Part 1: Introduction

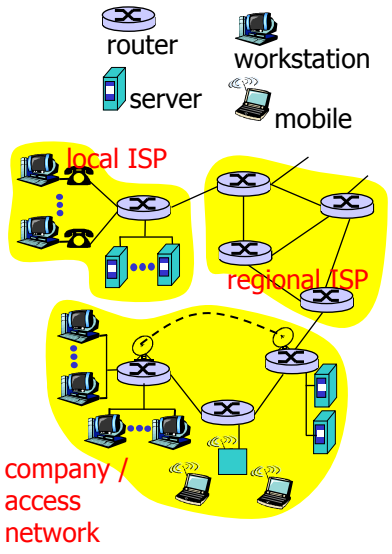
Goal:

- 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

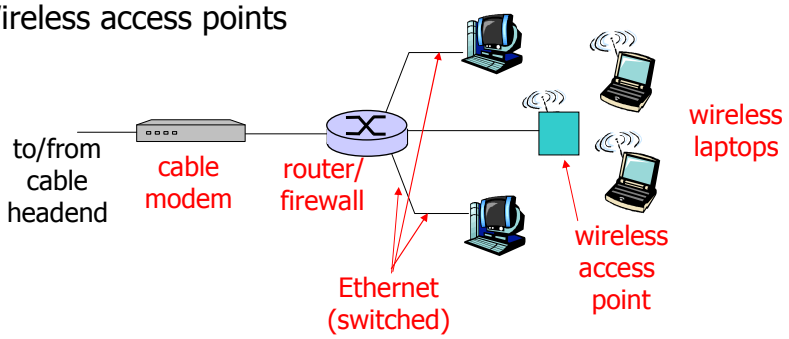
  running *network apps*
- *Communication links*
  - Fiber, copper, radio, satellite
- *Routers:* forward packets (chunks) of data through network



Example access net: Home network

Typical home network components:

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



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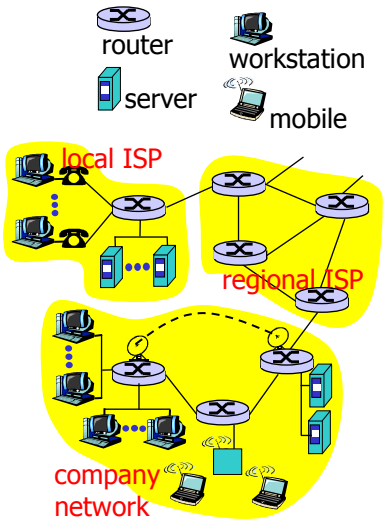
What's the Internet: "Nuts and bolts" view

- *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



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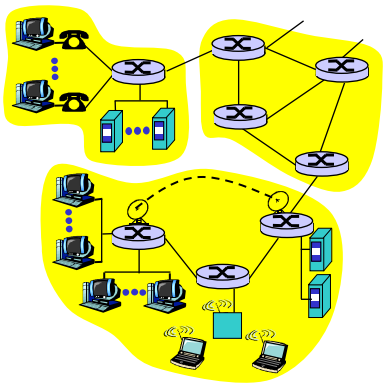
What's the Internet: A service view

- 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, …."



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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

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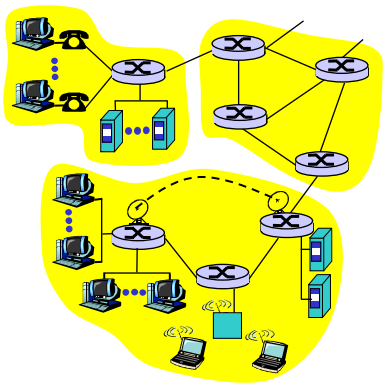
A closer look at network structure

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



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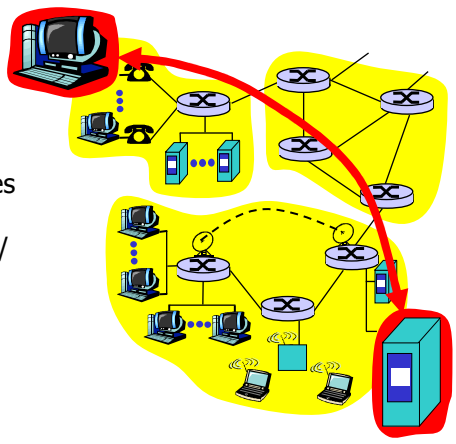
The network edge

- 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



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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

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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

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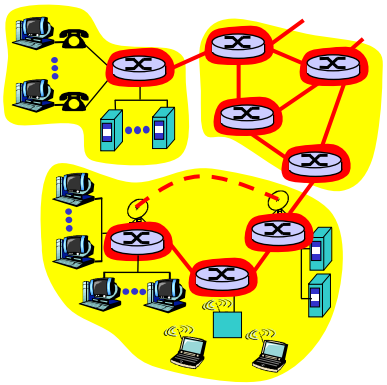
The network core

- 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"



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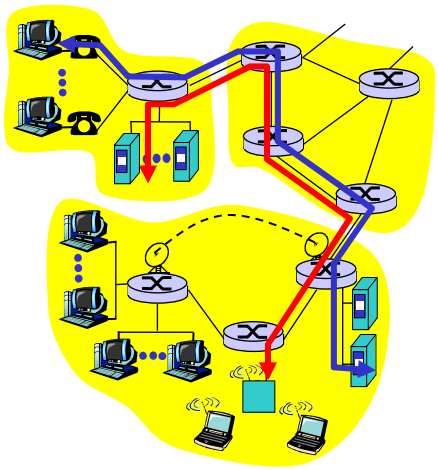
Network core: Circuit switching

End-end resources reserved for "call"

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



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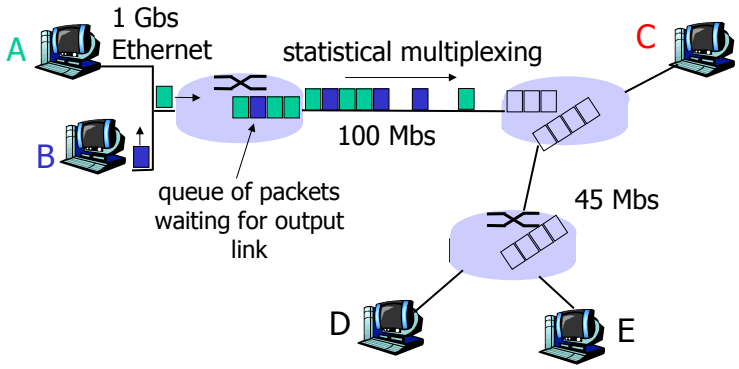
Network core: Packet switching

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

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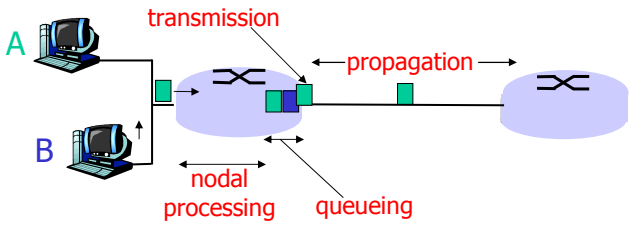
Delay in packet-switched networks

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



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Delay in packet-switched networks

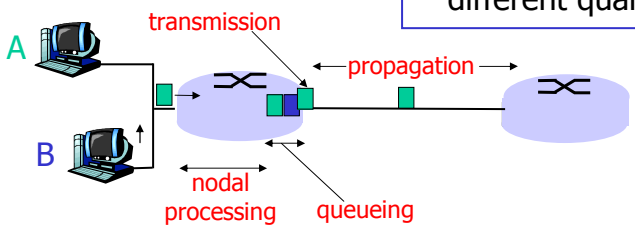
Transmission delay:

- 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

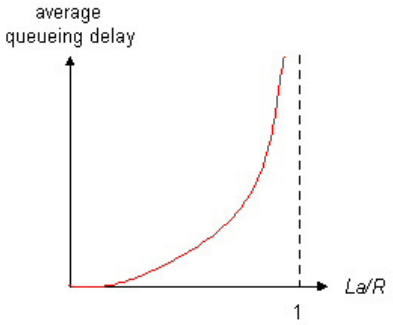
Note: s and R are *very* different quantities!



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

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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

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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

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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?

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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?

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- Can layering be considered harmful?

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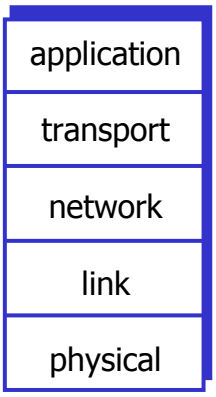
Internet protocol stack

- 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"



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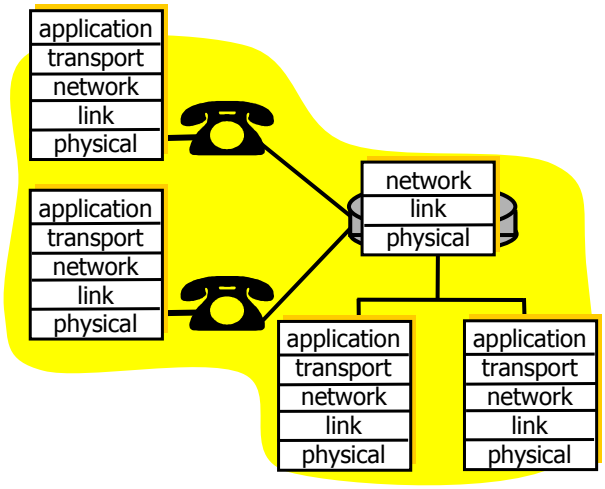
Layering: *Logical* communication

Each layer:

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



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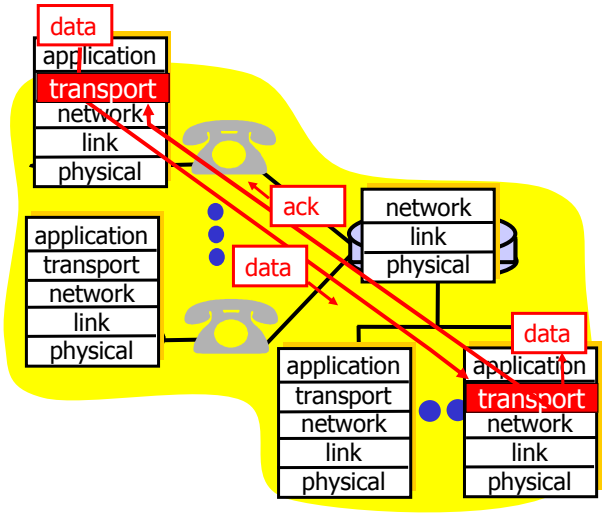
Layering: *Logical* communication

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



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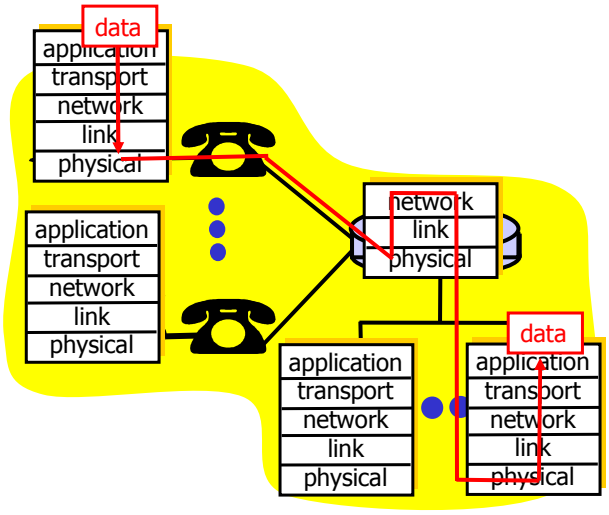
Layering: *Physical* communication



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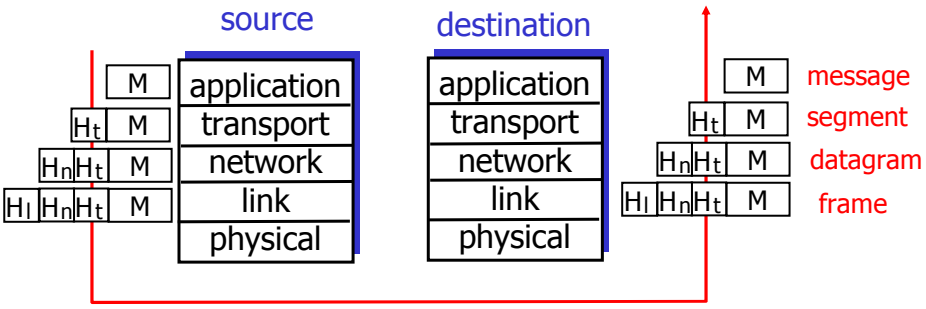
Protocol layering and data

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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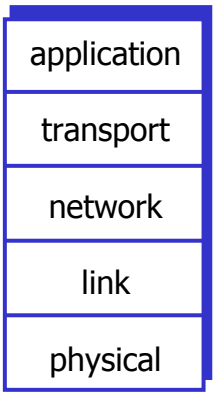

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What makes the Internet so sexy

- 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

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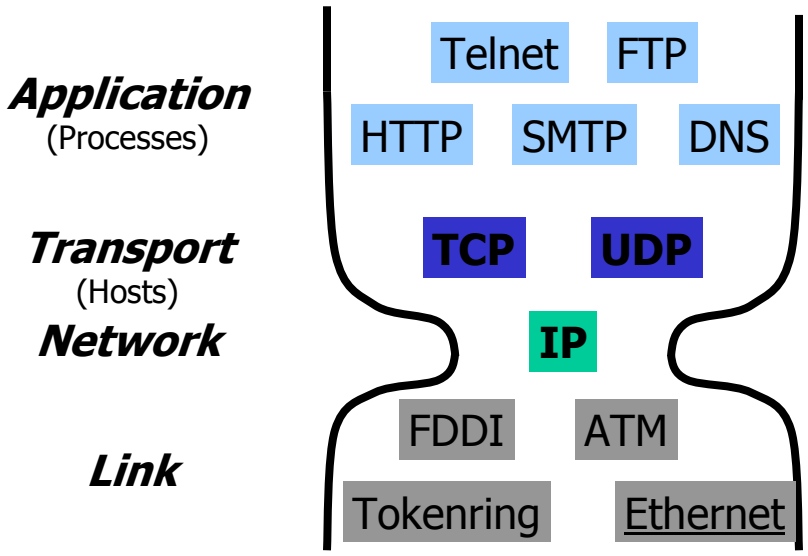
TCP/IP Protocol structure



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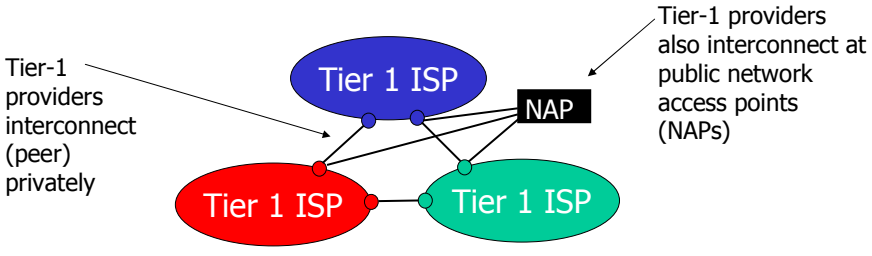
Internet structure: Network of networks

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



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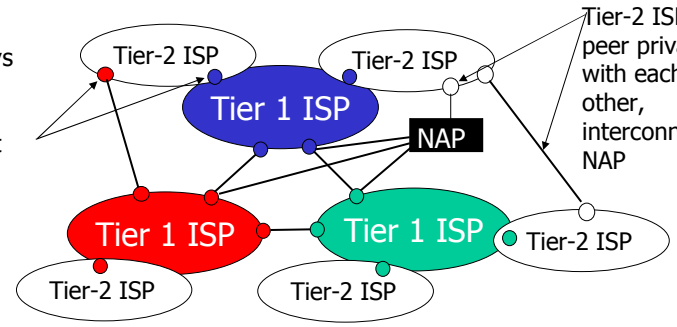
Internet structure: Network of networks

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

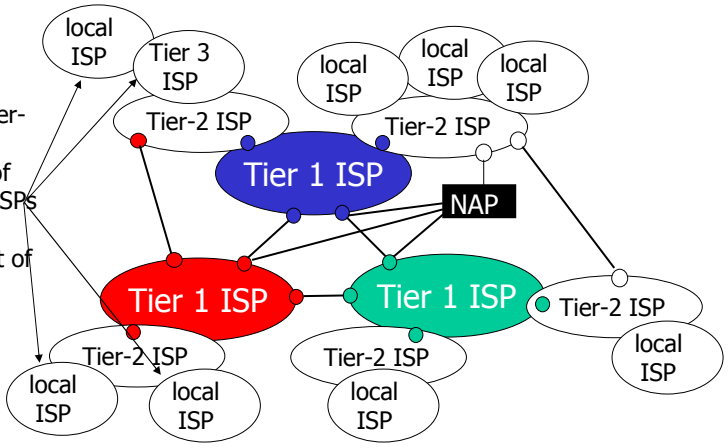
•Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet
• tier-2 ISP is c*ustomer* of tier-1 provider



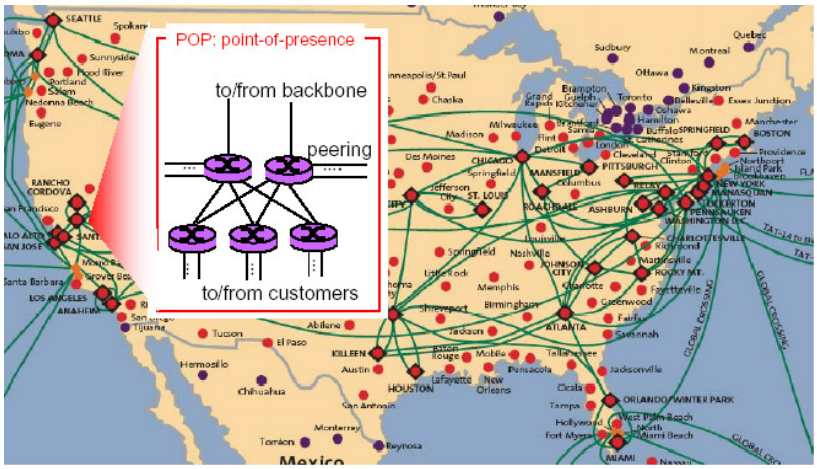
Internet structure: Network of networks

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

Local and tier-3 ISPs are *customers* of higher tier ISPs connecting them to rest of Internet



Example Tier-1 ISP: Sprint



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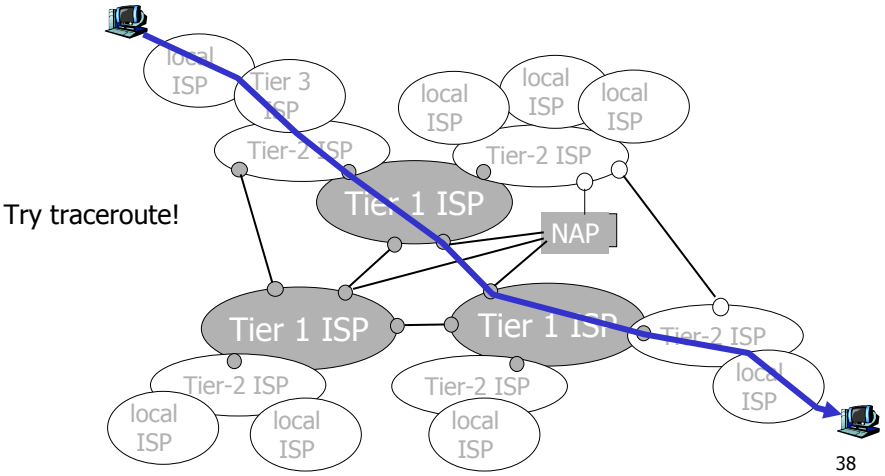
Internet structure: Network of networks

- A packet passes through many networks!



Try traceroute!

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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

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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

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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

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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

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