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CHAPTER 1
INTRODUCTION TO COMPUTER NETWORKS

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PhD. LE TRAN DUC

OUTLINE

1. About the course
2. What's the Internet?
3. What's the protocol?
4. Network edge: hosts, access network, physical media
5. Network core: packet/circuit switching, Internet structure
6. Network topology
7. Network Performance: loss, delay, throughput
8. Internet Structure
9. OSI model & TCP/IP model

1. ABOUT THE COURSE

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REFERENCES

1. Slides & Notes from lecturer
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3. Nguyễn Tấn Khôi (2004). Giáo trinh môn học Mạng máy tính. Trường ĐHBK - ĐHĐN
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6. Forouzan, B. A., & Mosharraf, F. (2012). Computer networks: a top-down approach (p. 931). McGraw-Hill.
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2. WHAT'S THE INTERNET?

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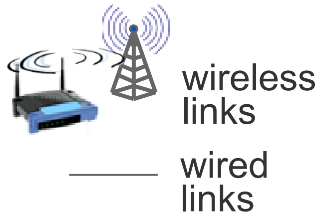
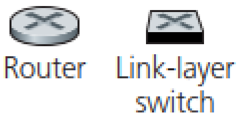
WHAT'S THE INTERNET: "NUTS & BOLTS" VIEW?

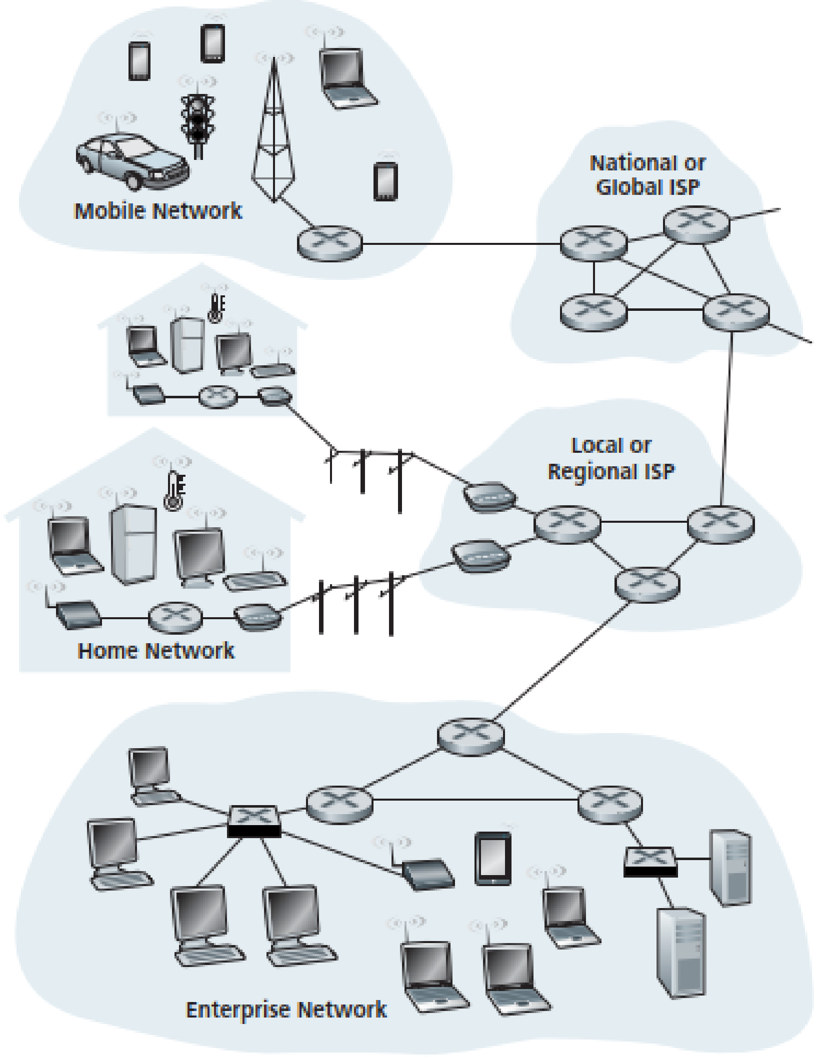
- **Billions of connected computing devices**:
  - *hosts = end systems*
  - running *network apps*

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



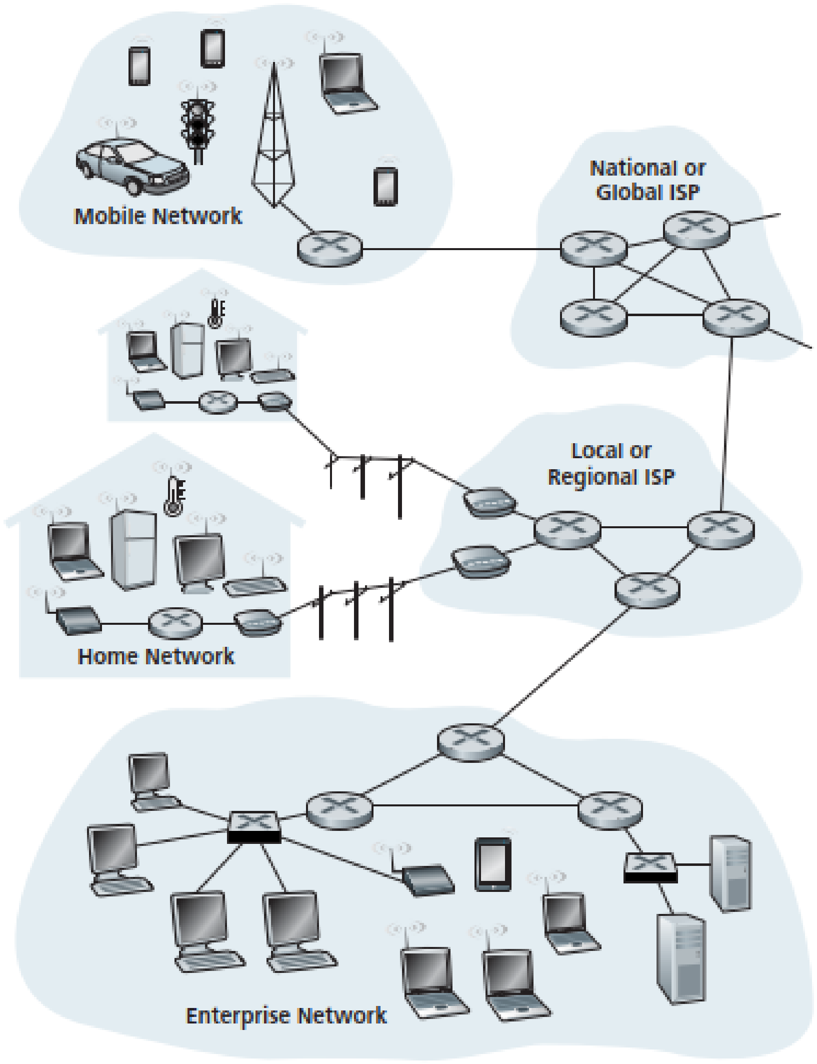
- ***Packet switches:* forward packets (chunks of data)**
  - *routers* and *switches*





WHAT'S THE INTERNET: "NUTS & BOLTS" VIEW?

- **Internet: "network of networks"**
  - Interconnected ISPs
- ***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



3. WHAT'S THE PROTOCOL

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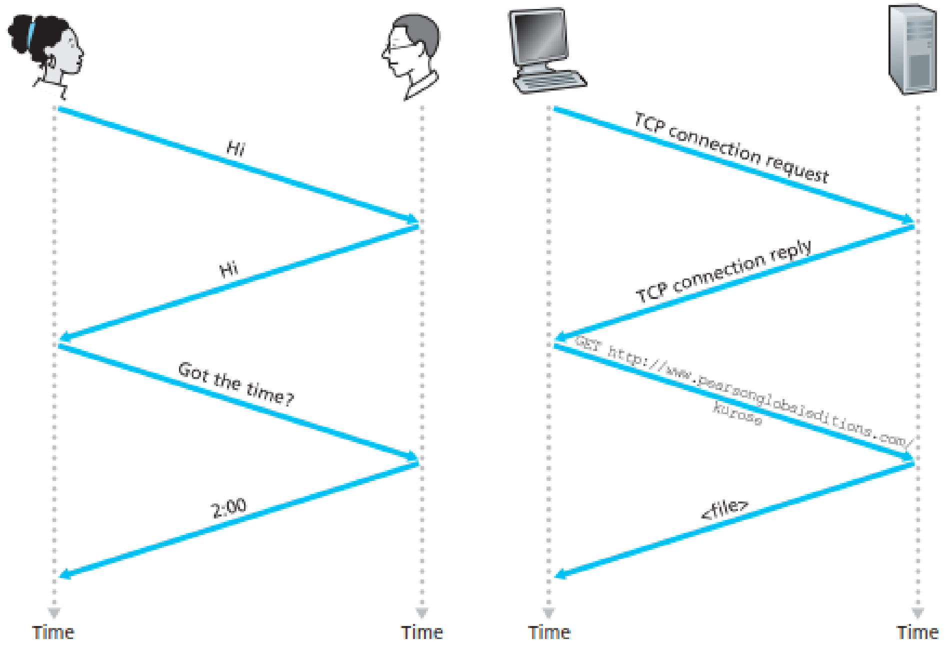
WHAT'S A PROTOCOL?

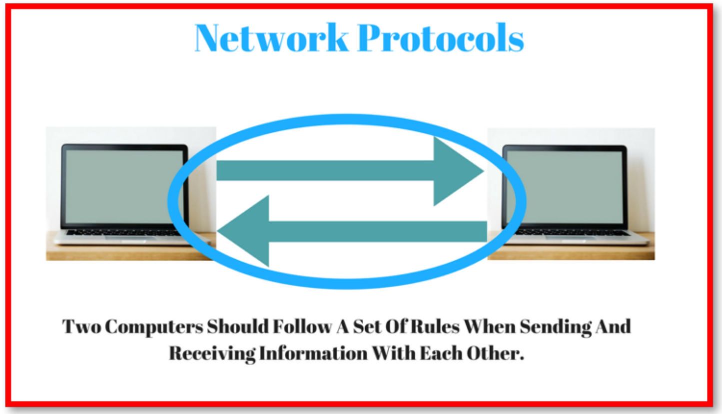
- **Human protocols:**
  - "what's the time?"
  - "I have a question"
  - introductions

… 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

4. NETWORK STRUCTURE

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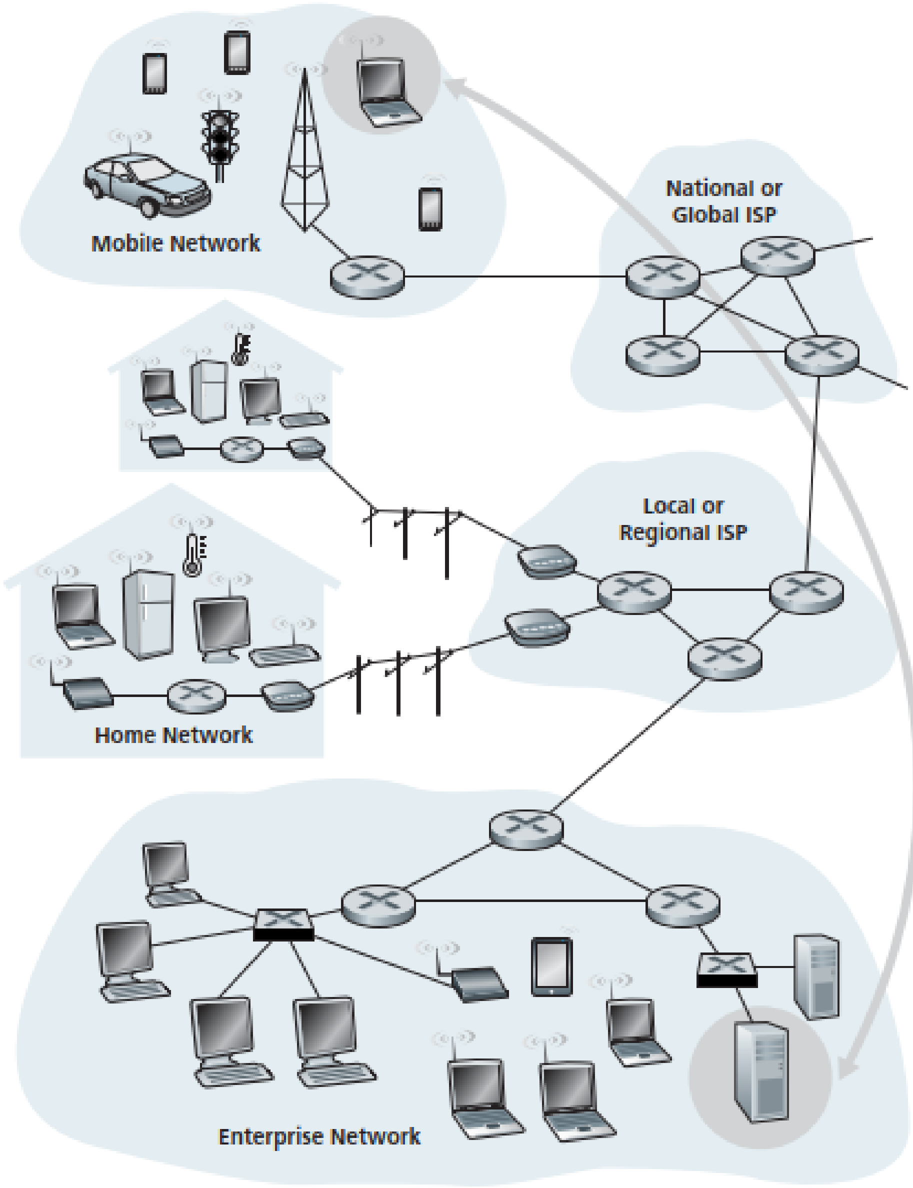
A CLOSER LOOK AT NETWORK STRUCTURE

- **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



End-system interaction

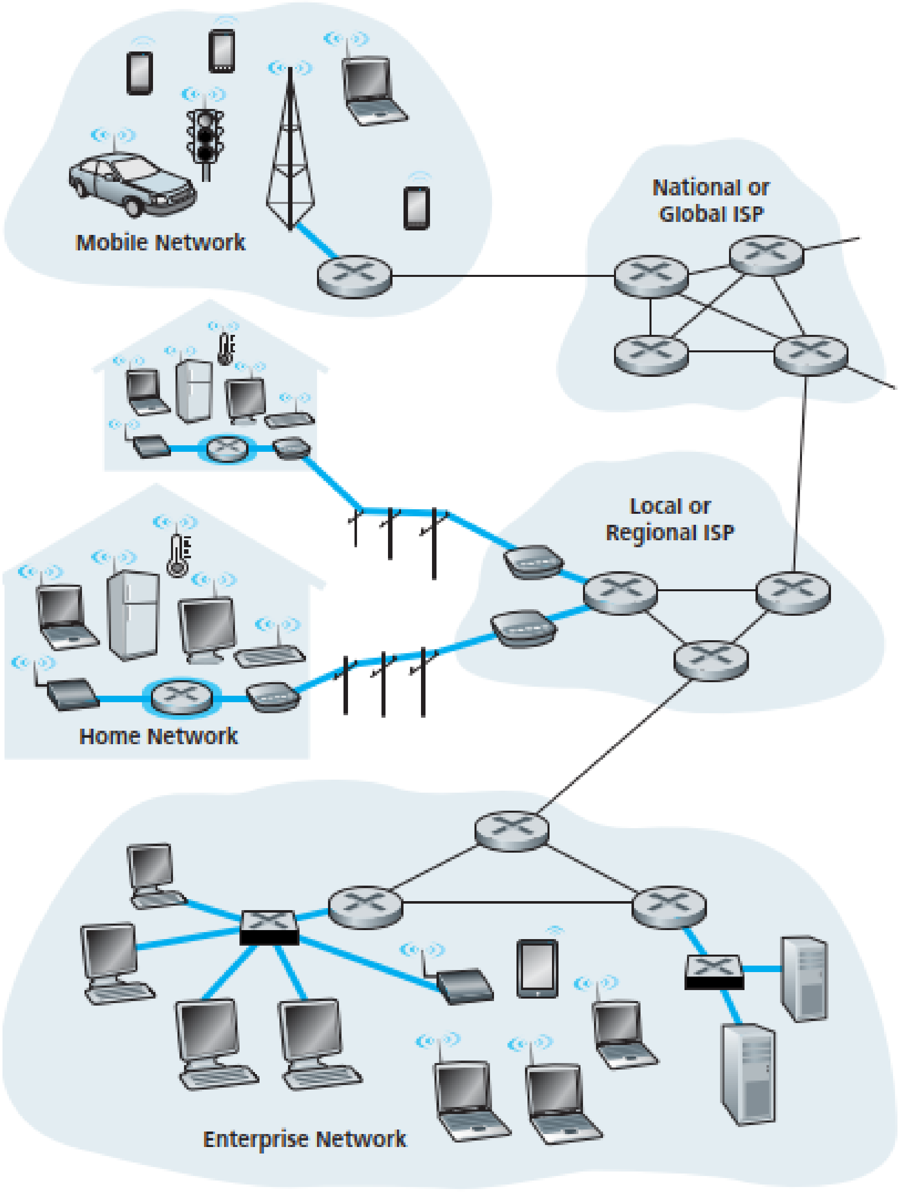
ACCESS NETWORK

Q: How to connect end systems to edge router?

- Home Access: DSL, Cable, FTTH, Dial-Up & Satellite
- Access in the Enterprise (and the Home): Ethernet and WiFi
- Wide-Area Wireless Access: 3G, LTE, 4G &5G

Keep in mind:

- bandwidth (bits per second) of access network?
- shared or dedicated?

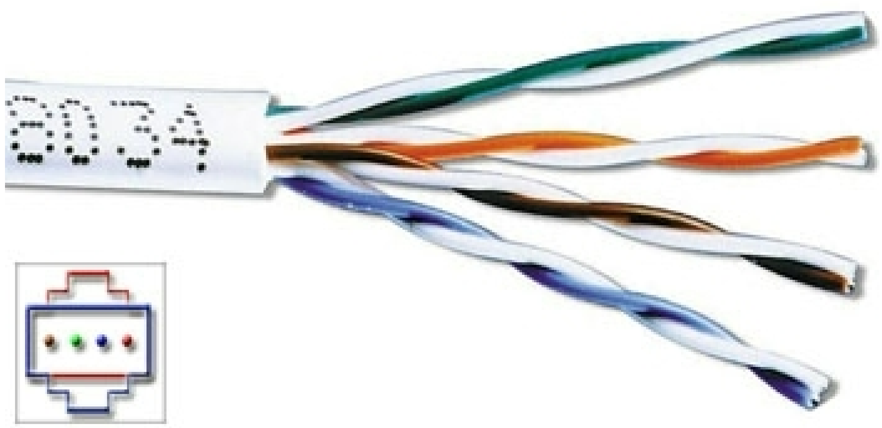


PHYSICAL MEDIA

- **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

Shielded twisted pair (STP)

Unshielded twisted pair (UTP)



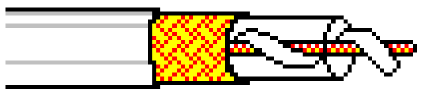
Twisted pair (TP)

- Two insulated copper wires
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6: 10Gbps

PHYSICAL MEDIA: COAX, FIBER

coaxial cable:

- two concentric copper conductors
- quite common in cable television systems
- bidirectional
- broadband:
  - multiple channels on cable



fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gbps transmission rate)
- low error rate:
  - repeaters spaced far apart (~100km)
  - immune to electromagnetic noise

PHYSICAL MEDIA: RADIO

- Signal carried in electromagnetic spectrum
- No physical “wire”
- Can penetrate wall
- Potentially carry a signal for long distances
- 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)
  - 54 Mbps or more
- Wide-area (e.g., cellular)
  - 4G, 5G cellular
- Satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 280 msec end-end delay
  - geosynchronous versus low altitude

5. NETWORK CORE

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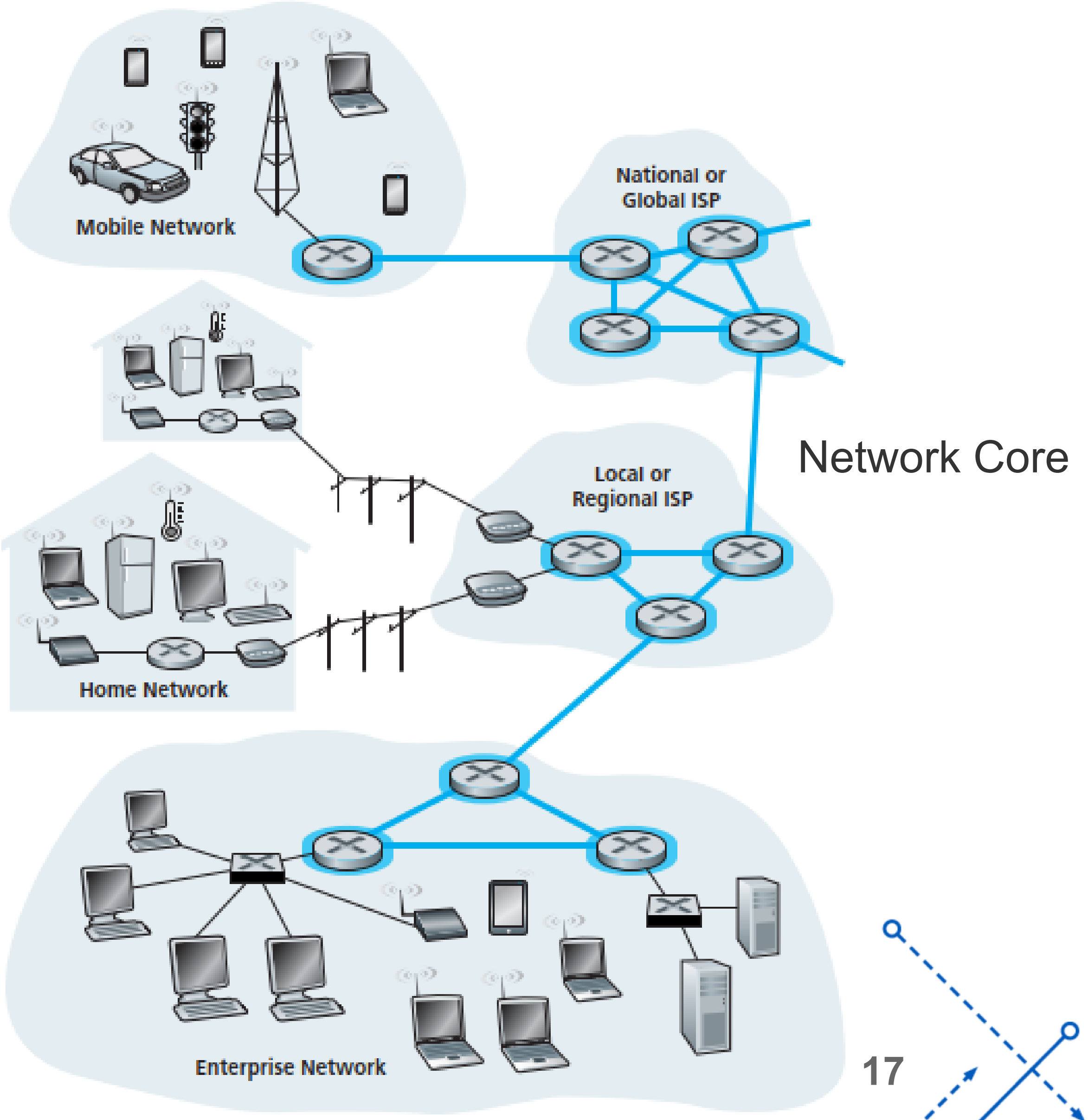
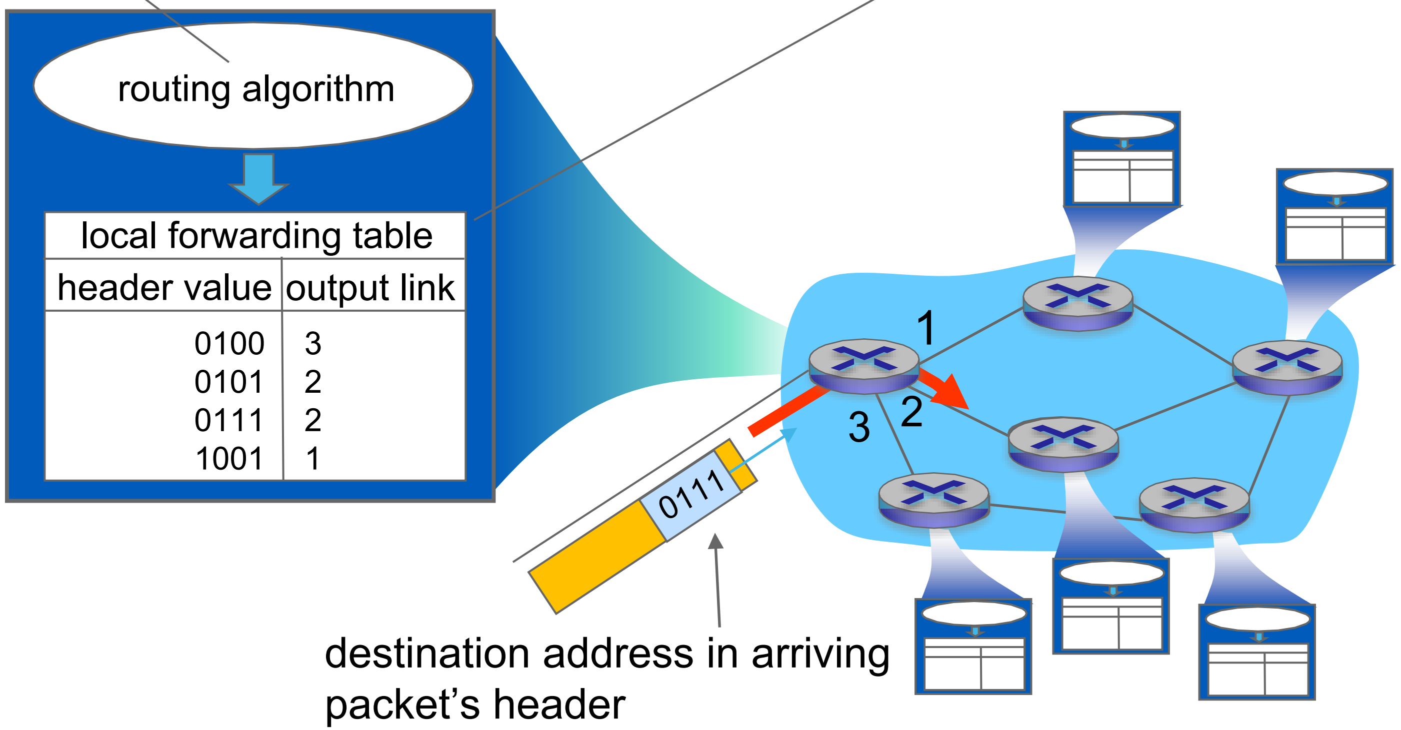
THE NETWORK CORE

- 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



NETWORK CORE FUNCTIONS

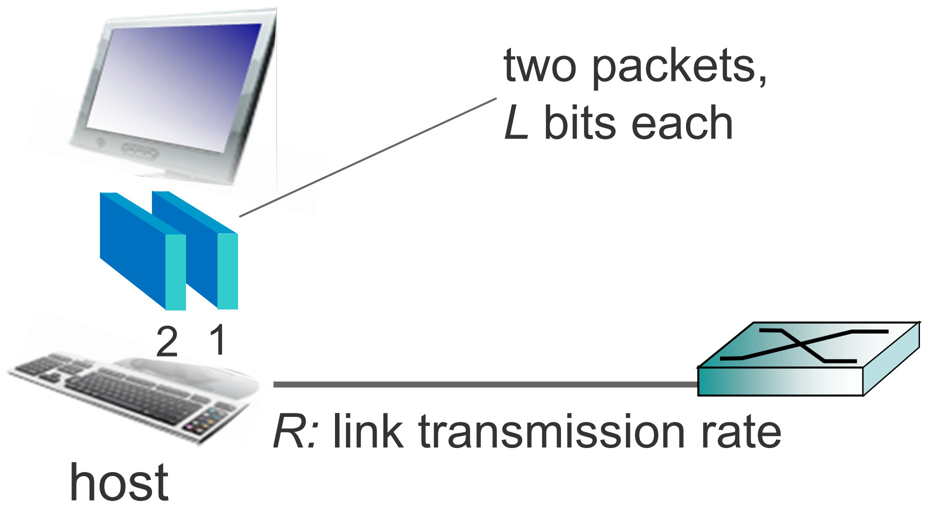
- ***routing***: determines source-destination route taken by packets
  - *routing algorithms*
- ***forwarding***: move packets from routers input to appropriate router output



HOST SENDS PACKETS OF DATA

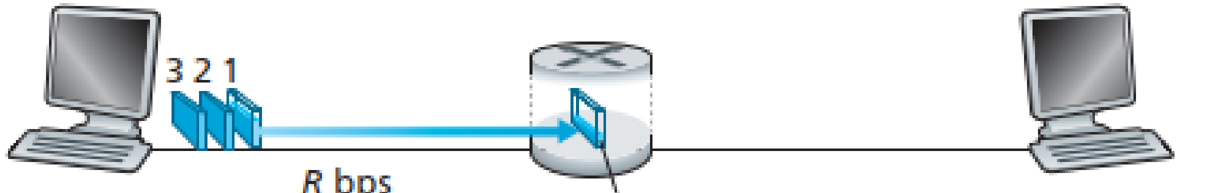
Host sending function:

- 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***



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

PACKET-SWITCHING: STORE-AND-FORWARD TRANSMISSION



- Takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- ***Store and forward****:* entire packet must arrive at router before it can be transmitted on next link
- end-end delay = 2*L*/*R* (assuming zero propagation delay)

One-hop numerical example:

- *L* = 7.5 Mbits
- *R* = 1.5 Mbps
- one-hop transmission delay = 5 sec

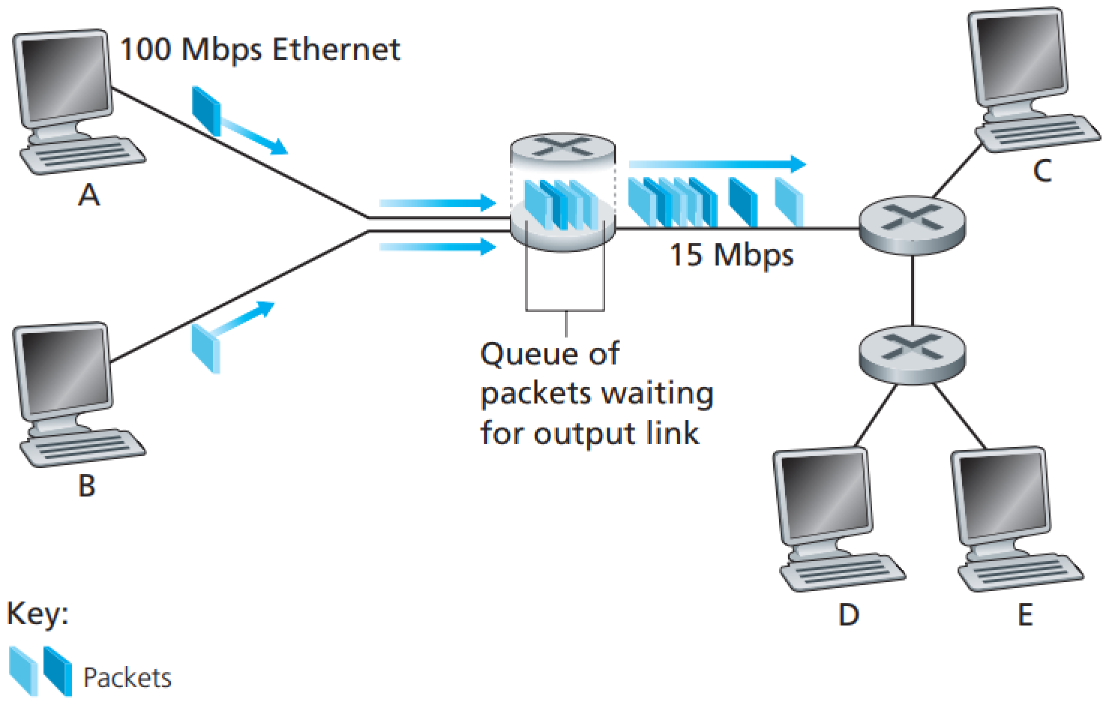
End-to-end delay if a path has N links (R rate/link) (or N-1 routers):

$$d_{\text{end-to-end}} = N\frac{L}{R}$$

PACKET-SWITCHING: QUEUEING DELAY & PACKET LOSS

- **Delay**:
  - Store-and-forward delays
  - Queuing delays
  - Propagation delays

- **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

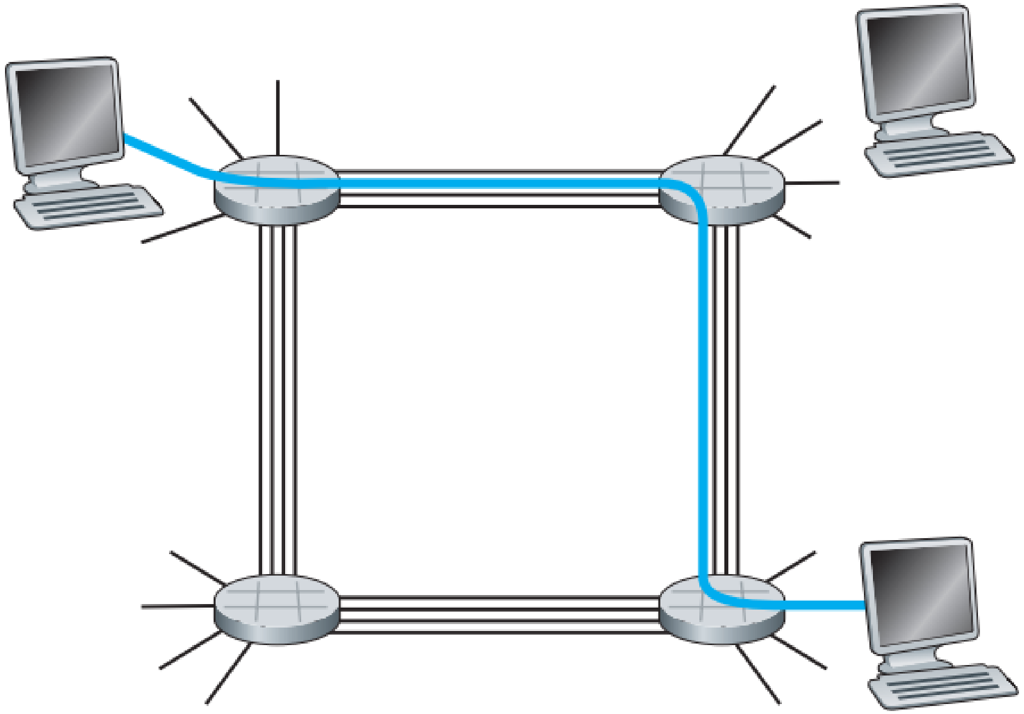


CIRCUIT SWITCHING

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
  - reserves a constant transmission rate (a fraction of link's trans. capacity)
- circuit segment idle if not used by call *(no sharing)*
- commonly used in traditional telephone networks

End- to-end connection between the two hosts



- Four circuit switches are interconnected by four links
- Each of these links has four circuits

PACKET SWITCHING versus CIRCUIT SWITCHING

Packet Switching	Circuit Switching
- The message is broken down into small packets - Every packet follows a different route	- Entire message is passed - There is a dedicated communication link
- Not suitable for real-time services (because of its variable & unpredictable end-to-end delays)	- Excellent for real-time communications
- Better sharing of transmission capacity	- When no data is transmitted, capacity is unused, but still committed.
- Simpler, less costly	- More complicated
- Allocates link use on demand	- Pre-allocates use of the transmission link regardless of demand

6. NETWORK TOPOLOGY

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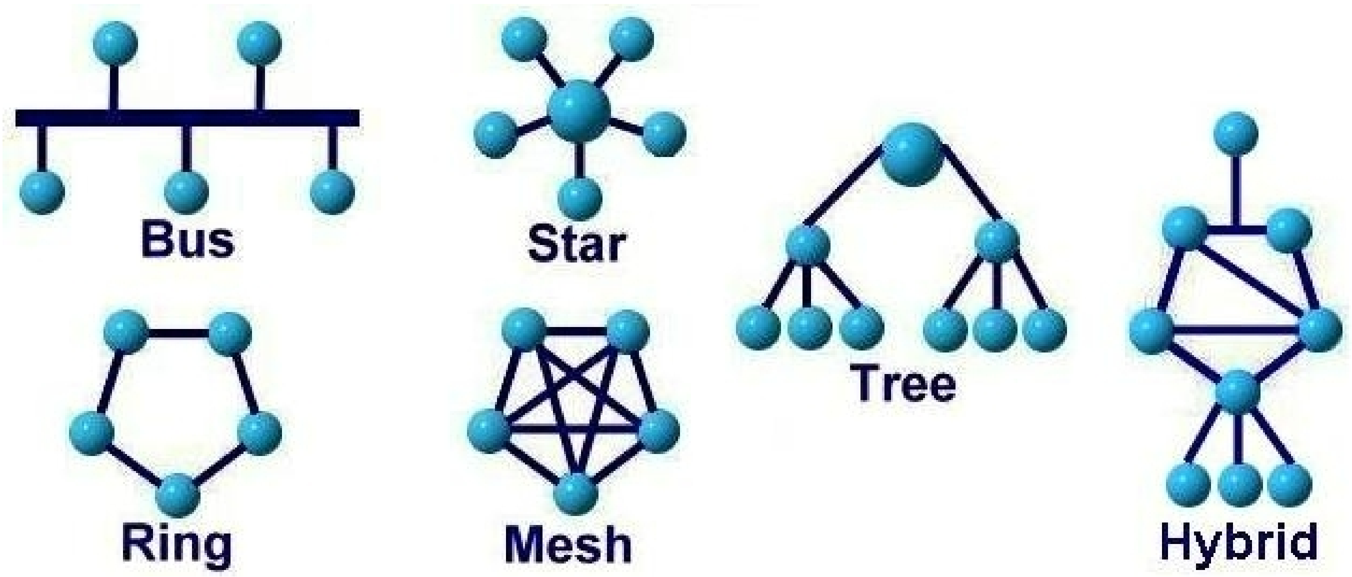
NETWORK TOPOLOGY

- **Network topology** is the arrangement of the elements (links, nodes, etc.) of a communication network.
- There are two approaches to network topology: physical and logical.
  - Physical network topology refers to the physical connections and interconnections between nodes and the network—the wires, cables, and so forth.
  - Logical network topology refers to the conceptual understanding of how and why the network is arranged the way it is, and how data moves through it.



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7. NETWORK PERFORMANCE

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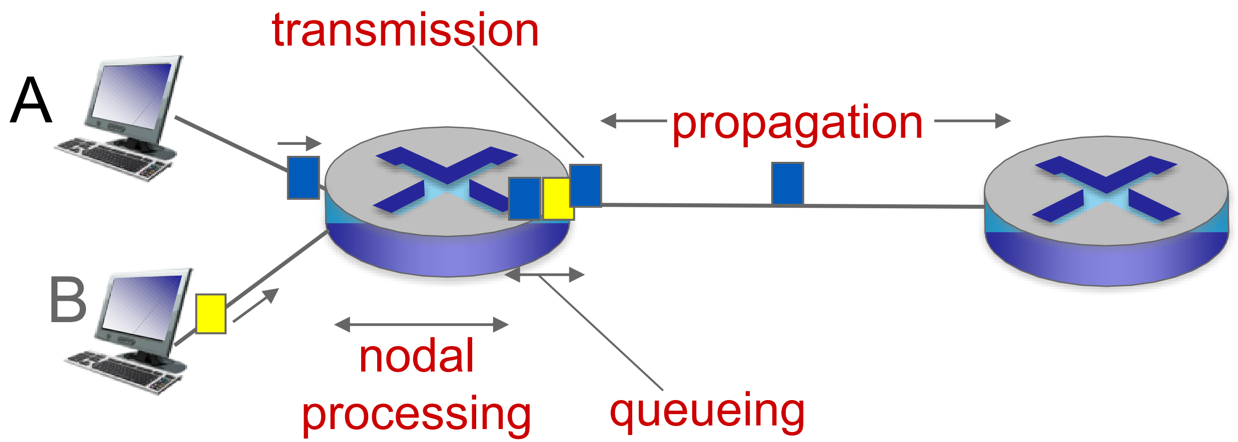
FOUR SOURCES OF PACKET DELAY



$$d_{\text{total}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

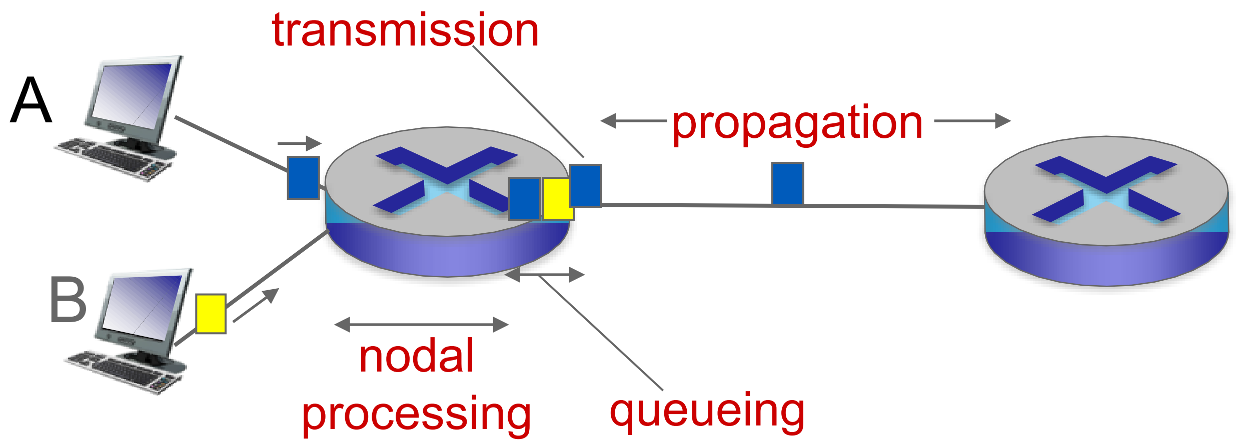
d_{proc}: nodal processing

- check bit errors
- examine the packet's header
- determine output link
- typically < ms

d_{queue}: queueing delay

- time waiting at output link for transmission onto the link
- depends on congestion level of router (traffic is heavy or not)
- the order of microseconds to milliseconds in practice

FOUR SOURCES OF PACKET DELAY



$$d_{total} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{trans}: transmission delay:

- the amount of time required to push all of the packet's bits into the link
- *L*: packet length (bits)
- *R*: link *bandwidth (bps) or trans. rate*
- $d_{trans} = L/R$
- On the order of microseconds to milliseconds

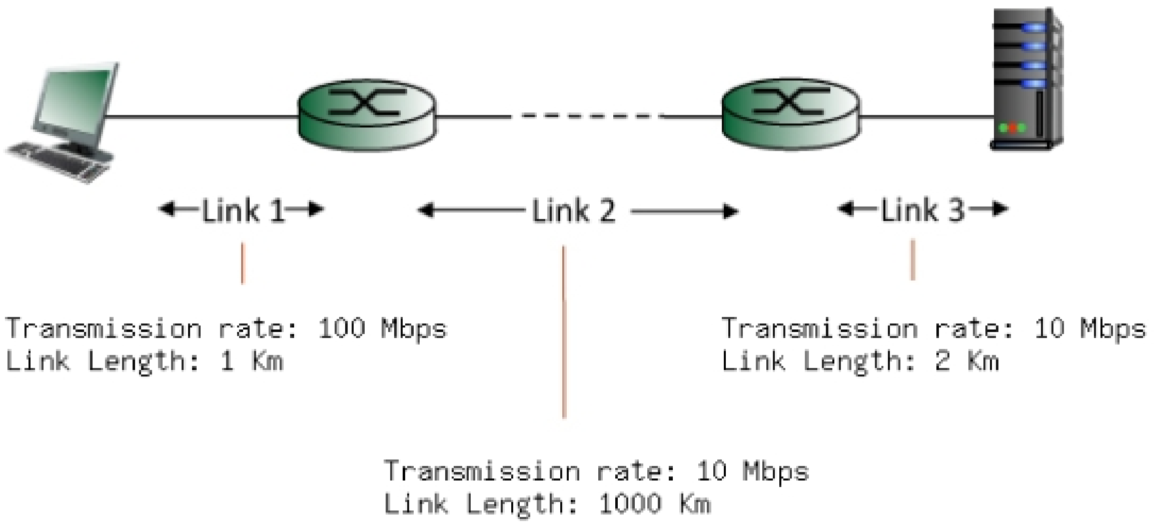
d_{trans} and d_{prop} *very* different

d_{prop}: propagation delay:

- time required to propagate from the beginning of the link to the next destination
- Depends on the physical medium
- *d*: length of physical link
- *s*: propagation speed (~2x10^8 m/sec – 3x10^8 m/sec)
- $d_{prop} = d/s$

Exercise: Computing transmission & propagation delay

Consider the figure below, with three links, each with the specified transmission rate and link length.



Find the end-to-end delay (including the transmission delays and propagation delays on each of the three links, but ignoring queueing delays and processing delays) from when the left host begins transmitting the first bit of a packet to the time when the last bit of that packet is received at the server at the right. The speed of light propagation delay on each link is 3x10**8 m/sec. Note that the transmission rates are in Mbps and the link distances are in Km. Assume a packet length of **4000** bits. Give your answer in milliseconds.

QUEUEING DELAY (REVISITED)

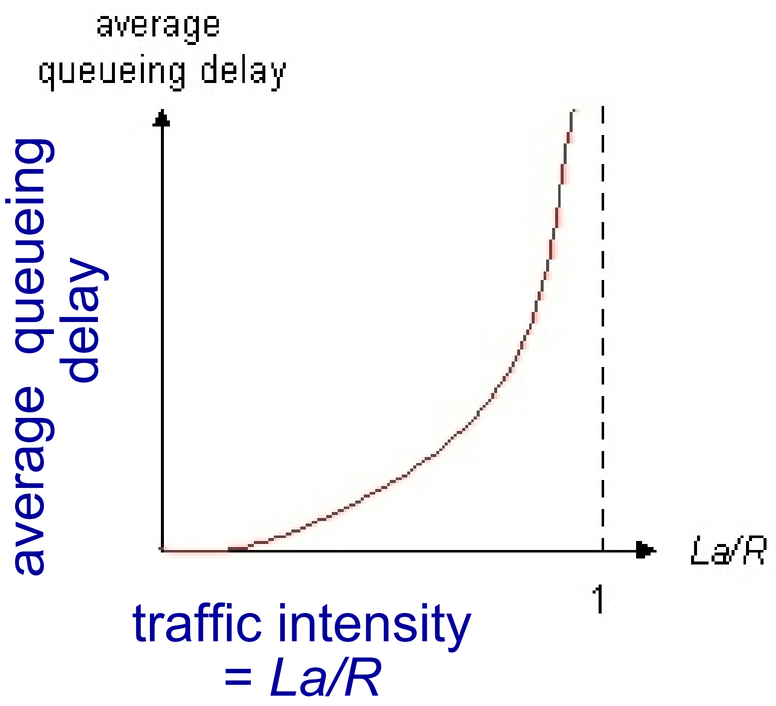
When is the queuing delay large and when is it insignificant?

→ Depends on:

- Arriving rate at the queue
- Transmission rate of the link
- Nature of the arriving traffic (traffic arriving pattern)

- *R:* transmission rate (bps) = rate at which bits are pushed out of the queue
- *L:* packet length (bits)
- a: average **packet** arrival rate

→La: average rate at which **bits** arrive at the queue



- ***La/R*** **~ 0: avg. queueing delay small**
- ***La/R*** **-> 1: avg. queueing delay large**
- ***La/R*** **> 1: more "work" arriving than can be serviced, average delay infinite!**
- ***La/R*** **< 1: nature of the arriving traffic affects the queuing delay**

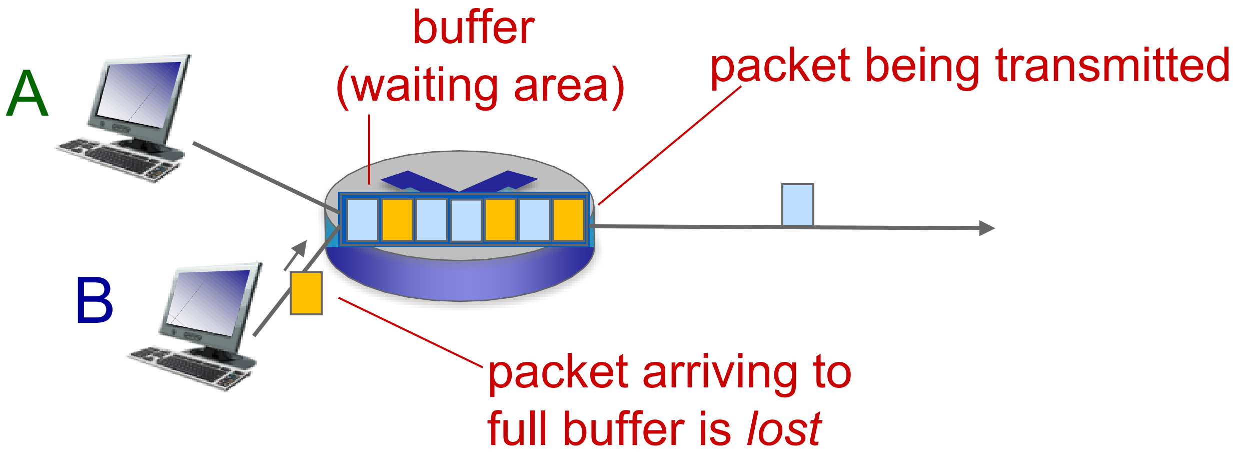
La/R ~ 0

La/R -> 1

Design your system so that the traffic intensity is no greater than 1.

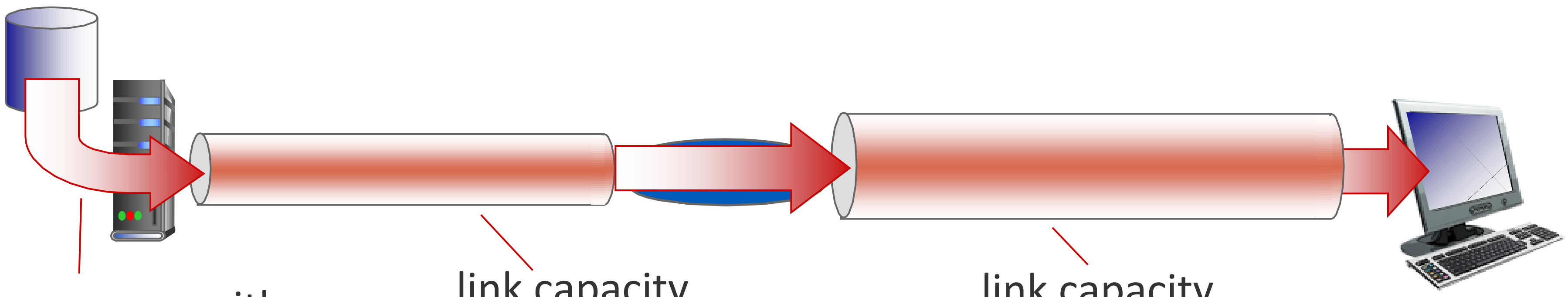
PACKET LOSS

- Queue (aka buffer) preceding link in buffer has finite capacity
- Packet arriving to full queue dropped (aka lost)
- Lost packet may be retransmitted by previous node, by source end system, or not at all



THROUGHPUT

- ***throughput***: rate (bits/time unit) at which bits transferred between sender/receiver
  - ***instantaneous***: rate at given point in time
  - ***average***: rate over longer period of time



server, with file of F bits to send to client

link capacity R_s bits/sec

link capacity R_c bits/sec

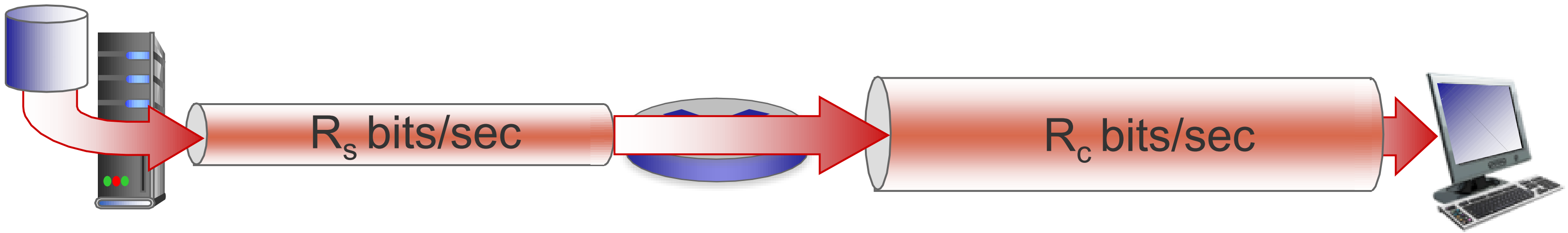
server sends bits (fluid) into pipe

pipe that can carry fluid at rate R_s bits/sec)

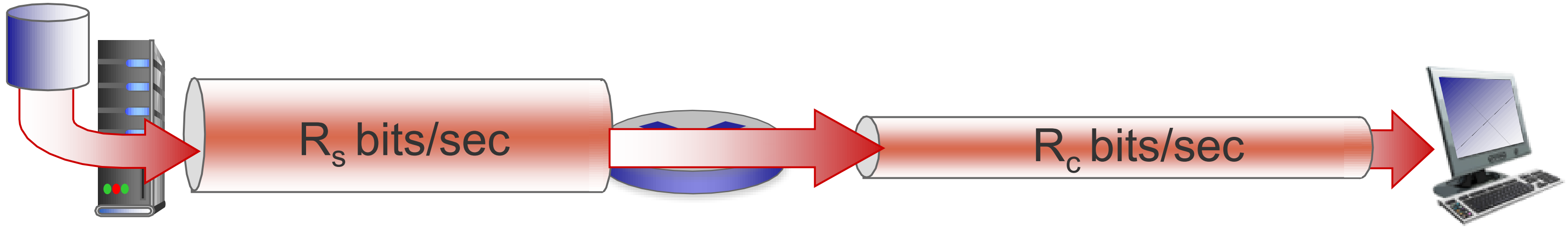
pipe that can carry fluid at rate R_c bits/sec)

THROUGHPUT

- $R_s < R_c$ What is average end-end throughput?



- $R_s > R_c$ What is average end-end throughput?



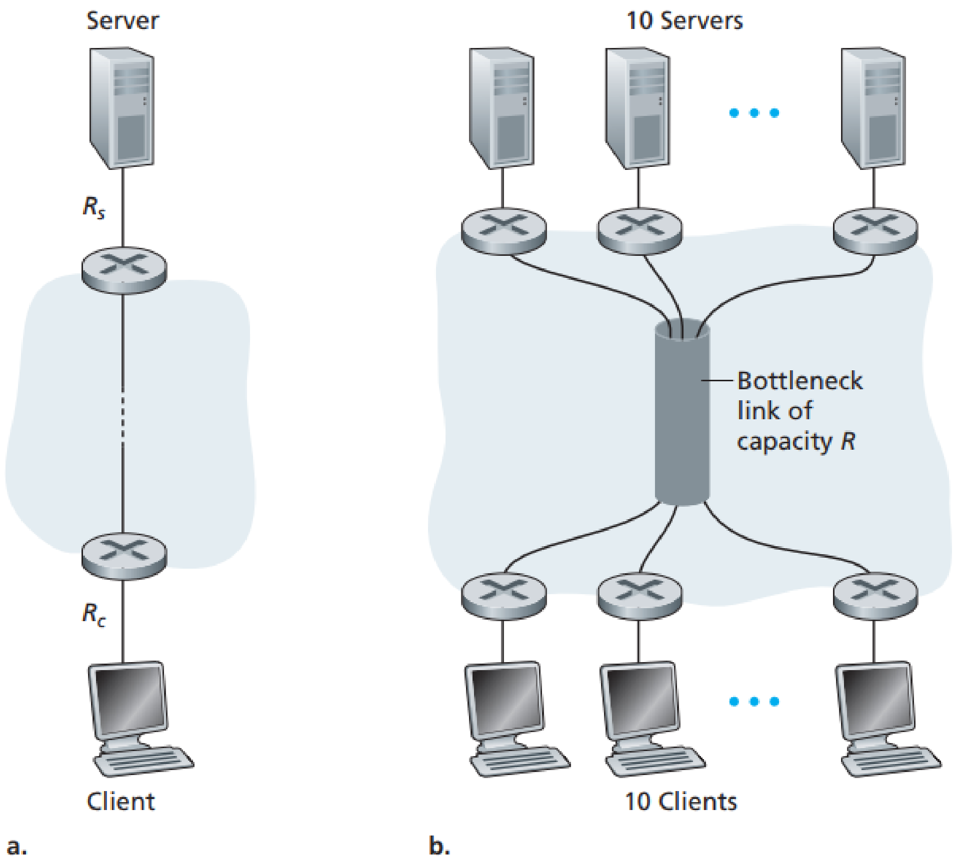
bottleneck link

link on end-end path that constrains end-end throughput

THROUGHPUT: INTERNET SCENARIO

- Per-connection end-end throughput: *min* $(R_c, R_s, R/10)$

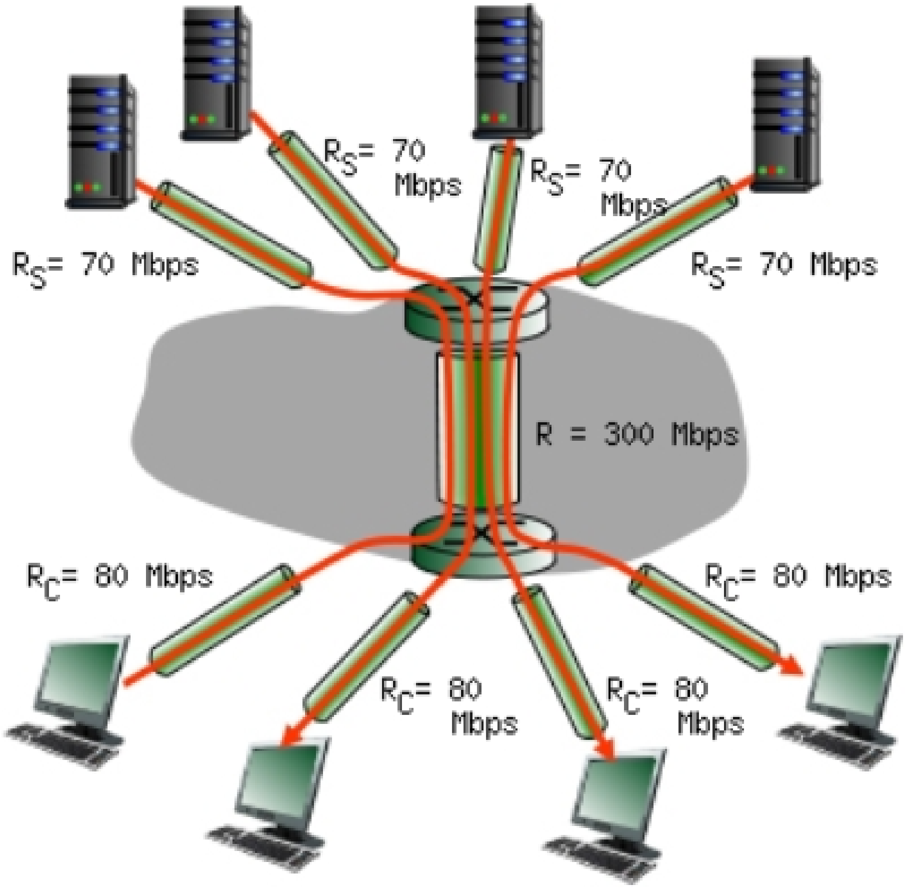
- In practice: R_c or R_s is often bottleneck (access network) *because the core of the Internet is over-provisioned with high speed links that experience little congestion*



10 connections (fairly) share backbone bottleneck link R bits/sec

THROUGHPUT: EXERCISE

Consider the scenario shown below, with four different servers connected to four different clients over four three-hop paths. The four pairs share a common middle hop with a transmission capacity of R = 300 Mbps. The four links from the servers to the shared link have a transmission capacity of R_S = 70 Mbps. Each of the four links from the shared middle link to a client has a transmission capacity of R_C = 80 Mbps per second. You might want to review Figure 1.20 in the text before answering the following questions:



1. What is the maximum achievable end-end throughput (in Mbps) for each of four client-to-server pairs, assuming that the middle link is fair-shared (i.e., divides its transmission rate equally among the four pairs)?
2. Which link is the bottleneck link for each session?
3. Assuming that the senders are sending at the maximum rate possible, what are the link utilizations for the sender links (R_S), client links (R_C), and the middle link (R)?

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8. INTERNET STRUCTURE

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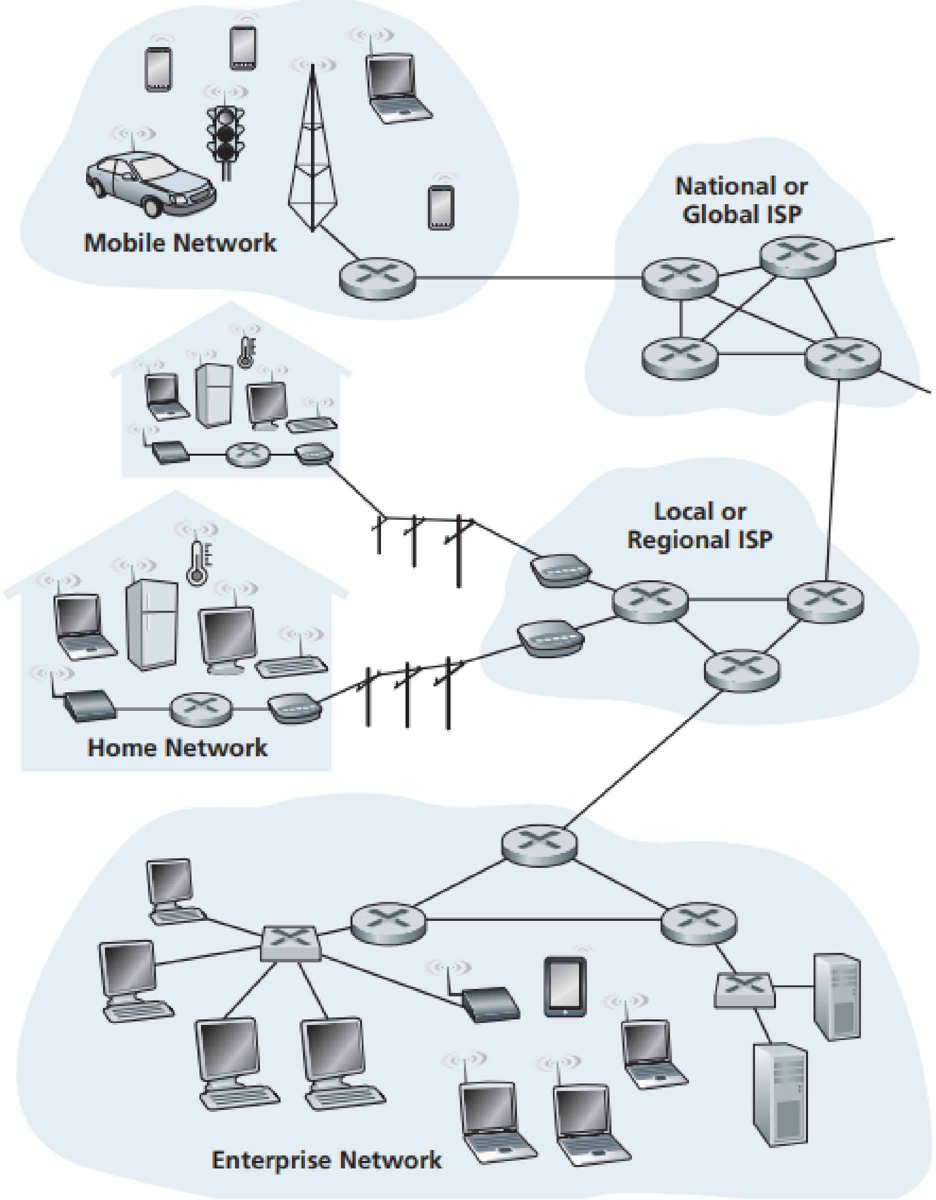
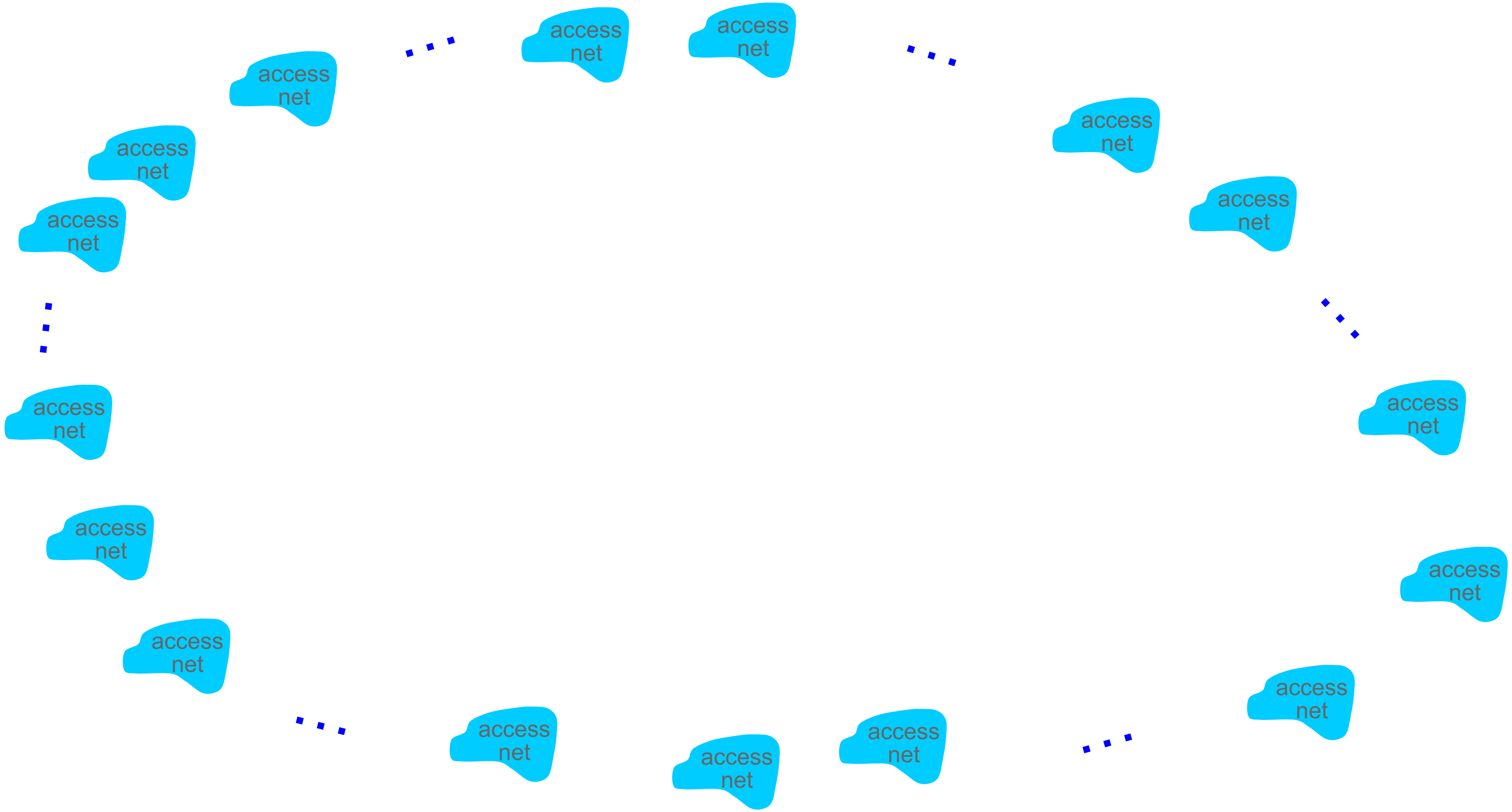
INTERNET STRUCTURE: NETWORK OF NETWORKS

- 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 rather than by performance considerations**.
- Let's take a stepwise approach to describe current Internet structure



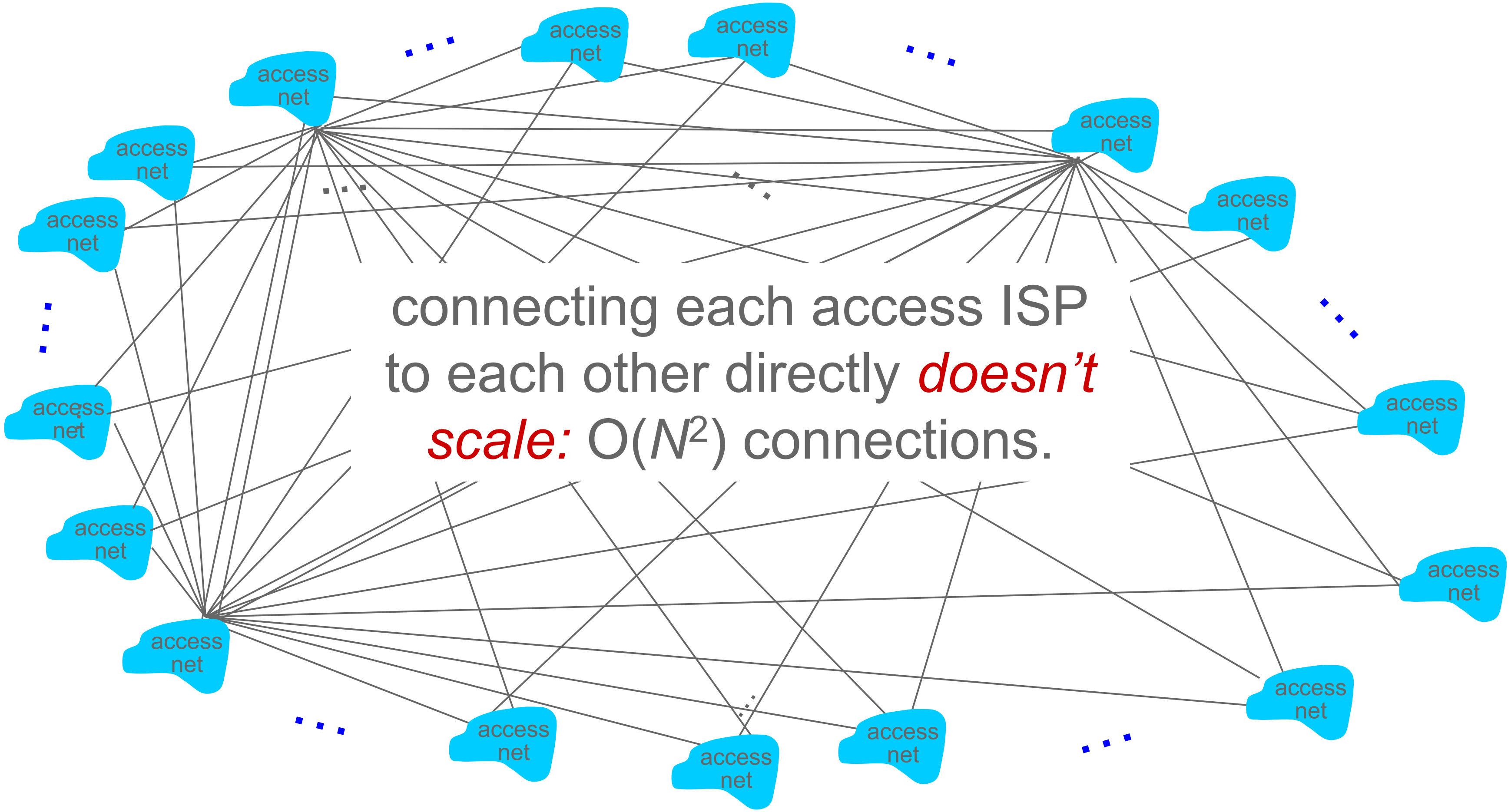
INTERNET STRUCTURE: NETWORK OF NETWORKS

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



INTERNET STRUCTURE: NETWORK OF NETWORKS

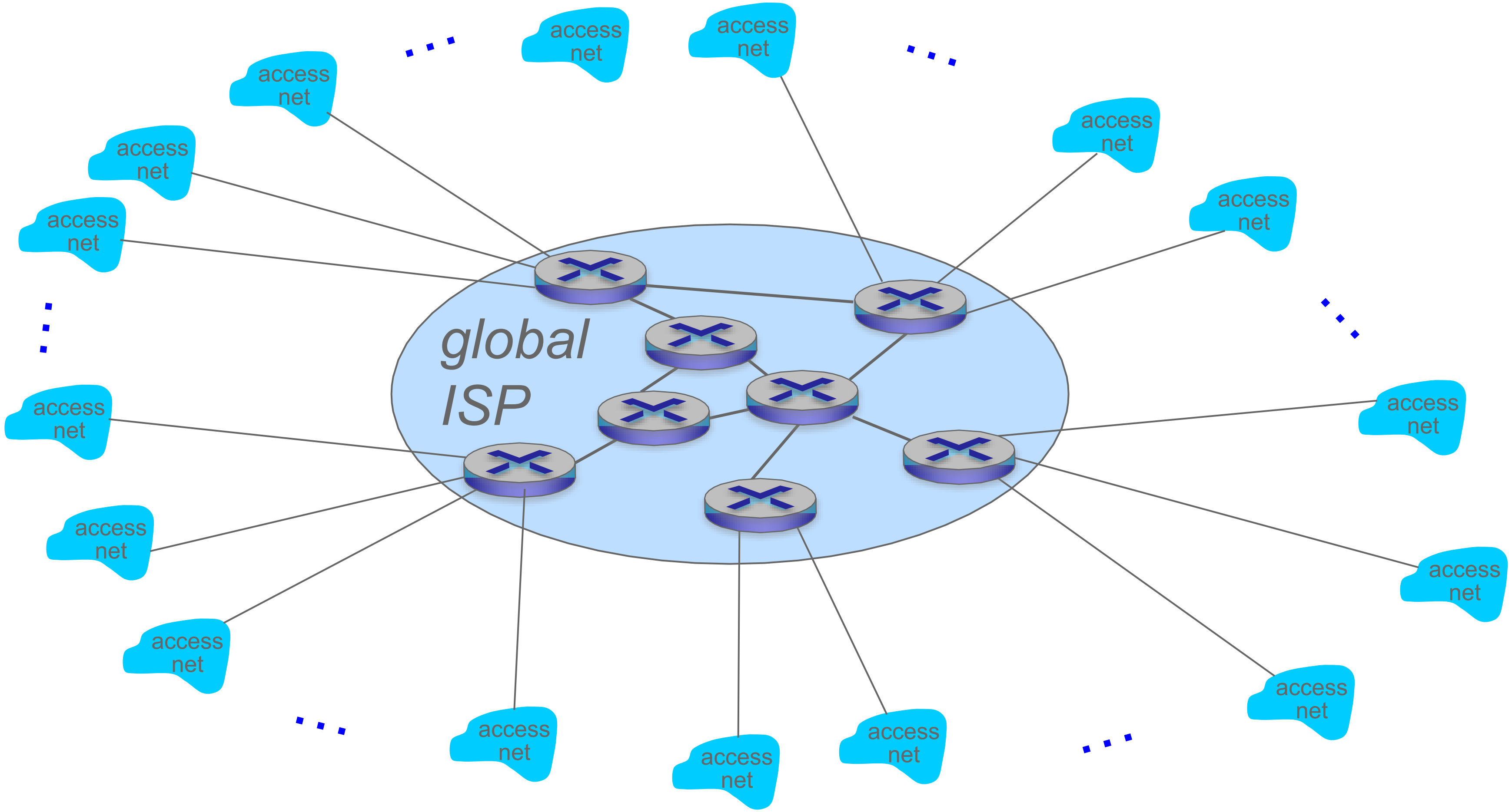
- ***Option***: *connect each access ISP to every other access ISP?*



connecting each access ISP to each other directly *doesn't scale:* O(N^2) connections.

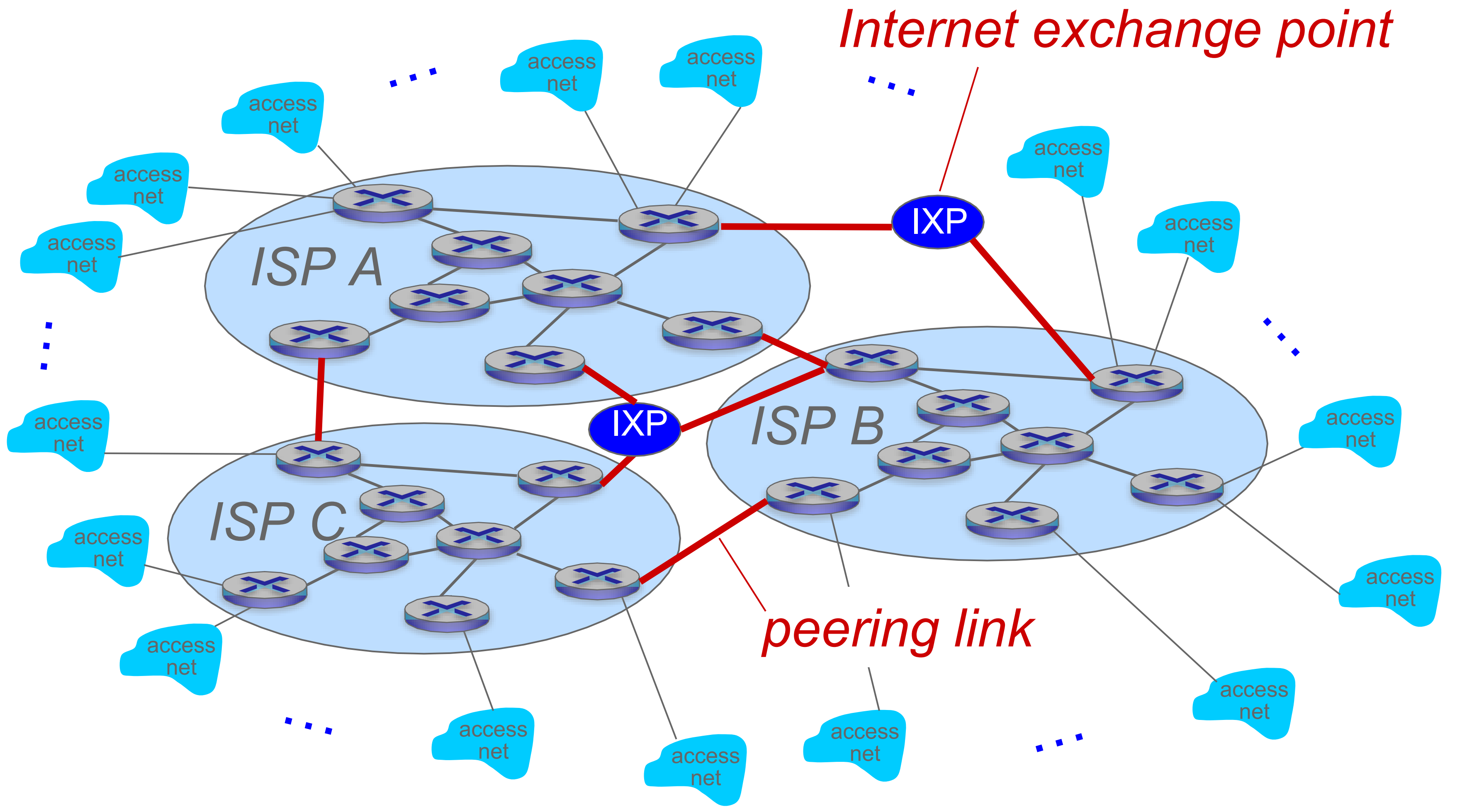
INTERNET STRUCTURE: NETWORK OF NETWORKS

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



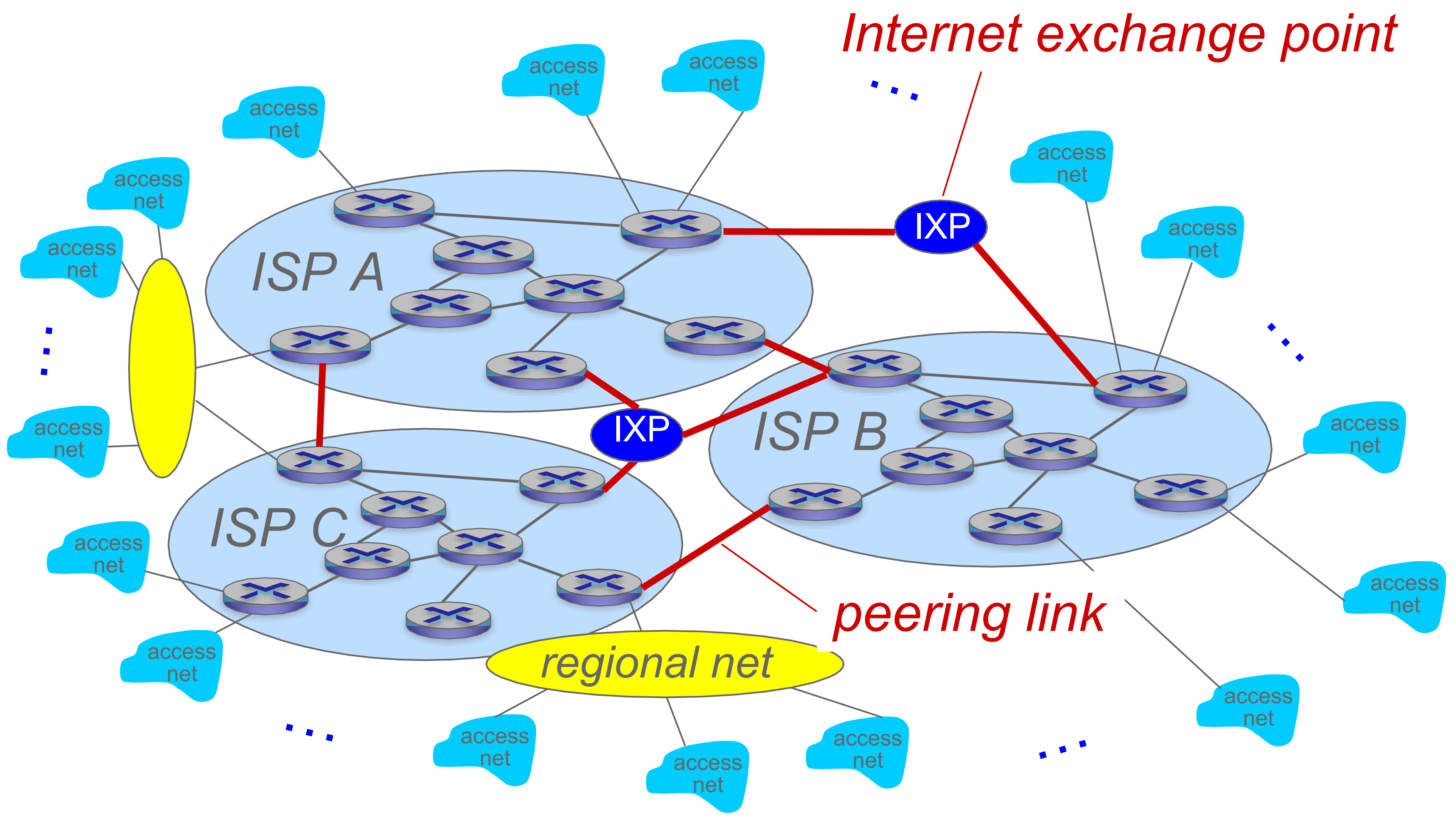
INTERNET STRUCTURE: NETWORK OF NETWORKS

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



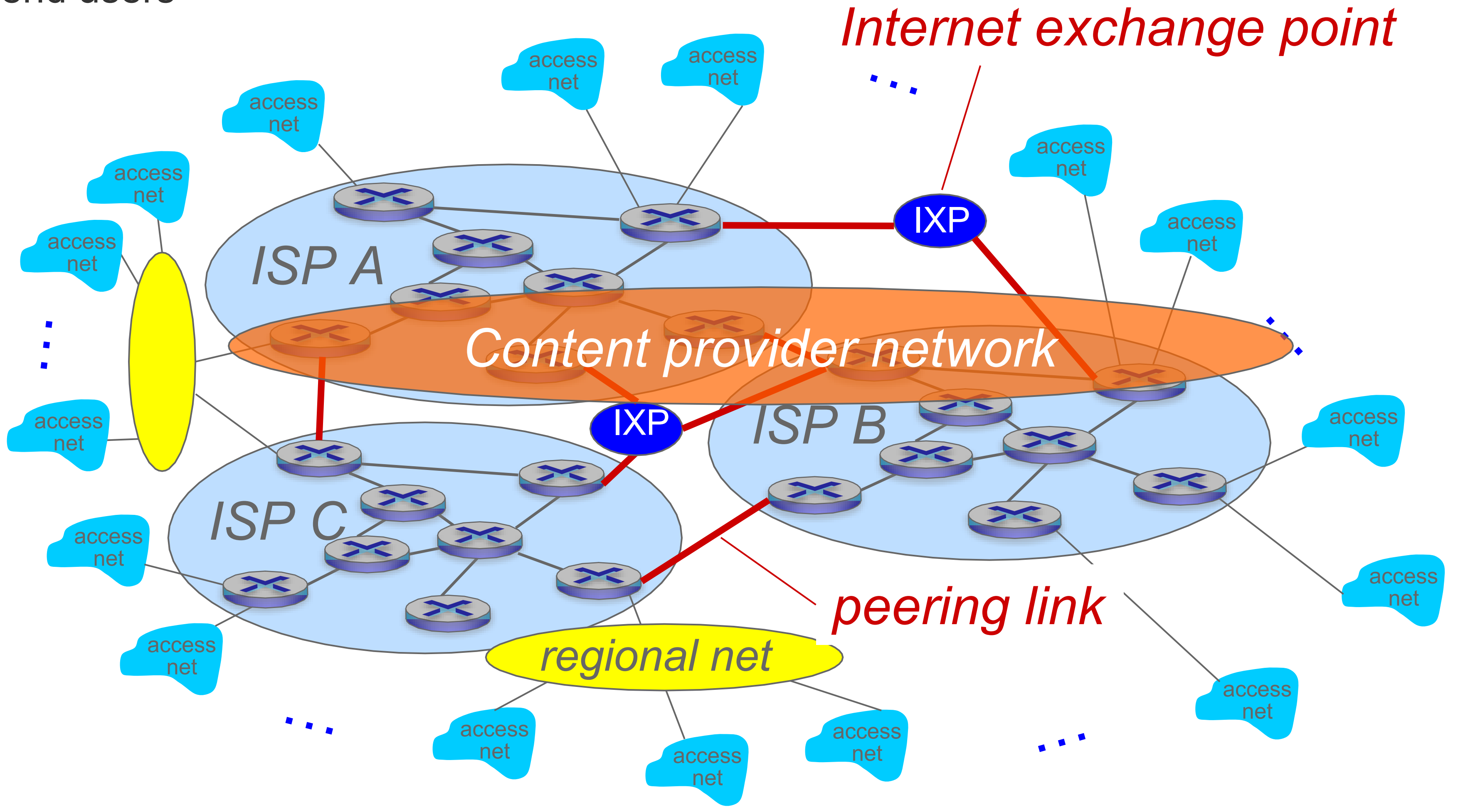
INTERNET STRUCTURE: NETWORK OF NETWORKS

… and **regional** networks may arise to connect access nets to ISPs

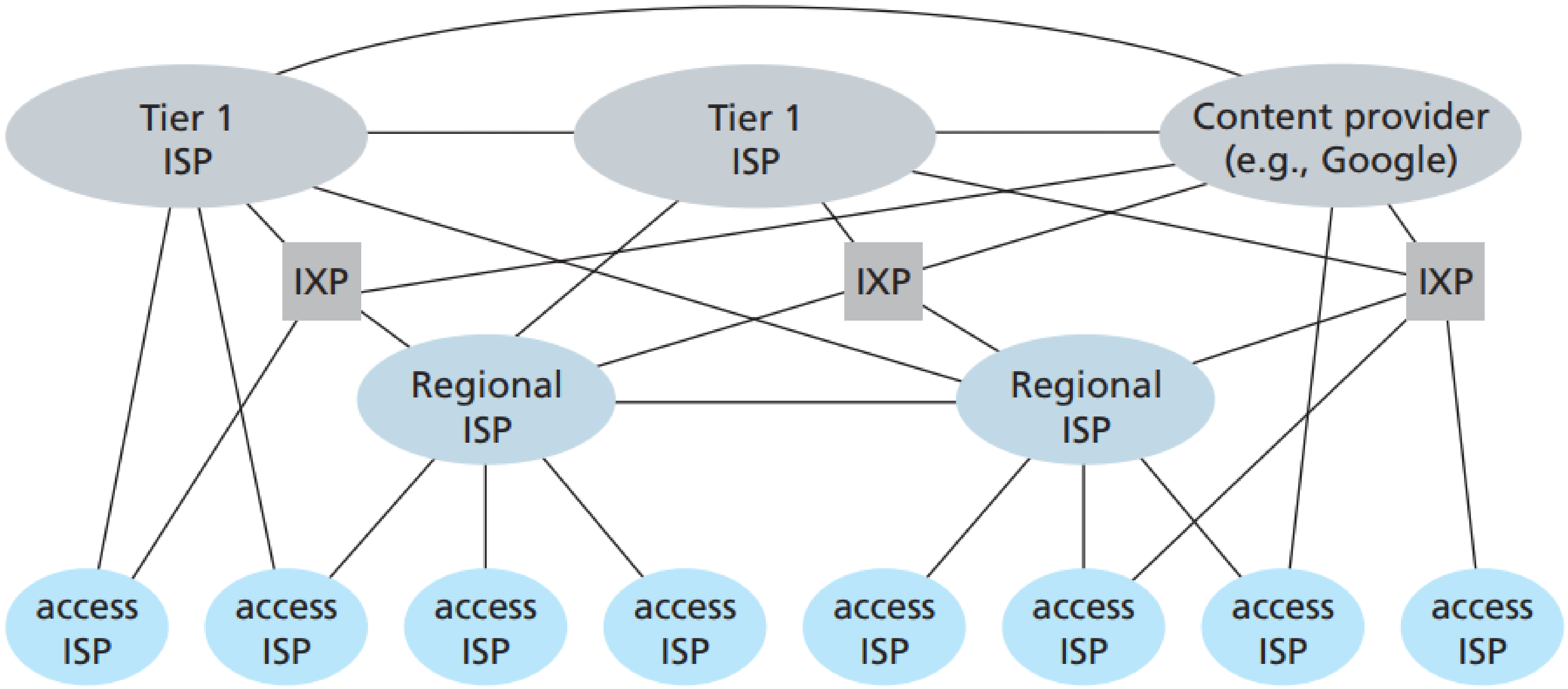


INTERNET STRUCTURE: NETWORK OF NETWORKS

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



INTERNET STRUCTURE: NETWORK OF NETWORKS



9. OSI MODEL & TCP/IP MODEL

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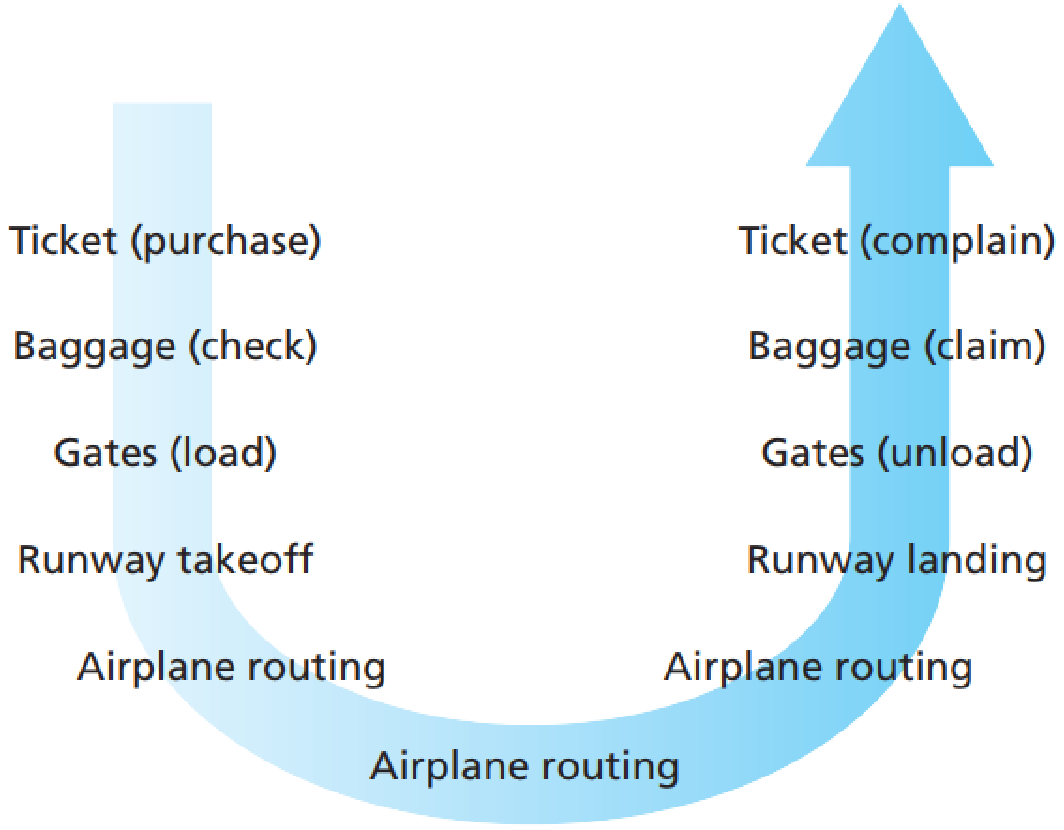
ORGANIZATION OF AIR TRAVEL

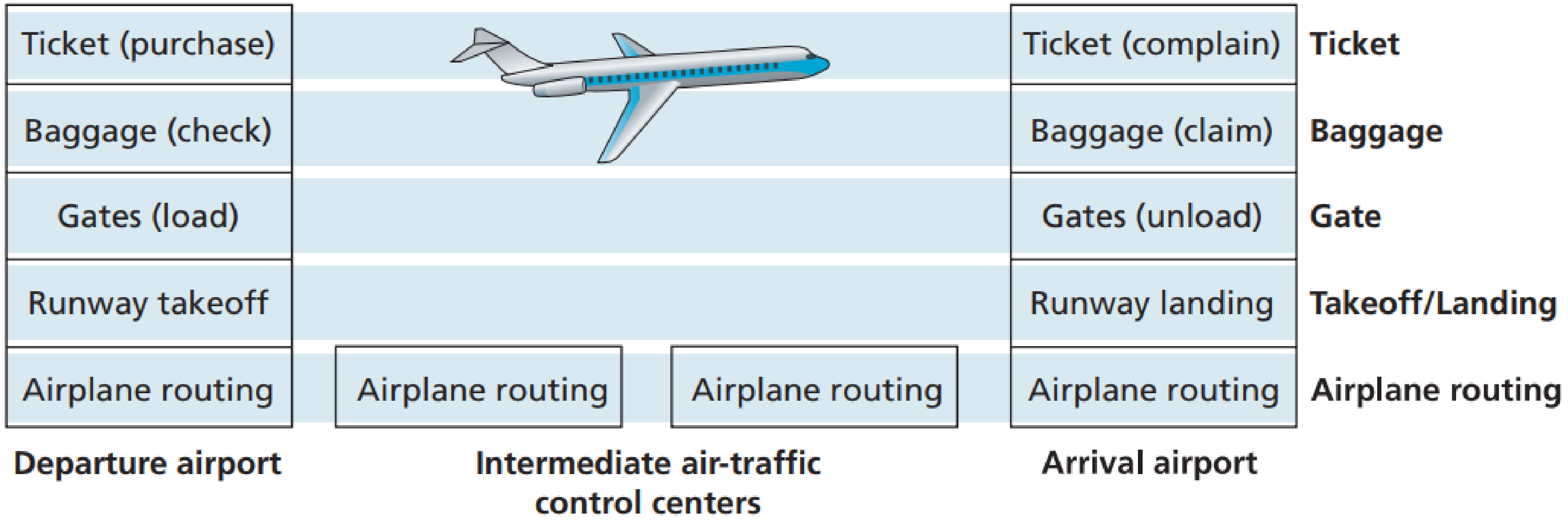
Describe the airline system

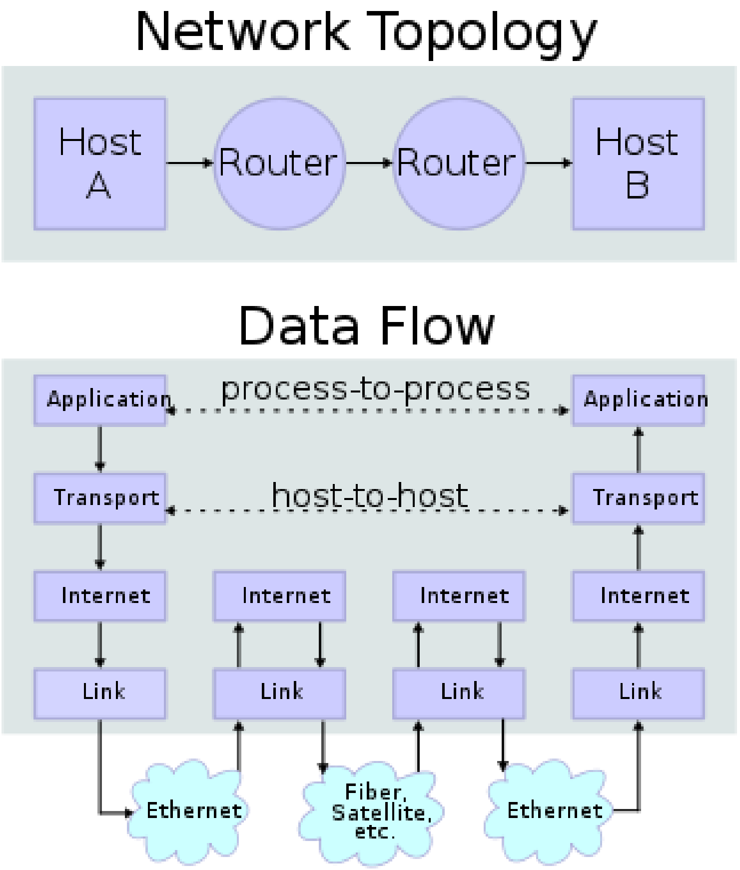


- a series of steps → **But there are functions repeated!!**

LAYERING OF AIRLINE FUNCTIONALITY

Look at the functionality in a *horizontal* manner





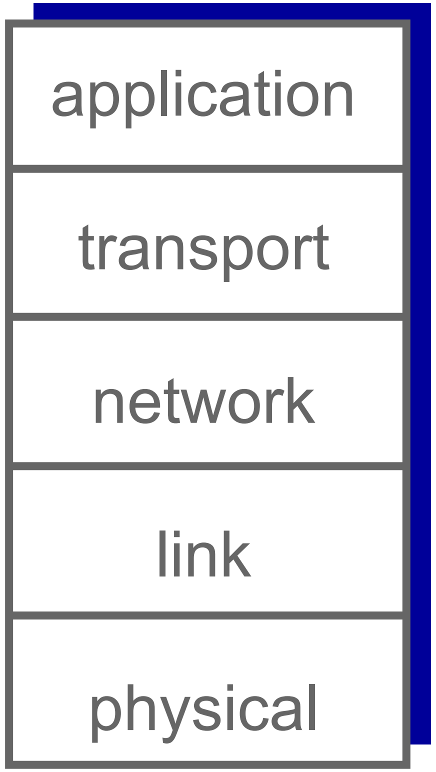
→ *The airline functionalities are divided into layers*

Layers*:* each layer implements a service

- by performing certain actions within that layer
- relying on services provided by layer below

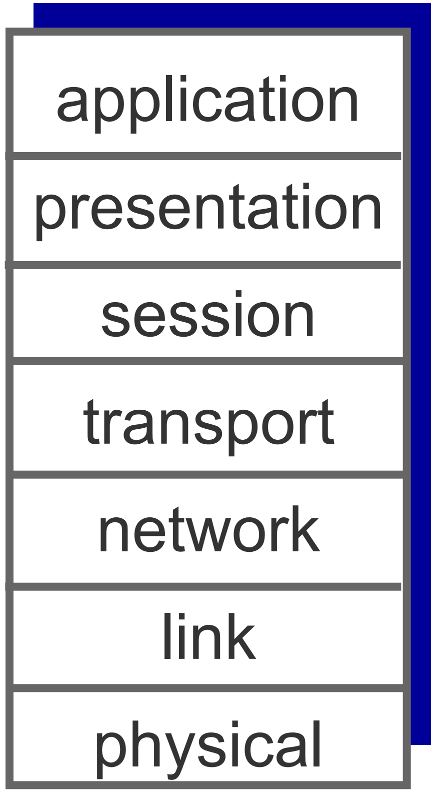
INTERNET PROTOCOL STACK

- ***Application**:* supporting network applications
  - FTP, SMTP, HTTP, DNS
  - The app. in one end system using the protocol to exchange **message** (packets of information) with the app. in another end system
- ***Transport**:* process-process data transfer, flow control
  - TCP, UDP
  - Reliable **end-to-end** delivery service
  - Transport application-layer messages
  - Transport-layer packet = **segment**
- ***Network**:* routing of **IP packet** from source to destination
  - Provides the service of delivering the segment **through a series of routers** to the transport layer in the destination host
  - IP, routing protocols
- ***Link-layer**:* data transfer between neighboring network elements
  - To move a **frame** from **one node to the next node** in the route
  - Reliable delivery between 2 adjacent nodes
  - Ethernet, 802.11 (Wi-Fi), PPP
- ***Physical**:* bits “on the wire” → Move individual bits within the frame from one node to the next



OSI REFERENCE MODEL

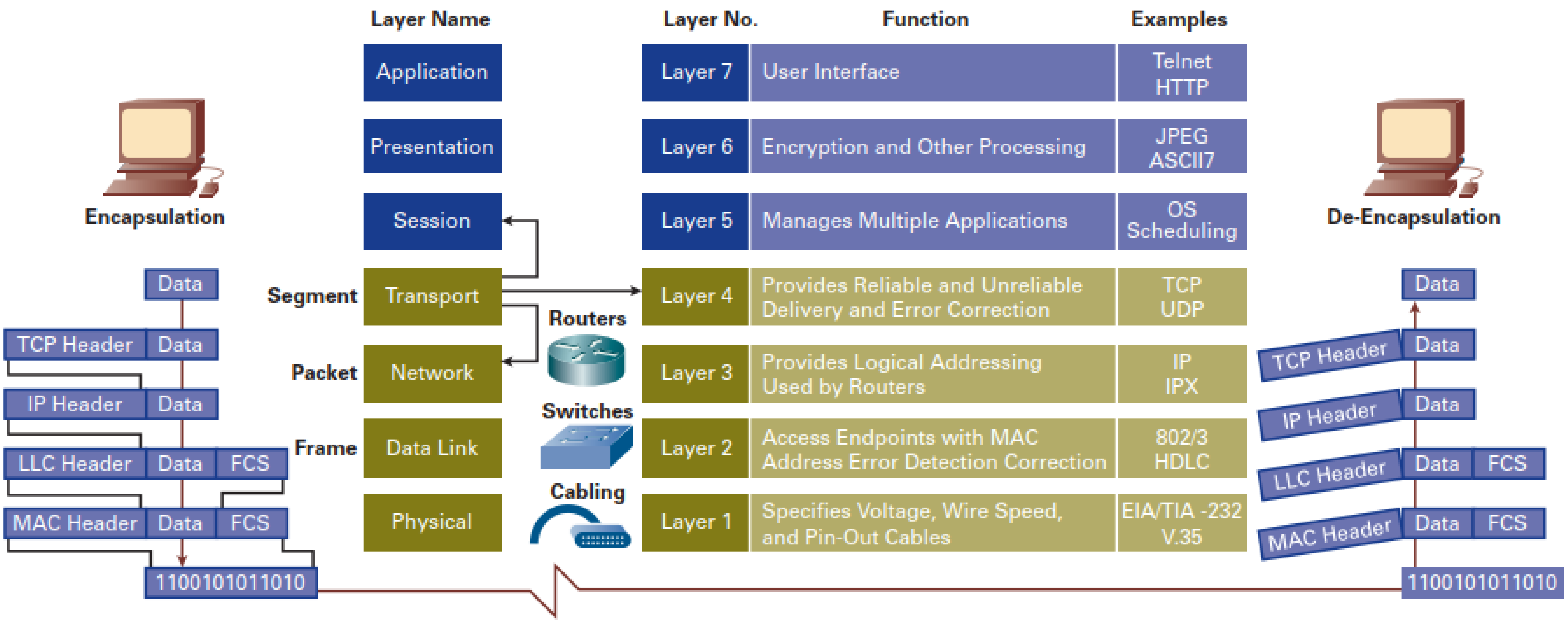
- ***presentation****:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- ***session****:* synchronization, checkpointing, recovery of data exchange
- Internet stack "**missing**" these layers!
  - these services, *if needed,* must be implemented in application
  - needed?



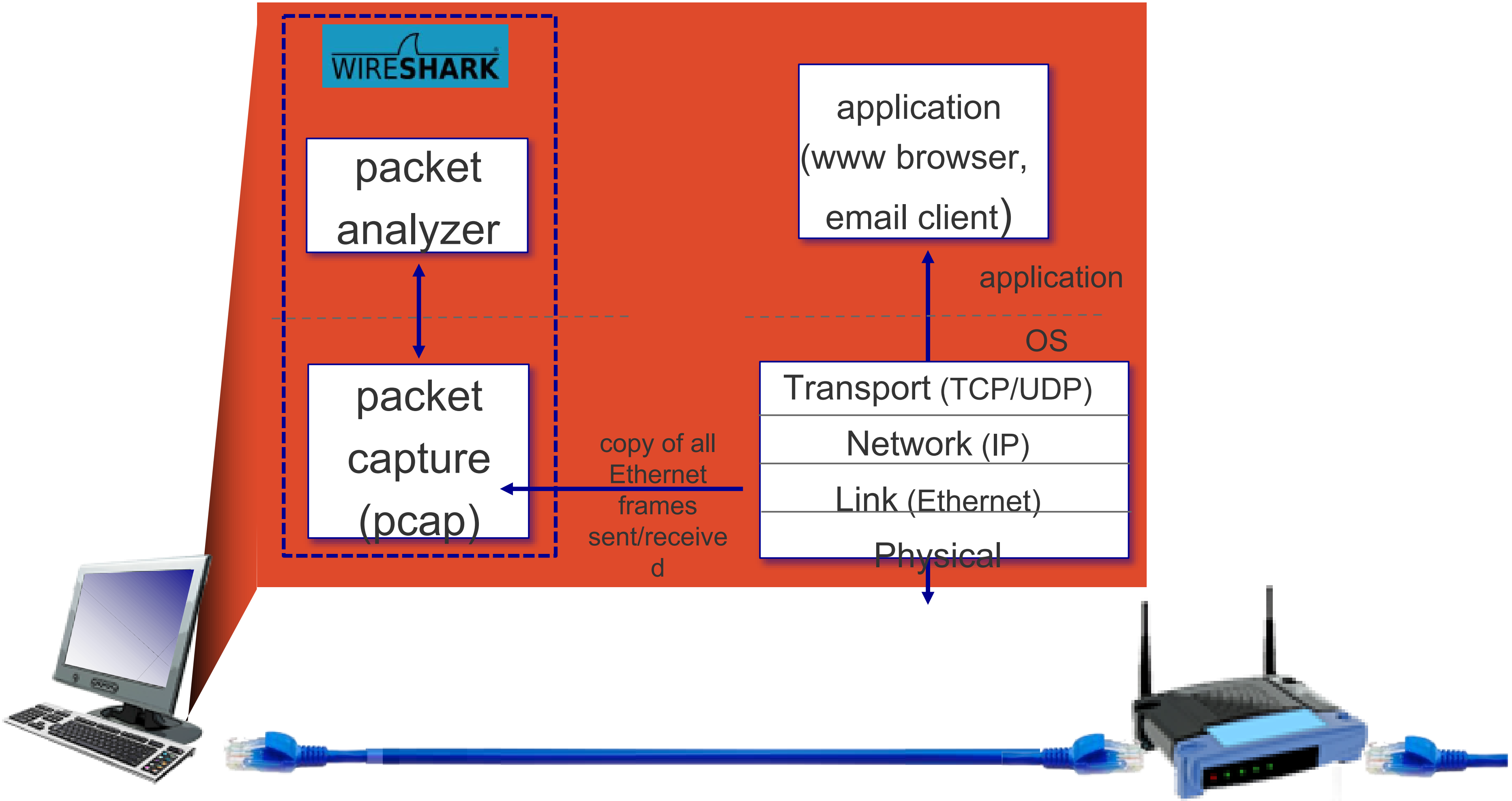
OSI REFERENCE MODEL

OSI model				
Layer			Protocol data unit (PDU)	Function[19]
Host layers	7	Application	Data	High-level APIs, including resource sharing, remote file access
	6	Presentation		Translation of data between a networking service and an application; including character encoding, data compression and encryption/decryption
	5	Session		Managing communication sessions, i.e., continuous exchange of information in the form of multiple back-and-forth transmissions between two nodes
	4	Transport	Segment, Datagram	Reliable transmission of data segments between points on a network, including segmentation, acknowledgement and multiplexing
Media layers	3	Network	Packet	Structuring and managing a multi-node network, including addressing, routing and traffic control
	2	Data link	Frame	Reliable transmission of data frames between two nodes connected by a physical layer
	1	Physical	Bit, Symbol	Transmission and reception of raw bit streams over a physical medium

OSI REFERENCE MODEL



WIRESHARK


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

ENCAPSULATION

Figure shows the physical path:

- data takes down a sending end system's protocol stack
- up and down the protocol stacks of a link -layer switch and router
- up the protocol stack at the receiving end system.

A packet has two types of fields: **header fields** and a **payload field**.

The payload is typically a packet from the layer above.