Computer Systems Principles

Internetworking

UMASSCS
SCHOOL OF COMPUTER SCIENCE

Learning Objectives

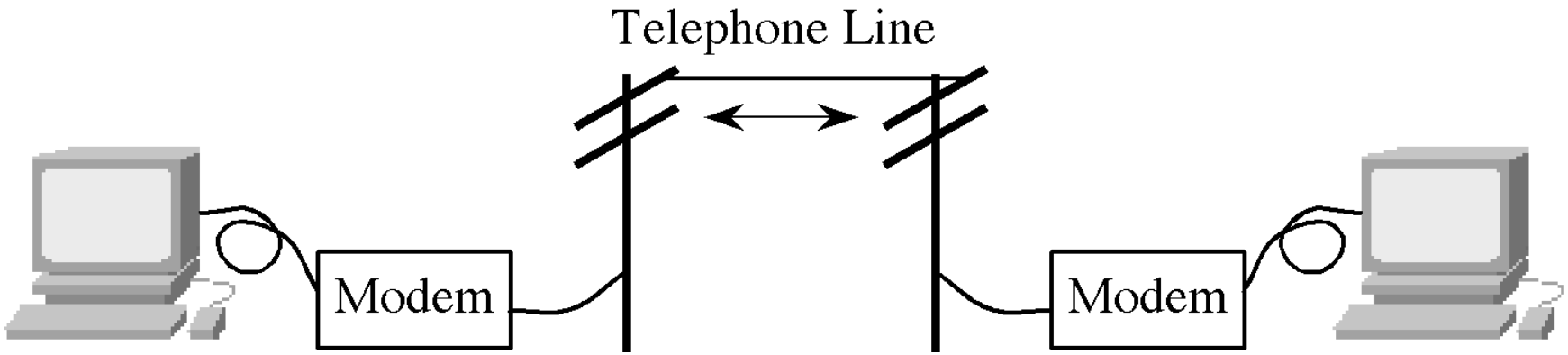
- Understand the “nuts and bolts” of the Internet
- How packets are sent through the network and concepts of encapsulation, routing
- Understand the concept of a protocol and the TCP/IP family of protocols
- Client-Server Interface

Data or Computer Networks

- Networks designed for computers to computers or computers to devices
  - vs. communication between human beings
- Digital information
  - vs. analog voice

- Not a continuous stream of bits, rather, discrete "packets", often with lots of silence in between
  - Dedicated circuit hugely inefficient
  - Packet switching invented

Internetworking



Modem = Modulator/demodulator
Modulation = translation of an electronic signal from a local form to a form suitable for signaling over long distances
Demodulation = translation back to the local form
Example: FM = *frequency modulation* … which is an *analog* technique
There are also numerous *digital* techniques

Major Internet Milestones

- 1960-1964 Basic concept of "packet switching" was independently developed by Baran (RAND) and Kleinrock (MIT)
  - AT&T insisted that packet switching would never work!

MIT TX-2

dial-up

SDC Q32

"Fun" internet appliances

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

Web-enabled toaster +
weather forecaster

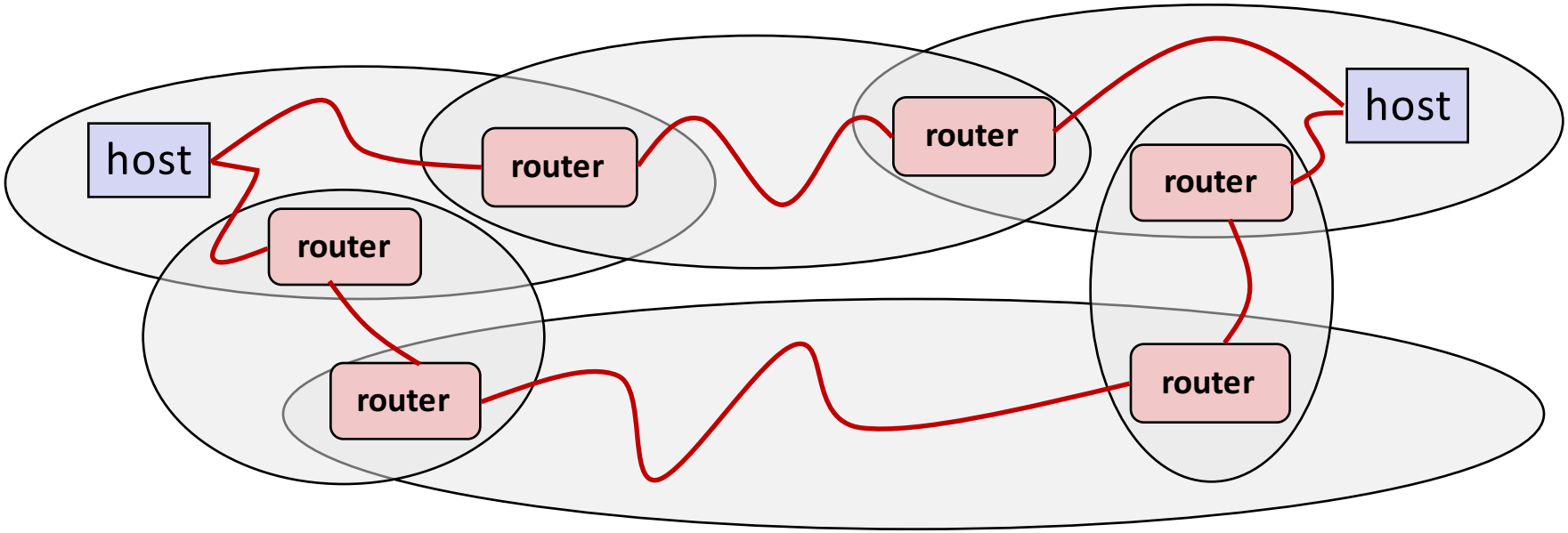
Tweet-a-watt:
monitor energy use

Internet
refrigerator

Slingbox: watch,
control cable TV remotely

Internet phones

Logical Structure of an internet



- Ad hoc interconnection of networks
  - No particular topology
  - Vastly different router & link capacities
- Send packets from source to destination by hopping through networks
  - *Router* forms bridge from one network to another – determines path
  - Different packets may take different routes

Physical media

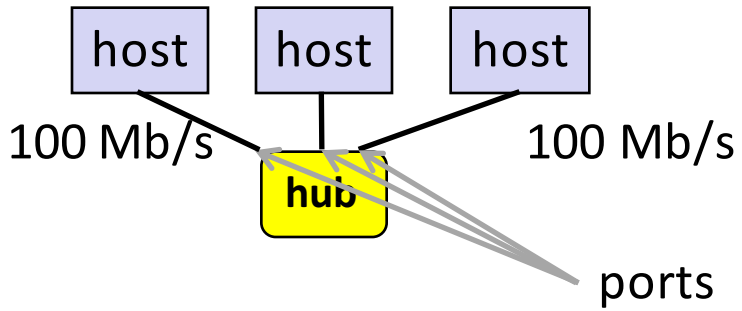
- bit: propagates between transmitter/receiver pairs
- physical link: what lies between a transmitter & a receiver
- guided media:
  - signals propagate in solid media: copper wire or optical fiber
- unguided media:
  - signals propagate freely, e.g., radio, sound

twisted pair (TP)

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

Lowest Level: Ethernet Segment

- Ethernet segment consists of a collection of hosts connected by wires (twisted pairs) to a hub

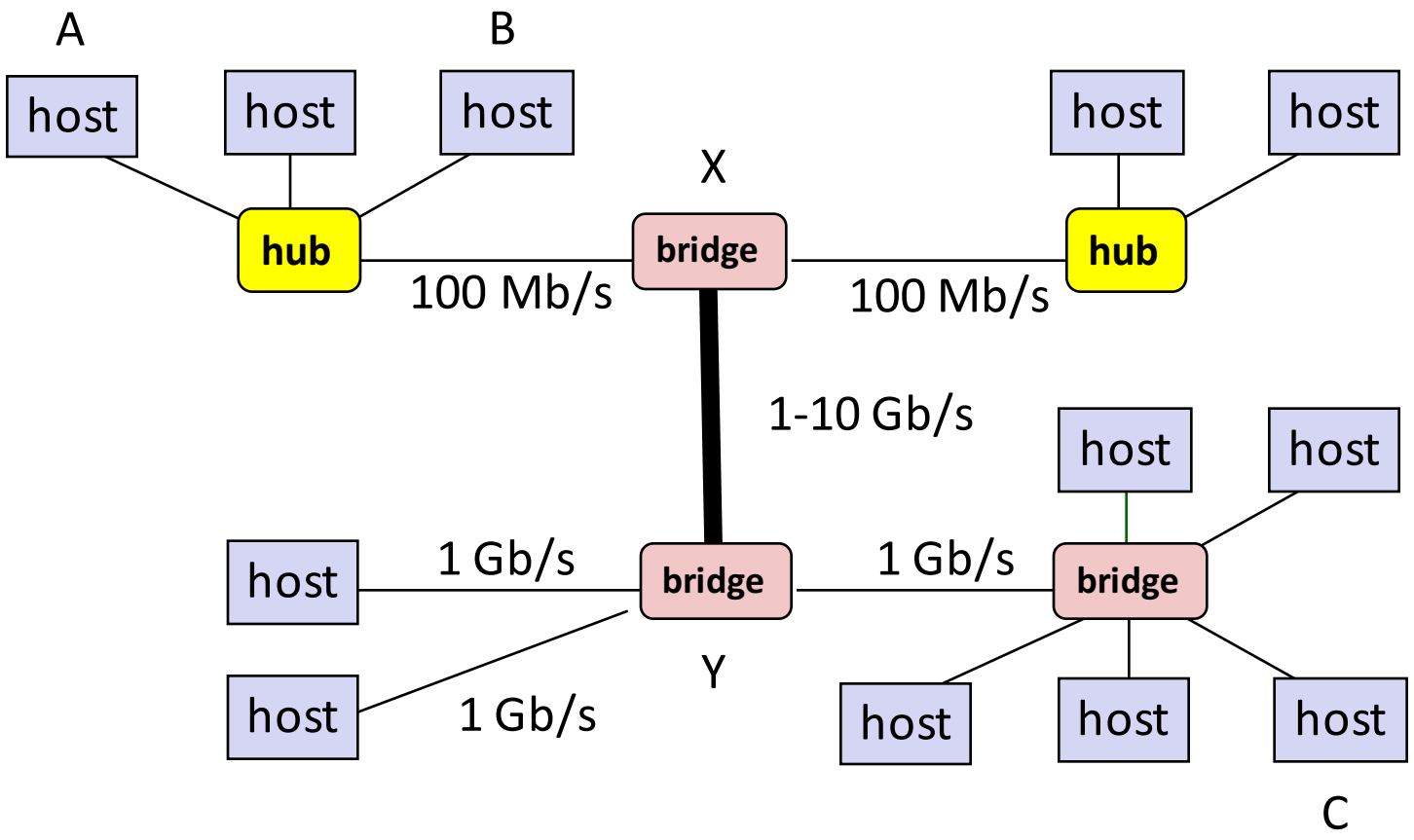


Operation

- Each Ethernet adapter has a unique 48-bit address
- Hosts send bits to any other host in chunks called frames
- Hub slavishly copies each bit from each port to every other port
- Every host sees every bit
  - Note: Hubs are largely obsolete
- Bridges (switches, routers) became cheap enough to replace them (advantage: they don't broadcast all traffic to all hosts)

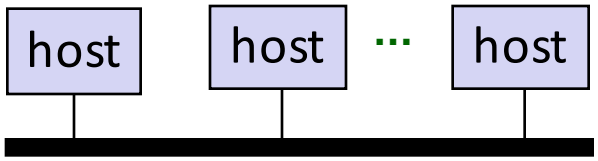
Next Level: Bridged Ethernet Segment

- Spans room, building, or campus
- Bridges cleverly learn which hosts are reachable from which ports and then selectively copy frames port to port.



Conceptual View of LANs

For simplicity, hubs, bridges, and wires are often shown as a collection of hosts attached to a single wire (which is the way Ethernet actually started!):



LAN = Local Area Network

compare:

WAN = Wide Area Network

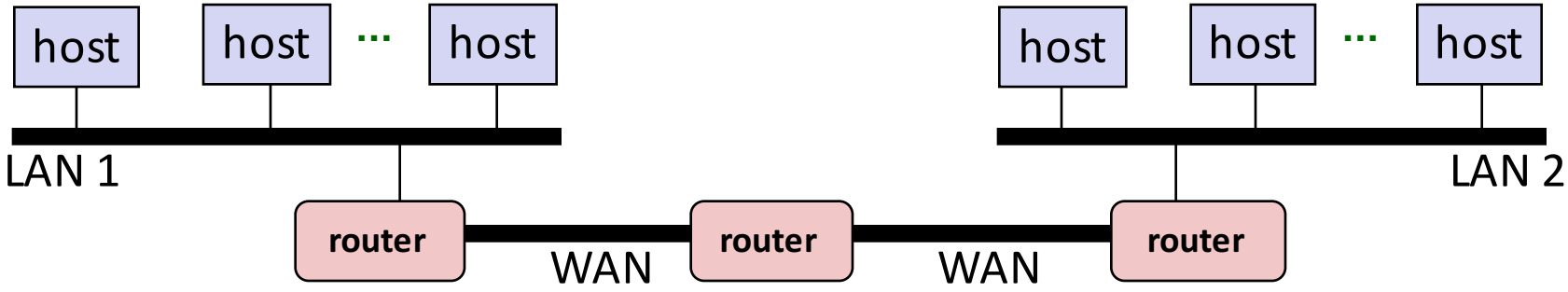
MAN = Metropolitan Area Network

(CAN = Campus Area Network??)

Next Level: internets

Multiple incompatible or distant LANs can be physically connected by specialized computers called routers

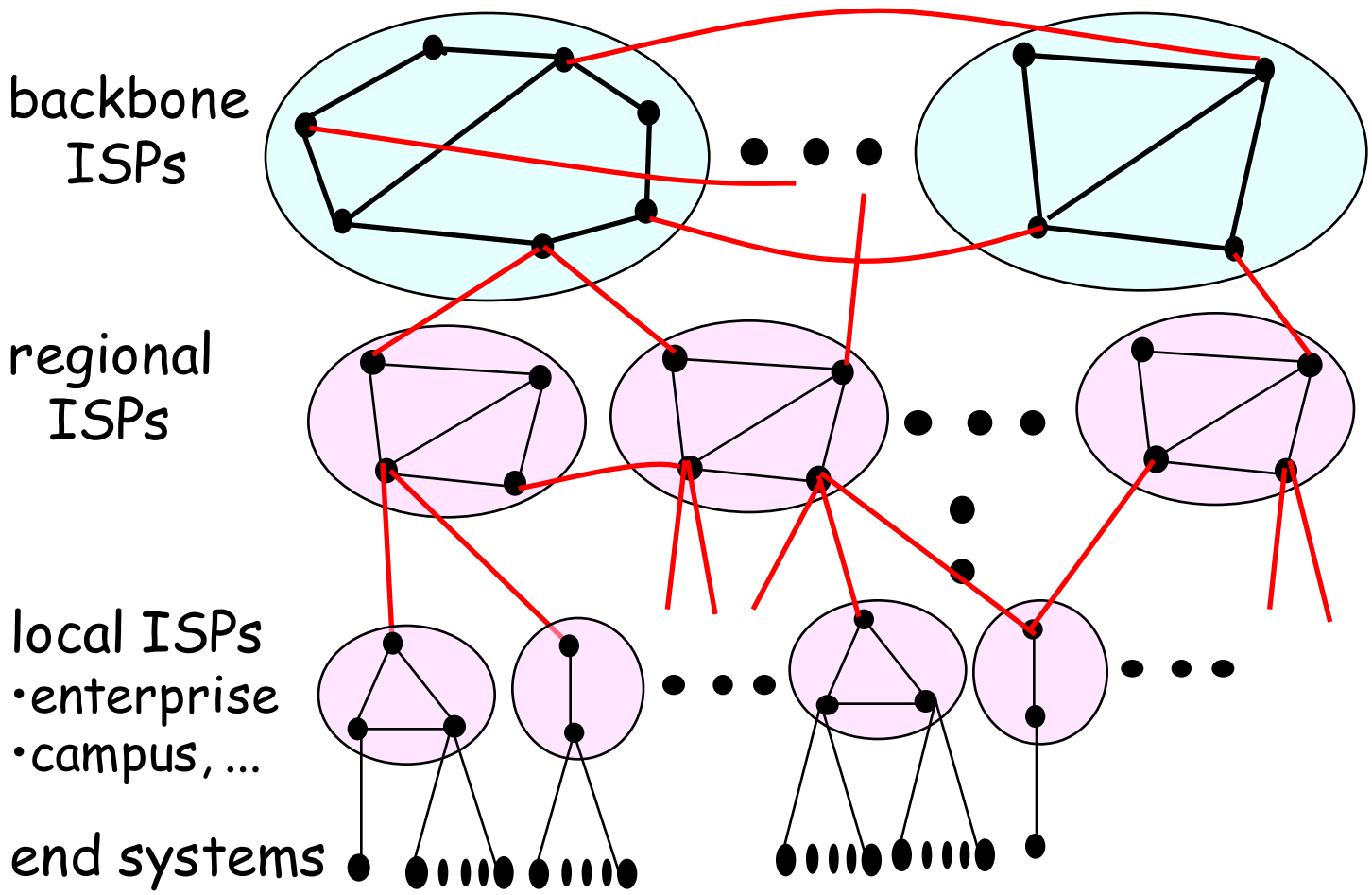
The connected networks are called an internet



LAN 1 and LAN 2 might be completely different, totally incompatible LANs (e.g., Ethernet, WiFi (802.11), T1-links, DSL)

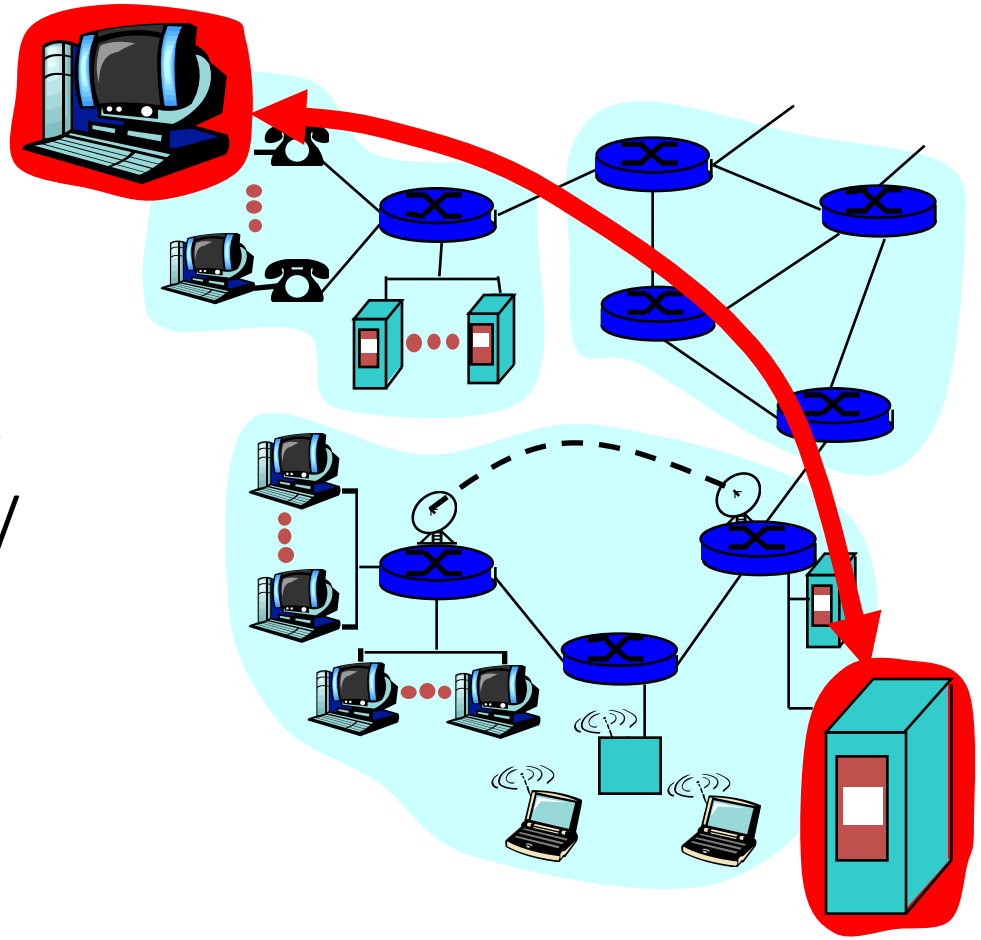
What is "the Internet"?

- network of networks: loosely hierarchical
- *communication links*: fiber, copper, radio, satellite
- *routers:* forward data packets
- *end-systems* run *network apps*
- *protocols*: TCP, IP, HTTP, FTP, PPP, ...



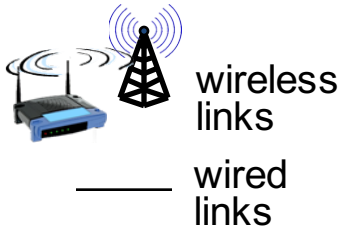
The network edge:

- end systems (hosts):
  - run application programs
  - e.g., WWW, email
  - at “edge of network”
- client/server model
  - client sends host requests, receives service from server
  - e.g., WWW client (browser)/ server; email client/server
- peer-peer model:
  - host interaction symmetric
  - e.g.: teleconferencing



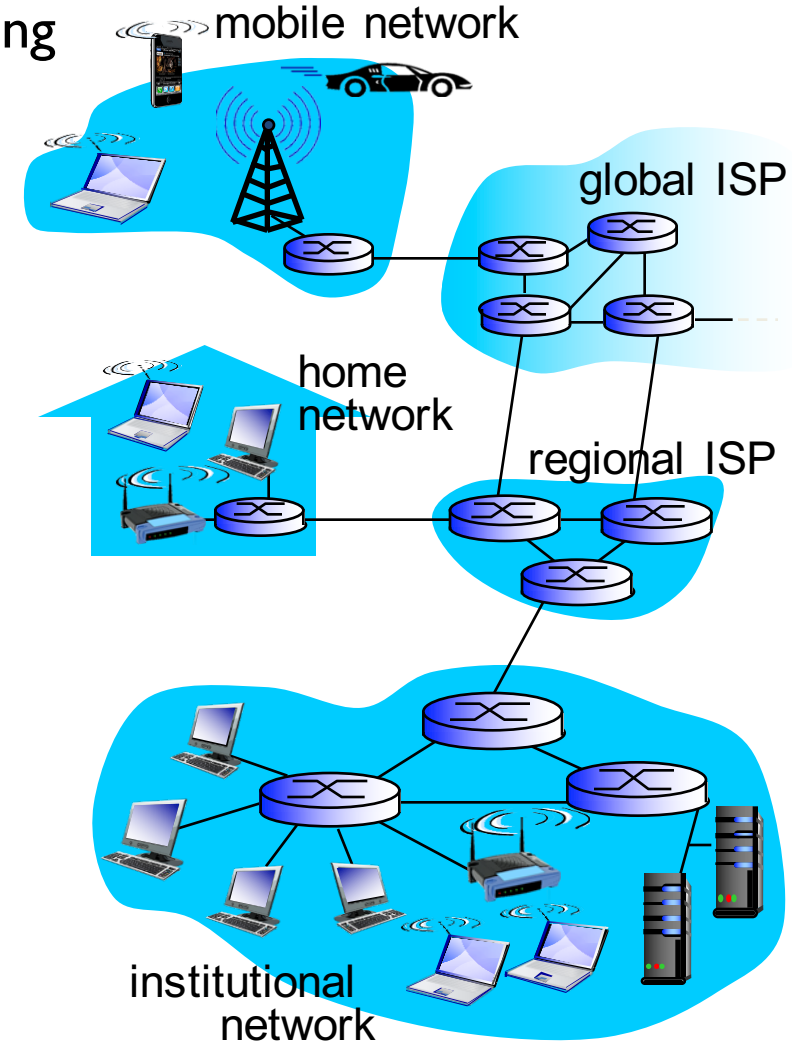
What's the Internet: "nuts and bolts" view

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



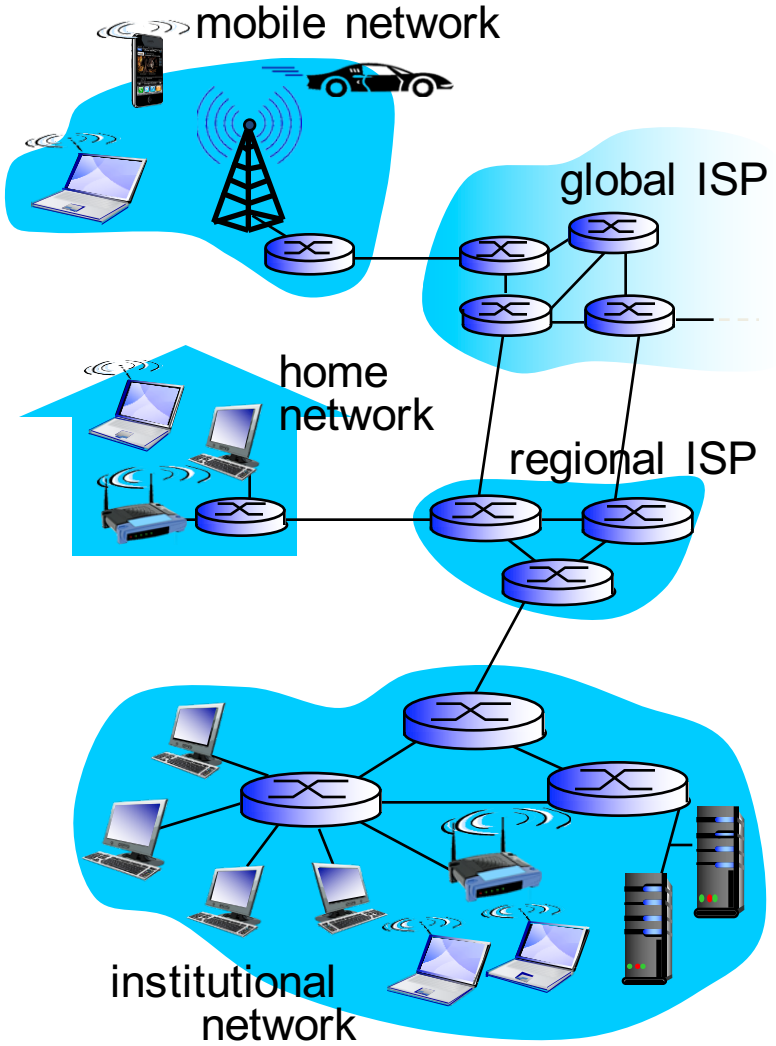
- communication links
  - fiber, copper, radio, satellite
  - transmission rate: bandwidth

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



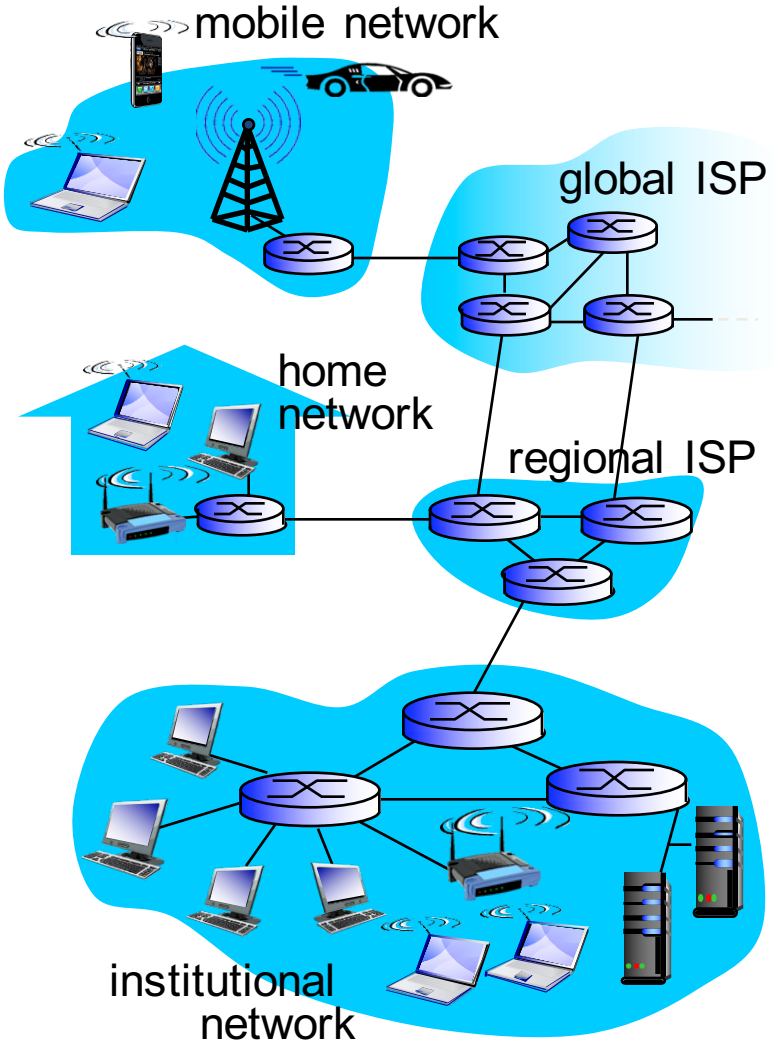
What's the Internet: "nuts and bolts" view

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



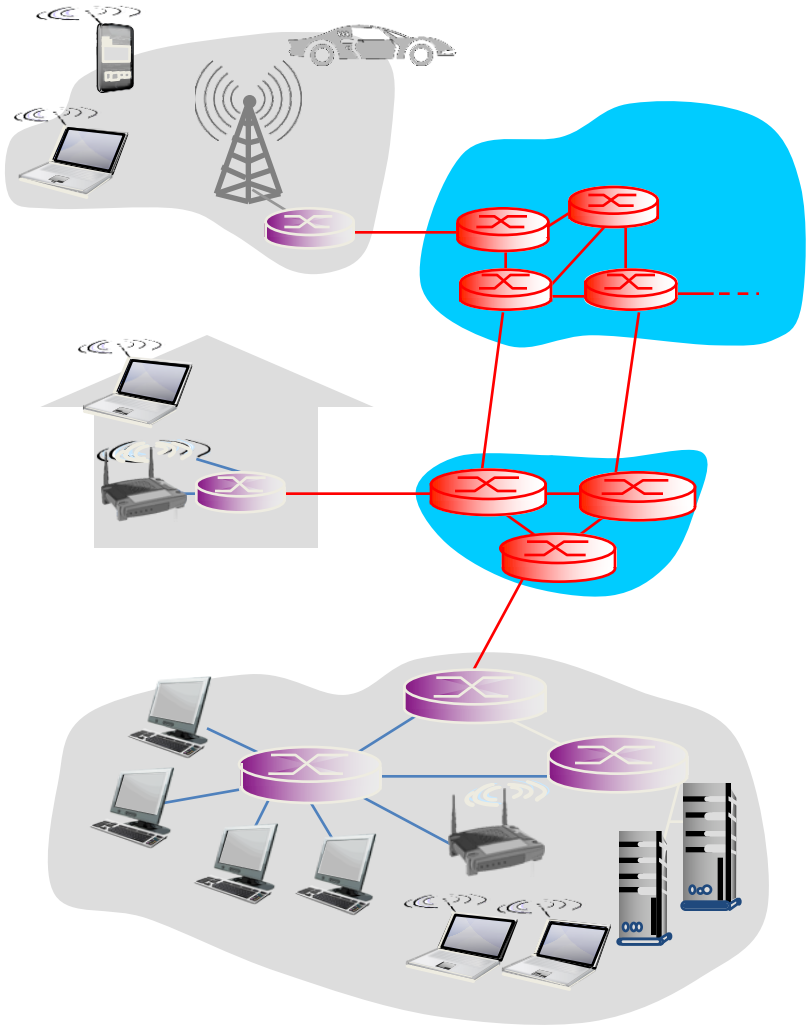
What's the Internet: a service view

- Infrastructure that provides services to applications:
  - Web, VoIP, email, games, e-commerce, social 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



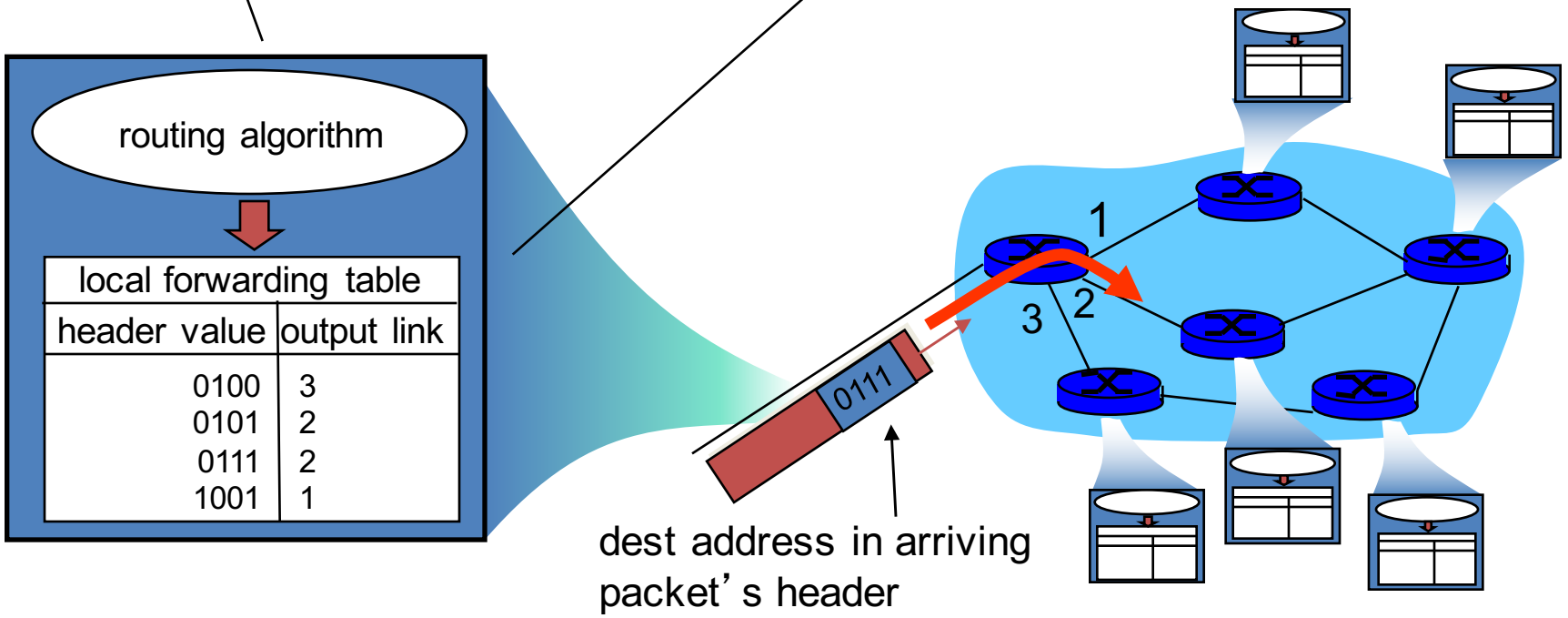
The network core

- 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



Two key network-core functions

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

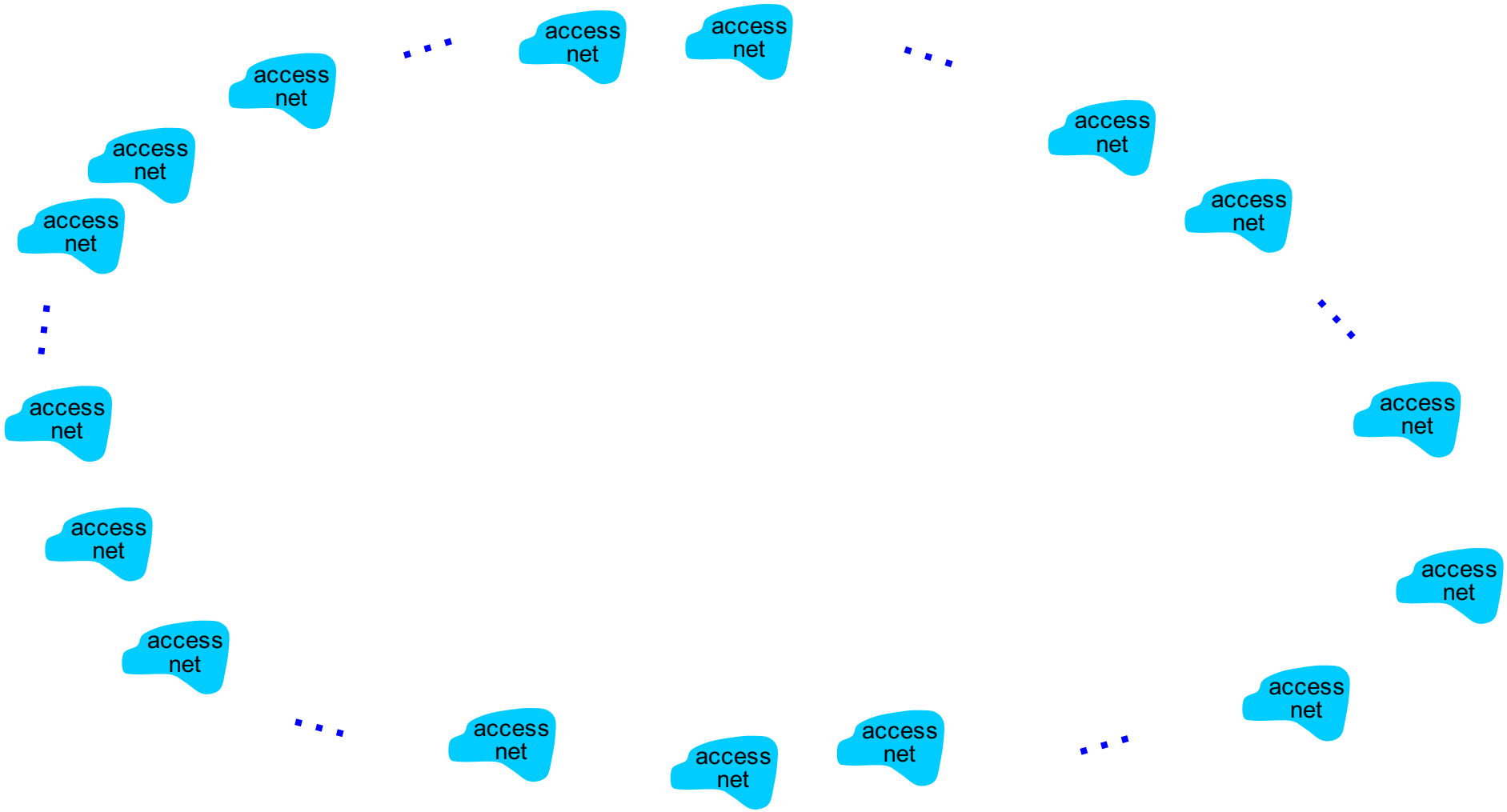


Internet structure: network of networks

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

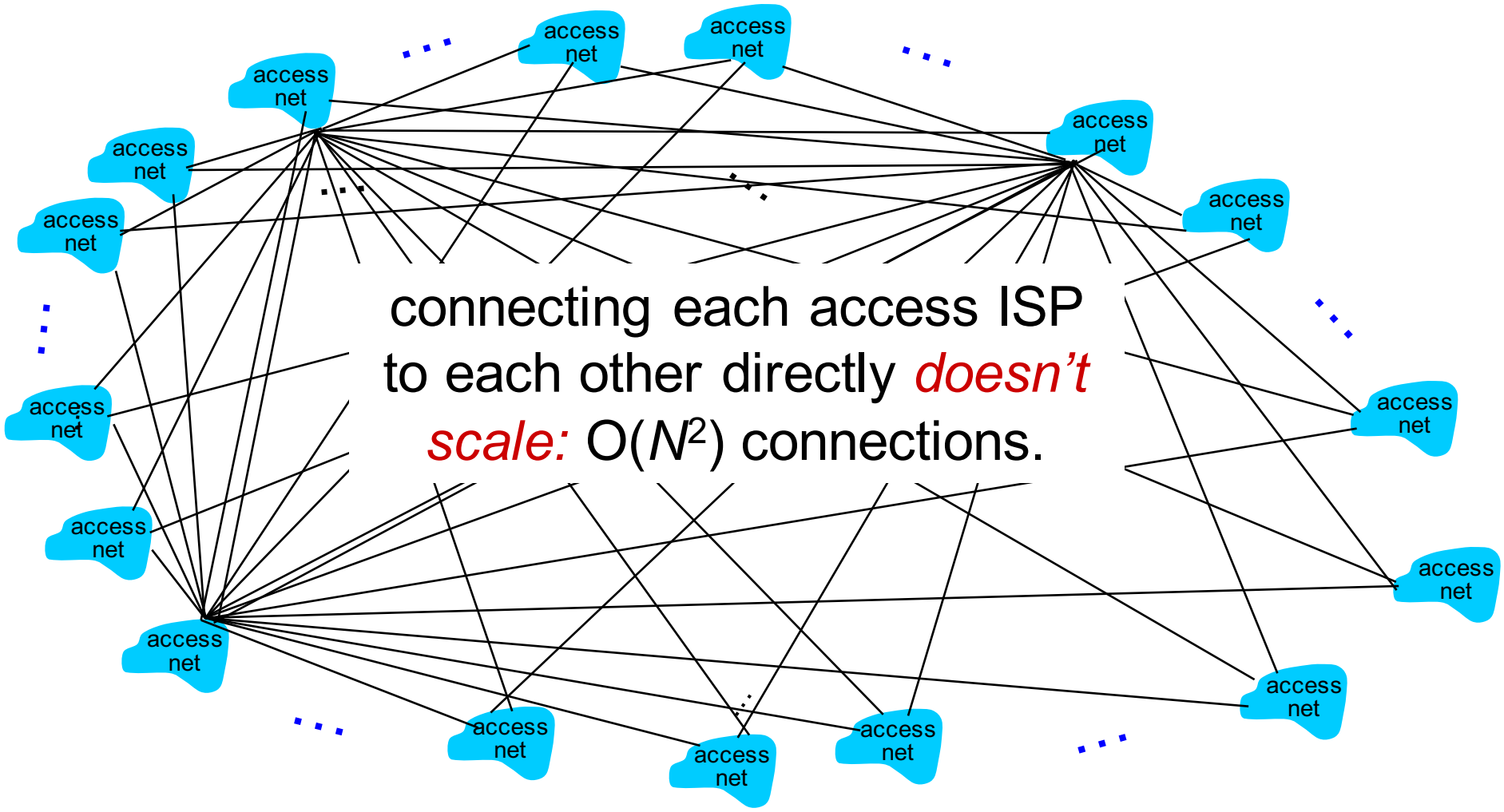
Internet structure: network of networks

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



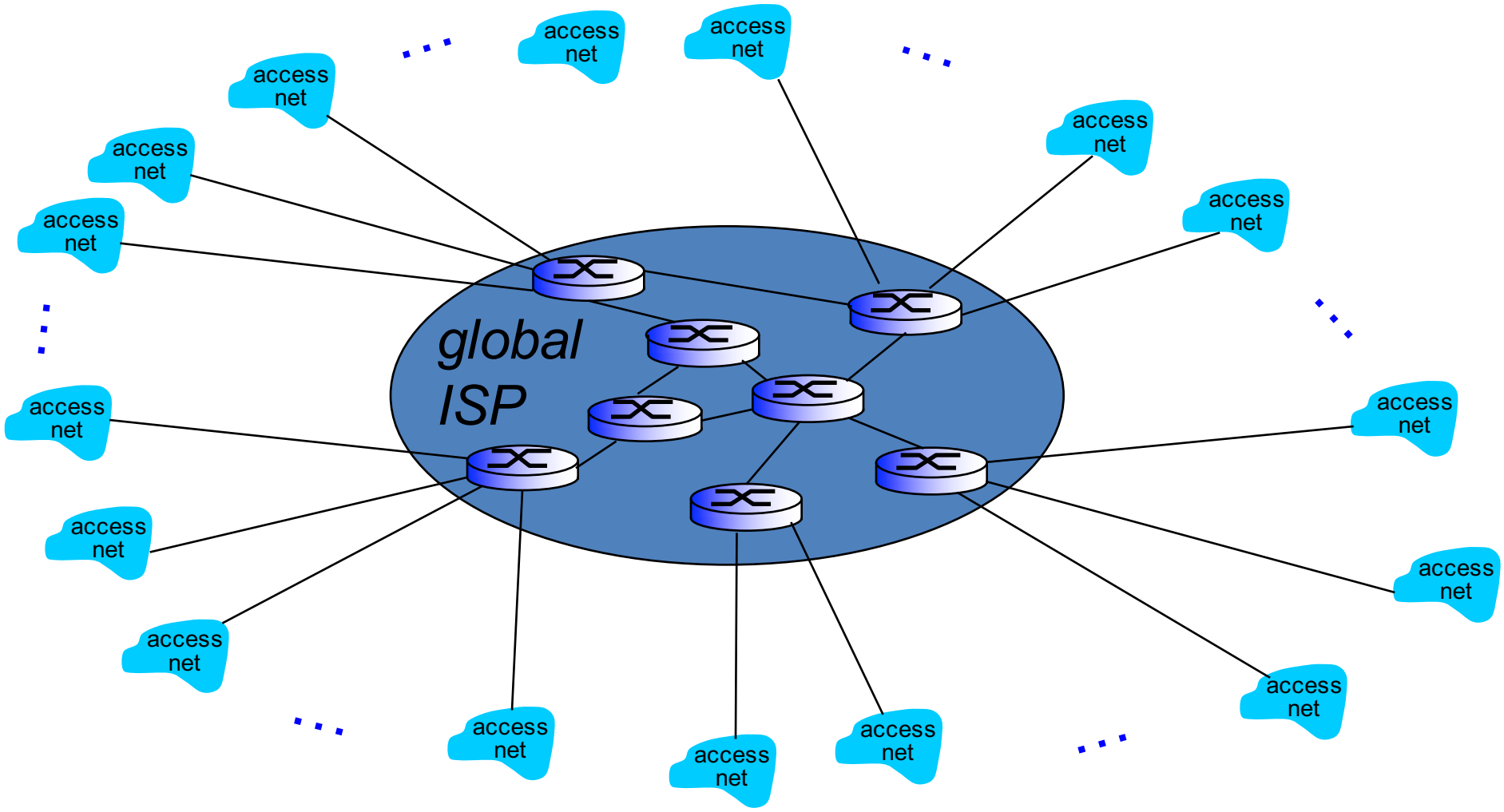
Internet structure: network of networks

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



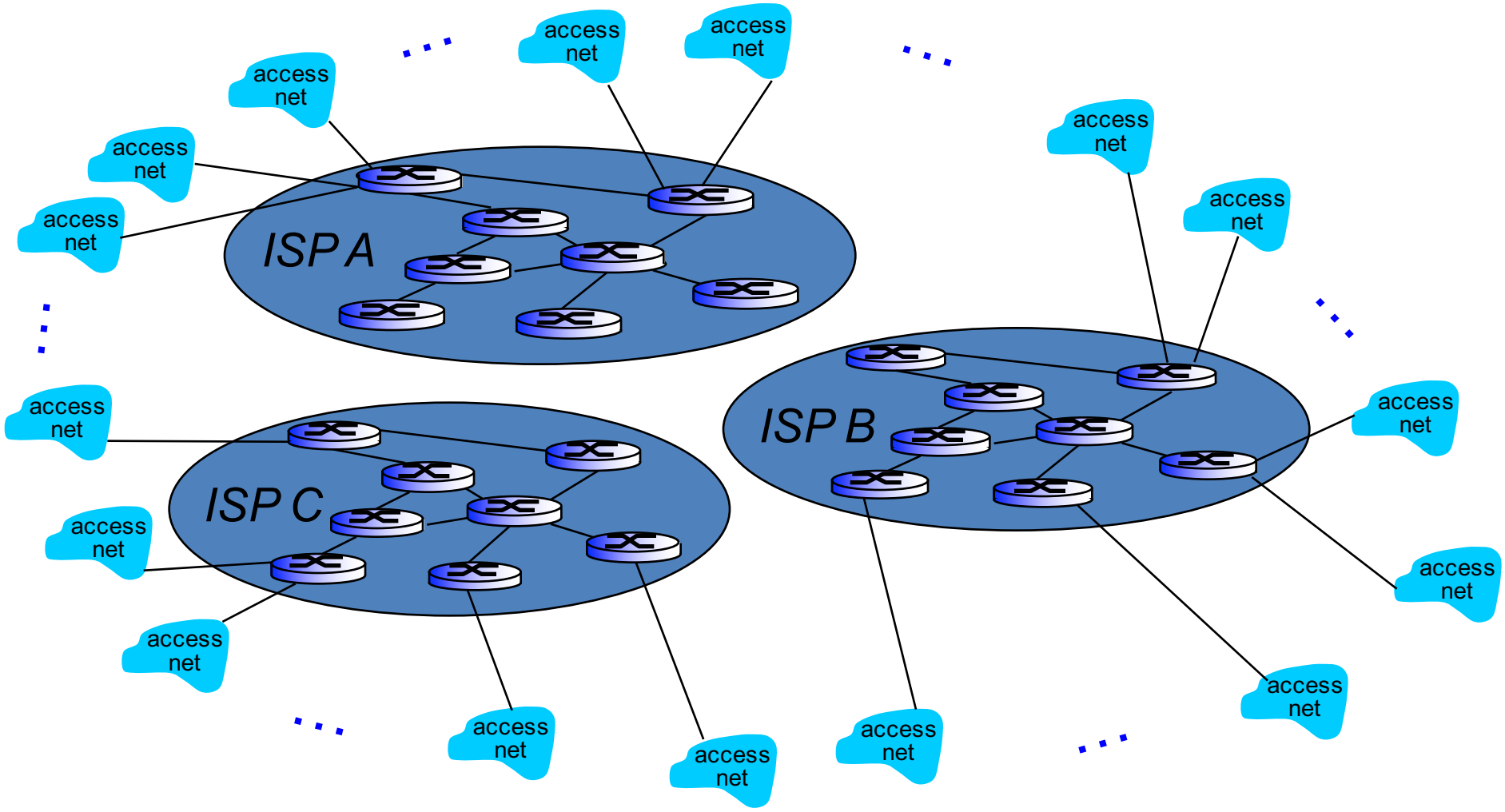
Internet structure: network of networks

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



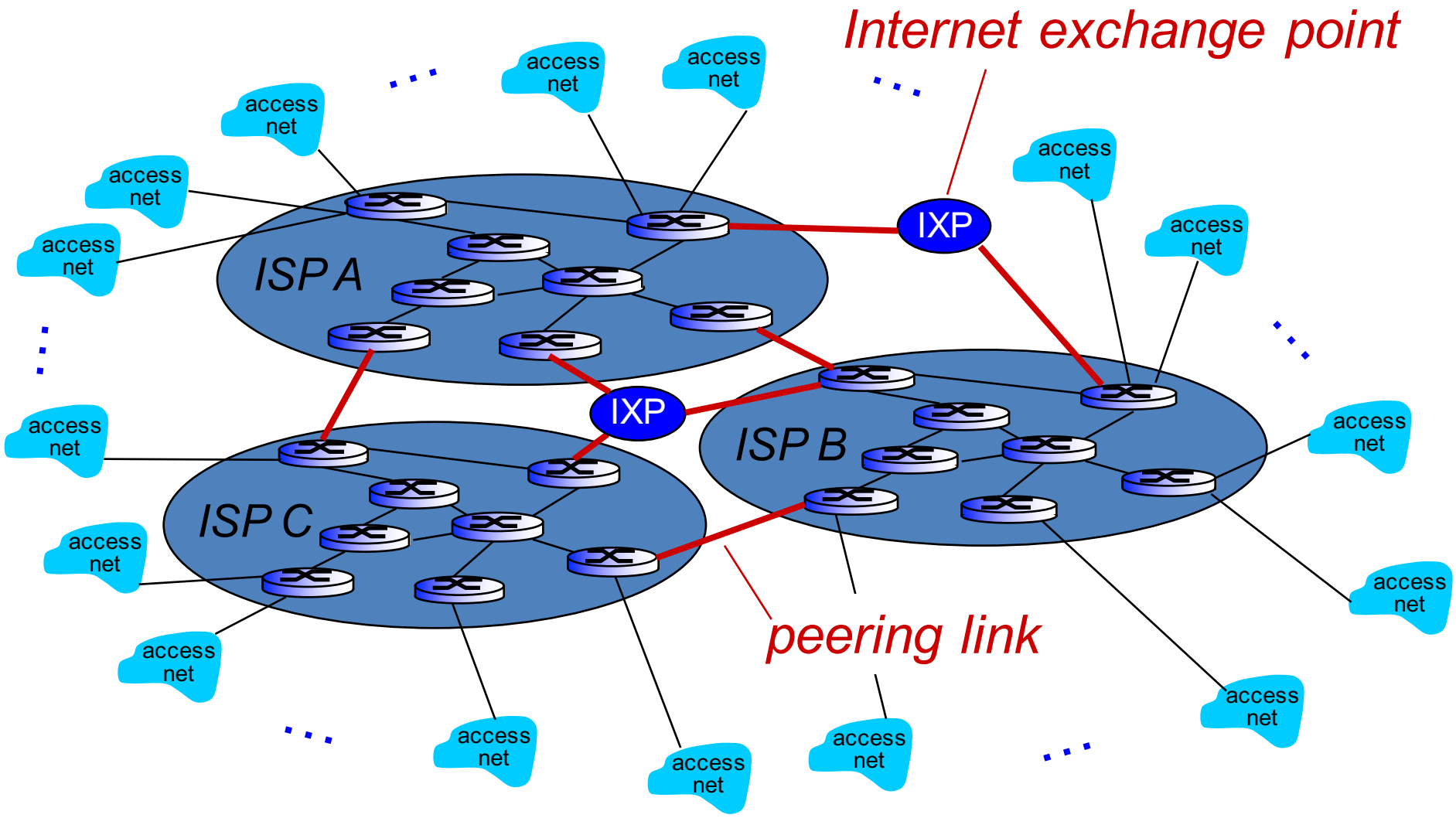
Internet structure: network of networks

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



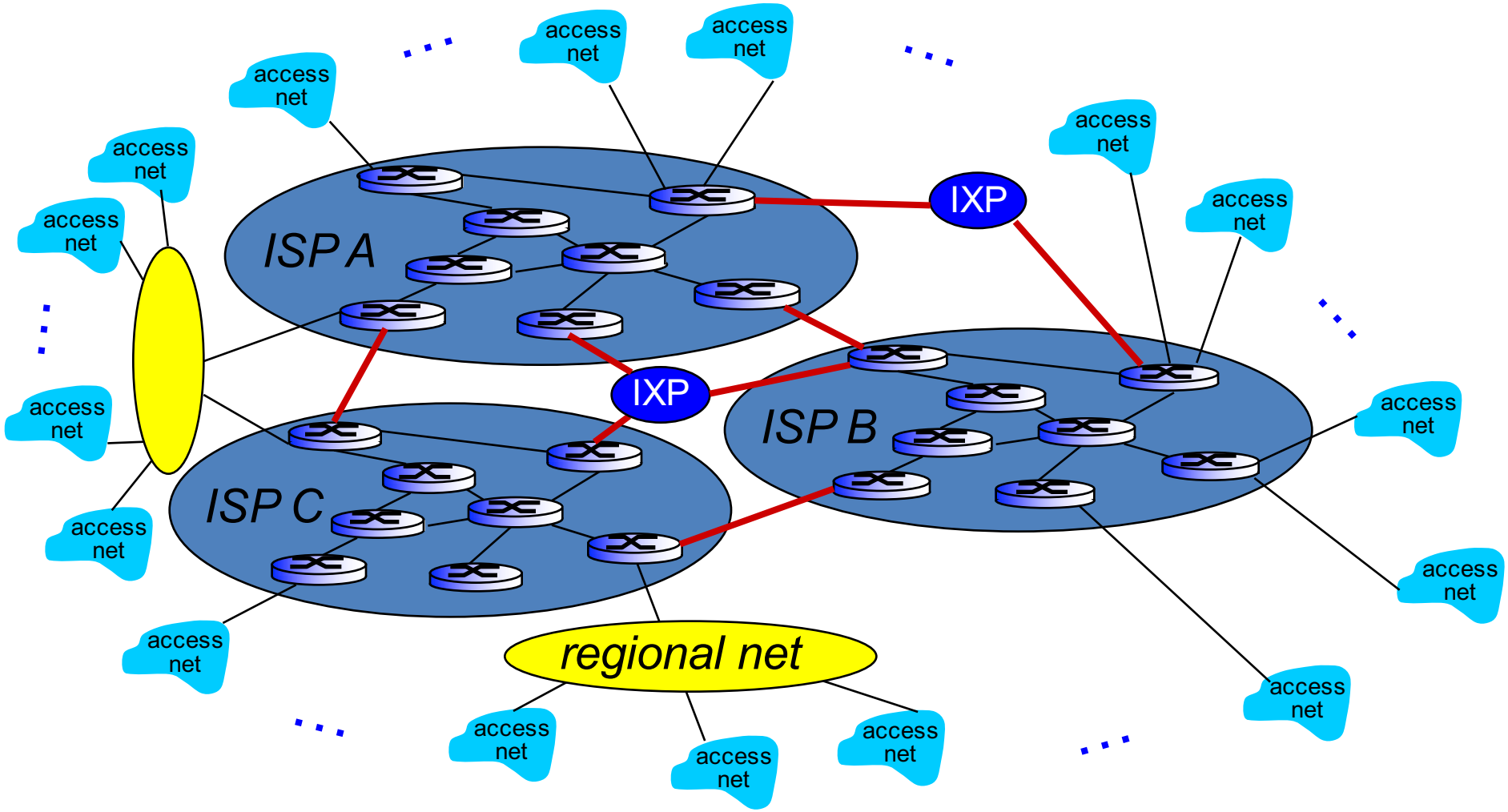
Internet structure: network of networks

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



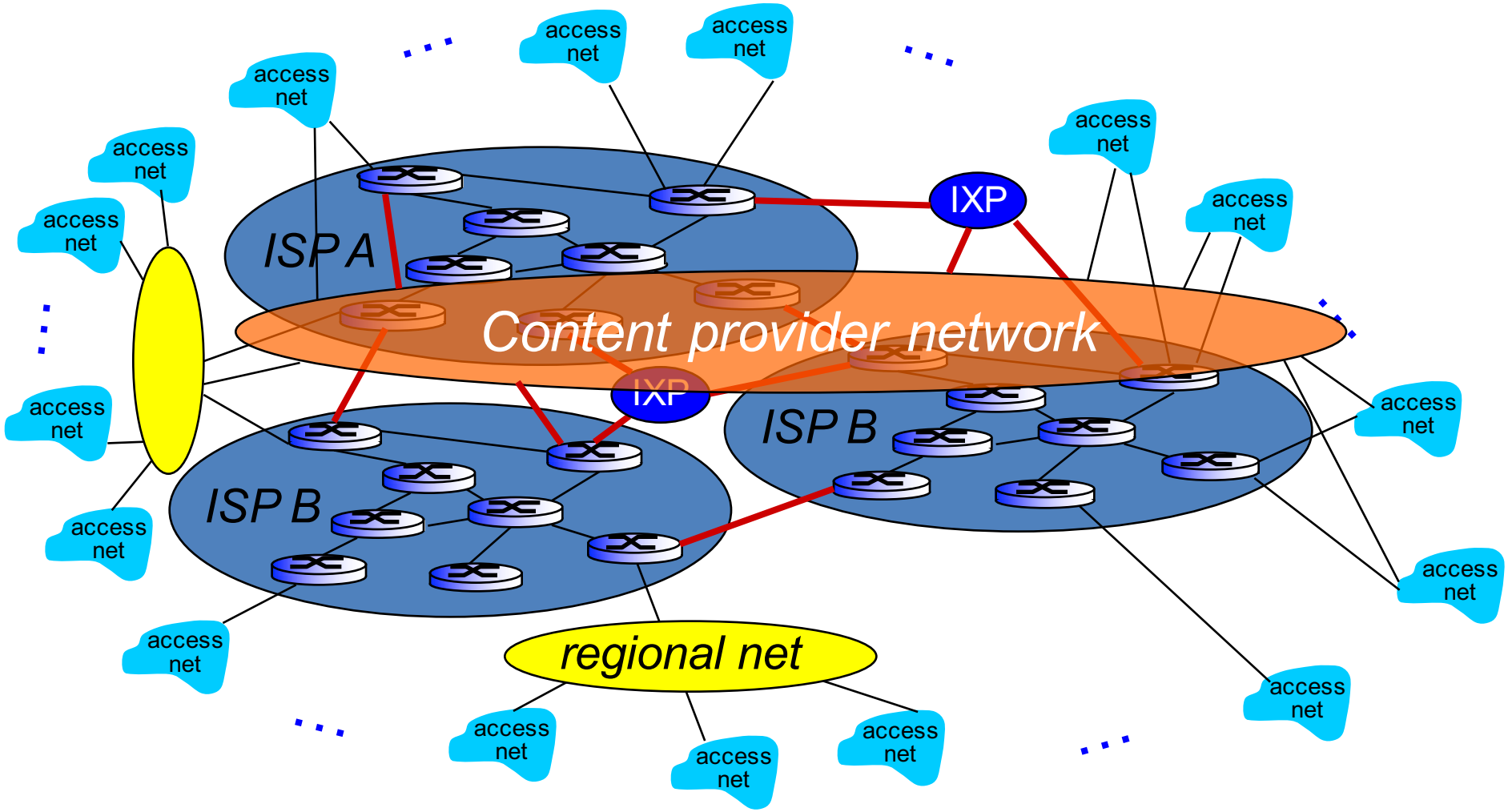
Internet structure: network of networks

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

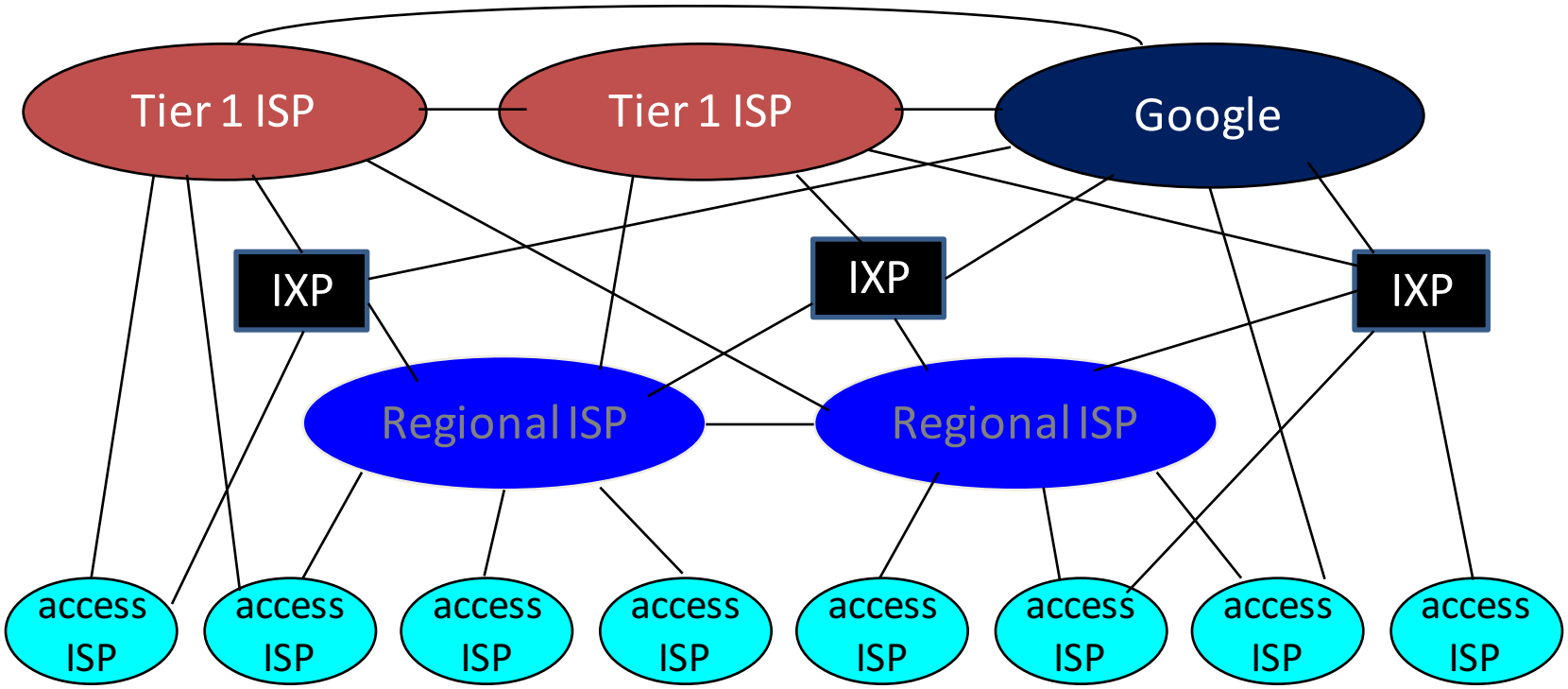


Internet structure: network of networks

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

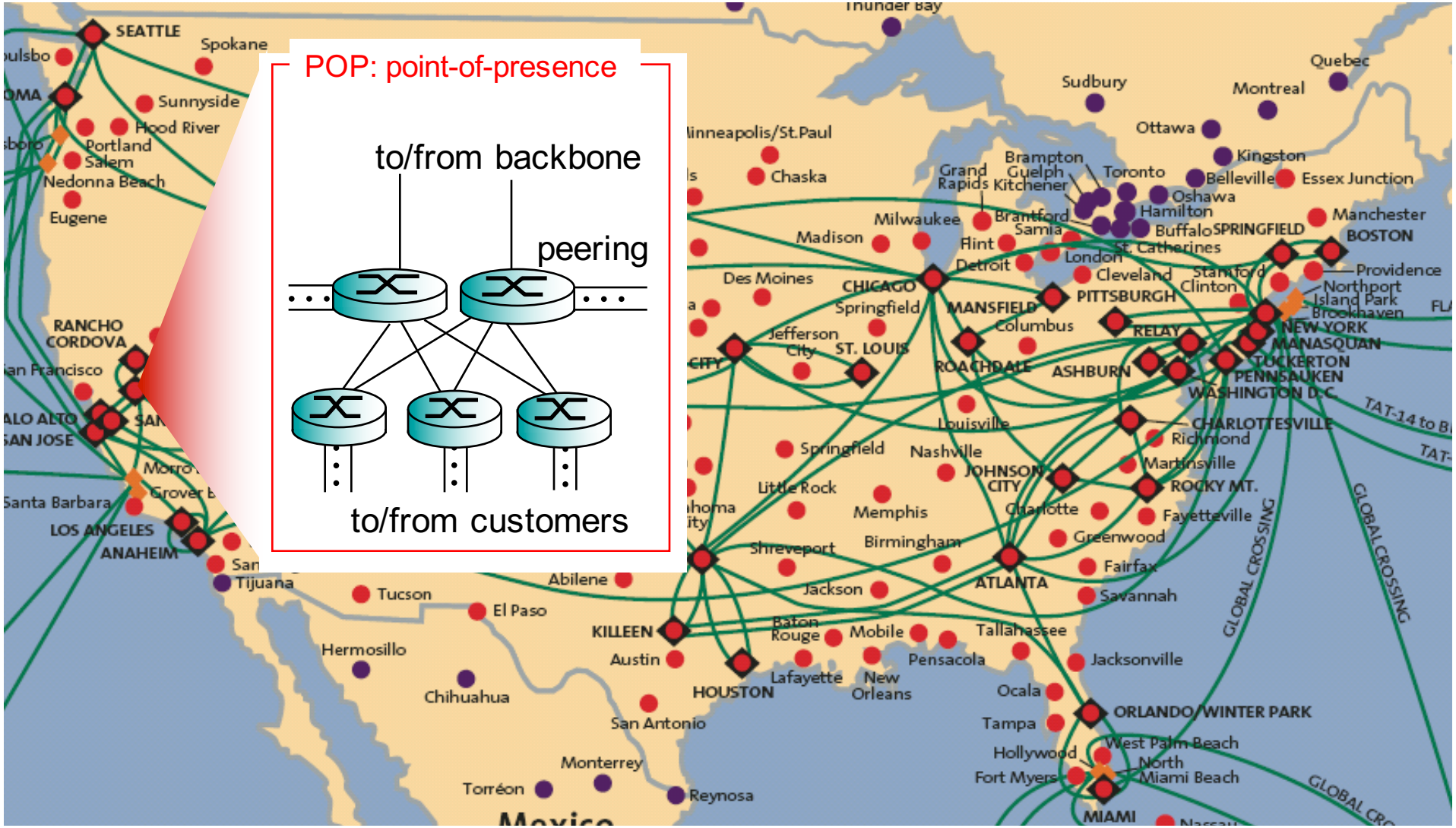


Internet structure: network of networks

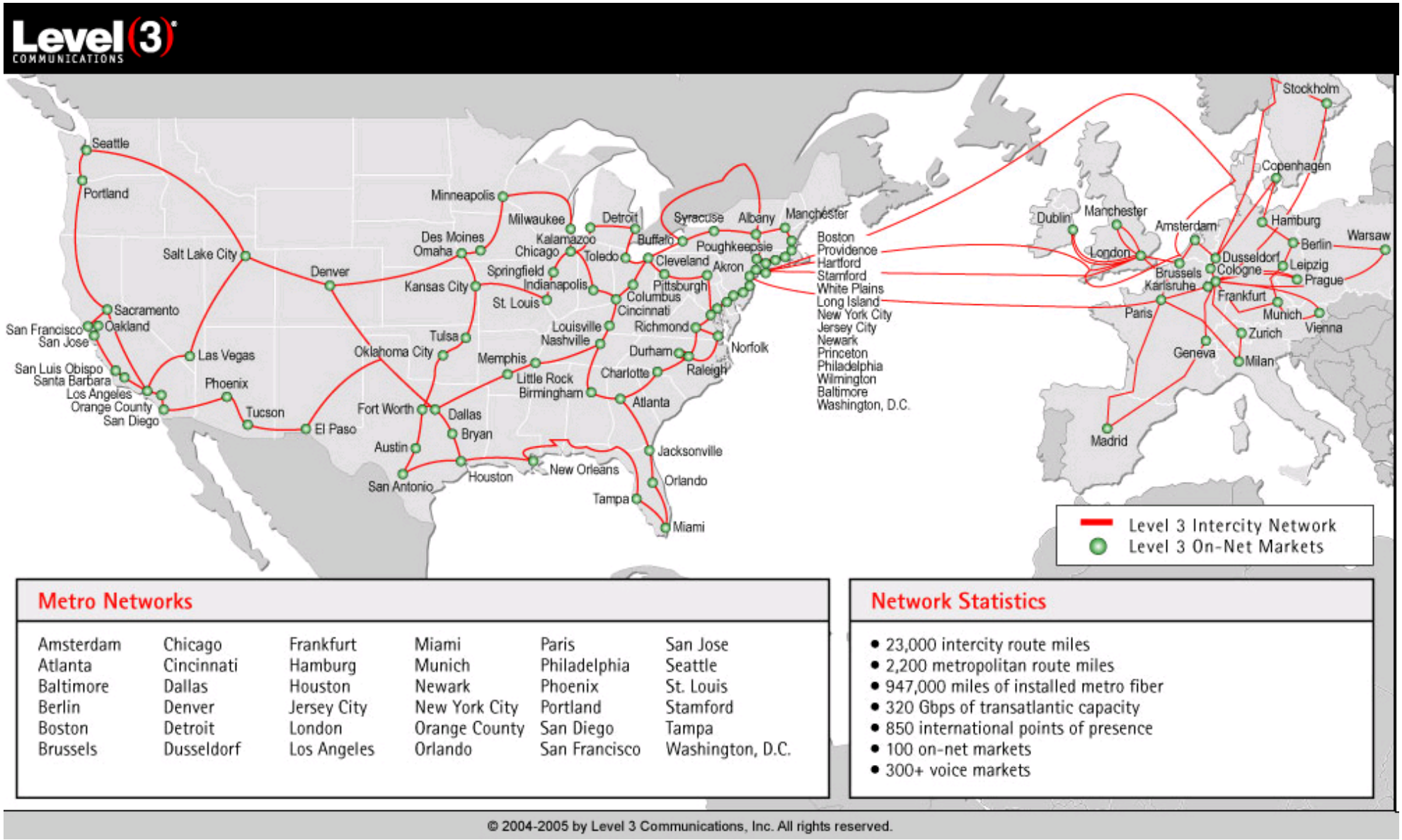


- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g, Google): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs

Tier-1 ISP: e.g., Sprint



Level 3 Backbone



AT&T Backbone

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

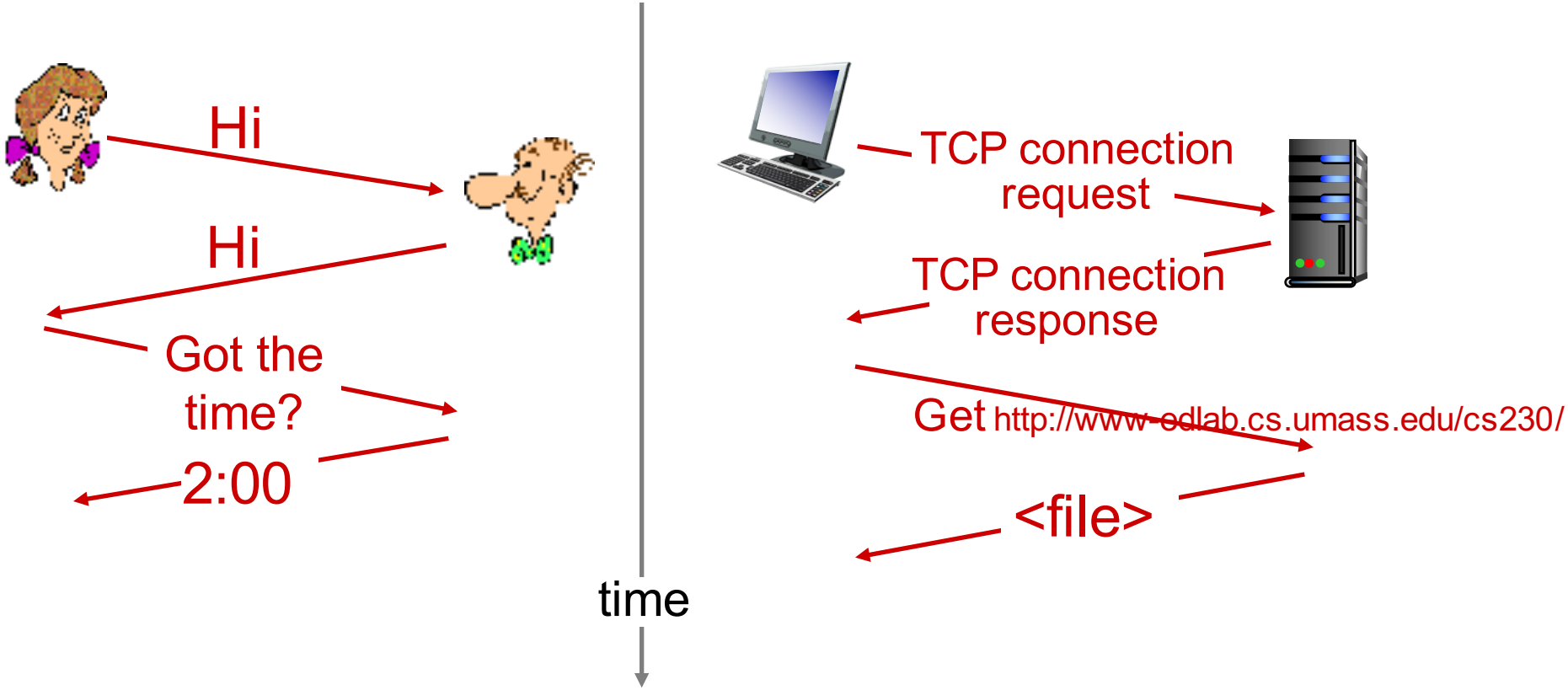
network protocols:

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

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

What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

Naming and Communication on the Internet

Original Idea

- Every node on the Internet would have a unique IP address
  - IP = Internet Protocol
- Everyone would be able to talk directly to everyone
- No secrecy or authentication
  - Messages visible to routers and hosts on the same LAN
  - Possible to forge source field in packet header

Shortcomings

- There aren't enough IP addresses available
- Don't want everyone to have access or knowledge of all other hosts
- Security issues mandate secrecy and authentication

The Notion of an Internet Protocol

Problem: How is it possible to send bits across incompatible LANs and WANs?

Solution: Protocol software running on each host and router smooths out the differences between the different networks

Create an Internet Protocol (i.e., set of rules) that governs how hosts and routers should cooperate when they transfer data from network to network

- TCP/IP is the primary protocol for the global IP Internet

What Does an Internet Protocol Do?

1. Provides a naming scheme
   - An internet protocol defines a uniform format for host addresses
   - Each host (and router) is assigned at least one of these internet addresses that uniquely identifies it
2. Provides a delivery mechanism
   - An internet protocol defines a standard transfer unit (packet)
   - Packet consists of header and payload
     - Header: contains info such as packet size, source and destination addresses
     - Payload: contains data bits sent from source host

How is the Internet like an ogre?

A) It guards access to the castle (servers)

B) It enforces protocols

C) It has layers

D) It’s green, like Shrek

E) It can be risky

How is the Internet like an ogre?

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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 network?

…. or at least our discussion of networks?

Why layering?

dealing with complex systems:

explicit structure allows the identification and relationship of a complex system's pieces

- Use a layered reference model for discussion

modularization eases maintenance, updating of system:

- change of implementation of one layer's service is transparent to rest of system
- e.g., a change in gate procedure for an airline doesn't affect rest of system

Internet protocol stack

application: supporting network applications

- FTP, SMTP, HTTP

transport: process-process data transfer

- TCP, UDP

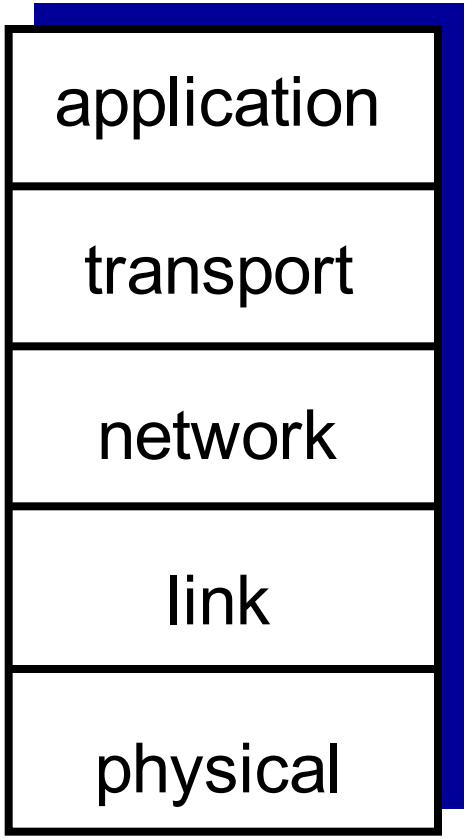
network: routing of datagrams from source to destination

- IP, routing protocols

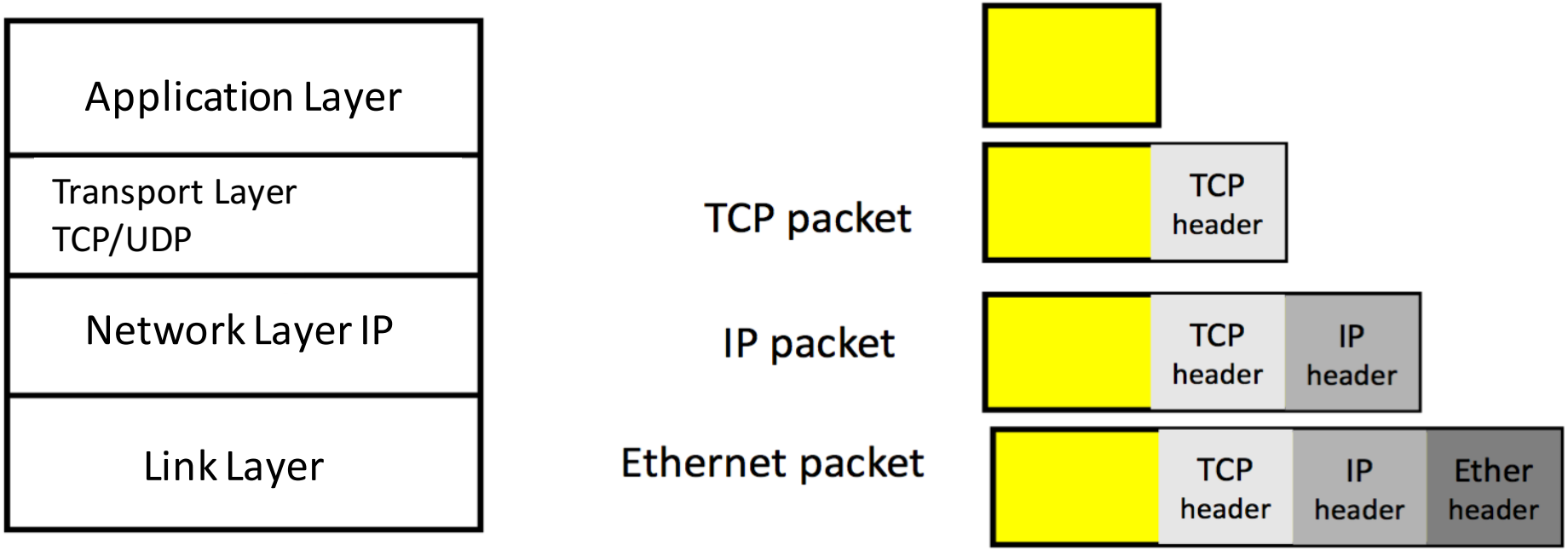
link: data transfer between neighboring network elements

- Ethernet, 802.111 (WiFi), PPP

physical: bits "on the wire"

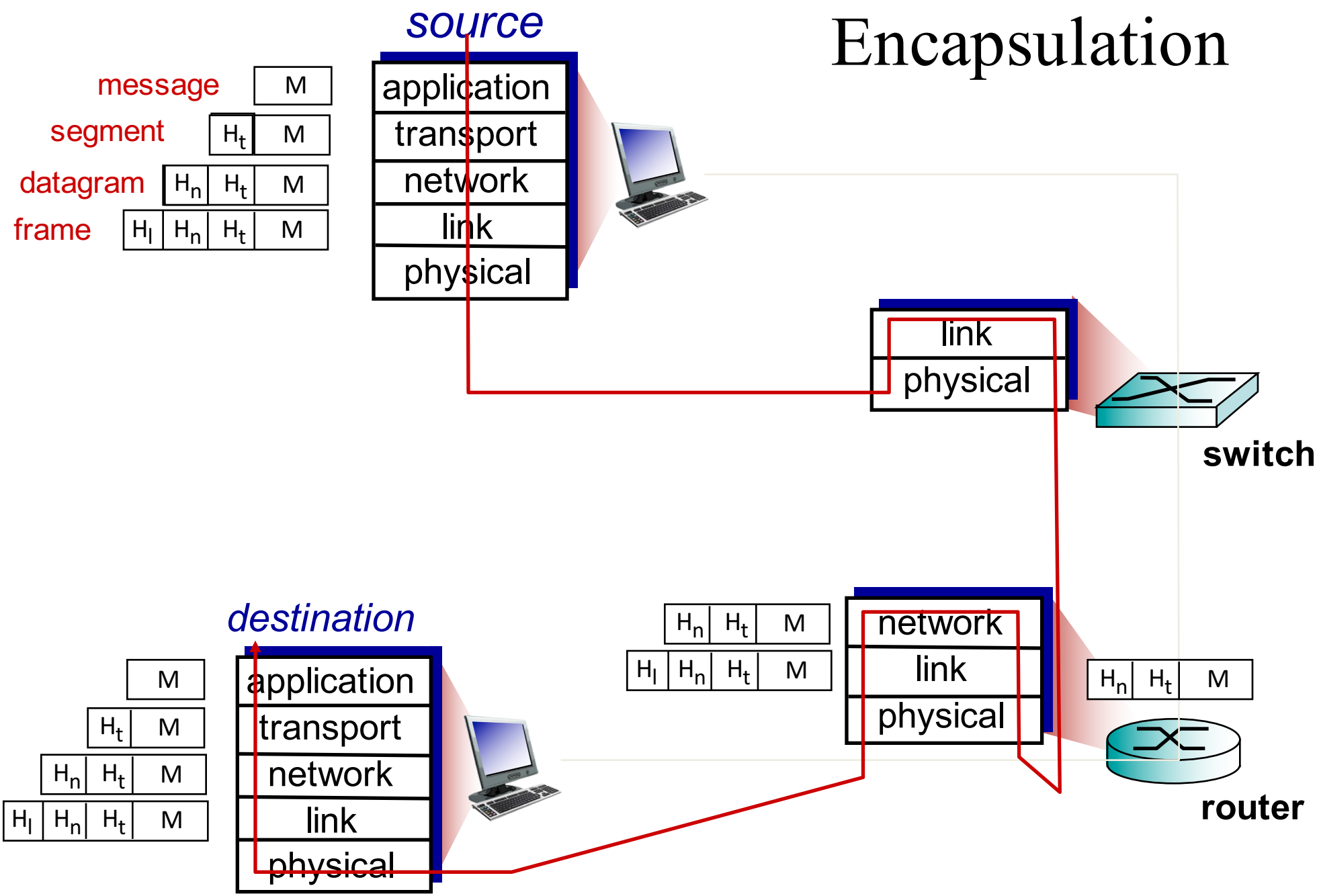


Encapsulation: The Internet stack

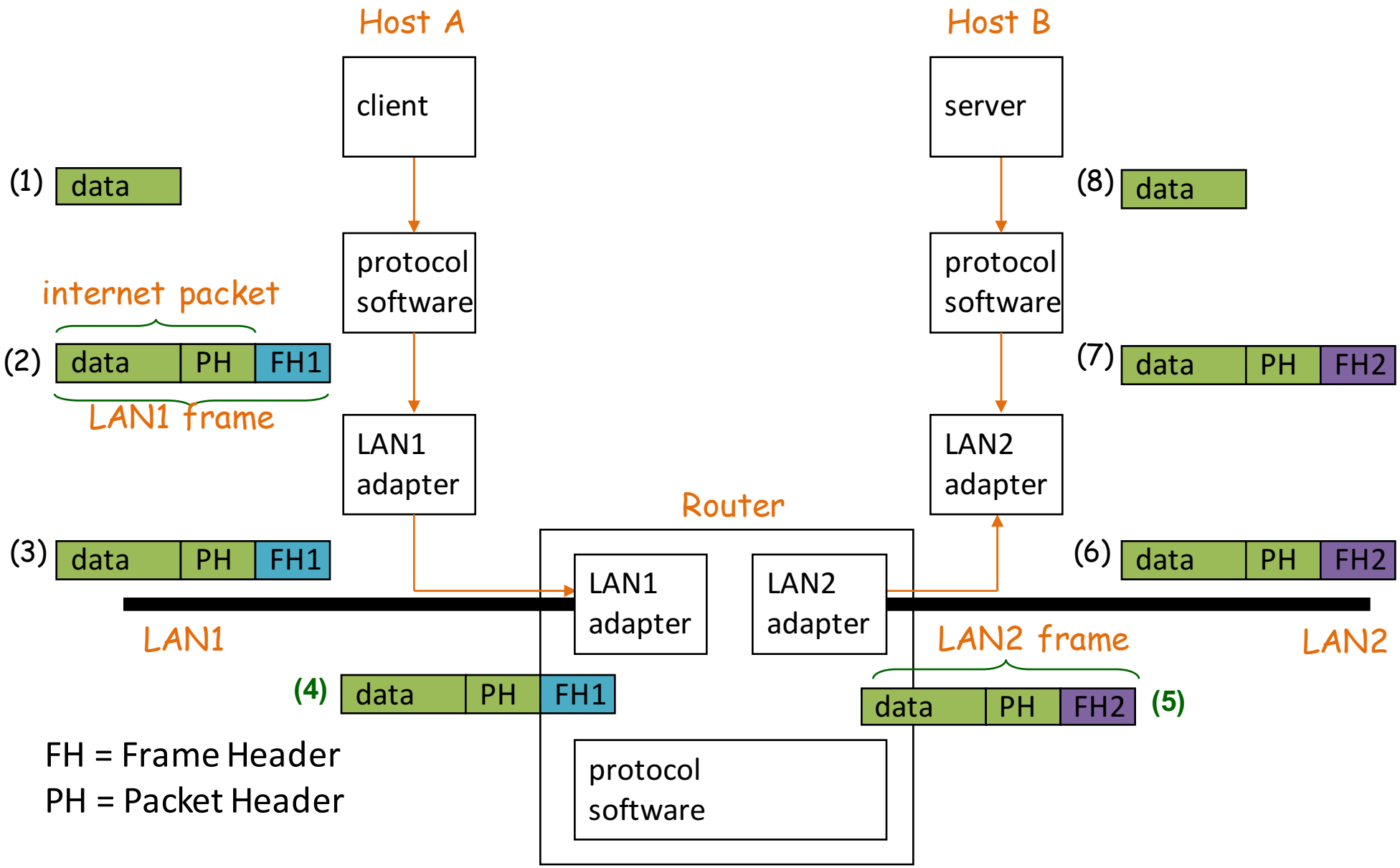


- Transport layer:
  - UDP: unreliable datagram delivery between two processes on different hosts
  - TCP: reliable byte-stream between two processes, congestion control
- Network layer:
  - Find a multi-hop path to destination and forward packets along (routing)
- Link layer (and below)
  - Bits – analog transmission – dealing with bits, framing, error correction/detection, access to the medium (consider WiFi, etc.)

Encapsulation



Transferring Data Over an internet



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A Programmer's View of the Internet

- Hosts are mapped to a set of 32-bit IP addresses
  - Example: 128.119.240.84 … 4 decimal values that each fit into an 8-bit byte (0x8077f054)
  - The future: 128-bit IP addresses

- The set of IP addresses is mapped from a set of identifiers called Internet domain names
  - www.cs.umass.edu maps to 128.119.240.84

- A process on one Internet host can communicate with a process on another Internet host over a connection

Internet Protocols

- A host is “directly” connected to other hosts whose addresses that match within the ***netmask*** (here the netmask is 255.255.255.0 or 0xffffff00):

  192.168.1.100 is on the same subnet as

  - 192.168.1.28

  192.168.1.100 is not on the same subnet as

  - 192.168.2.100

Next Class

- Building a socket interface!

Adapted from slides by R. Bryant and D. O'Hallaron

Adapted from slides by J.F Kurose and K.W. Ross