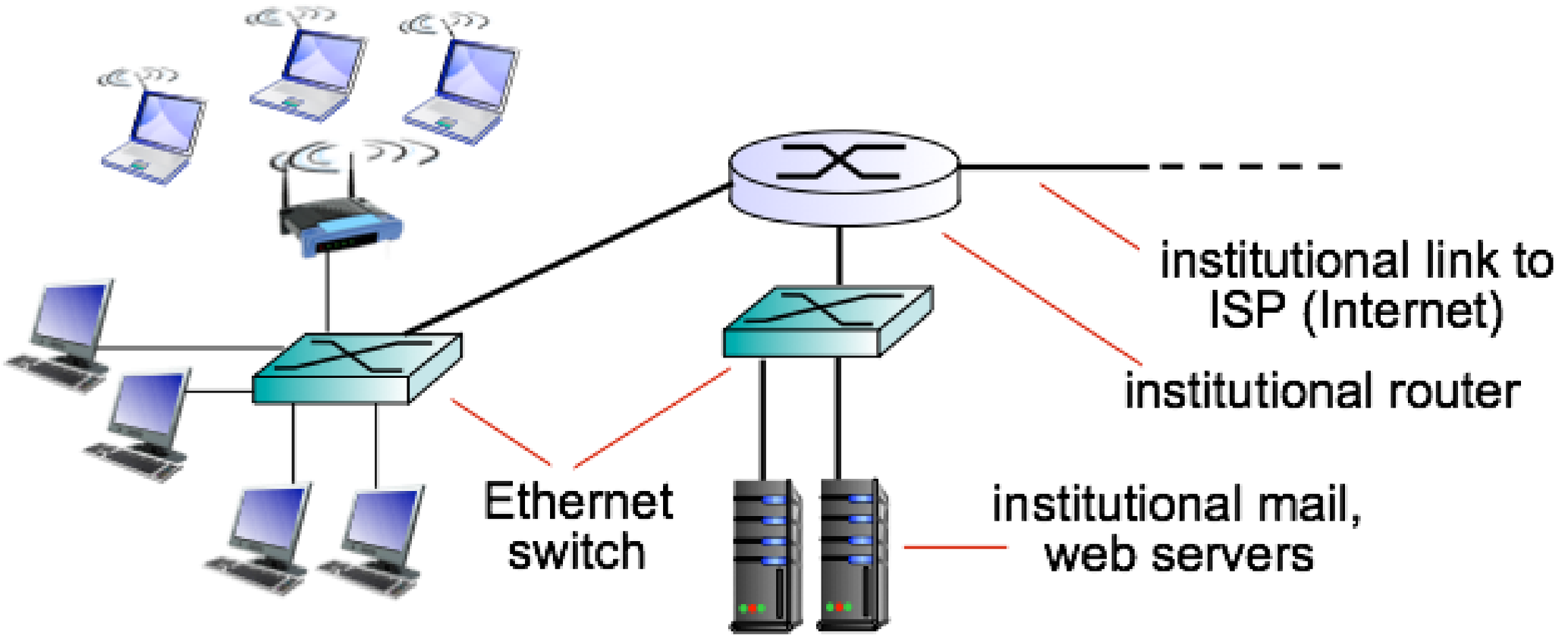


frequency division multiplexing: different channels transmitted in different frequency bands

Access Net: Home Network



Enterprise Access Networks (Ethernet)



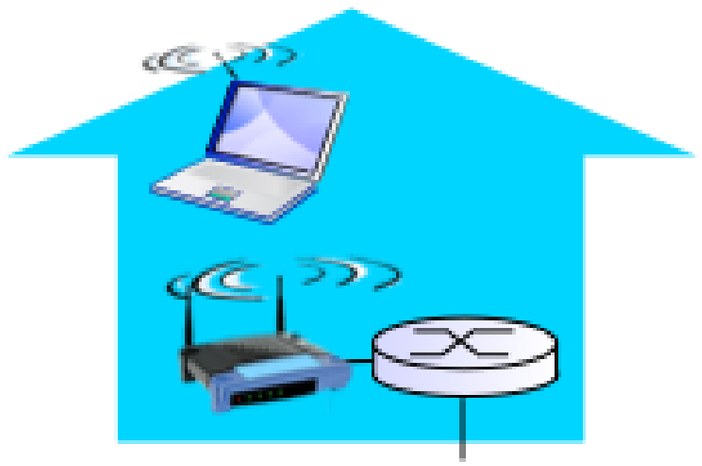
- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

Wireless Access Networks

- shared *wireless* access network connects end system to router
  - via base station aka "access point"

wireless LANs:

- within building (100 ft)
- 802.11b/g (WiFi): 11, 54 Mbps transmission rate



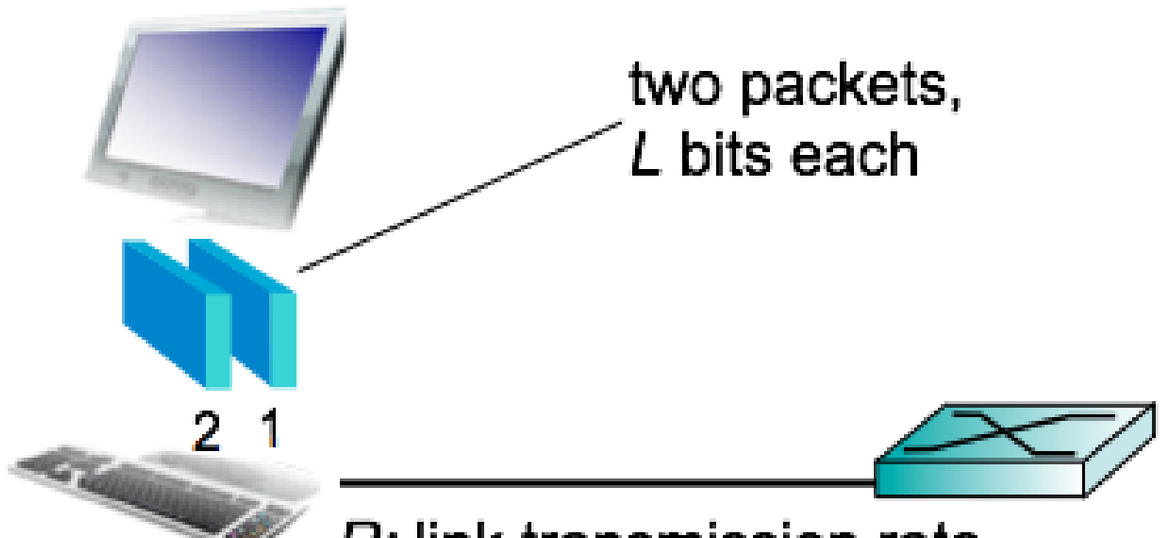
wide-area wireless access

- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE

Host: Sends *Packets* of Data

host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length *L* bits
- transmits packet into access network at *transmission rate R*
  - link transmission rate, aka link *capacity, aka link bandwidth*



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

Physical Media

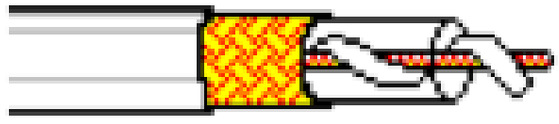
- bit: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

twisted pair (TP)

- two insulated copper wires

coaxial cable:

- two concentric copper conductors
- bidirectional



fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit

Physical Media: Radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

radio link types:

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ few Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

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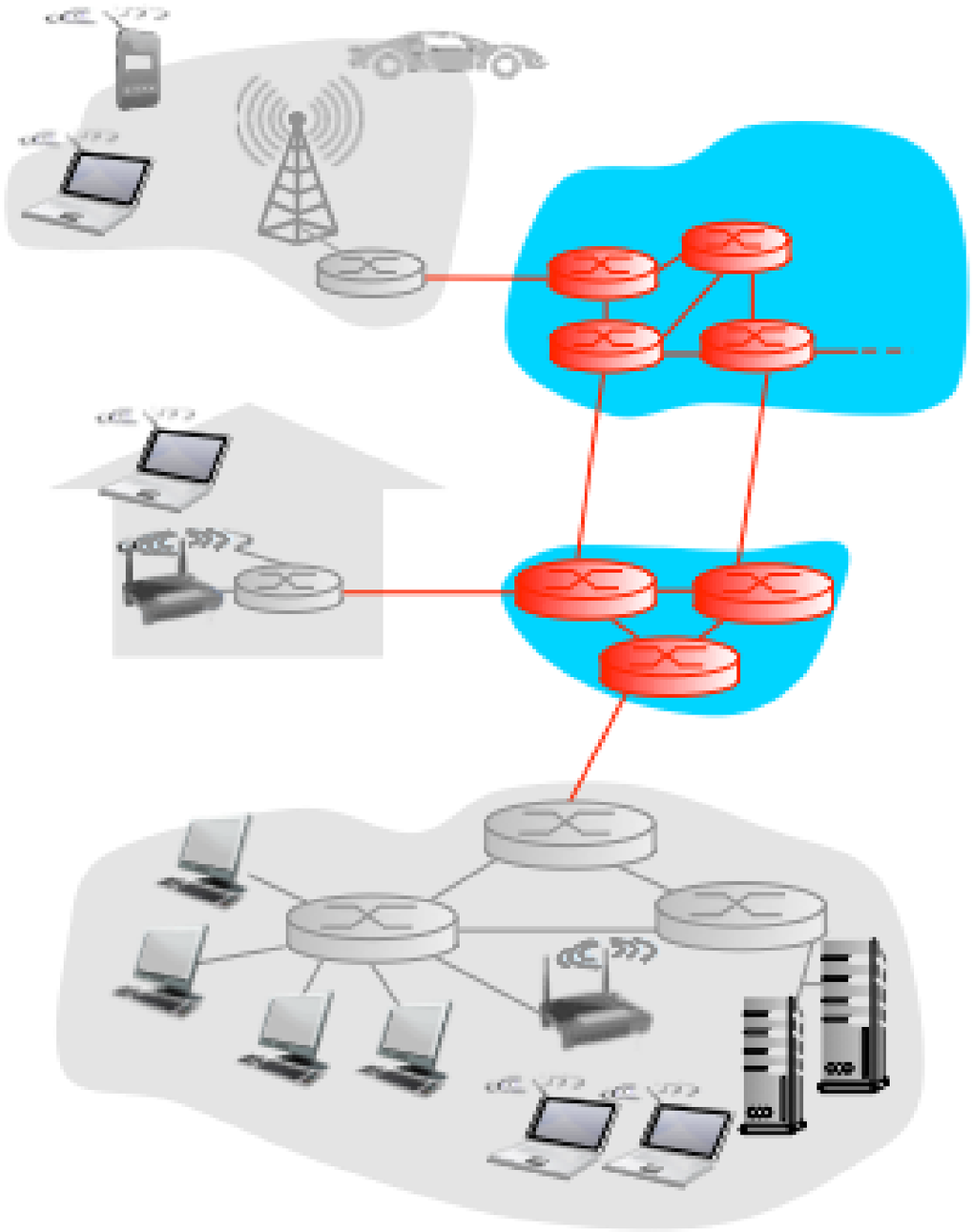
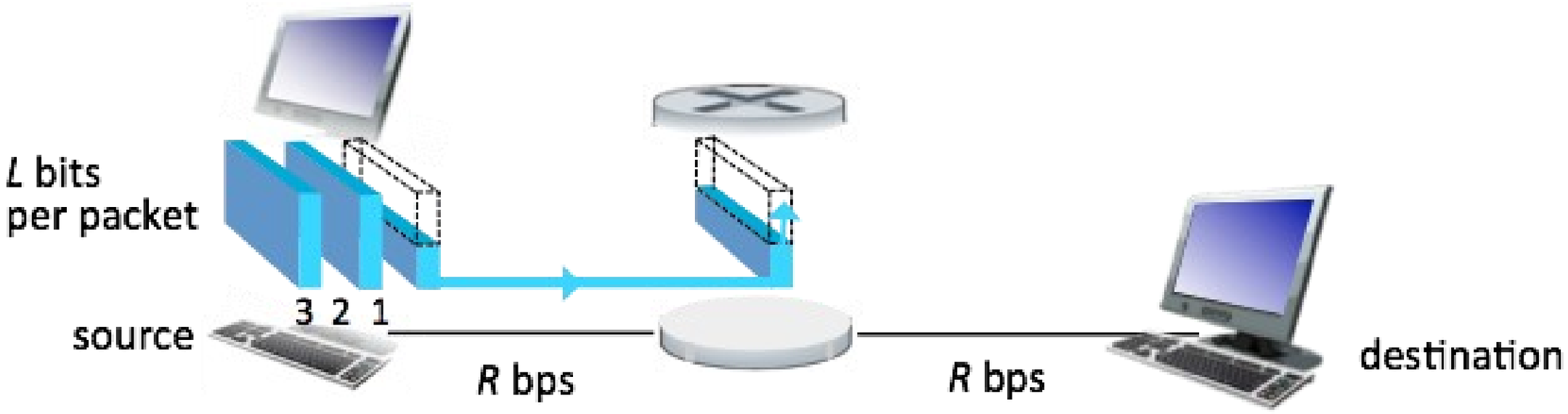
The Network Core

- 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

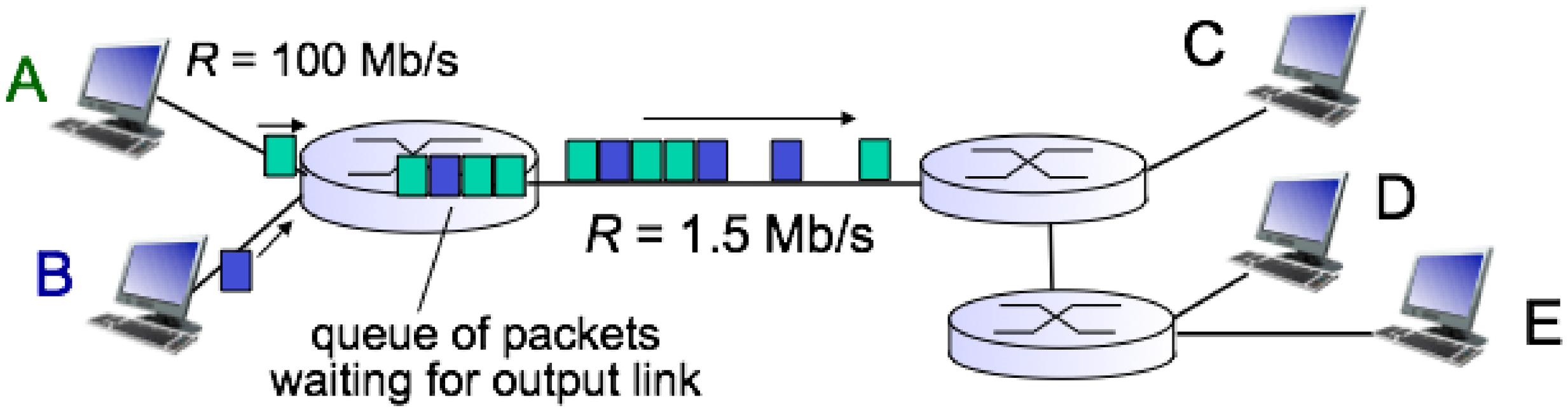


Packet-Switching: Store-and-forward



- *store and forward:* entire packet must arrive at router before it can be transmitted on next link

Packet Switching: Queueing Delay, Loss



queuing and loss:

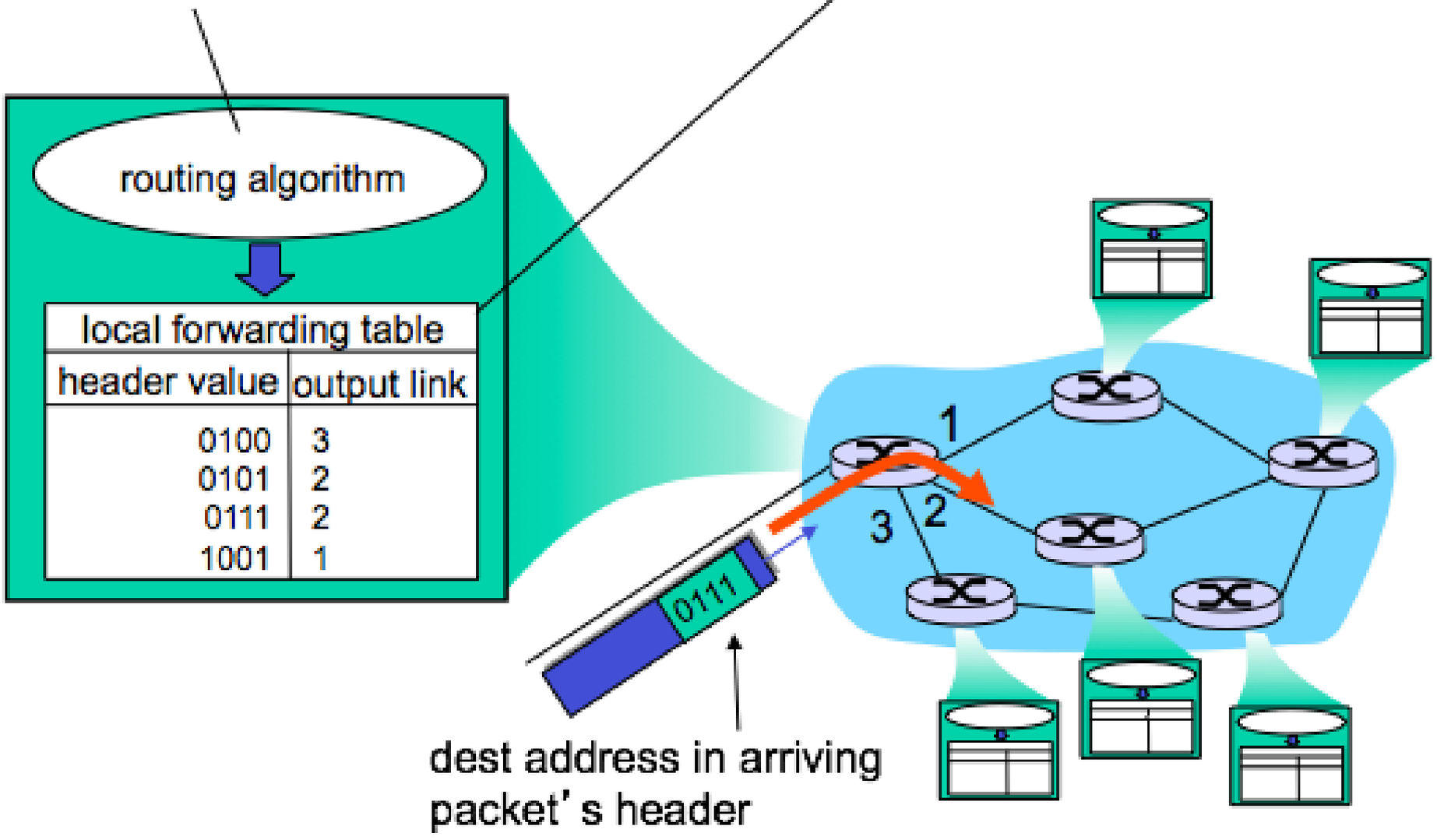
- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

Two Key Network Functions

routing: determines source-destination route taken by packets

- *routing algorithms*

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

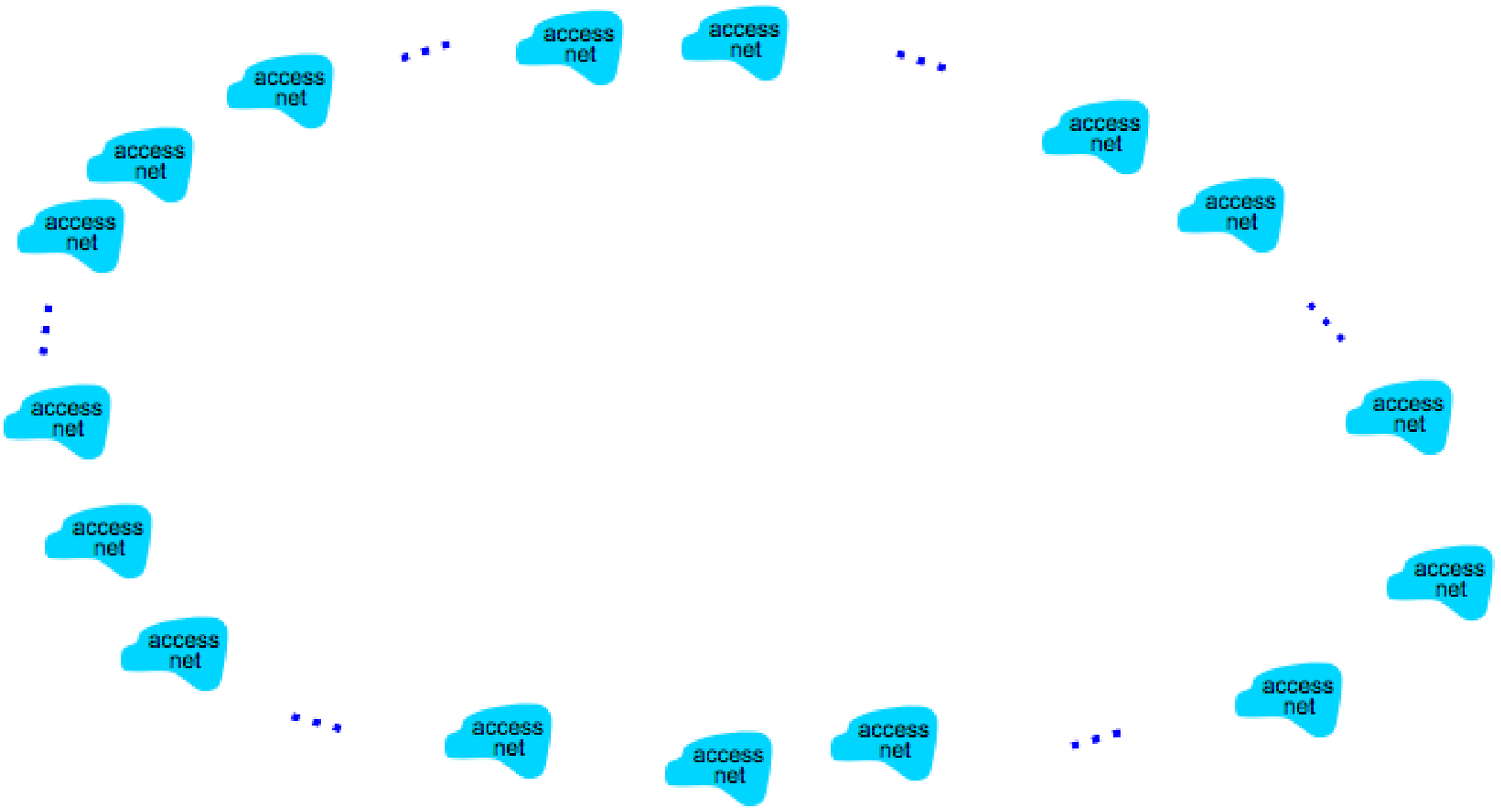


Internet Structure: Network of Networks

- End systems connect to Internet via access ISPs (Internet Service Providers)
  - Residential, company and university ISPs

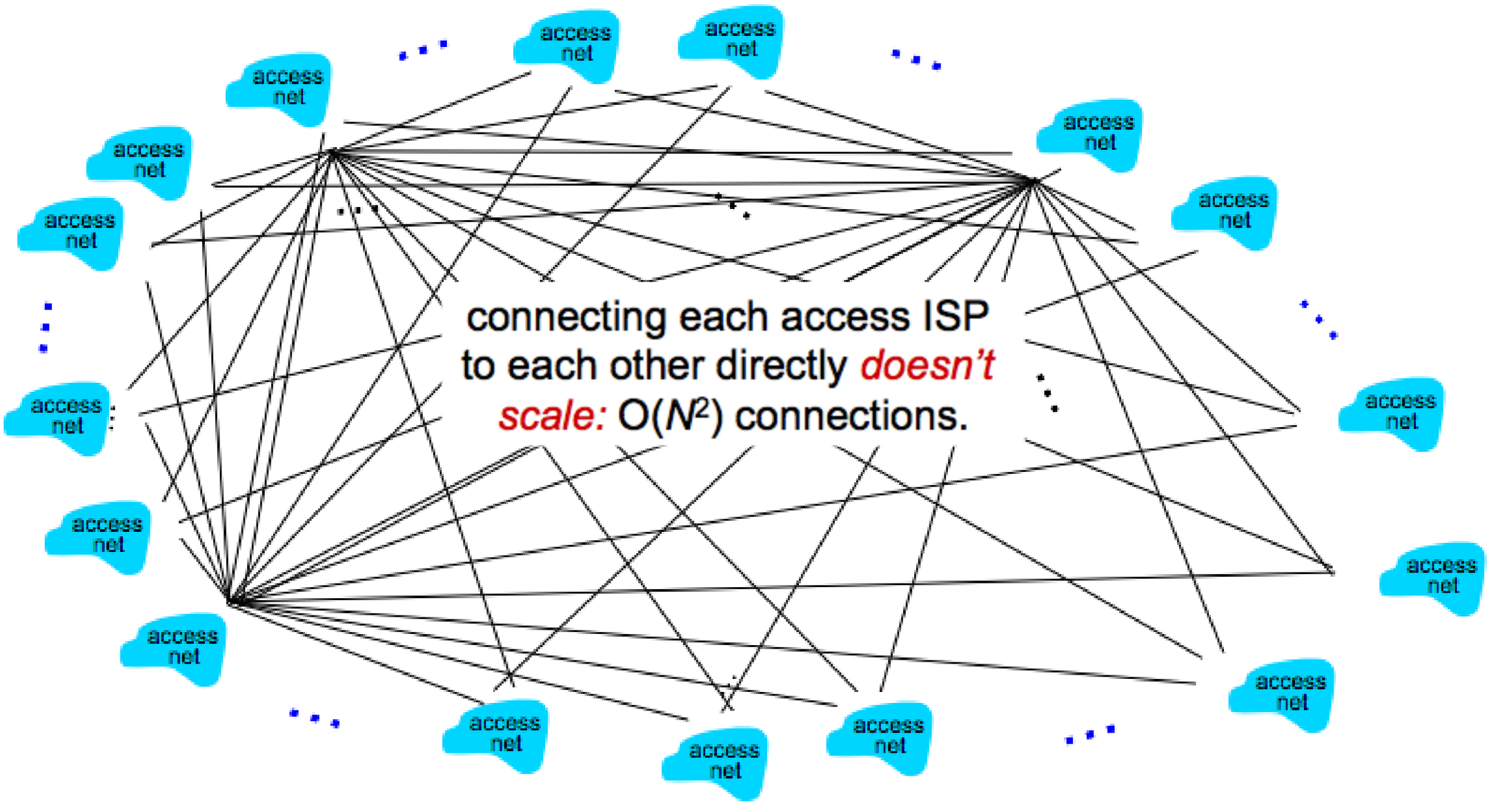
Internet Structure: Network of Networks

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



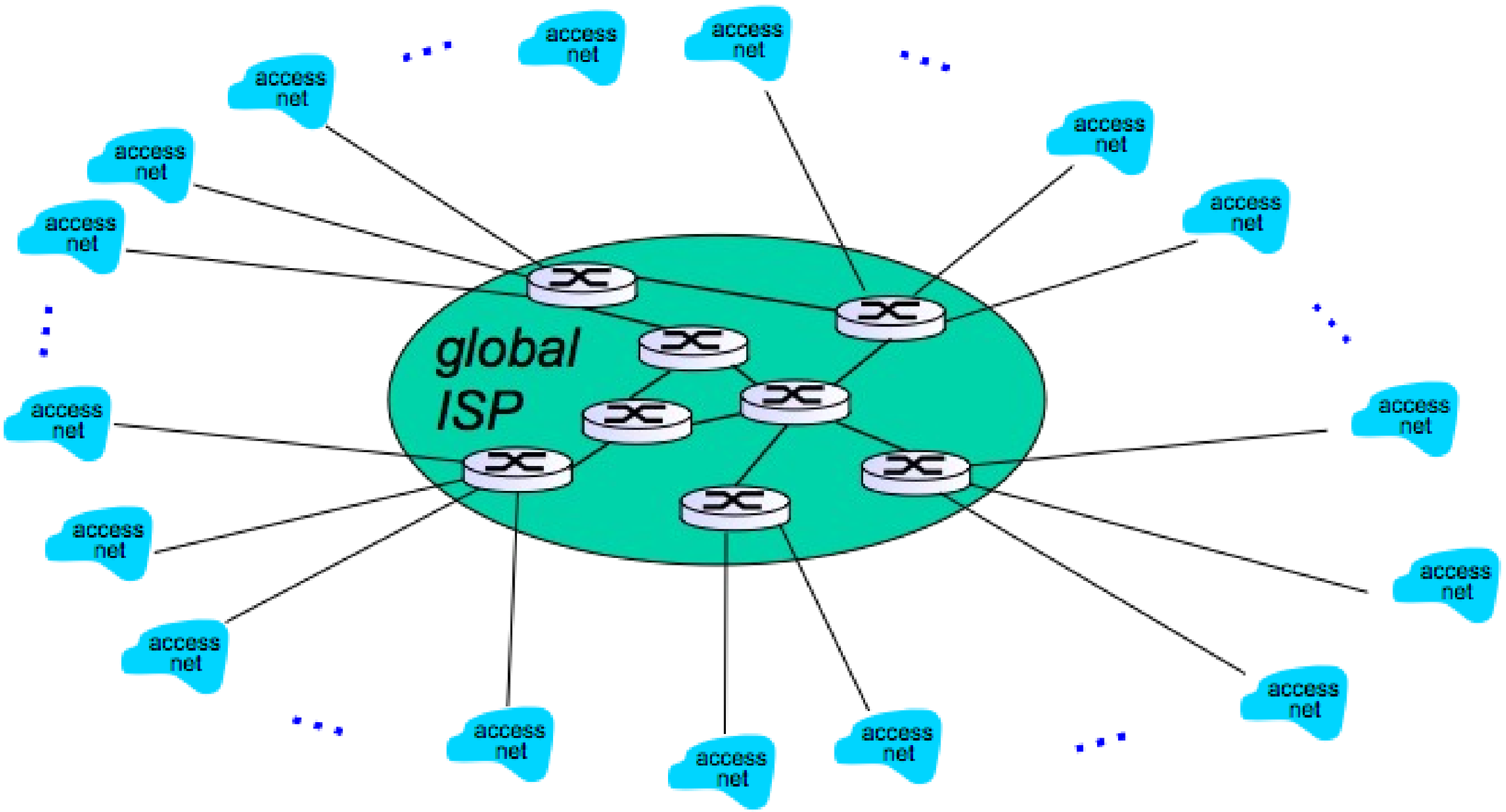
Internet Structure: Network of Networks

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



Internet Structure: Network of Networks

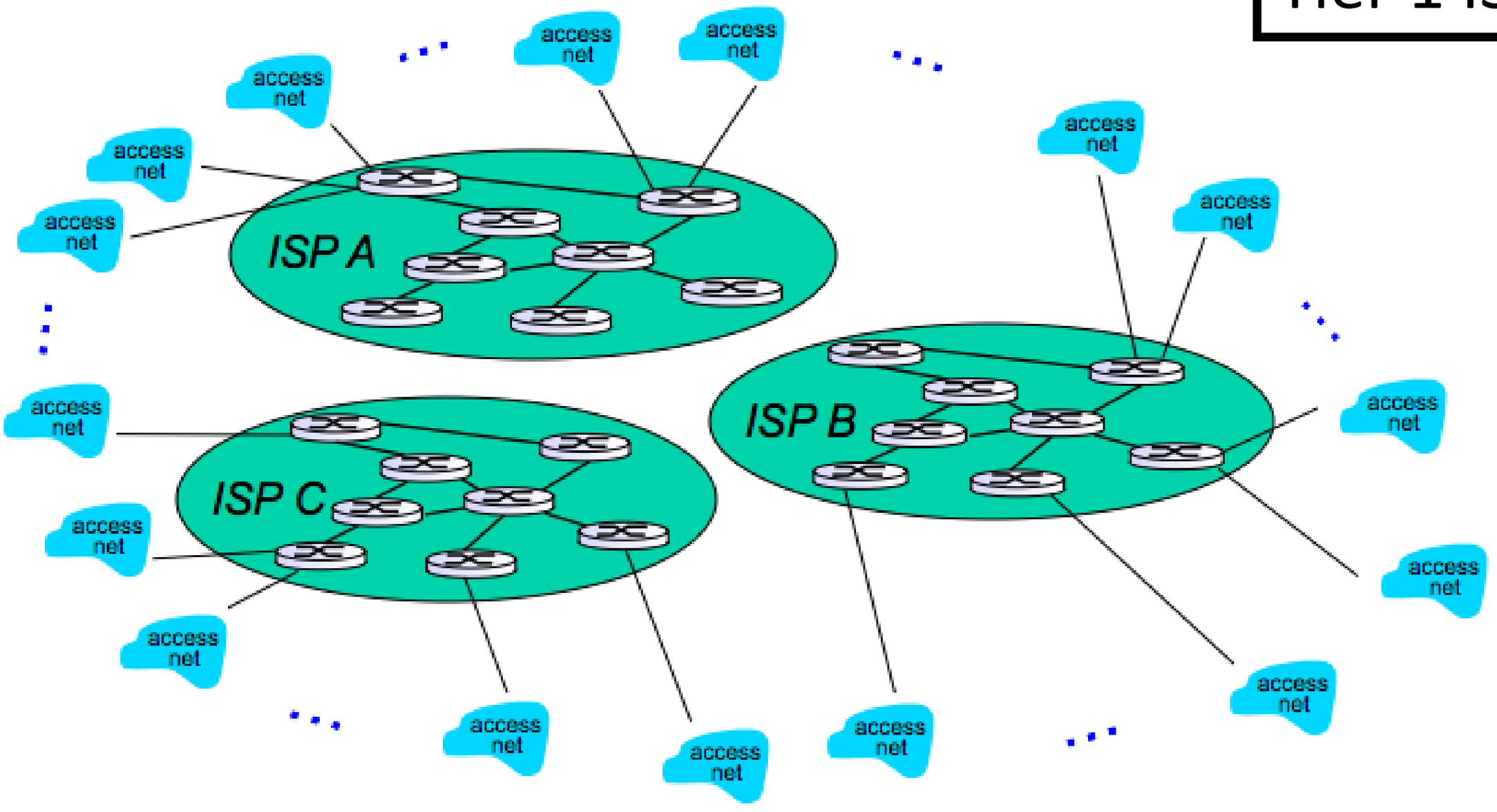
Option: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.



Internet Structure: Network of Networks

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

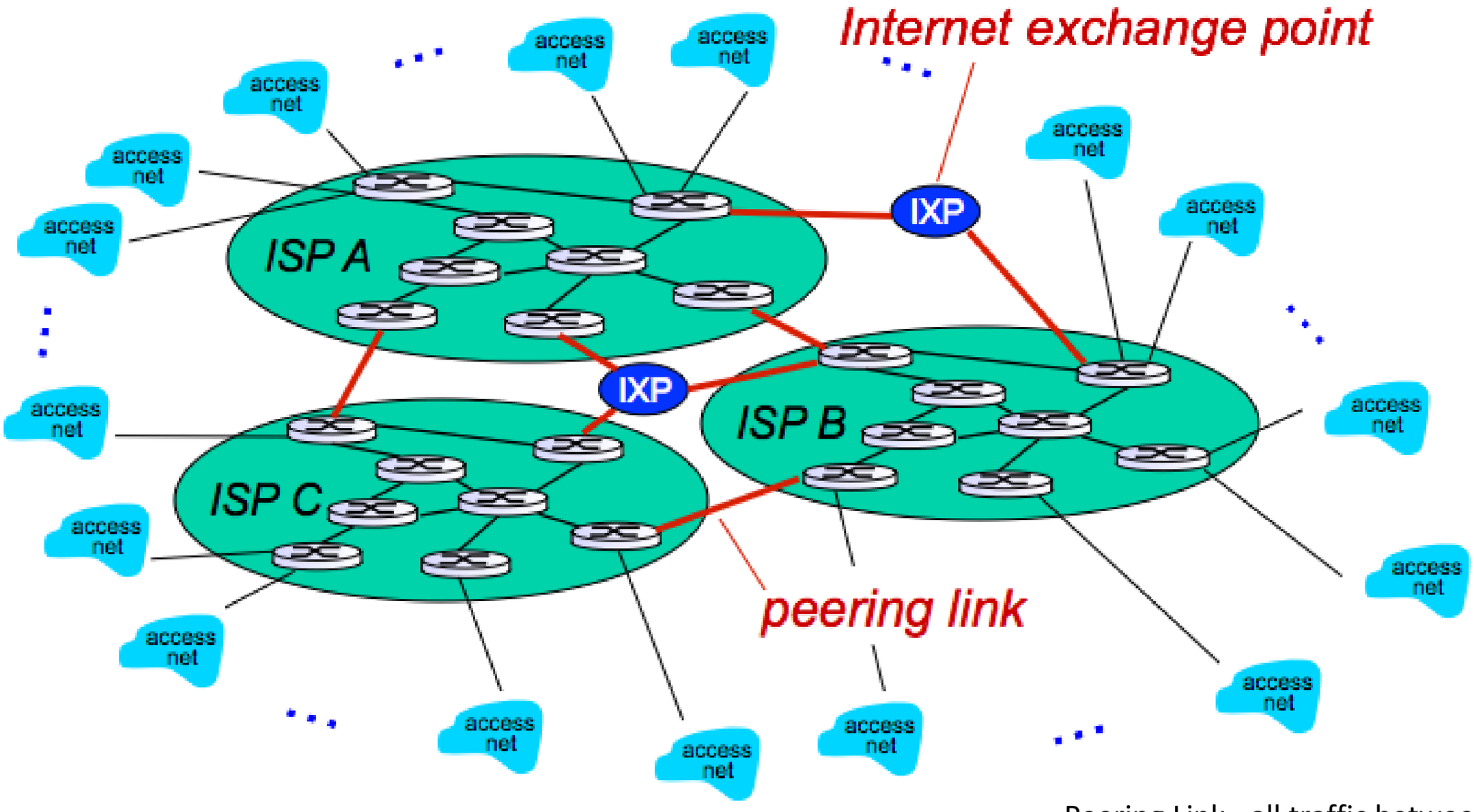
Tier 1 ISPs



Internet Structure: Network of Networks

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

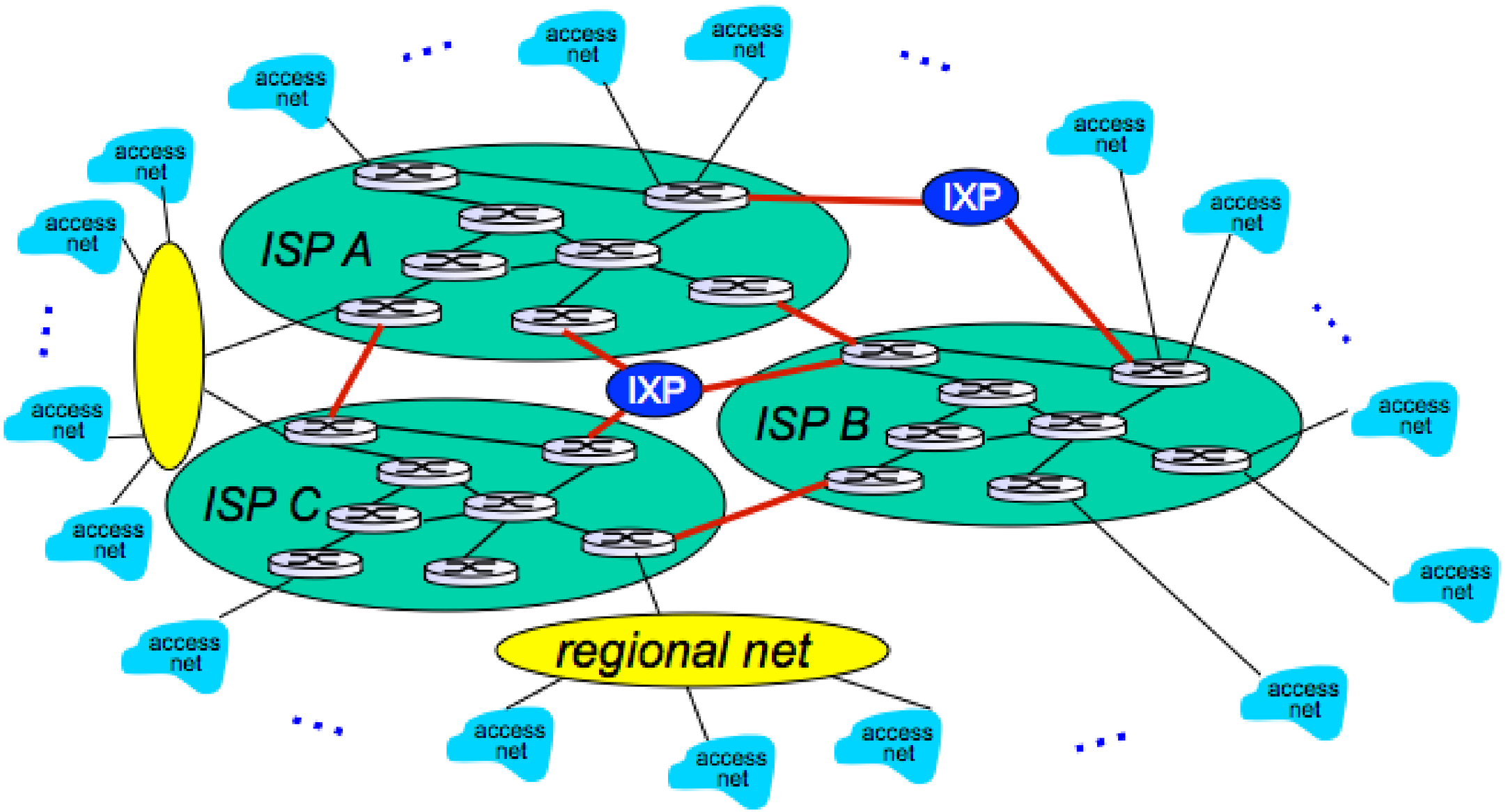
IXP- 3rd party company sets up an exchange point where multiple ISPs can peer together (about 300 IXPs)



Peering Link - all traffic between two ISPs travels through one direct connection

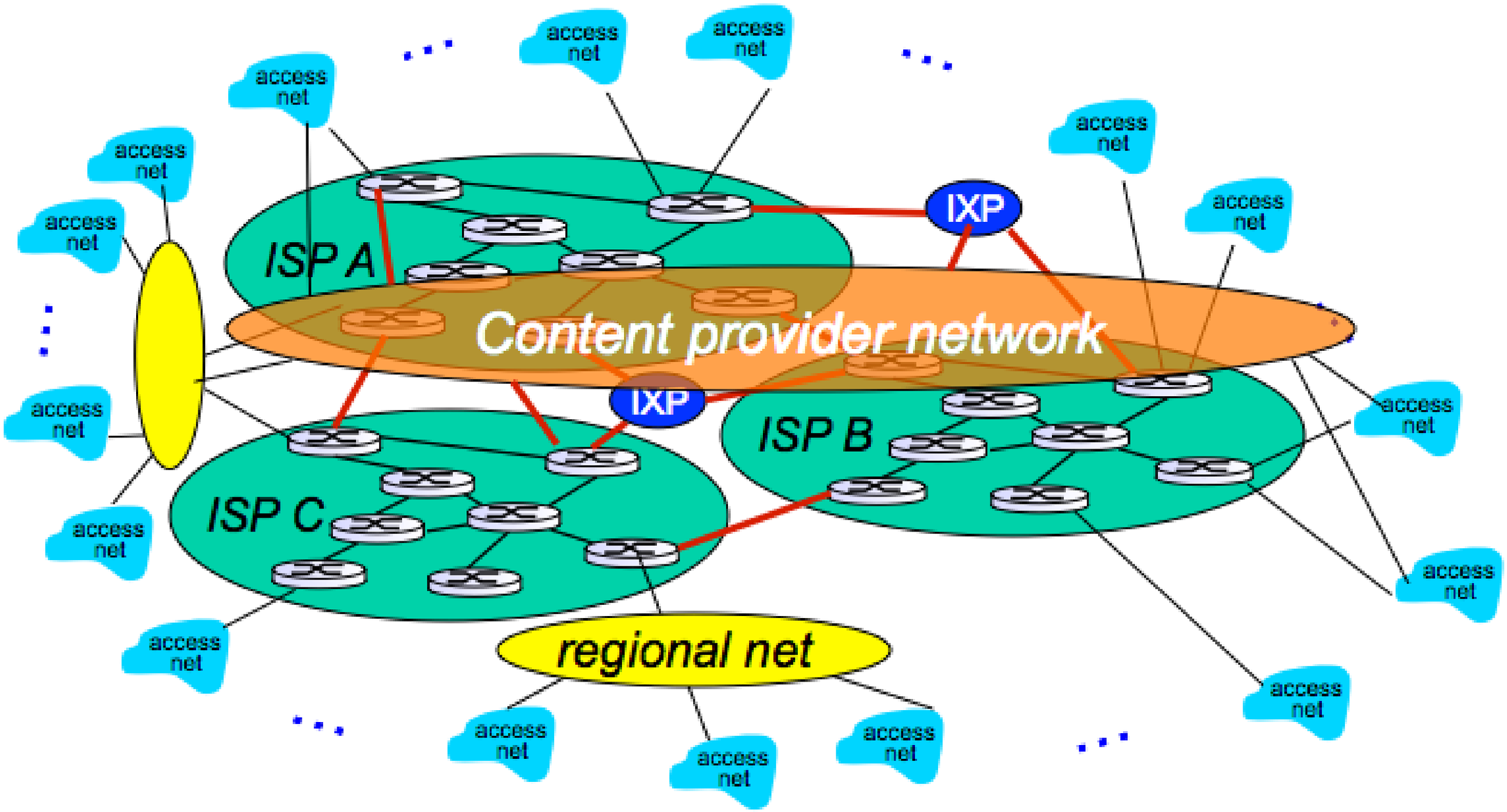
Internet Structure: Network of Networks

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



Internet Structure: Network of Networks

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



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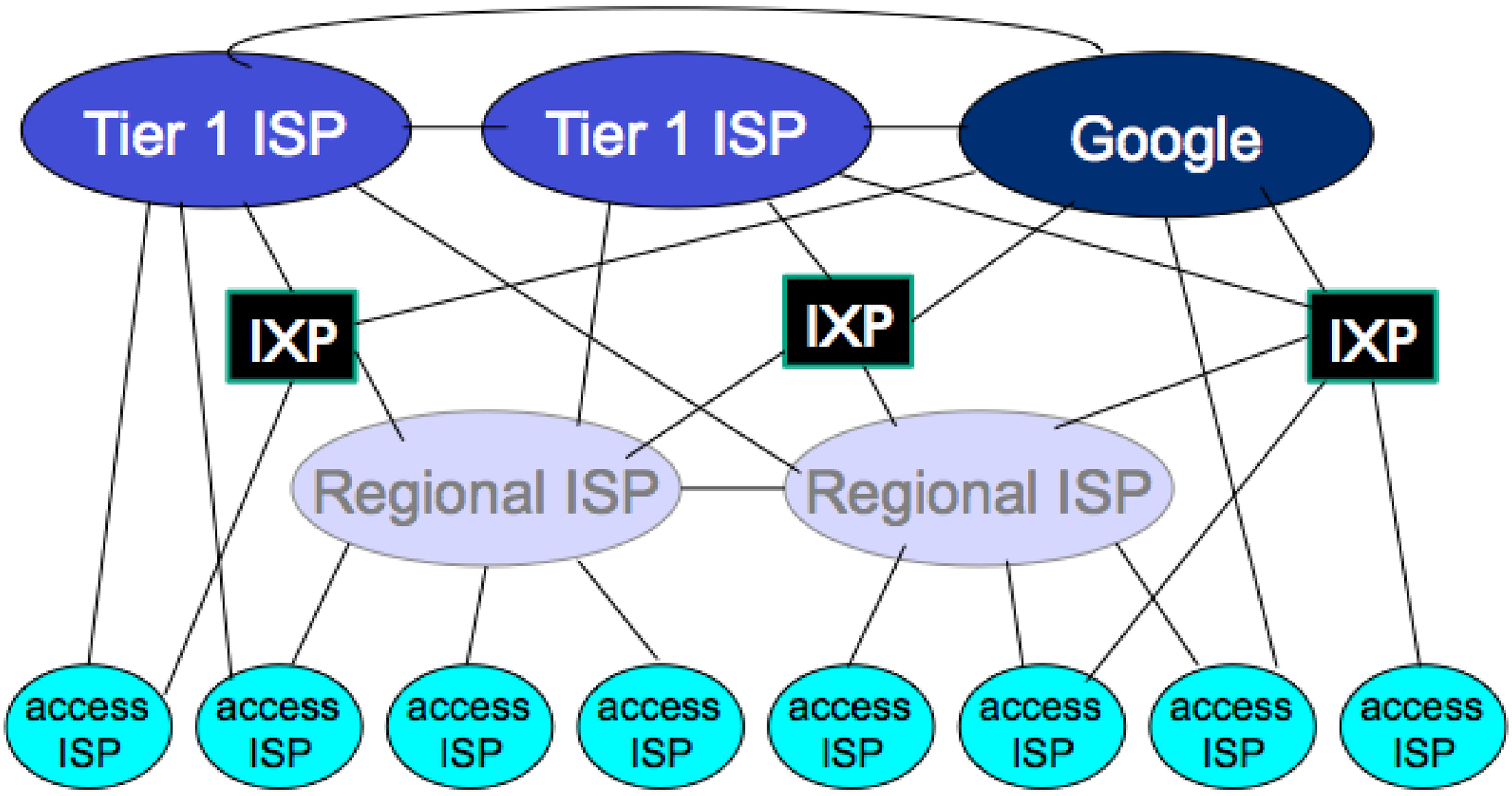
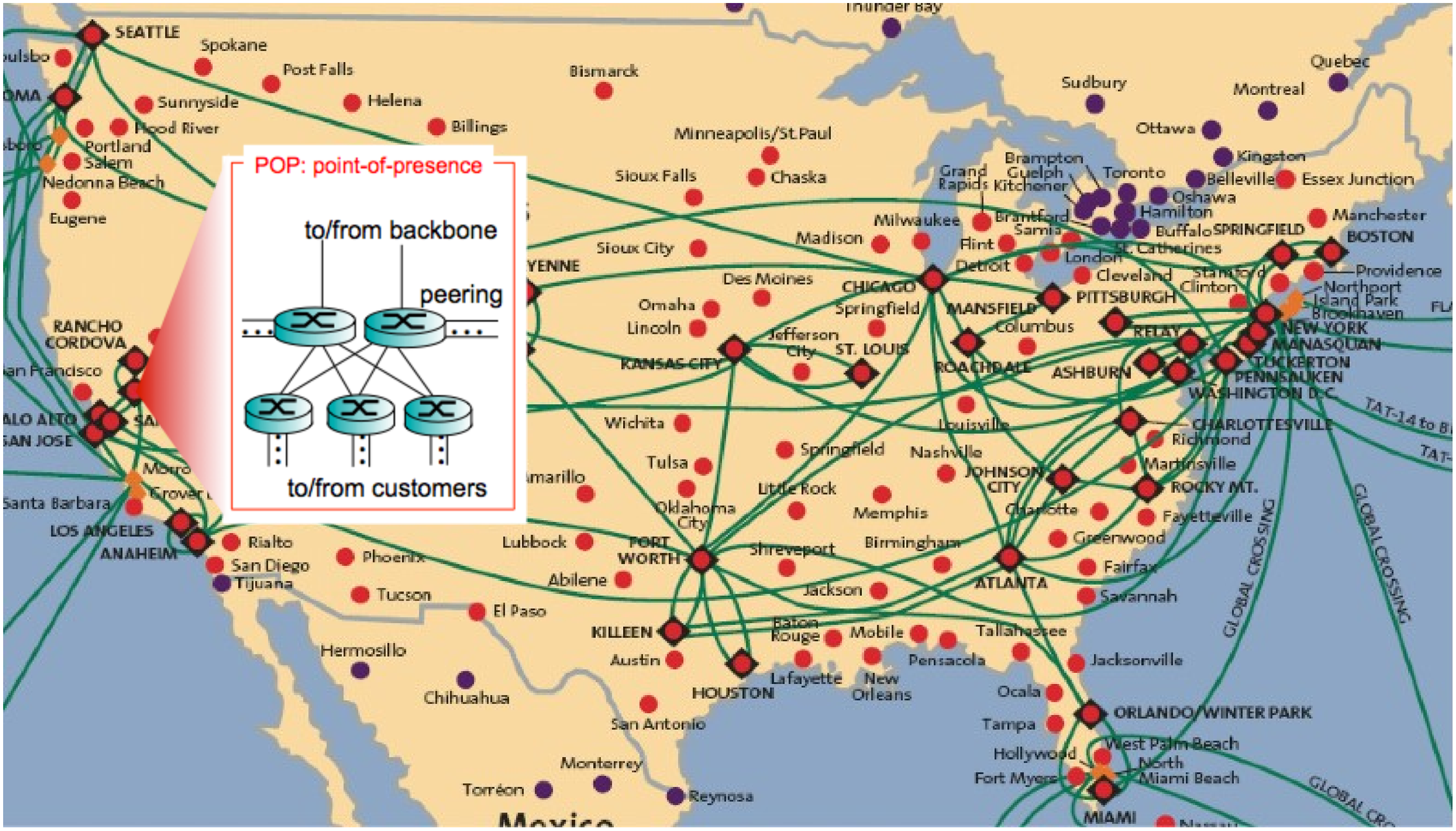


- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Google private network bypasses upper tiers by peering with lower tiers directly

Google has over 50 data centers some with over 100,000 servers, all interconnected via Googles private TCP/IP network

Tier-1 ISP: Sprint



POP: ISP to ISP connections

Sets of routers in the provider's network
where customer ISPs can connect into provider ISP

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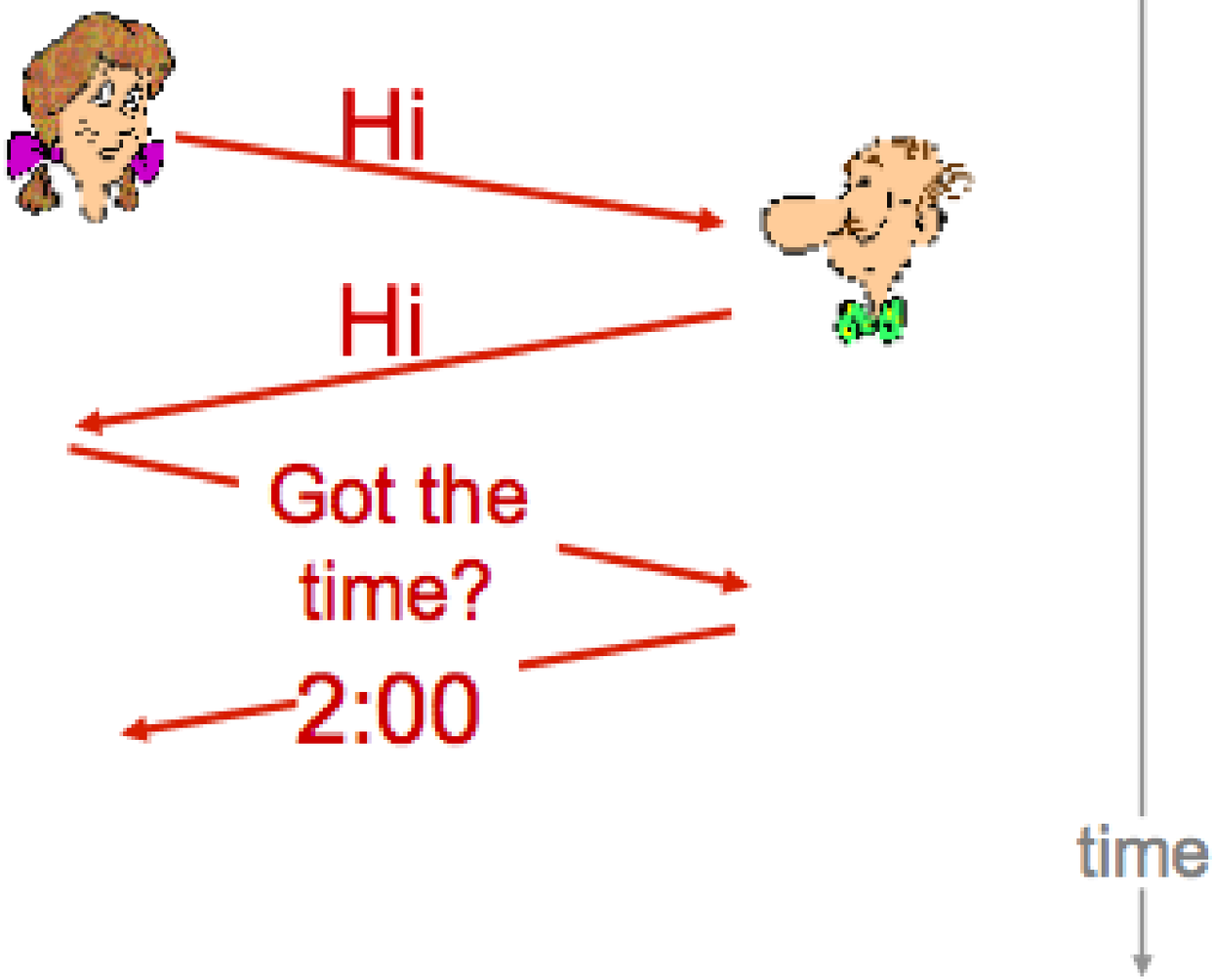
What’s a Protocol?

What's a Protocol?

A Human Protocol



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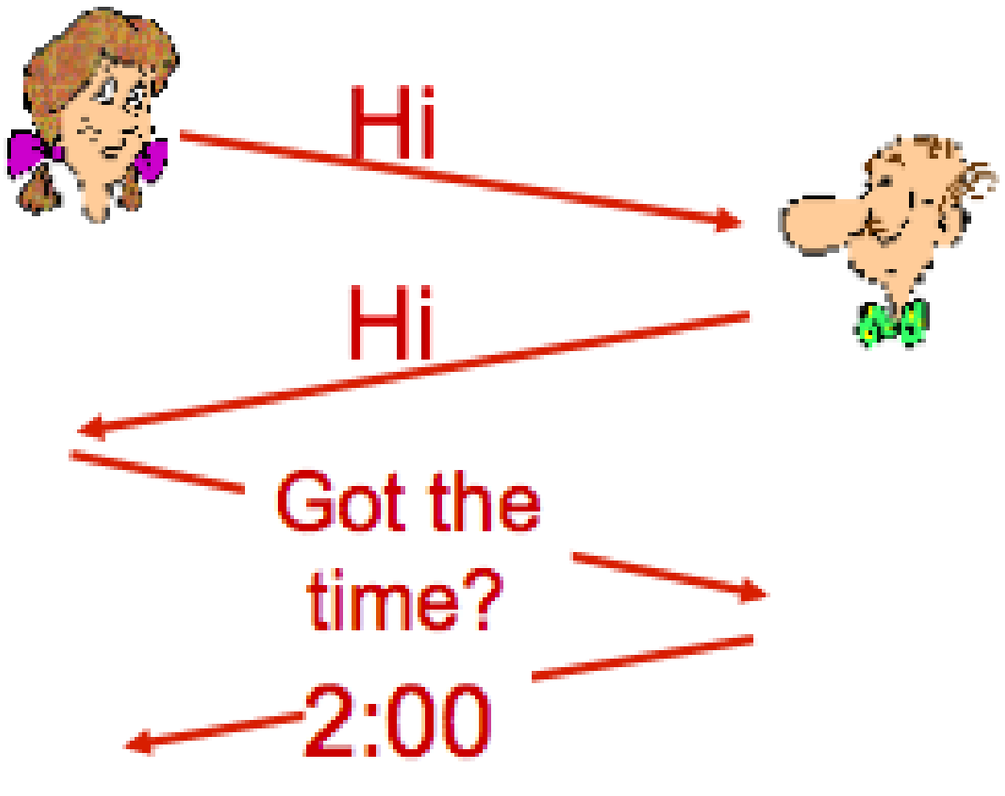
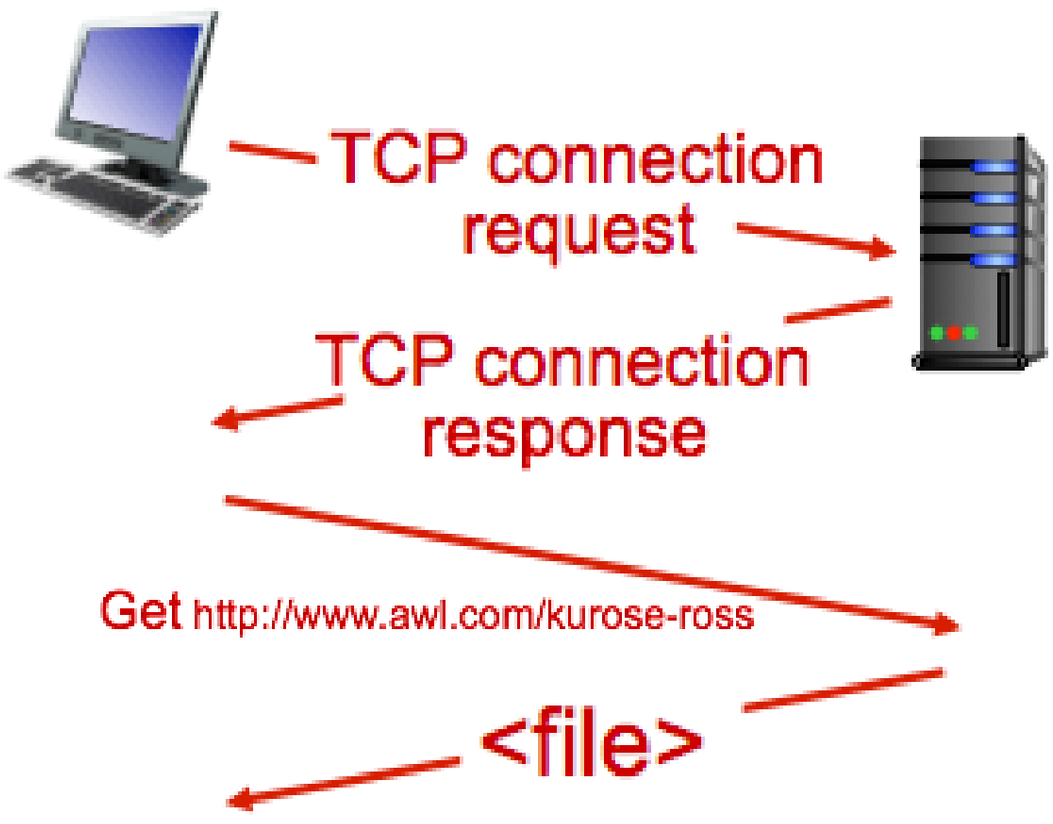


A Computer Network Protocol



time

What's a Protocol?

human protocols:

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

… specific msgs sent

… specific actions taken when msgs received, or other events

network protocols:

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

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

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 network?

…. or at least our discussion of networks?

Problem Scenario

Web

Email

Bittorrent

VoIP

- This is a nightmare scenario
- Huge amounts of work to add new apps or media
- Limits growth and adoption

Ethernet

802.11

Bluetooth

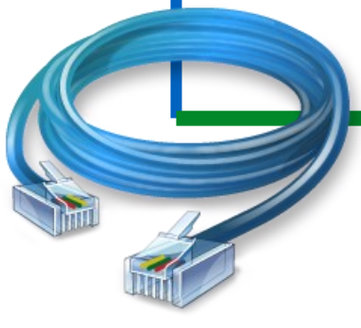
Cellular

More Problems

Bittorrent

Bittorrent

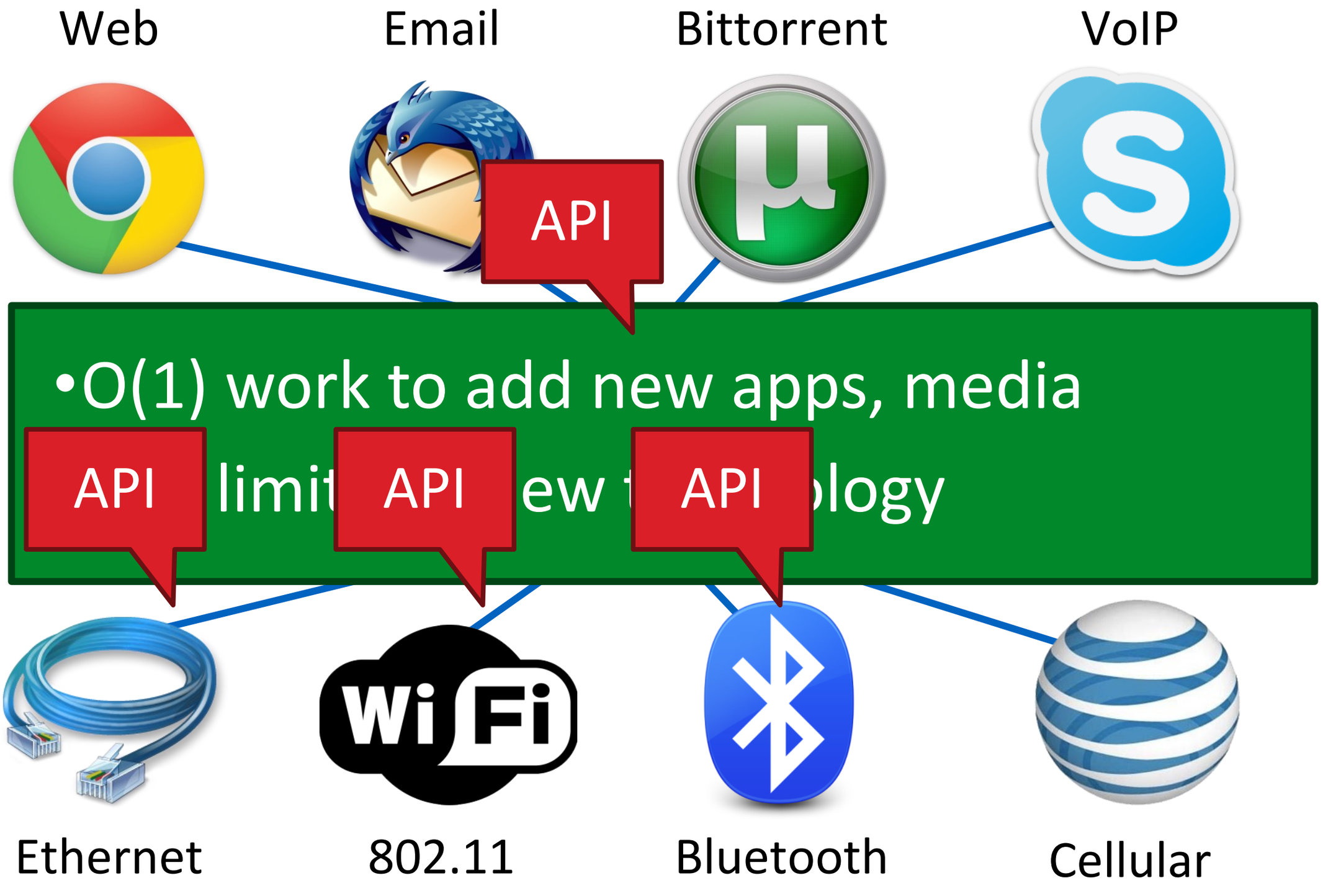
Application endpoints may not be on the same media



Ethernet

802.11

Solution: Use Indirection

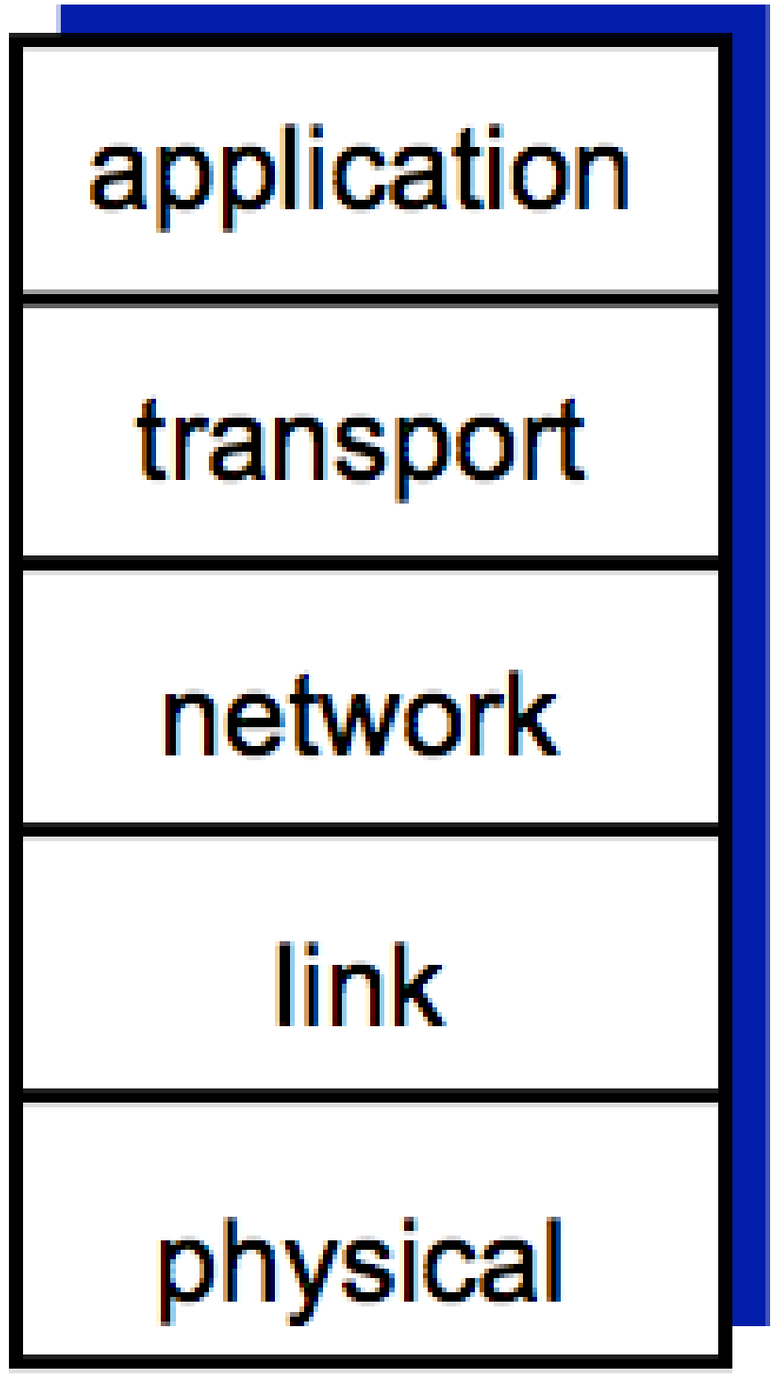


Layers, Protocols, Interfaces

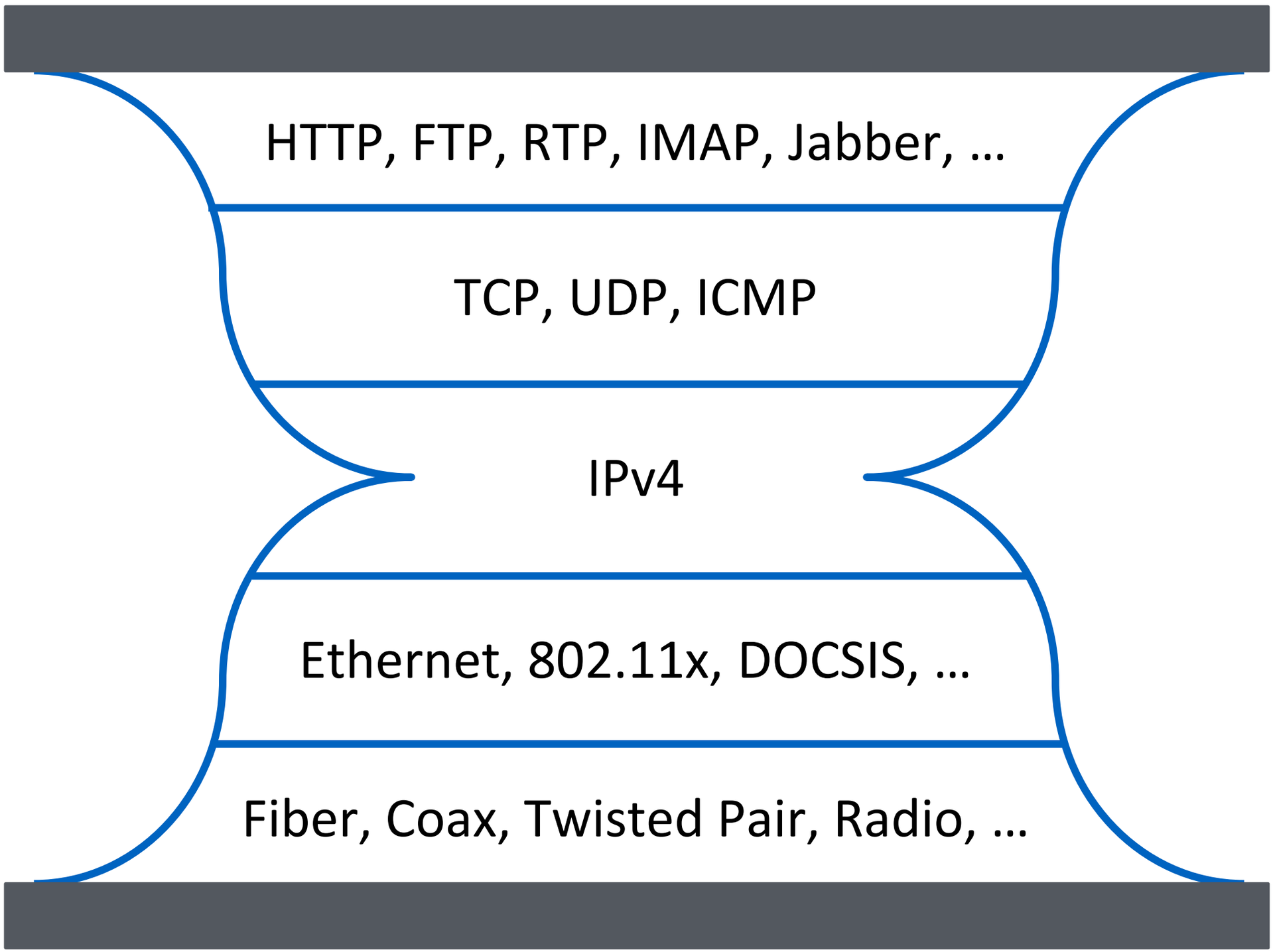
- Networks organized as a **stack of layers**
  - Offer services to the layer above it using a well-defined **interface** (programming language analogy: libraries hide details while providing a service)
    - Reduces design complexity
- **Protocols:** Logical “horizontal” conversations at any layer (between peers)
- **Data Transfer:** each layer passes data & control information over the interfaces (between neighboring layers)

Internet Protocol Stack

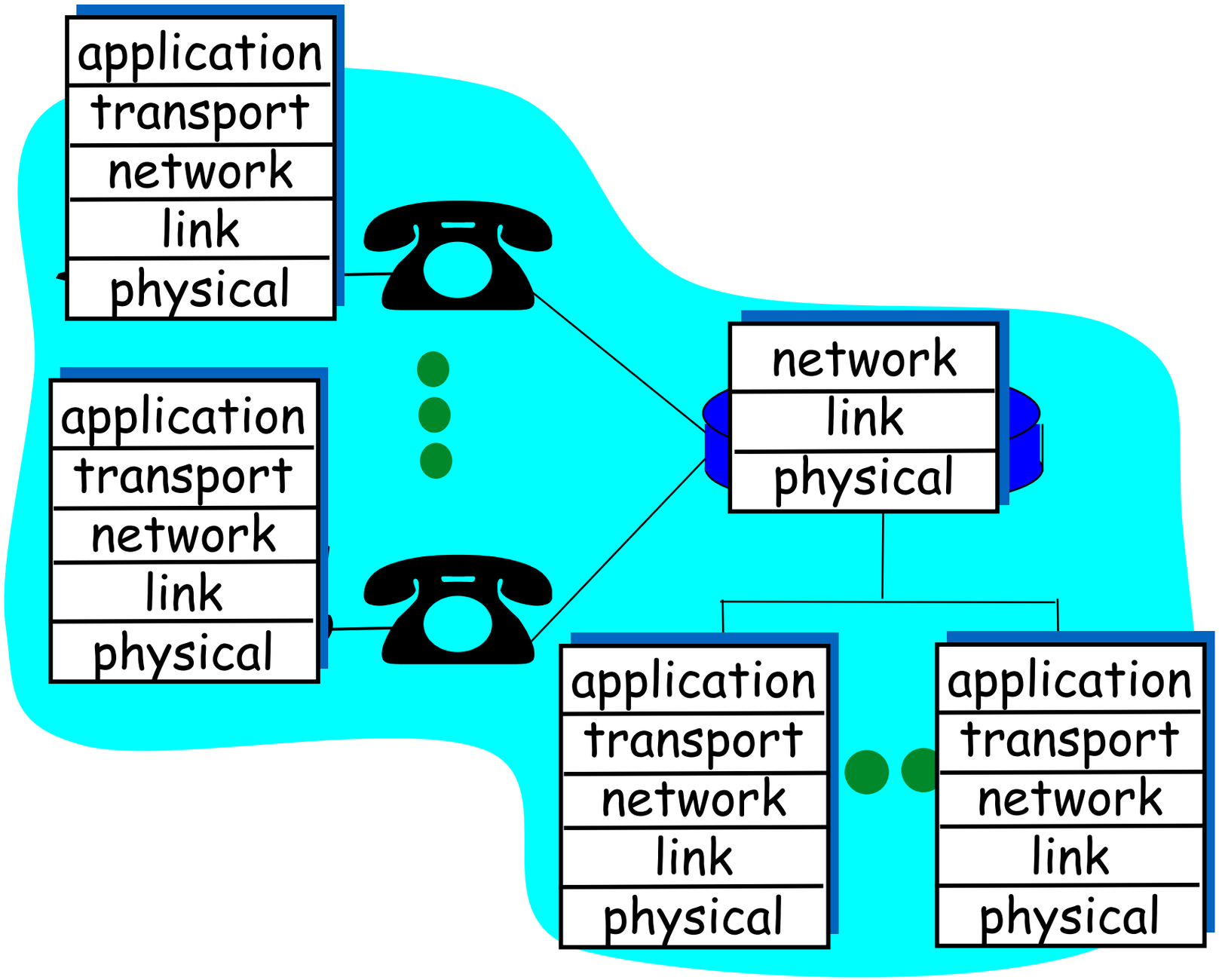
- *application:* supporting network applications
  - FTP, SMTP, HTTP
- *transport:* process-process data transfer
  - TCP, UDP
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi),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



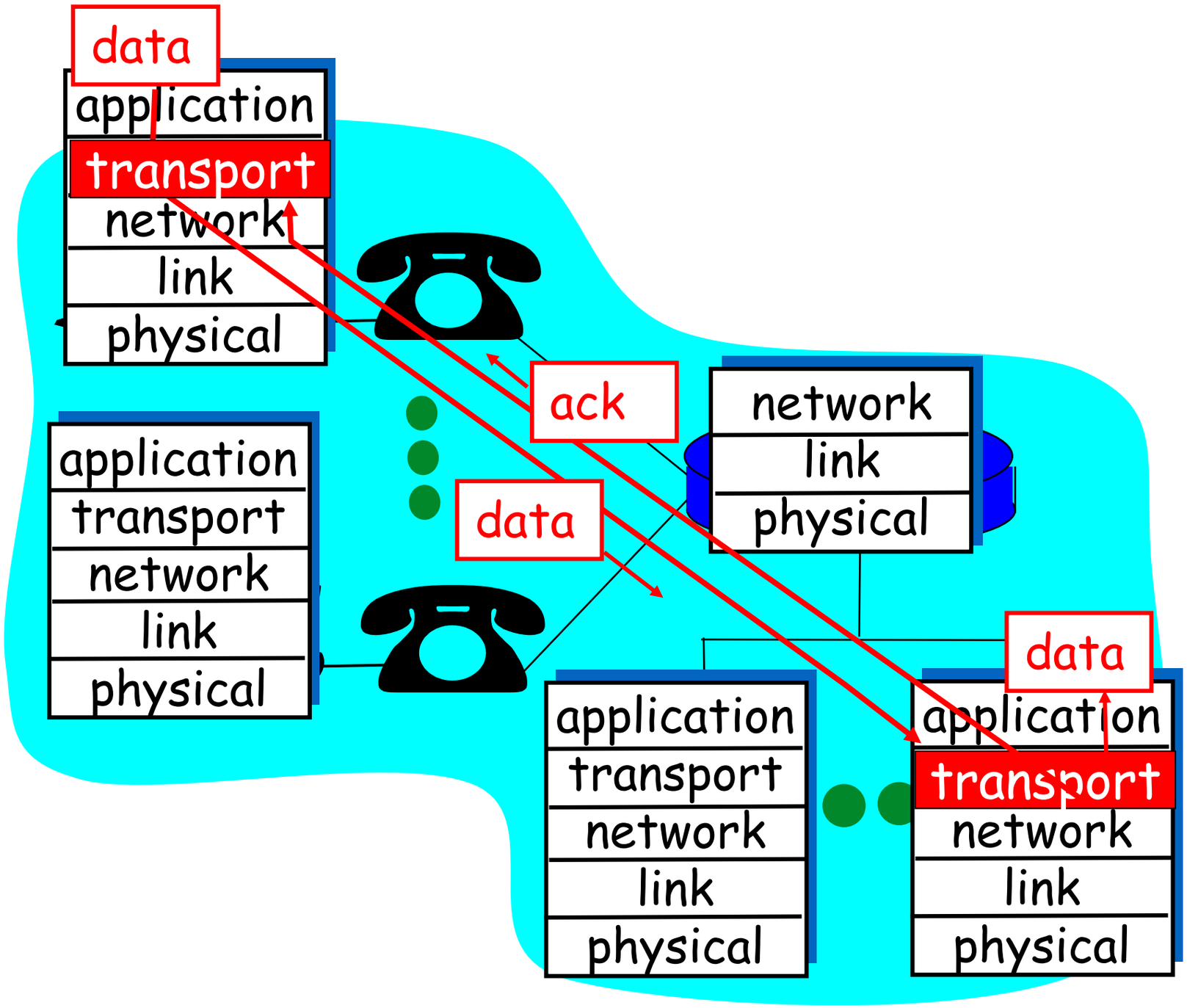
The Hourglass



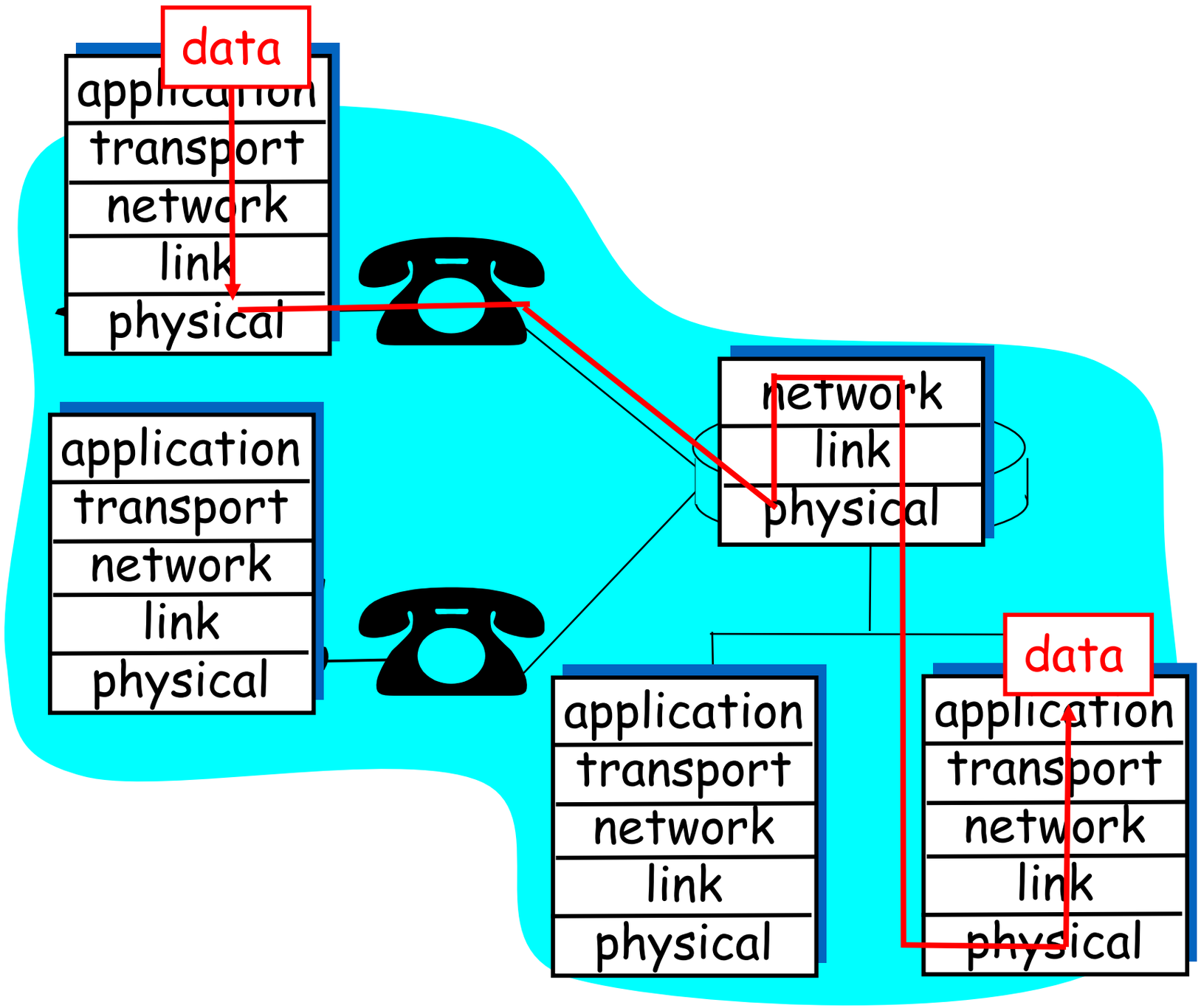
Layering: logical communication



Layering: ***logical*** communication



Layering: ***physical*** communication



Encapsulation: Layering and data

Each layer takes data from above

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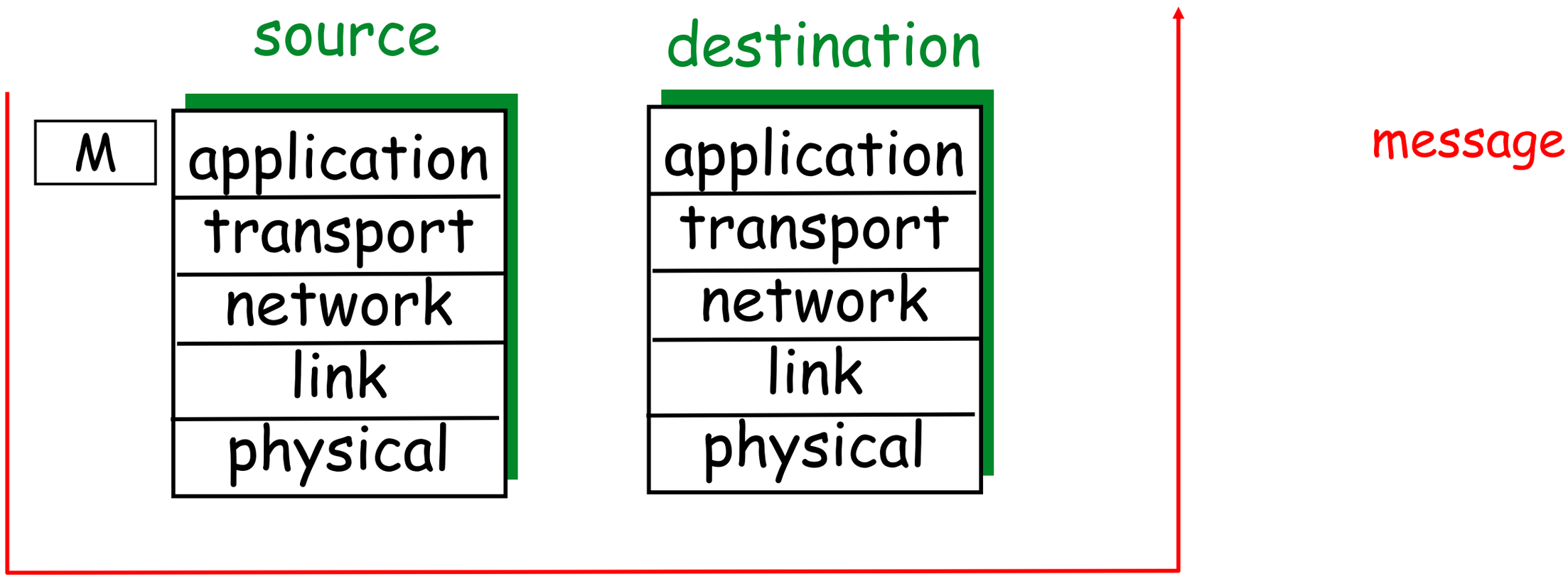

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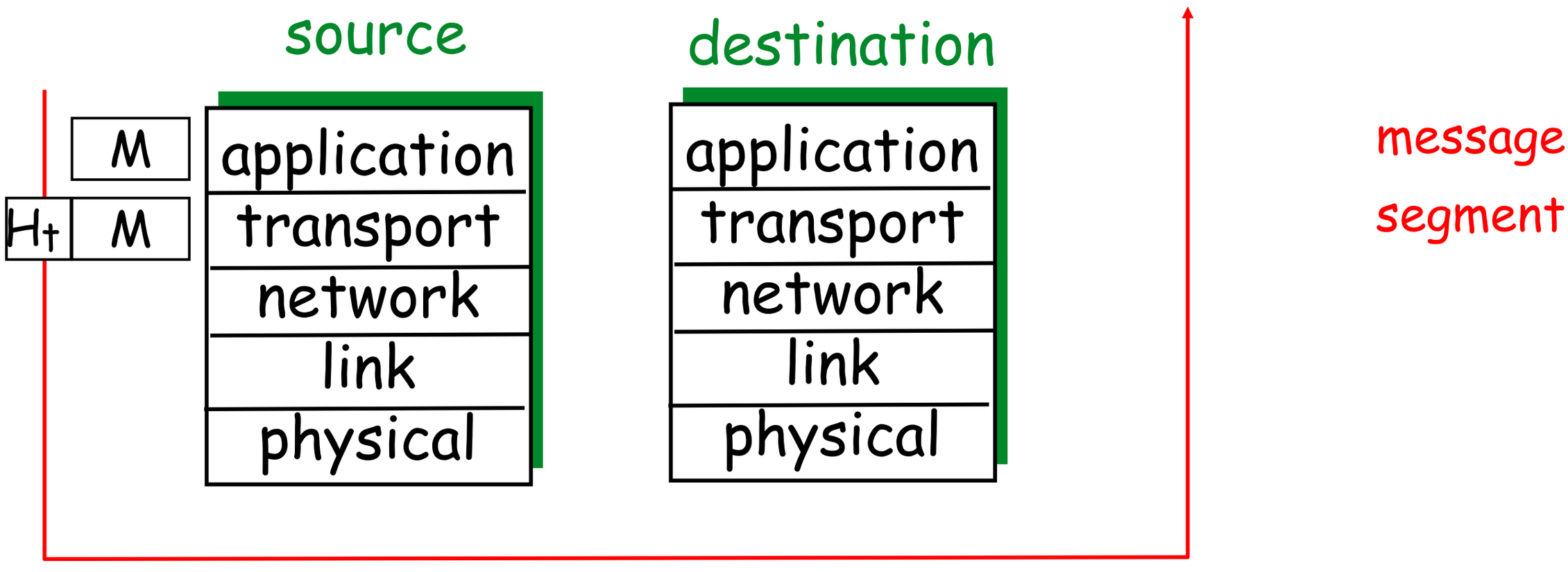

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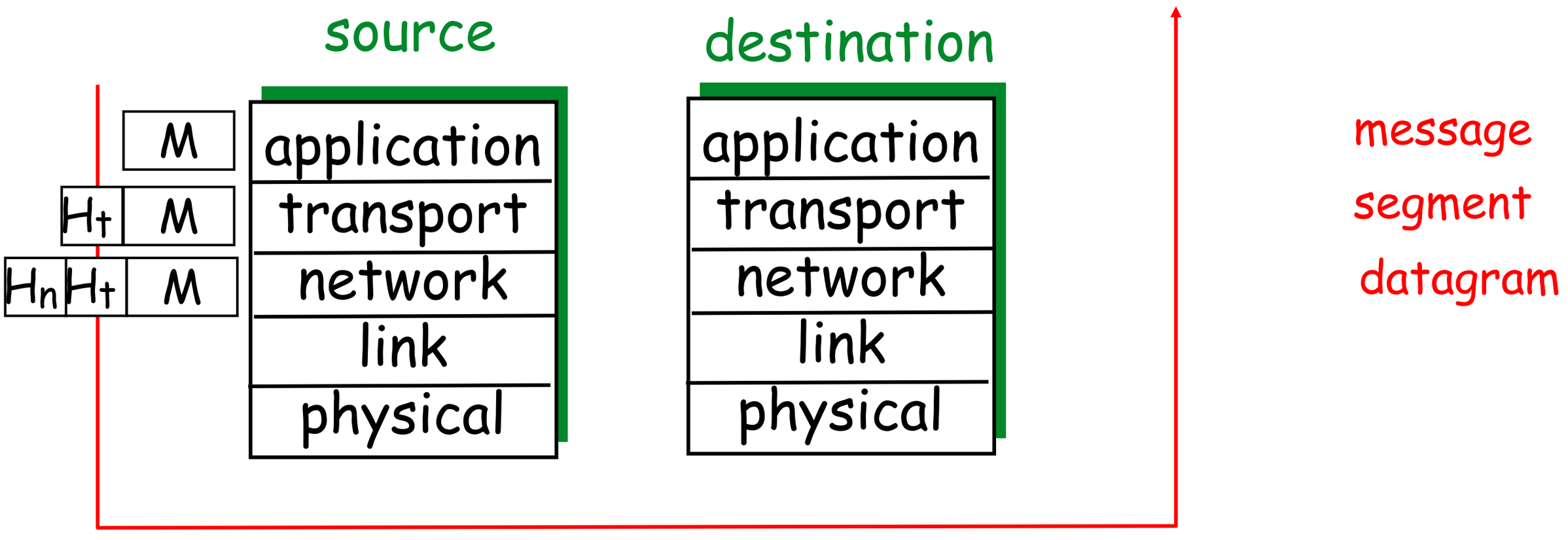

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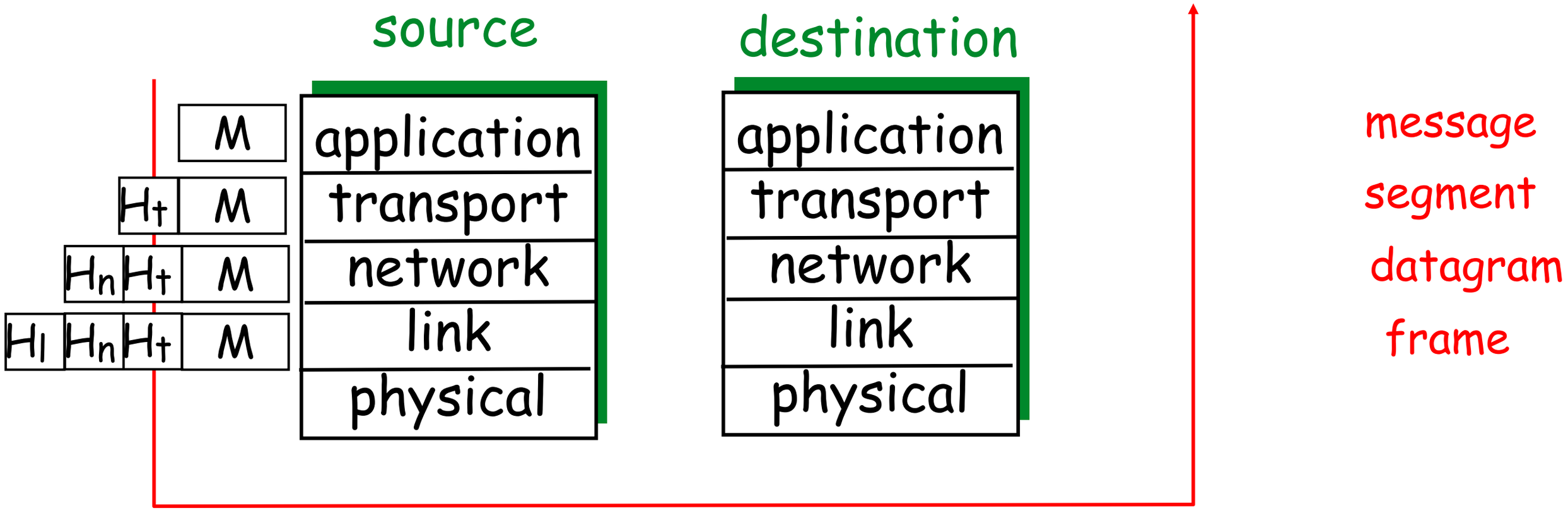

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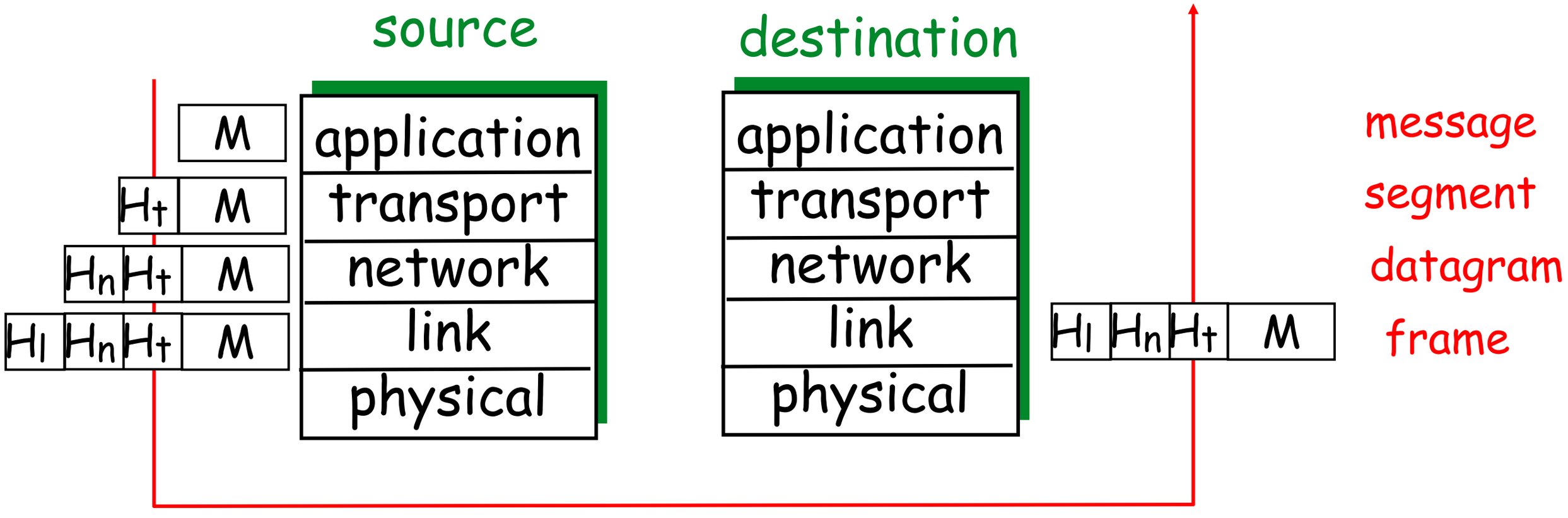

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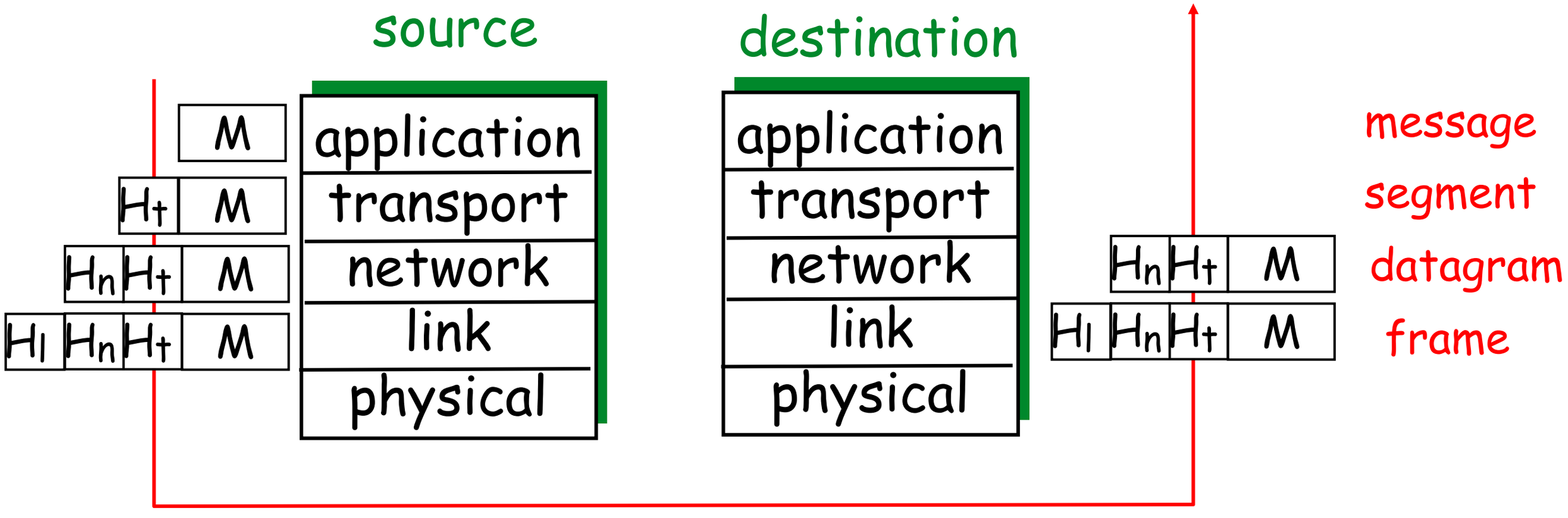

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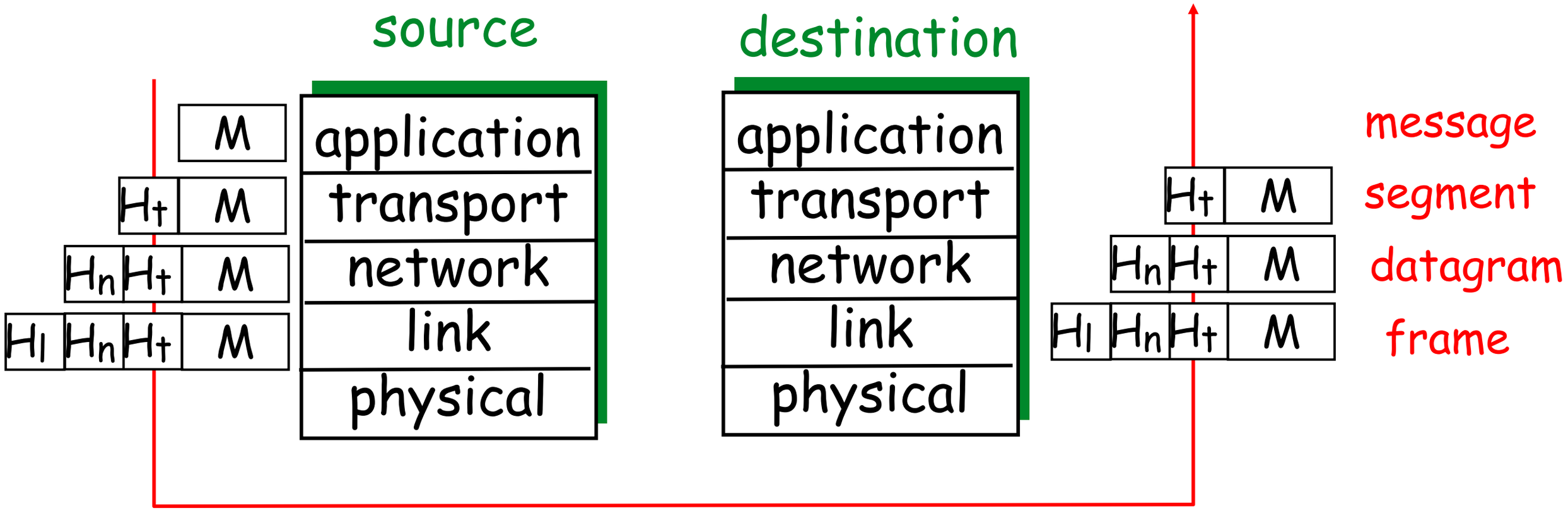

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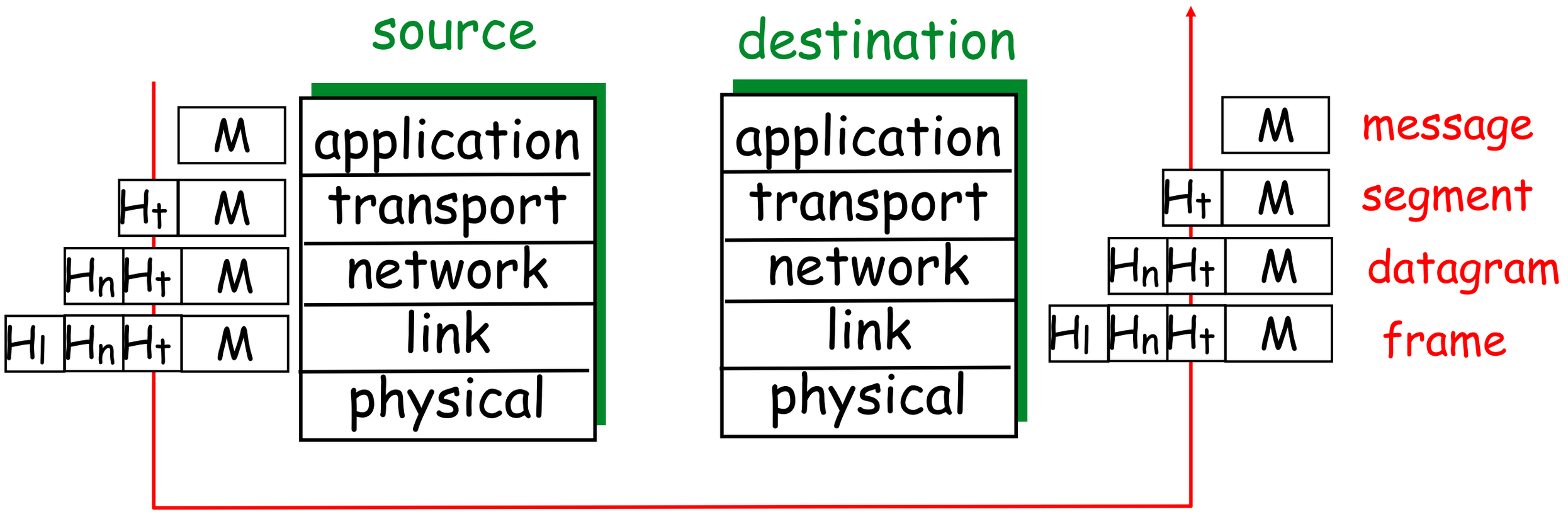

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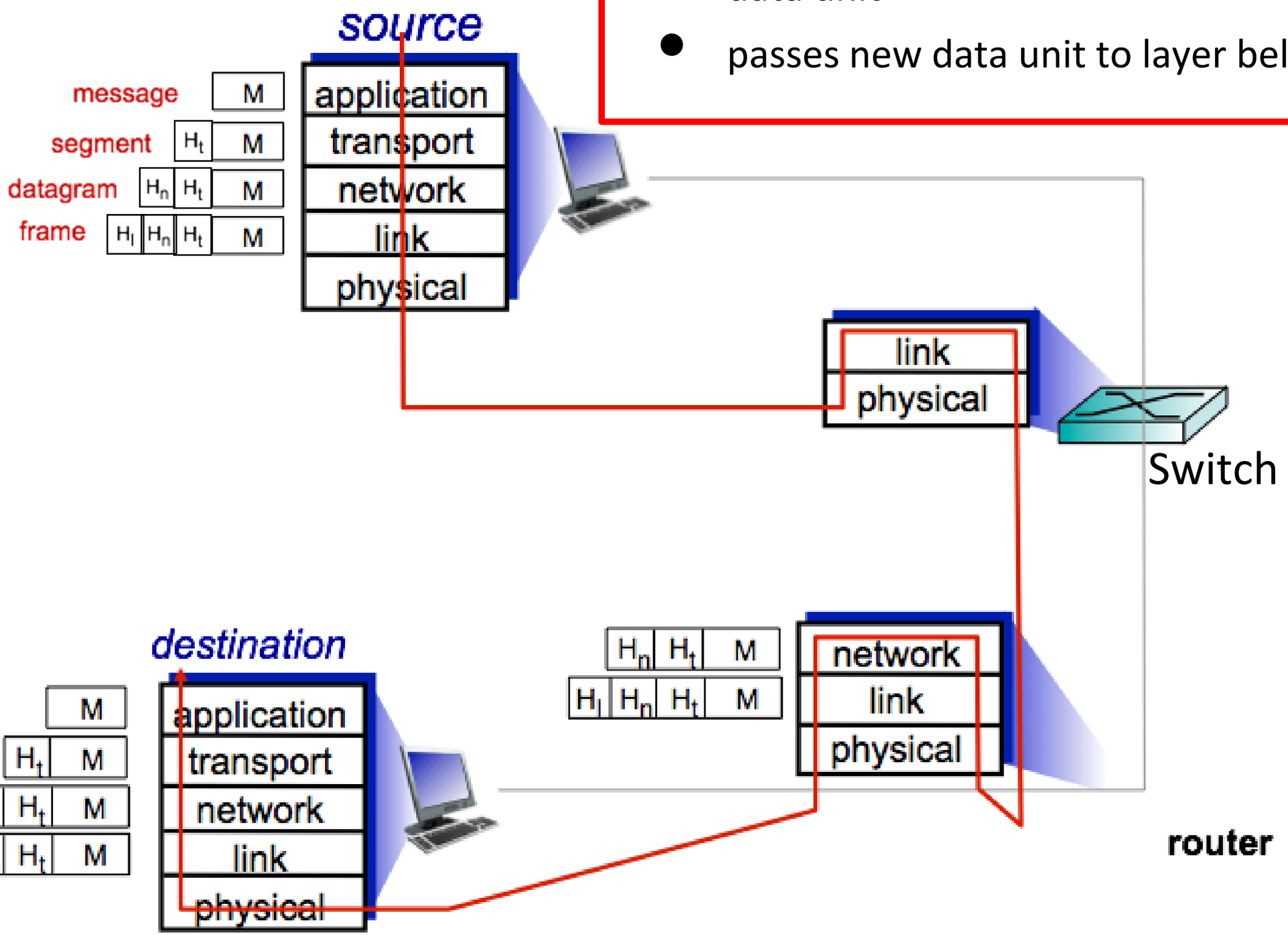


Roadmap

- What is the Internet?
- Network Edge
  - End systems, access networks, links
- Network Core
  - Packet switching, network structure
- Protocol Layers, service models
- Network Security
- History

Network Security

- field of network security
  - how bad "entities" may attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks
- Internet not originally designed with (much) security in mind
  - *original vision:* "a group of mutually trusting users attached to a transparent network" ☺
  - Internet protocol designers playing "catch-up"
  - security considerations in all layers!

Bad guys/girls/organizations ("entities"): can put malware into hosts via Internet

- malware can get in host from a virus, worm, or Trojan horse.

- spyware malware can record keystrokes, web sites visited, upload info to collection site.

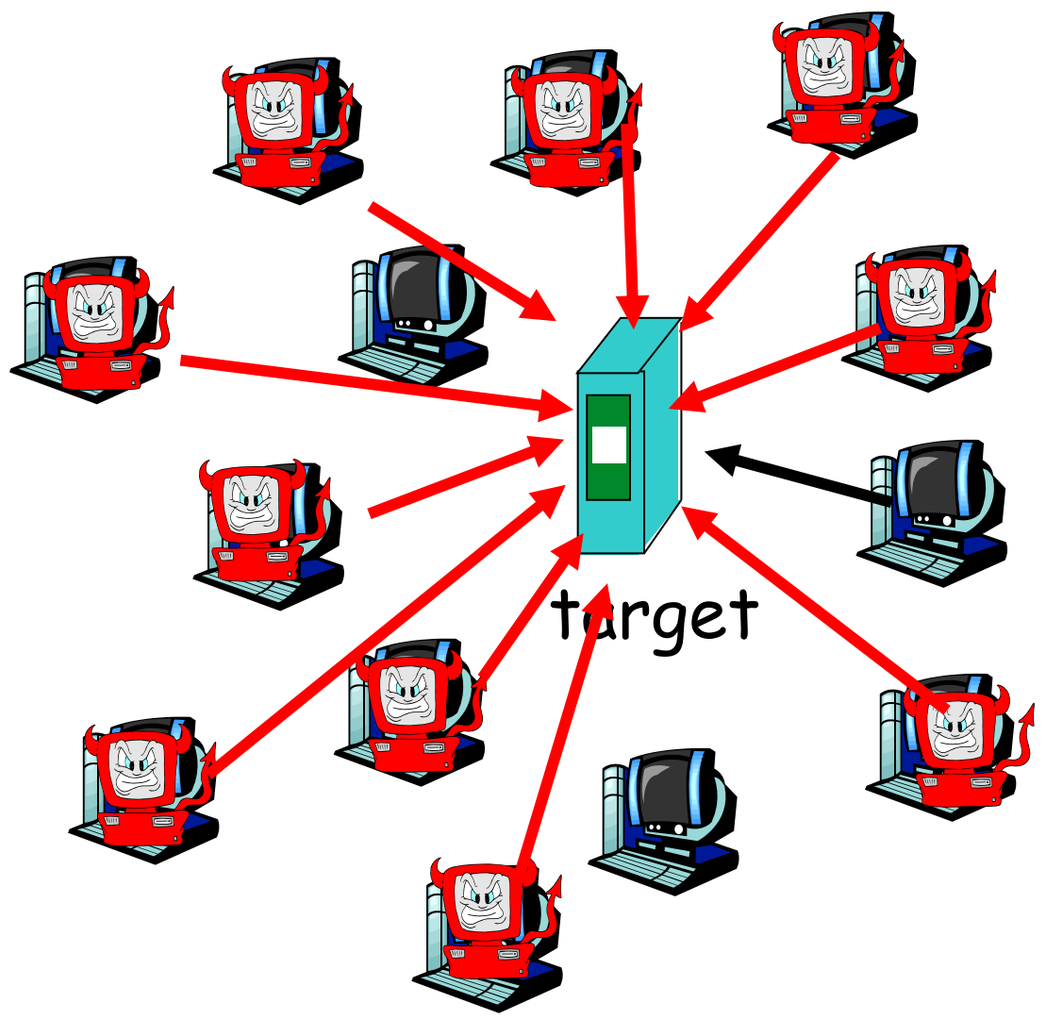
- infected host can be enrolled in botnet, used for spam and DDoS attacks.

- malware often self-replicating: from one infected host, seeks entry into other hosts

Bad "entities" can attack servers and network infrastructure

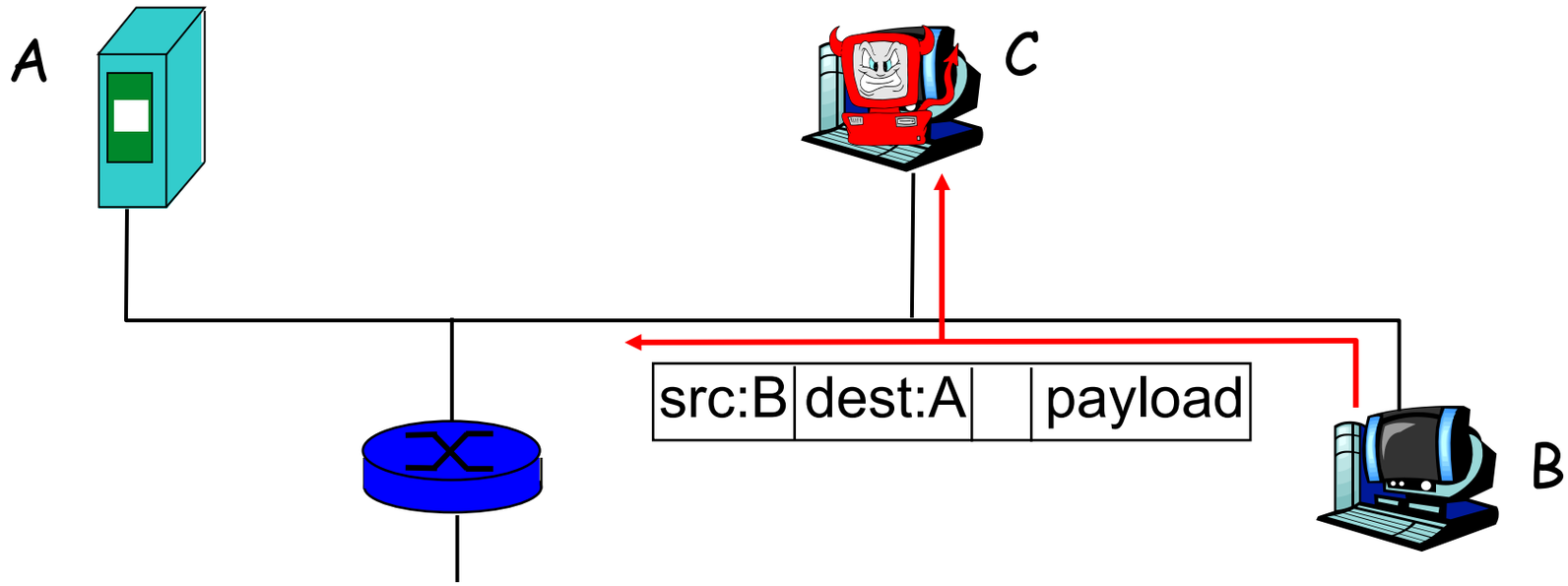
Denial of Service (DoS): attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts



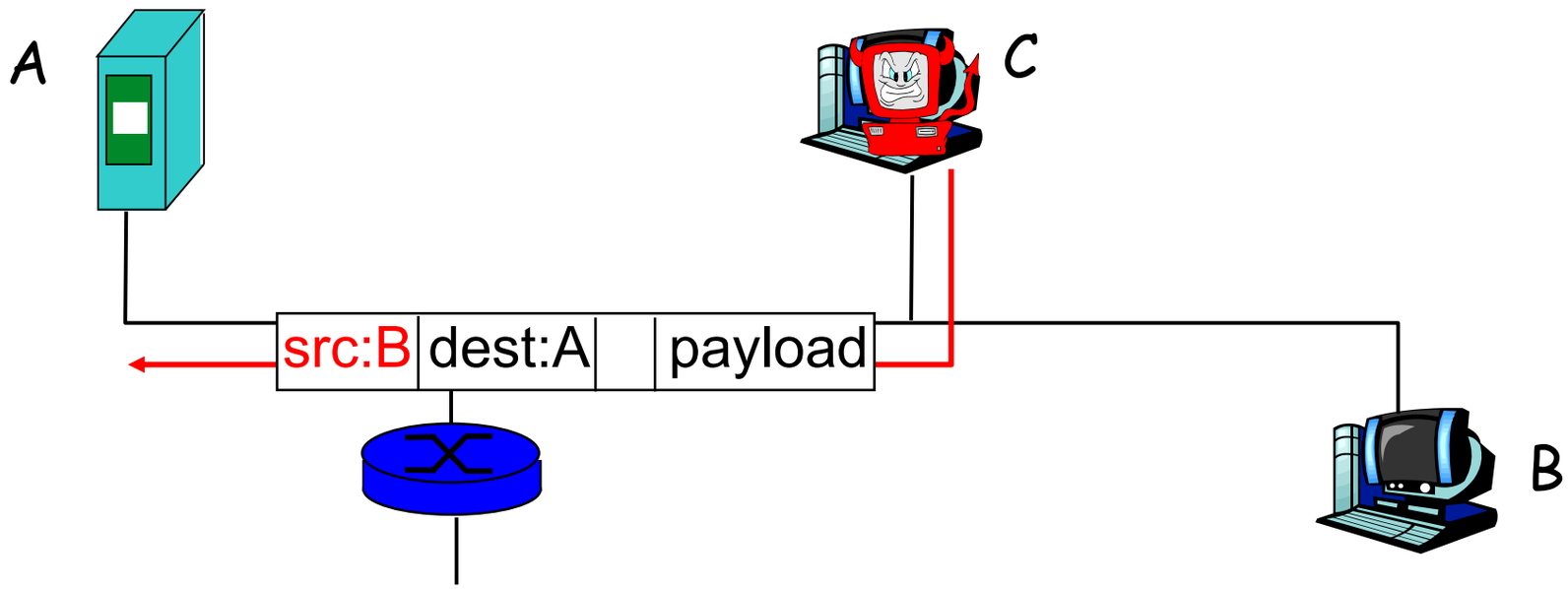
Bad “entities” can “sniff”

Broadcast medium allow packet
sniffers (in promiscuous mode)
to listen to packets to others



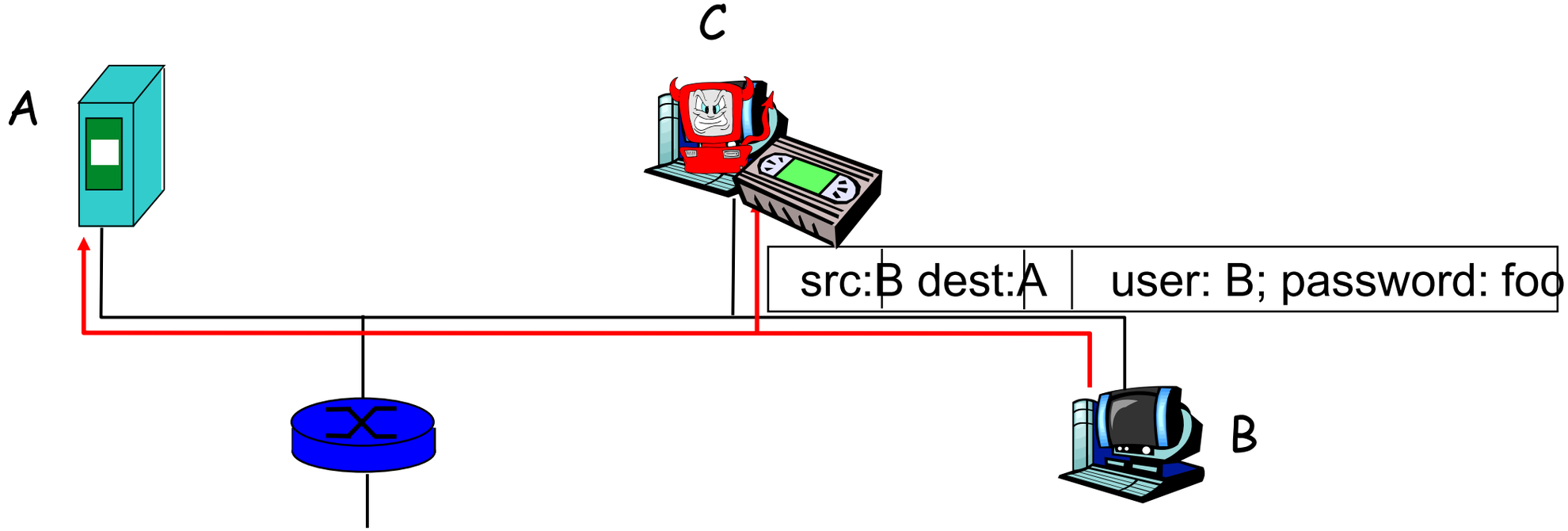
Bad “entities” can use false source addresses

IP spoofing: send packet with false source address



Bad "entities" can record and playback

record-and-playback: sniff sensitive info (e.g., password), and use later



… AND lots more …

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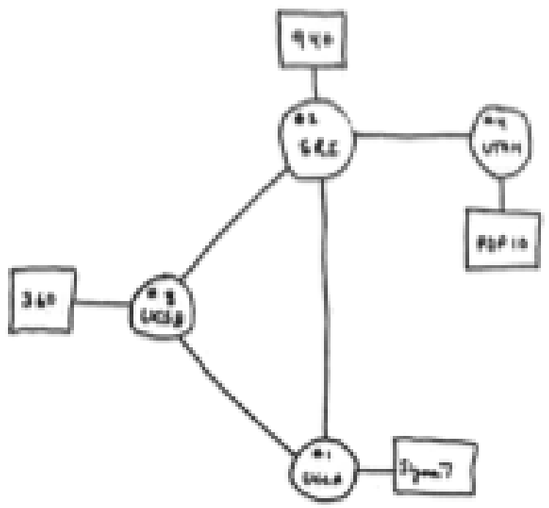
Internet History

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

DNS - Domain Name Server

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

2,9 billion users 2014 ??

- ~~~750 million~~ hosts — 2,7 billion users 2013
  - Smartphones and tablets
- Aggressive deployment of broadband access
- Increasing ubiquity of high-speed wireless access
- Emergence of online social networks: — 1.23 billion users2014
  - Facebook: soon ~~one billion users~~ — 1.11 billion users March 2013
- Service providers (Google, Microsoft) create their own networks
  - Bypass Internet, providing "instantaneous" access to search, emai, etc.
- E-commerce, universities, enterprises running their services in "cloud" (eg, Amazon EC2)

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