Part 1: Introduction

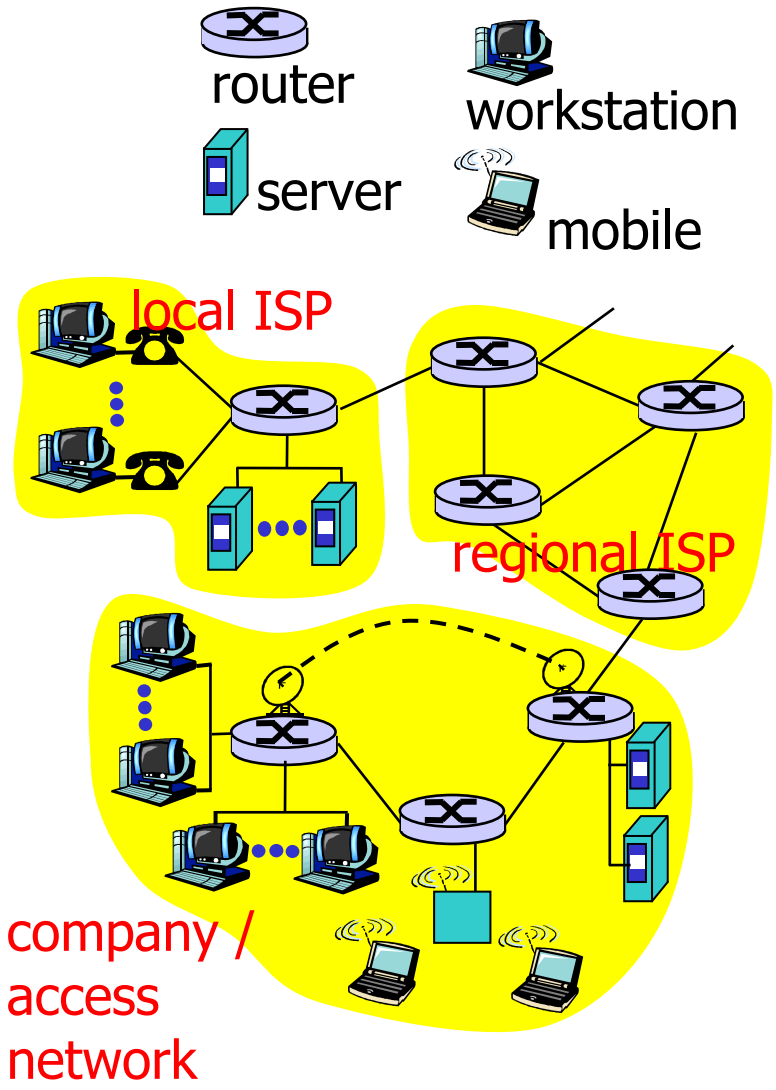
Goal:

- Review of how the Internet works
- Overview
  - Get context
  - Get overview, "feel" of the Internet
- Application layer protocols and addressing
- Network layer / Routing
- Link layer / Example

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

- Millions of connected computing devices: *hosts, end-systems*
  - PC's workstations, servers
  - PDA's, phones, toasters

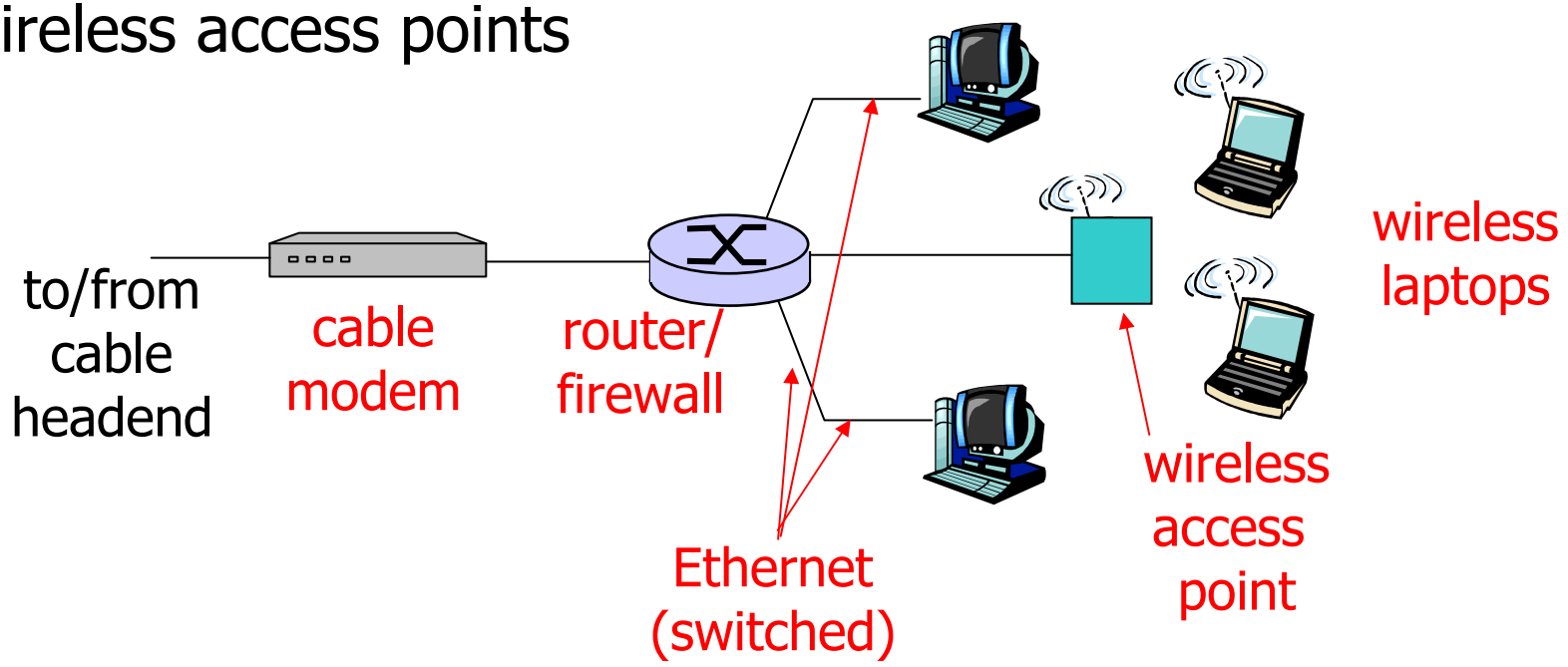
  running *network apps*
- *Communication links*
  - Fiber, copper, radio, satellite
- *Routers:* forward packets (chunks) of data through network



Example access net: Home network

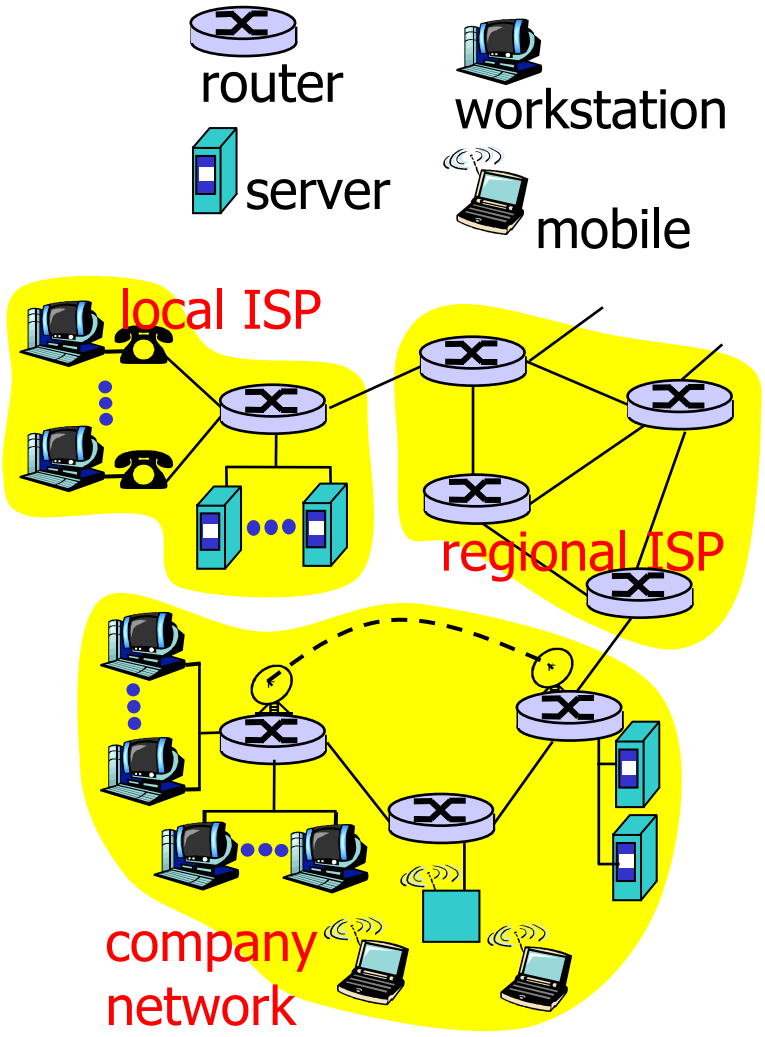
Typical home network components:

- ADSL or cable modem
- router/firewall
- Ethernet
- Wireless access points



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

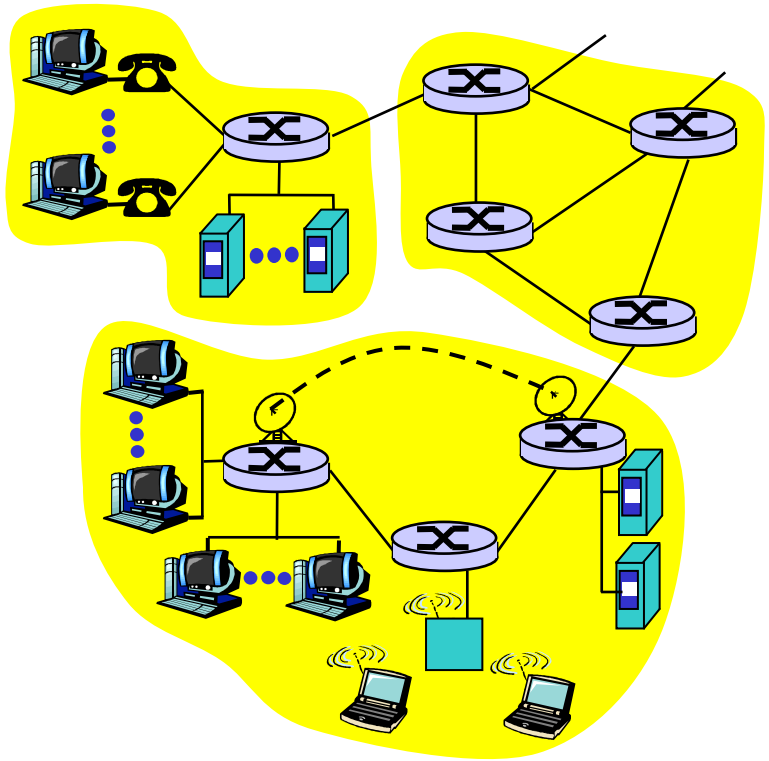
- *Protocols*: control sending, receiving of messages
  - E.g., TCP, IP, HTTP, FTP, PPP
- *Internet:* "network of networks"
  - Loosely hierarchical
  - Public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet: A service view

- Communication *infrastructure* enables distributed applications:
  - WWW, email, games, e-commerce, database, voting,
  - More?
- Communication services provided:
  - Connectionless
  - Connection-oriented
- Cyberspace [Gibson]:

  "a consensual hallucination experienced daily by billions of operators, in every nation, …."

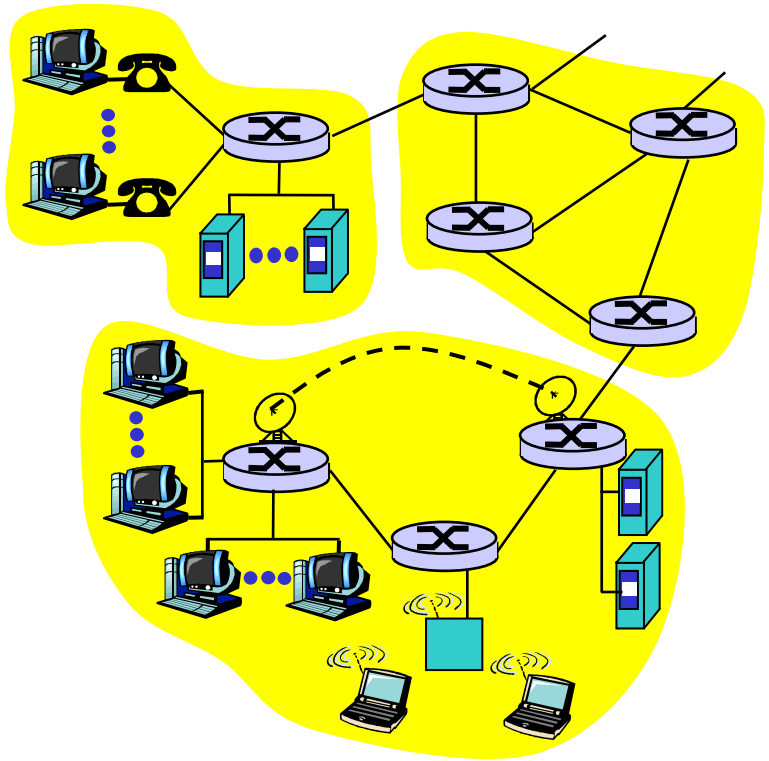


Principles of the Internet

- Edge vs. core (end-systems vs. routers)
  - Dumb network
  - Intelligence at the end-systems
- Different communication paradigms
  - Connection oriented vs. connection less
  - Packet vs. circuit switching
- Layered system
- Network of collaborating networks

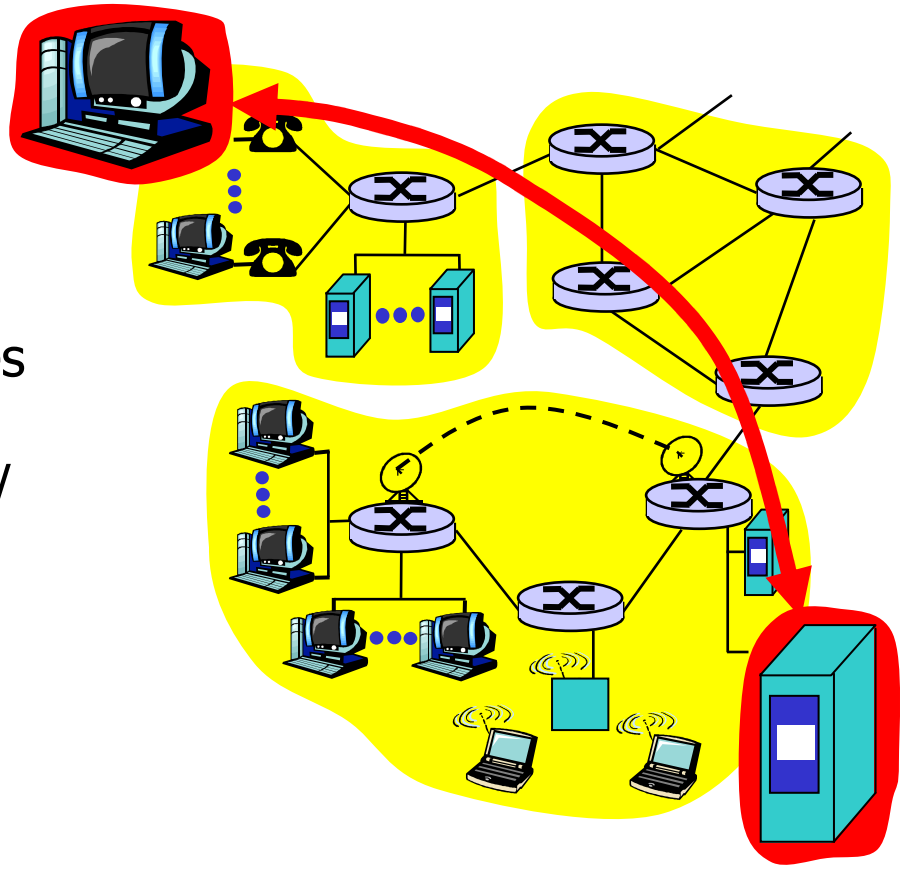
A closer look at network structure

- Network edge:
  applications and hosts
- Network core:
  - Routers
  - Network of networks
- Access networks, physical media:
  Communication links



The network edge

- End systems (hosts):
  - Run application programs
  - E.g., WWW, email
  - At "edge of network"
- Client/server model
  - Client host requests, receives service from server
  - E.g., WWW client (browser)/ server; email client/server
- Peer-2-peer model:
  - Host interaction symmetric
  - E.g.: File sharing



Network edge: Connection-oriented service

Goal: data transfer between end systems

- *Handshake:* setup (prepare for) data transfer ahead of time
  - Hello, hello back human protocol
  - *Set up "state"* in two communicating hosts
- TCP – Transmission Control Protocol
  - Internet's connection-oriented service

TCP service [RFC 793]

- *Reliable, in-order* byte-stream data transfer
  - Loss: acknowledgements and retransmissions
- *Flow control:*
  - Sender won't overwhelm receiver
- *Congestion control:*
  - Senders "slow down sending rate" when network congested

Network edge: Connectionless service

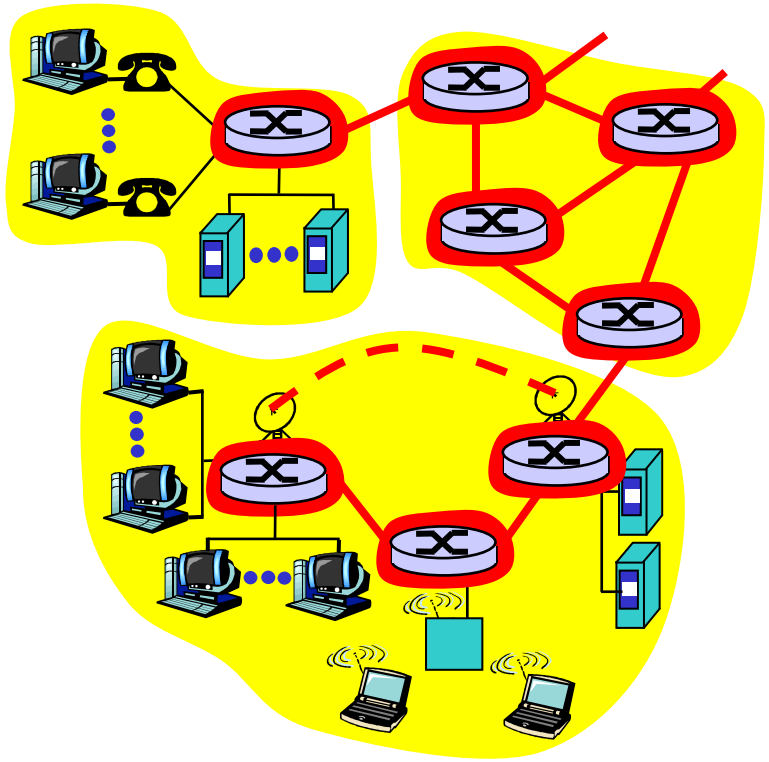
Goal: Data transfer between end systems

- Same as before!

- UDP – User Datagram Protocol [RFC 768]: Internet's connectionless service
  - Unreliable data transfer
  - No flow control
  - No congestion control

The network core

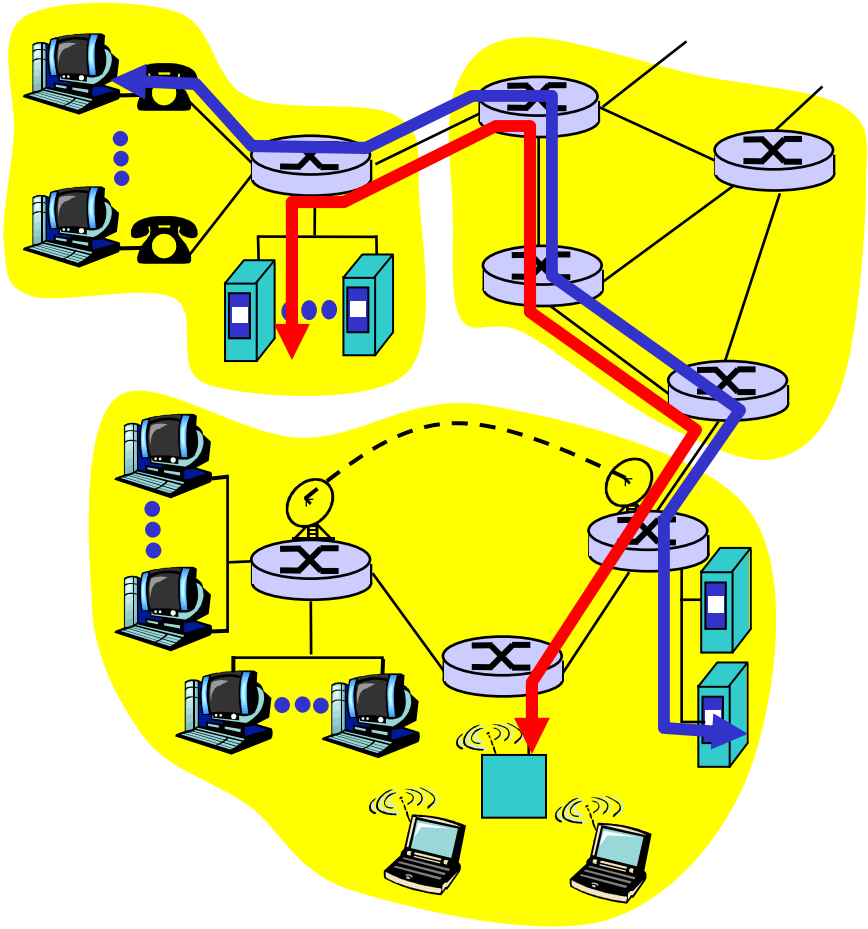
- Mesh of interconnected routers
- *The* fundamental question: How is data transferred through net?
  - Circuit switching: Dedicated circuit per call: telephone net
  - Packet switching: Data sent through net in discrete "chunks"



Network core: Circuit switching

End-end resources reserved for "call"

- Link bandwidth, switch capacity
- Dedicated resources: no sharing
- Circuit-like (guaranteed) performance
- Call setup required

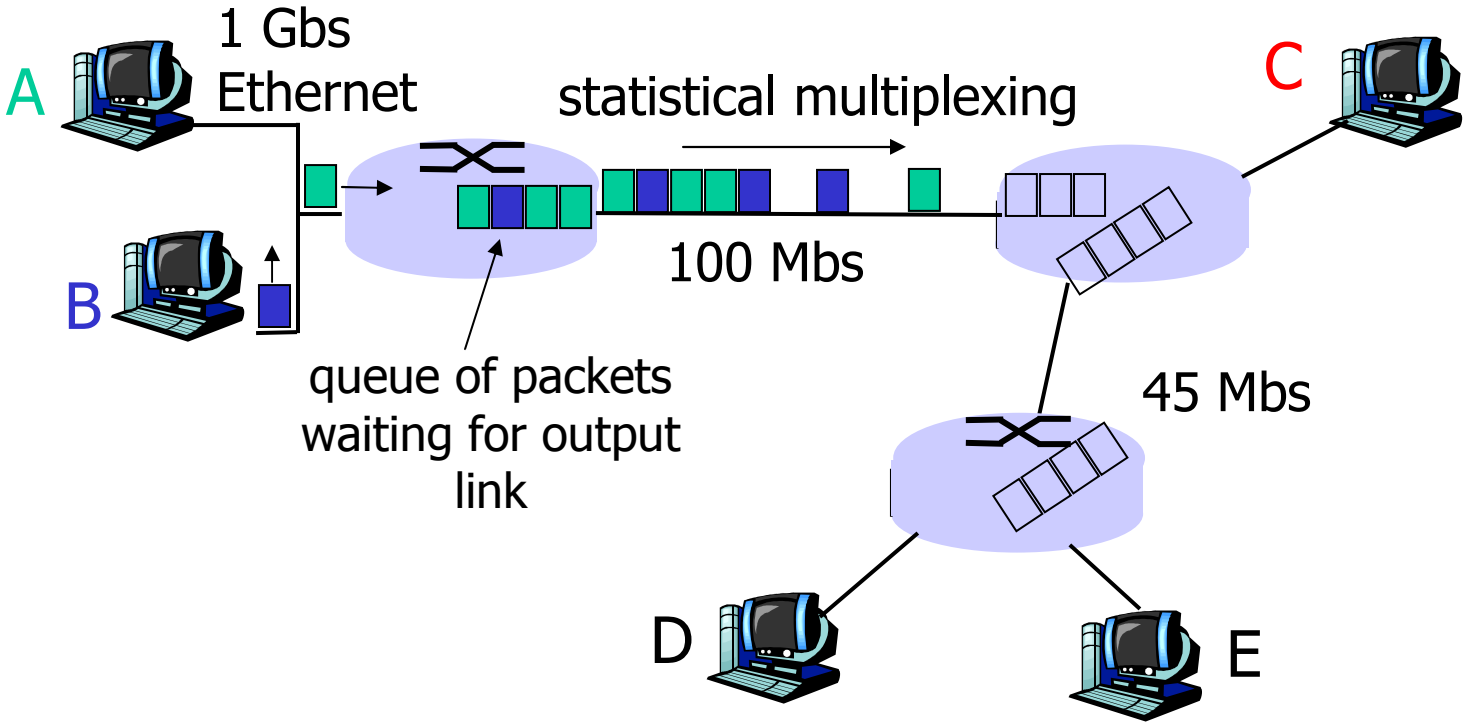


Network core: Packet switching

Each end-end data stream divided into *packets*

- Users' A, B packets *share* network resources
- Each packet uses full link bandwidth
- Resources used *as needed*

Network core: Packet switching



Packet-switching versus circuit switching:
Human restaurant analogy

Network core: Packet switching

Resource contention:

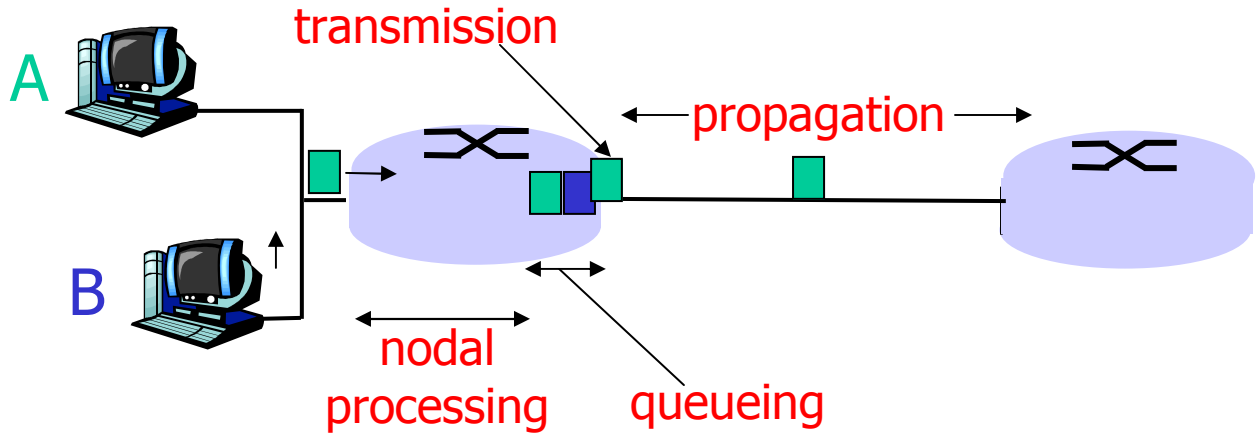
- Aggregate resource demand can exceed amount available
- Congestion: Packets queue, wait for link use
- Store and forward:
  Packets move one hop at a time
  - Transmit over link
  - Wait turn at next link

Delay in packet-switched networks

Packets experience delay on end-to-end path

- Four sources of delay at each hop

- Nodal processing
  - Check bit errors
  - Determine output link
- Queueing
  - Time waiting at output link for transmission
  - Depends on congestion level at router



Delay in packet-switched networks

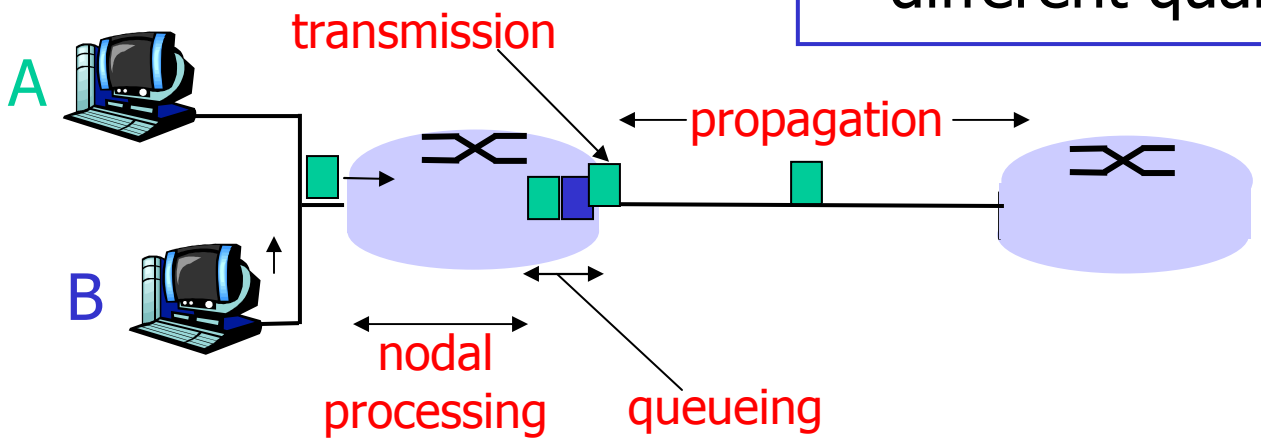
Transmission delay:

- R = link bandwidth (bps)
- L = packet length (bits)
- Time to send bits into link = L/R

Propagation delay:

- d = length of physical link
- s = propagation speed in medium (~$2x10^8$ m/sec)
- Propagation delay = d/s

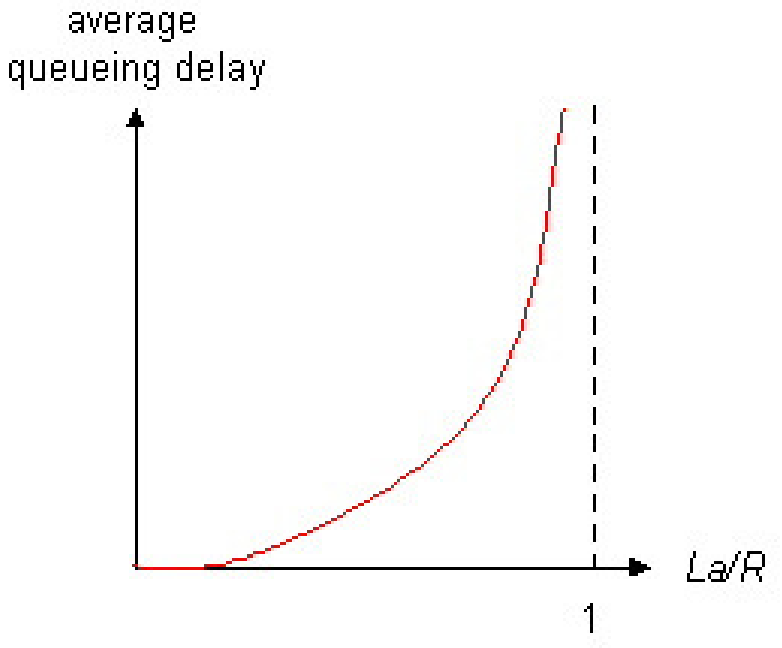
Note: s and R are *very* different quantities!



Queueing delay

- R = link bandwidth (bps)
- L = packet length (bits)
- A = average packet arrival rate

Traffic intensity = La/R



- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more "work" arriving than can be serviced
  => average delay infinite!

Packet switching vs. circuit switching

Is packet switching a "slam dunk winner?"

- Great for bursty data
  - Resource sharing
  - No call setup
- Excessive congestion: Packet delay and loss
  - Protocols needed for reliable data transfer, congestion control
- Key question: How to provide circuit-like behavior?
  - Bandwidth guarantees needed for audio/video apps

Packet-switched networks: Routing

- *Goal:* Move packets among routers from source to destination
- Datagram network:
  - *Destination address* determines next hop
  - Routes may change during session
  - Analogy: Drive towards dst. and ask for directions
- Virtual circuit network:
  - Fixed path determined at *call setup time*, remains fixed through call
  - Each packet carries tag (virtual circuit ID); Tag determines next hop
  - Routers maintain per-call state
  - Analogy: Fixed driving instructions

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!

- 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 in our discussion of networks?

Why layering?

Dealing with complex systems:

- Explicit structure allows identification, relationship of complex system's pieces
  - Layered reference model for discussion
- Modularization eases maintenance, updating of system
  - Change of implementation of layer's service transparent to rest of system
  - E.g., change in gate procedure does not affect rest of system
- Layering considered harmful?

Protocol "Layers"

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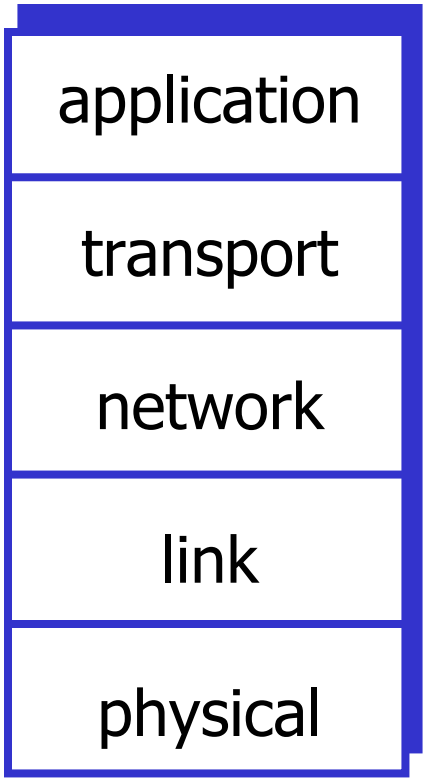
- Can layering be considered harmful?

Internet protocol stack

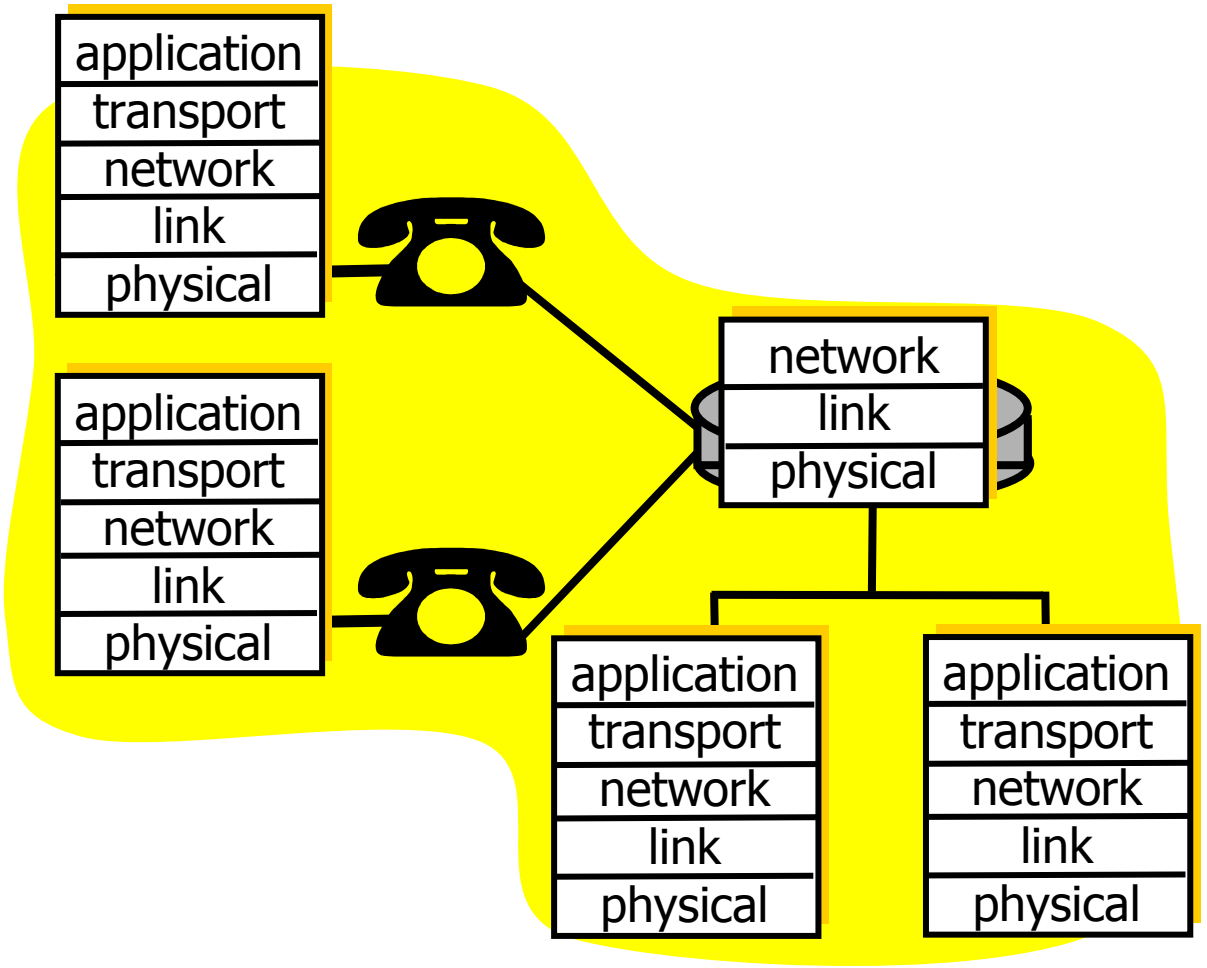
- Application: Supporting network applications
- Transport: Host-host data transfer
- Network: Uniform format of packets, routing of datagrams from source to destination
- Link: Data transfer between neighboring network elements
- Physical: Bits "on the wire"



Layering: *Logical* communication

Each layer:

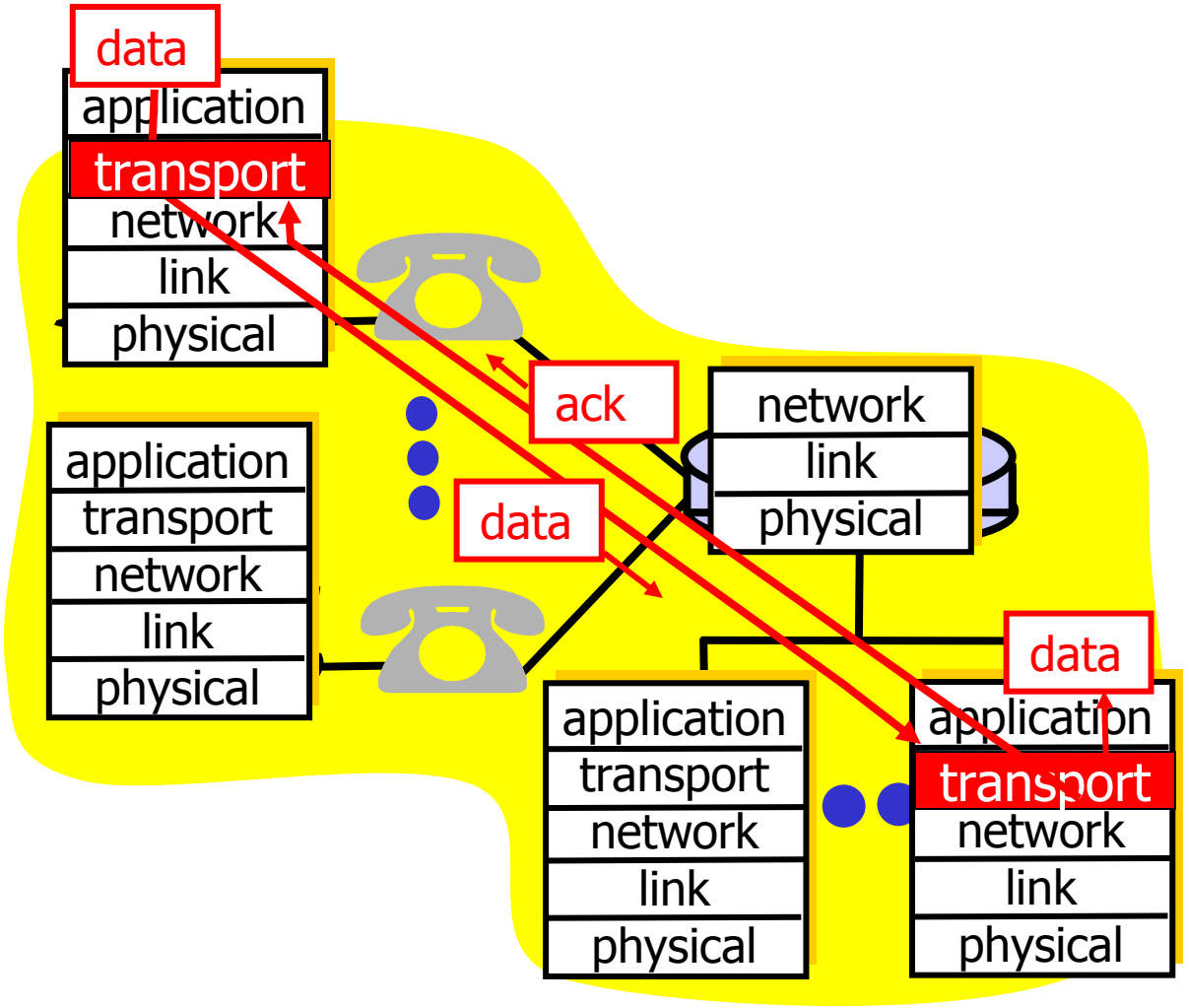
- Distributed
- "Entities" implement layer functions at each node
- Entities perform actions, exchange messages with peers



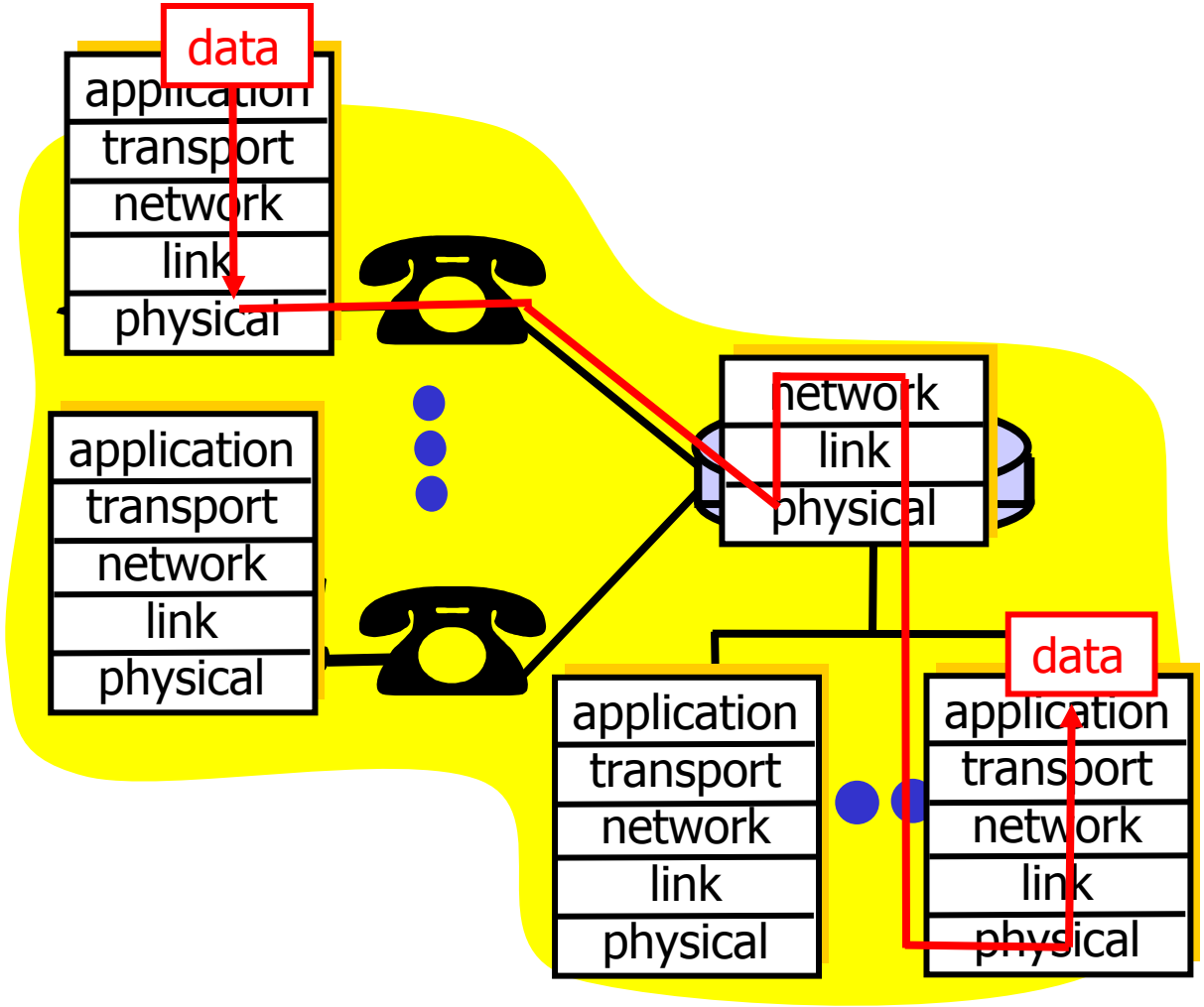
Layering: *Logical* communication

E.g., transport

- Take data from application
- Add addressing, reliability check info to form "datagram"
- Send datagram to peer
- Wait for peer to ack receipt
- Analogy: post office



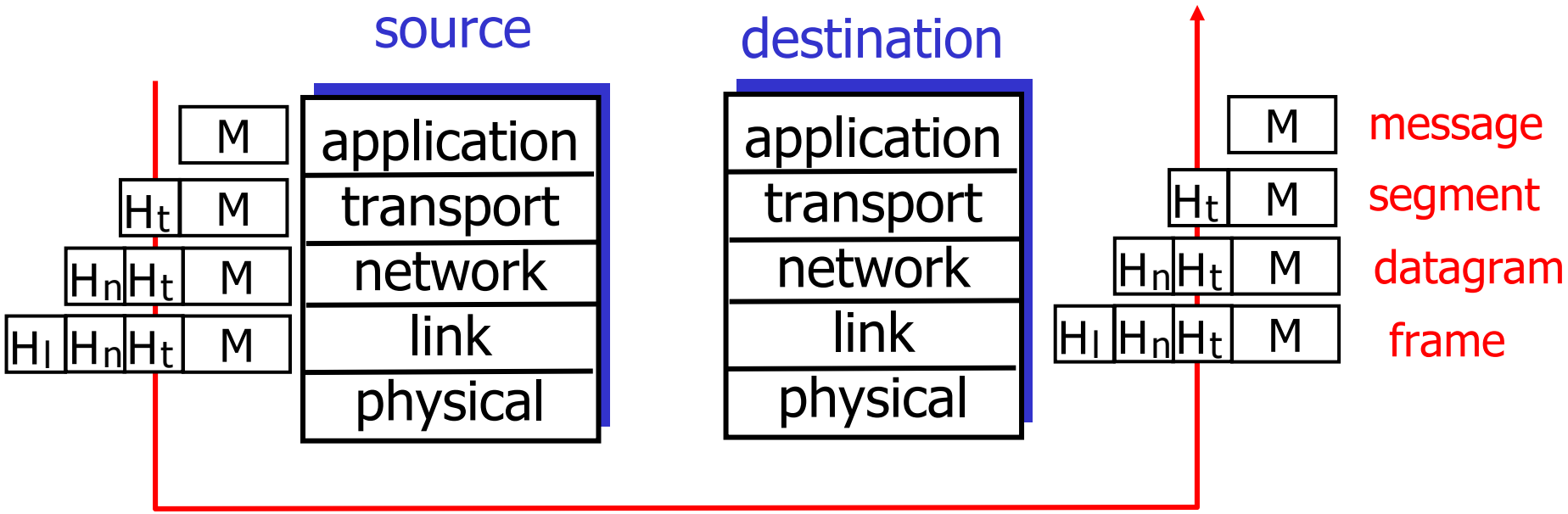
Layering: *Physical* communication



Protocol layering and data

Each layer takes data from above

- Adds header information to create new data unit
- Passes new data unit to layer below



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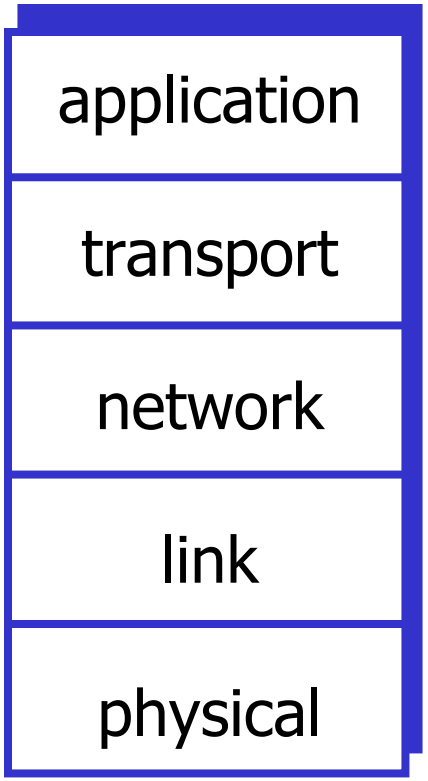


What makes the Internet so sexy

- Applications can be deployed by anybody that is connected to the Internet
  (Fundamentally different to the Telephone world)
- Multi-service network:
  Everything over the Internet
  - Every application protocol over IP
  - IP over any network technology

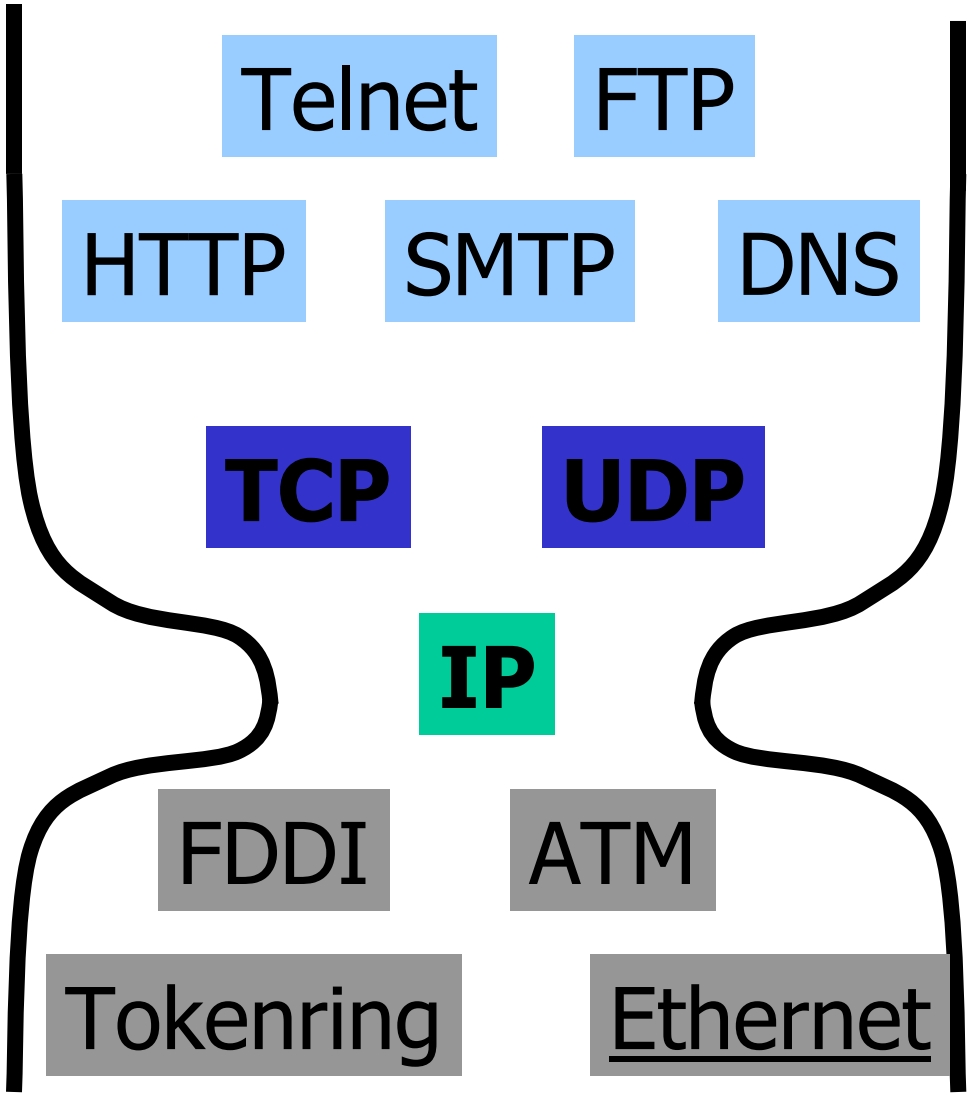
TCP/IP Protocol structure

Application
(Processes)

Transport
(Hosts)

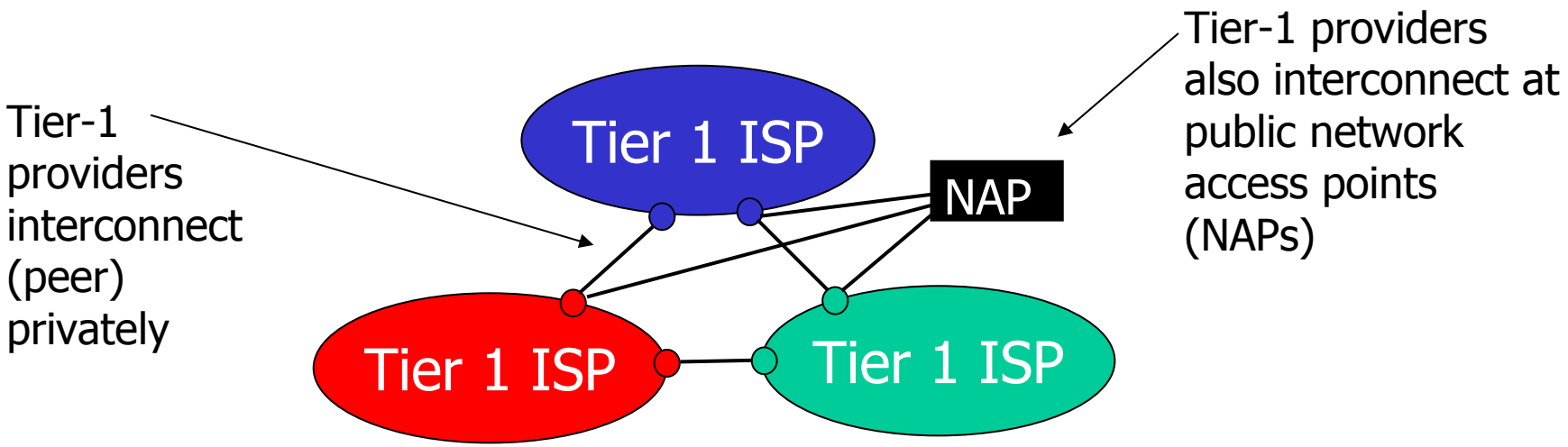
Network

Link



Internet structure: Network of networks

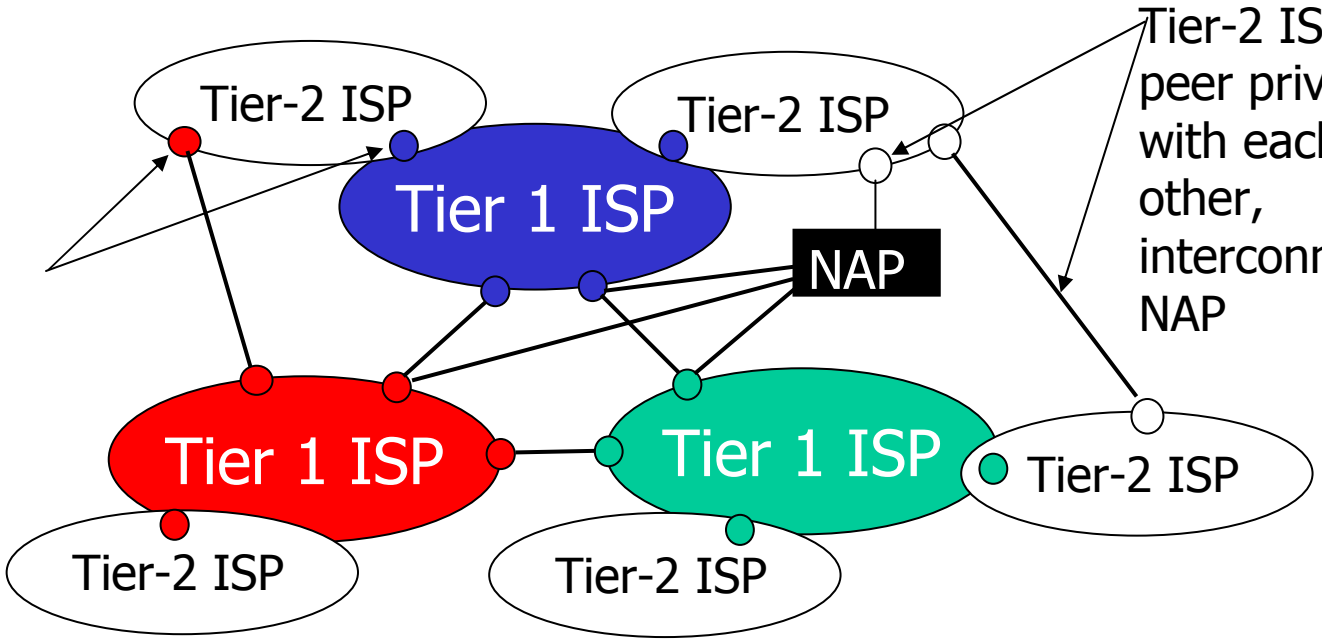
- Roughly hierarchical
- At center: "tier-1" ISPs (e.g., UUNet, BBN/Genuity, Sprint, AT&T), national/international coverage
  - Treat each other as equals



Internet structure: Network of networks

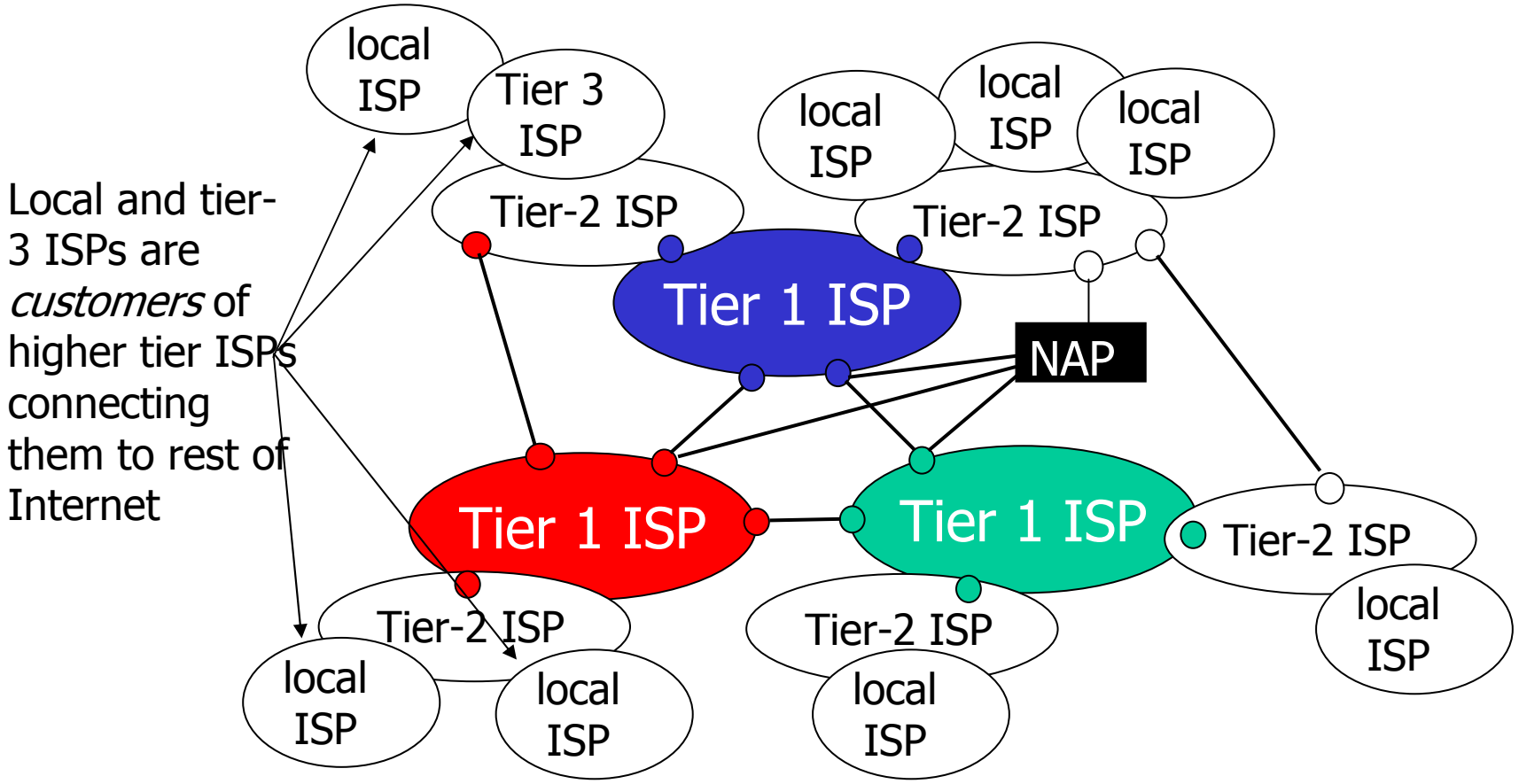
- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

•Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet
• tier-2 ISP is c*ustomer* of tier-1 provider

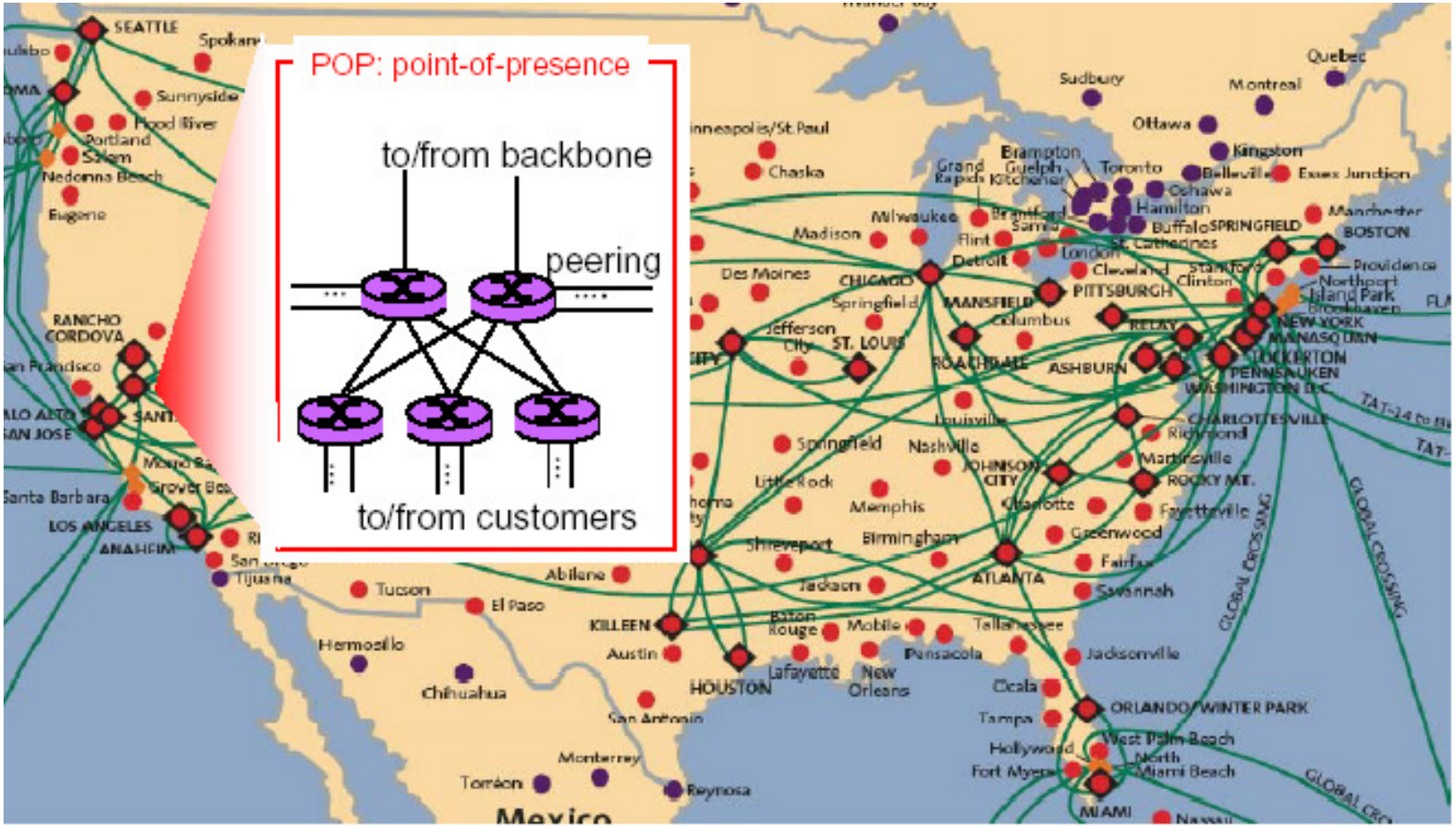


Internet structure: Network of networks

- "Tier-3" ISPs and local ISPs
  - Last hop ("access") network (closest to end systems)

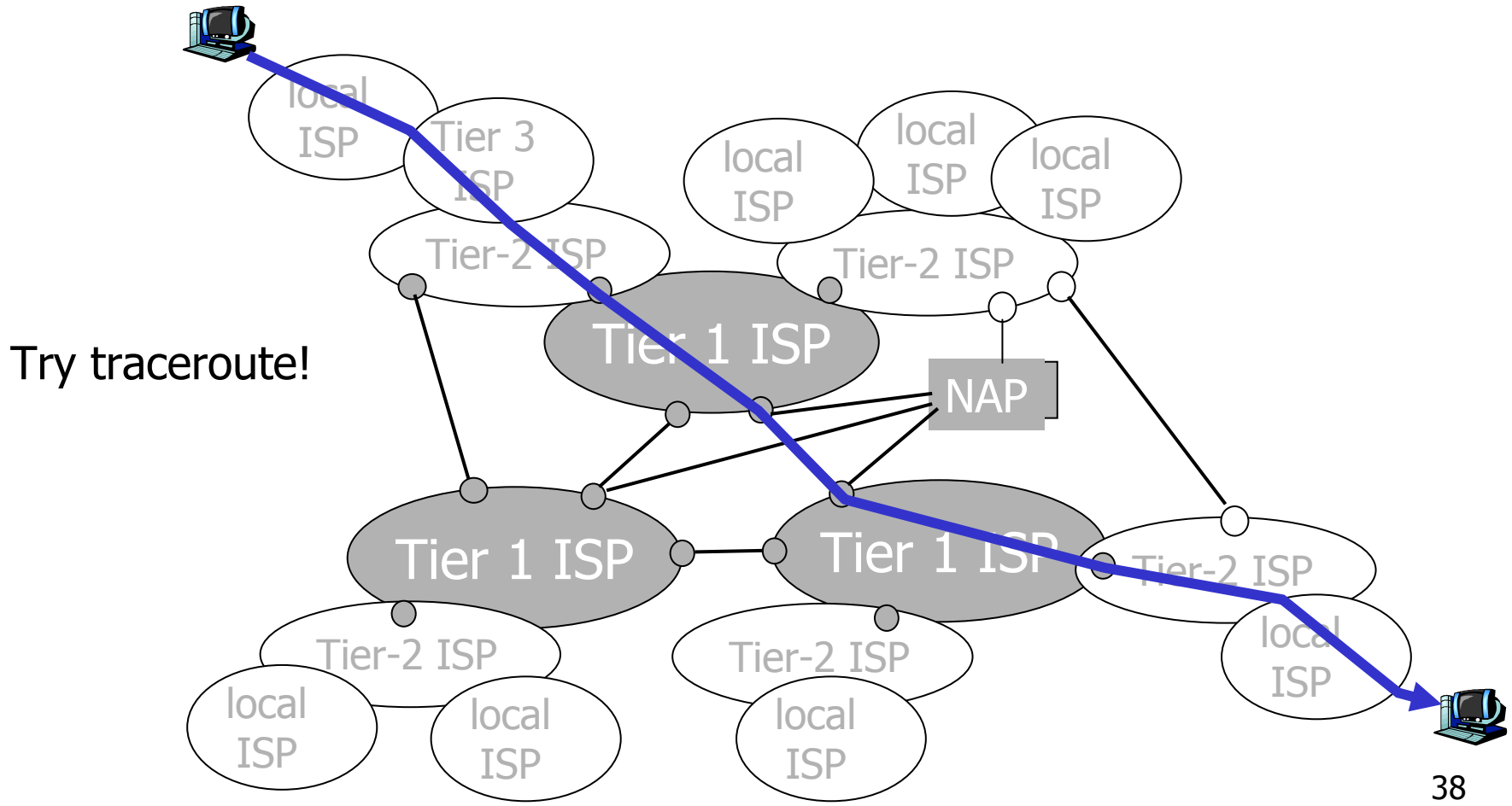


Example Tier-1 ISP: Sprint



Internet structure: Network of networks

- A packet passes through many networks!



Internet philosophy

- Interconnect networks
  - Accross multiple different technologies
- Requirements on these networks
  - Minimal assumption about network capabilities => some data should be transmitted from time to time

  ⇒ „Best Effort“ paradigma
- High survivability
  - Mesh
  - Intermediate nodes do not maintain per host state

  => „End-to-end“ paradigma
- Layering with simple application interface
  - Sockets

Internet design philosophy

In order of importance:

- Connect existing networks
- Survivability
- Support multiple types of service
- Must accommodate a variety of networks
- Allow distributed management
- Allow host attachment with a low level of effort
- Be cost effective
- Allow resource accountability

Internet terminology

- internet
  - Collection of packet switched networks interconnected by routers running the IP/TCP protocols
- The „Internet“
  - Public Internet (in contrast to Intranets)
- End system == host attached to network
- Router = gateway = intermediate system
  - Routes packets between its attached networks
- Firewall (device placed at network boundaries)
  - Restricts packet flows to improve security

Internet terminology (2.)

- Name
  - Identifies an object (e.g., an end system)
- Address
  - Identifies where an object is located (here IP address)
- Name to address translation (and vice versa)
  - Links names and addresses
    - mail.zrz.TU-Berlin.DE ⇔ 130.149.4.15
- Interface
  - Network attachment (≥ 1 interfaces = multihomed)
- Route
  - How to get to an objects location
- Network prefix
  - Set of addresses