CS 455/555 / Spring 2013
Intro to Networks and Communications

Whirlwind Introduction to the Internet (part 1)

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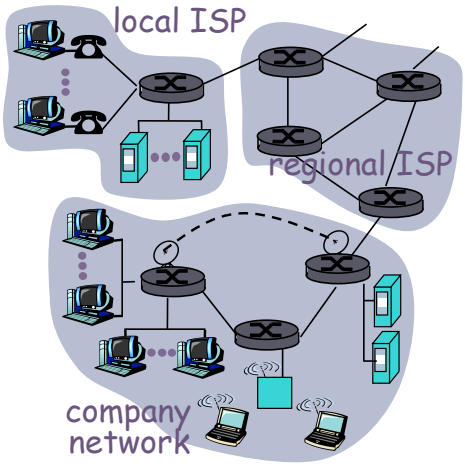
A Whirlwind Introduction to the Internet
Overview

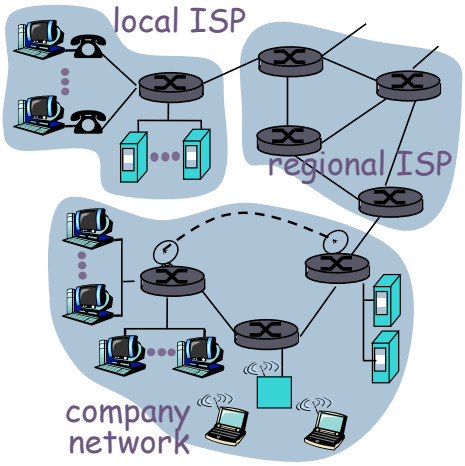
- What's the Internet (KR 1.1)
- Network Edge (KR 1.2)
- Network Core (KR 1.3)
- Performance: Loss and Delay (KR 1.4)
- Protocol Layering (KR 1.5)
- Networks Under Attack (KR 1.6)
- History (KR 1.7)

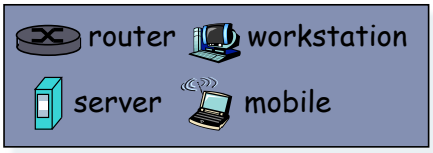


Just What is the Internet?

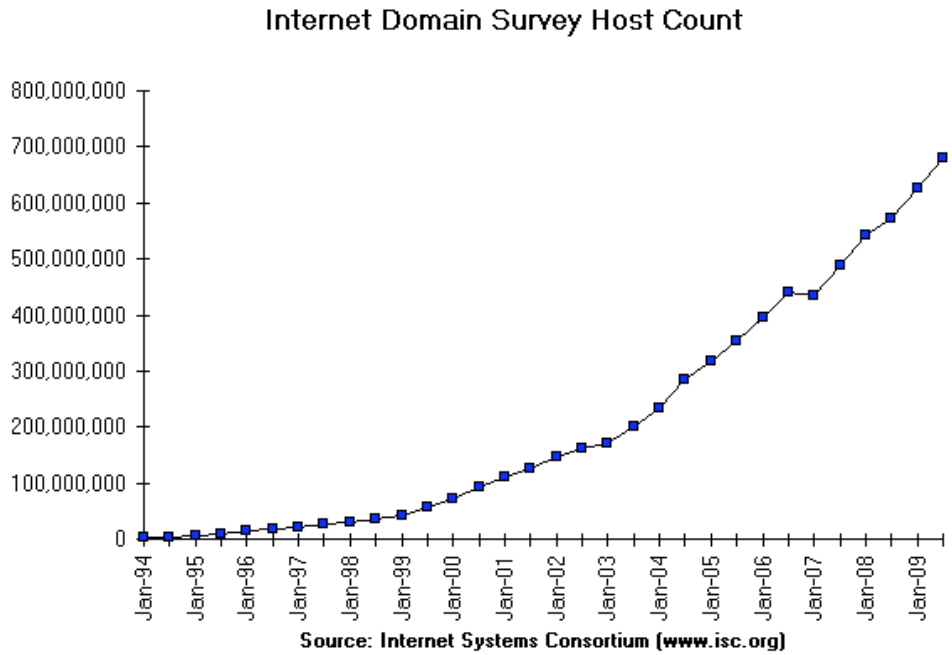
The "nuts and bolts" view

- Millions of connected computing devices
  - hosts = end-systems
  - running network apps
- Communication links (KR 1.2)
  - Different media (fiber, copper wire, radio, satellite)
  - Different transmission rates – bits per second (bps)
    - 10^3 (Kbps) to 10^6 (Mbps) to 10^9 (Gbps)
- Routers (KR 1.3)
  - forward packets of data though the network



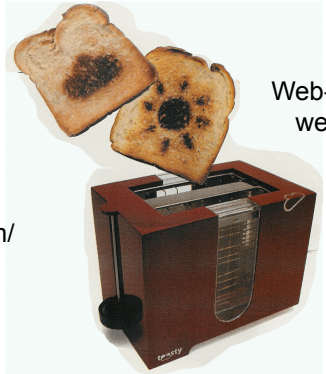


Growth of the Internet



"Cool" 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

Aside

Typical Networking Units

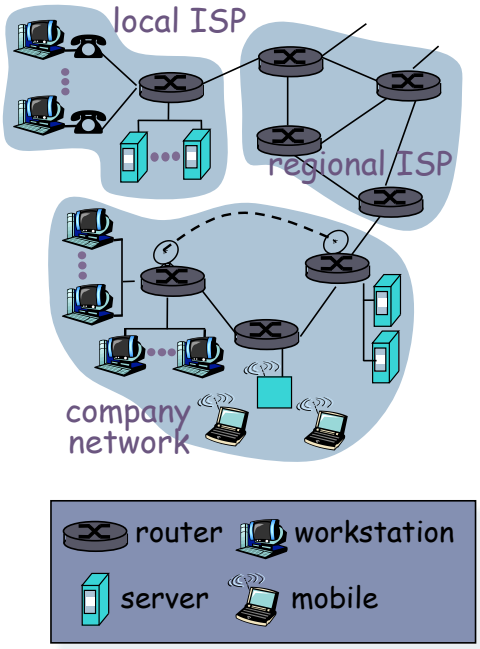
- Speed
  - bits per second (bps)
  - Kilo (K) = 10^3 = 1,000
  - Mega (M) = 10^6 = 1,000,000
  - Giga (G) = 10^9 = 1,000,000,000
- Capacity / Size
  - bytes (B)
  - Kilo (K) = 2^{10} = 1,024
  - Mega (M) = 2^{20} = 1,048,576
  - Giga (G) = 2^{30} = 1,073,741,824
- Time
  - seconds (s)
  - milli (m) = 10^{-3} = 0.001
  - micro (μ) = 10^{-6} = 0.000001

Remember:
8 bits to 1 byte
(8b = 1B)

Just What is the Internet?

The "nuts and bolts" view

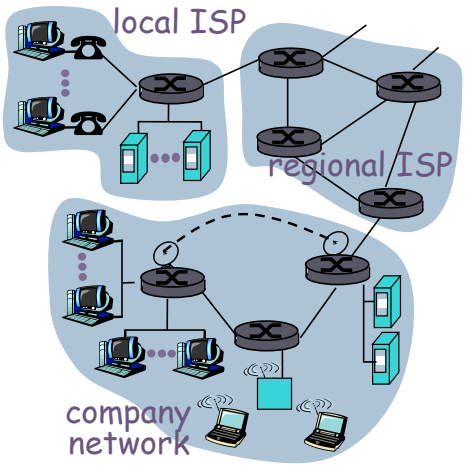
- Protocols: control sending, receiving of messages
  - E.g., TCP, IP, HTTP, SMTP, ….
- Internet: "network of networks"
  - Loosely hierarchical
  - Public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



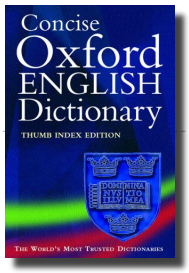
Just What is the Internet?

The "services" view

- A communication infrastructure enabling distributed applications:
  - web, email, VoIP, games, e-commerce, file-sharing, voting, ...
- Communication services provided to apps:
  - reliable data delivery from source to destination
  - "best effort" (unreliable) data delivery



The Nuts & Bolts View
What is a protocol?



Main Entry: pro-to-col

1: An original draft, minute, or record of a document or transaction

2a: A preliminary memorandum often formulated and signed by diplomatic negotiators as a basis for a final convention or treaty

b: The records or minutes of a diplomatic conference or congress that show officially the agreements arrived at by the negotiators

3a: A code prescribing strict adherence to correct etiquette and precedence (as in diplomatic exchange and in the military services)

b: A set of conventions governing the treatment and especially the formatting of data in an electronic communications system

4: A detailed plan of a scientific or medical experiment, treatment, or procedure

The Nuts & Bolts View
What is a protocol?

- Human protocols:
  - "Do you have the time?"
  - "I have a question"
  - Introductions
- Both:
  - Specific messages sent
  - Specific actions taken when messages (or other events) received
- Network protocols:
  - Machines rather than humans
  - All communication activity in Internet governed by protocols

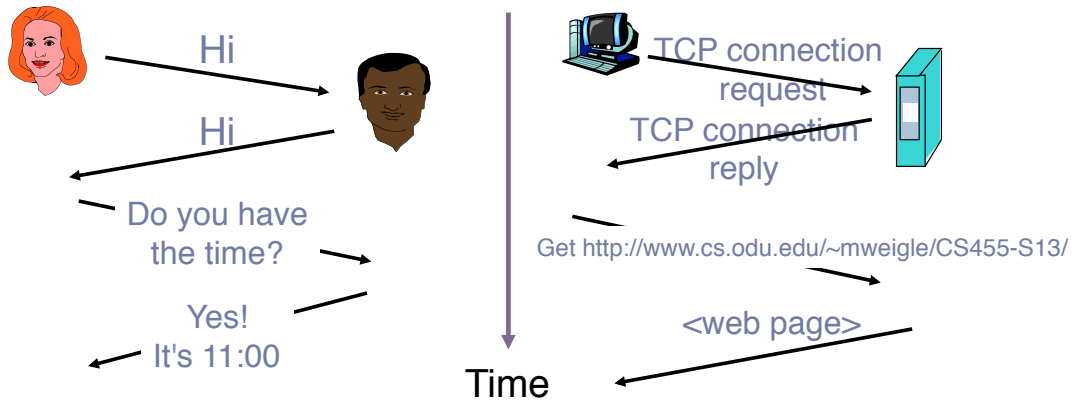
Protocols define format, order of messages sent and received among network entities, and actions taken on message transmission, receipt

What is a protocol?

A specification for a set of message exchanges

Human protocols: Get the time from a stranger

Computer protocols: Get the class time from a web server



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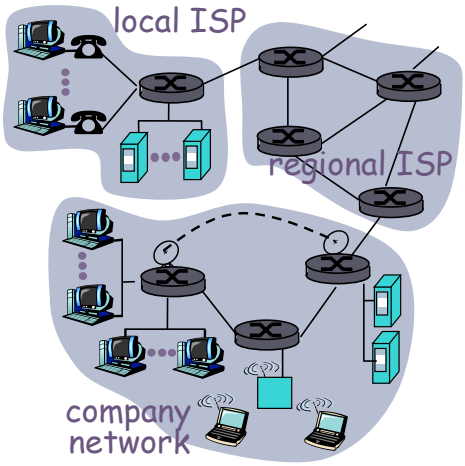
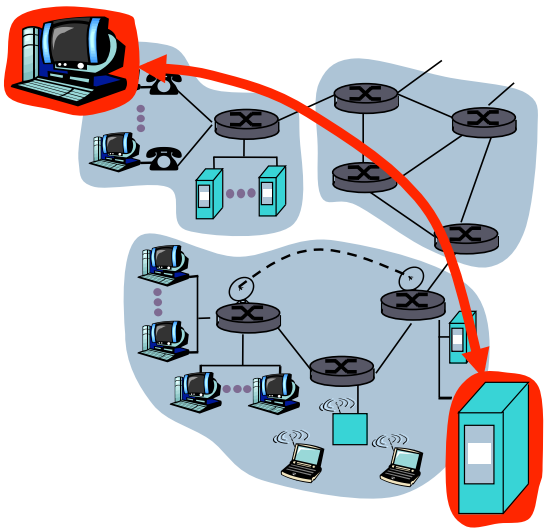


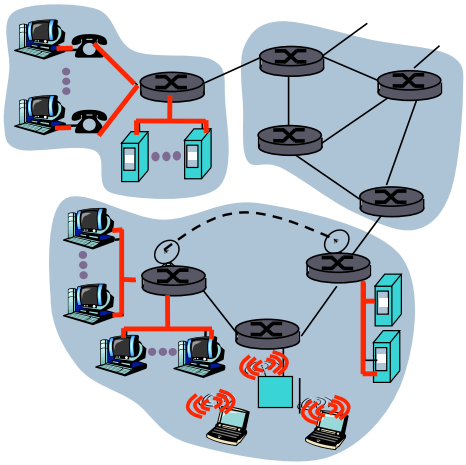
The Structure of the Internet
Network Edge and Access

- Network edge:
  - applications running on hosts
    - "host" = "end system"
- Access networks, physical media:
  - wired, wireless communication links
- Network Core:
  - interconnected routers
  - network of networks

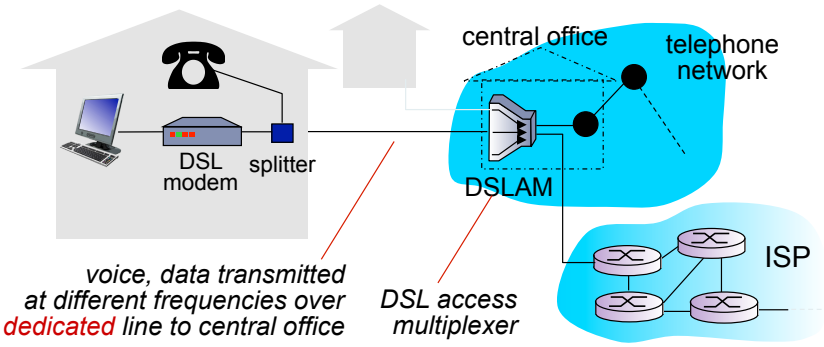


Network Structure
Access Networks

- How to connect end-systems to edge router?
  - Home access
  - Enterprise access
  - Wireless access
- Issues:
  - Transmission speed (bits per second) of access network
  - Shared or dedicated?

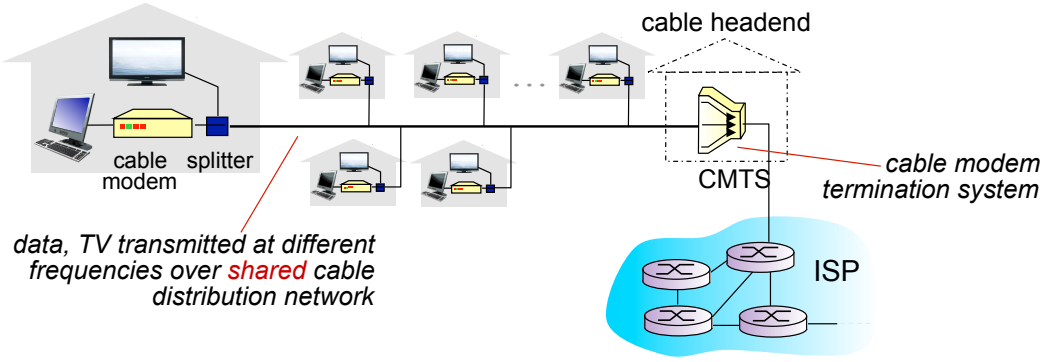


Access Networks
Digital Subscriber Line (DSL)



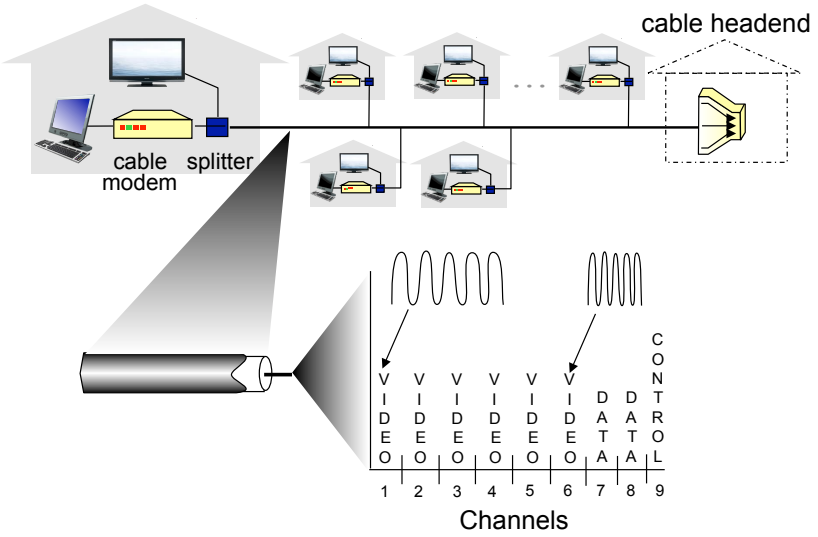
- Use existing telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access Networks
Cable



- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes share access network to cable headend
  - unlike DSL, which has dedicated access to central office

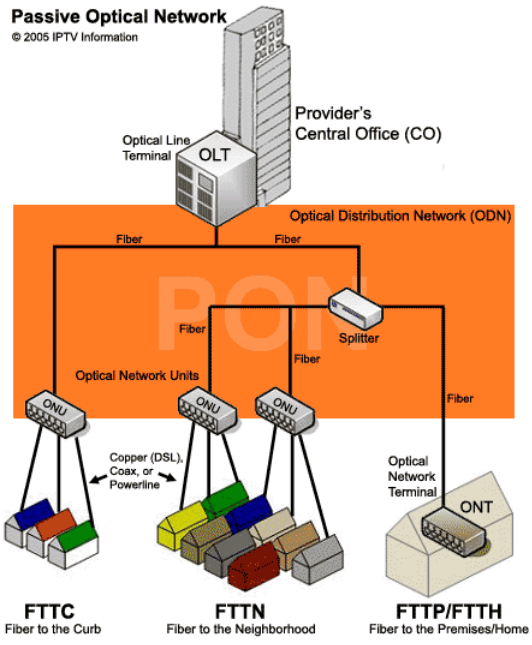
Access Networks
Cable



frequency division multiplexing: different channels transmitted in different frequency bands

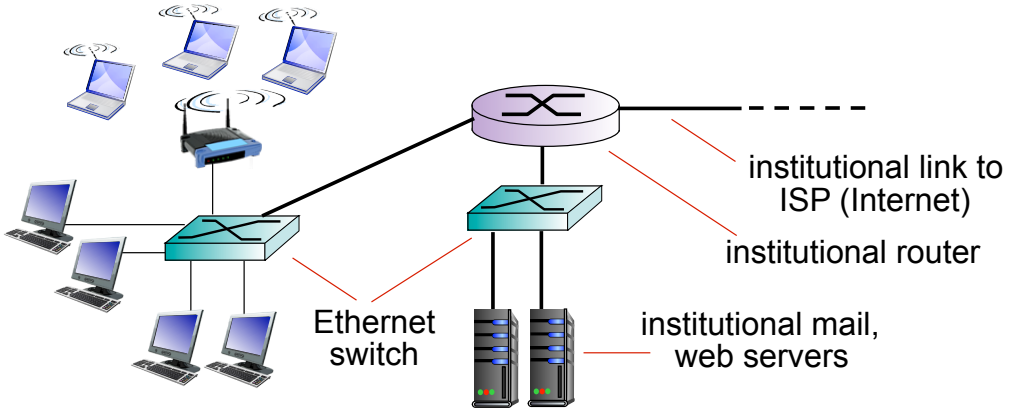
Access Networks
Fiber to the Home

- Optical links from central office to the home
- Two competing optical technologies
  - Active Optical Network (AON)
  - Passive Optical Network (PON) - Verizon FIOS
- Much higher Internet rates
  - down - 10-20 Mbps
  - up - 2-10 Mpbs
- Fiber also carries television and phone services



http://www.iptvinformation.net/content/binary/08.22.2005-PON-Network.gif

Access Networks
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

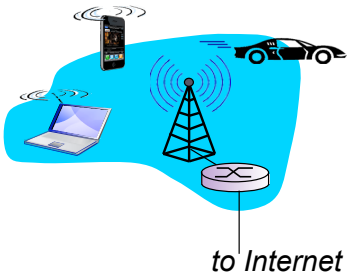
Access Networks
Comparison

Access Technology	Upstream	Downstream	Shared/ Dedicated to Router
DSL	1-2.5 Mbps	10-24 Mbps	dedicated
cable	2 Mbps	<30 Mbps	shared
fiber	2-10 Mbps	10-20 Mbps	shared
Ethernet	10 Mbps - 10 Gbps	10 Mbps - 10 Gbps	dedicated

Access Networks

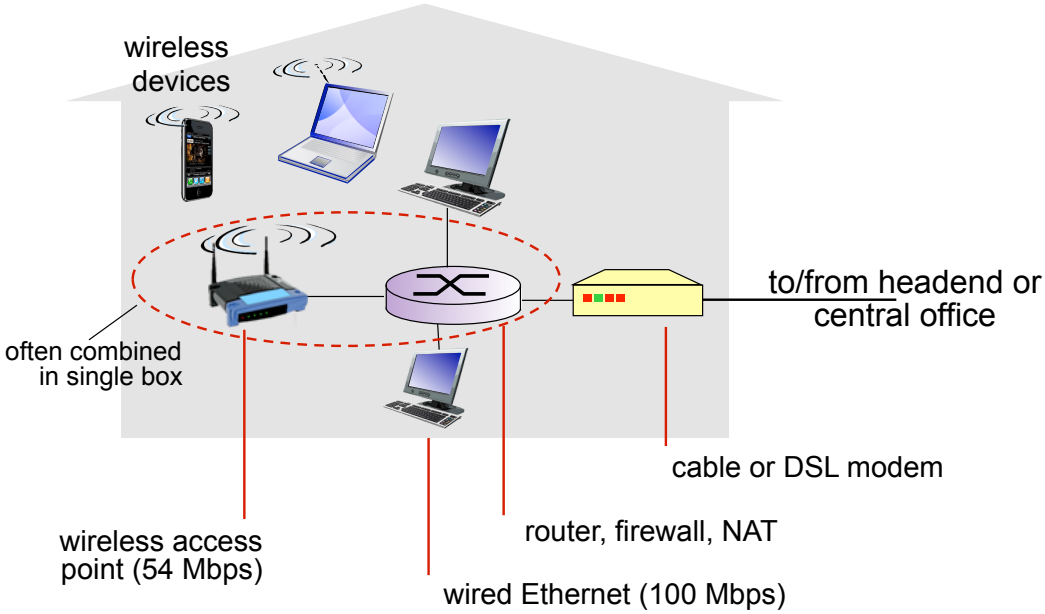
Wireless access networks

- Shared wireless access network connects end-system to router
- Wireless LANs
  - radio spectrum replaces wire
  - transmit to base station (aka access point), which is connected via wire
  - 100 feet
  - 802.11b/g (WiFi): 11 or 54 Mbps
- Wide-area wireless access
  - via cellular network
  - 10s of kms
  - 1-10 Mbps
  - 3G, 4G: LTE



Wireless Access Networks

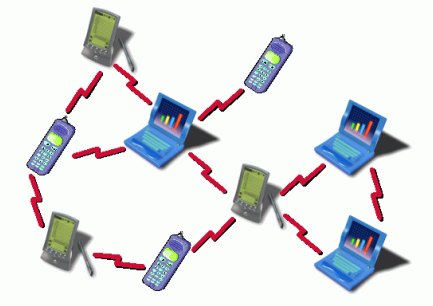
Home Networks



Wireless Networks

Other Types

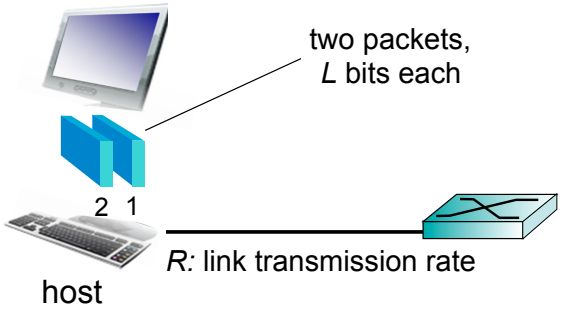
- Ad-Hoc Networks
  - no base station
  - nodes communicate directly with each other
- Mobile Ad-Hoc Networks (MANET)
  - ad-hoc network where the nodes can move
- Vehicular Ad-Hoc Networks (VANET)
  - MANET where the nodes are vehicles



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 
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6: 10 Gbps

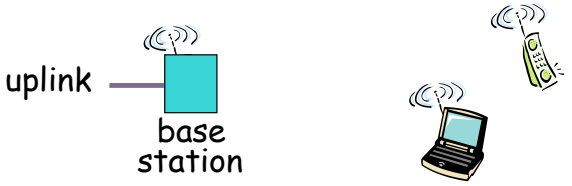
Physical Media
Coaxial and fiber optic cable

- Coaxial cable
  - Wire (signal carrier) within a wire (shield)
  - Bi-directional transmission
  - Broadband
    - multiple channels on cable
    - HFC (cable)

- Fiber optic cable
  - Glass fiber carrying light pulses
  - High-speed operation:
    - high-speed point-to-point transmission (e.g., 10s-100s Gbps)
  - Low signal attenuation – long distances
  - Low error rate
    - repeaters spaced far apart
    - immune to electomagnetic noise
  - Prevalent in the Internet backbone

Physical Media
Radio

- Signal carried in electro-magnetic spectrum
  - No physical "wire"
- Bi-directional
- Physical environment effects propagation
  - Reflection
  - Obstruction by objects
  - Interference



- Radio link types:
  - LAN (e.g., WiFi)
    - 11 Mbps, 54 Mbps
  - Wide-area (e.g., cellular)
    - 3G: ~few Mbps
  - Satellite
    - Kbps to 45Mbps
    - 270 ms end-end delay
    - Used in telephone networks, Internet backbone, and increasingly for residential access

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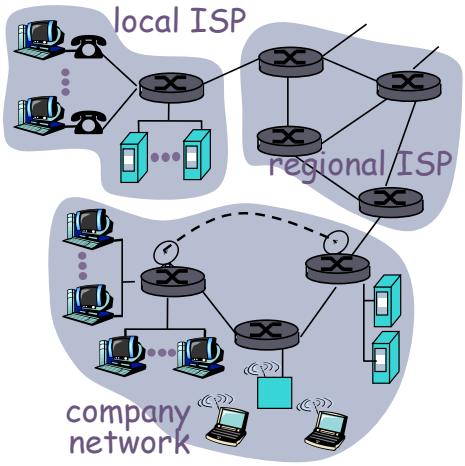
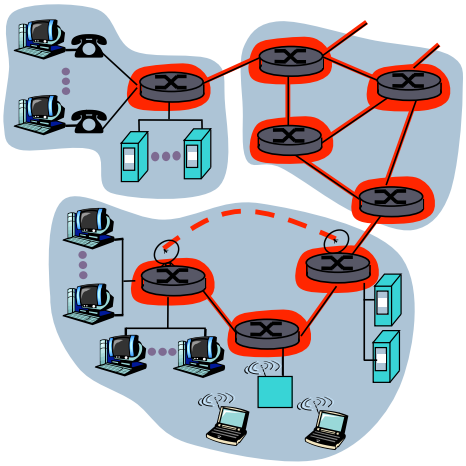


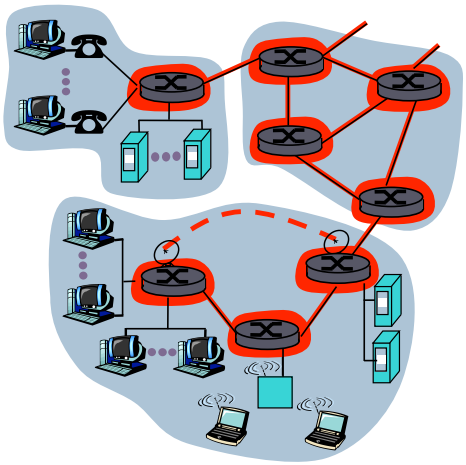
Network Structure
The network core

- A mesh of interconnected routers
- The fundamental question: How is data routed through the network?
  - Packet switching: data sent in discrete chunks (packets); each has a path chosen for it
  - Circuit switching: dedicated circuit (path) per call used by all data (e.g., telephone)

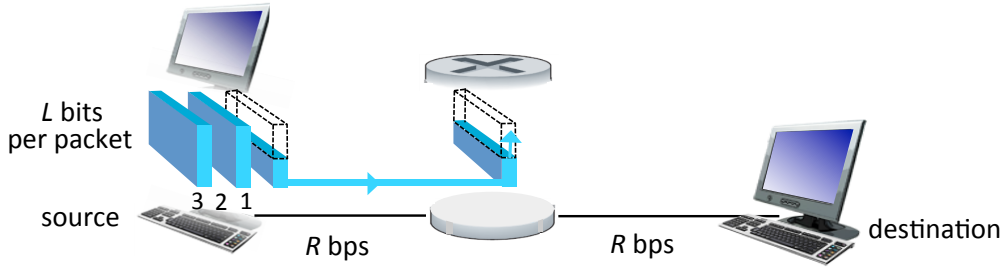


The Network Core
Packet Switching

- 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

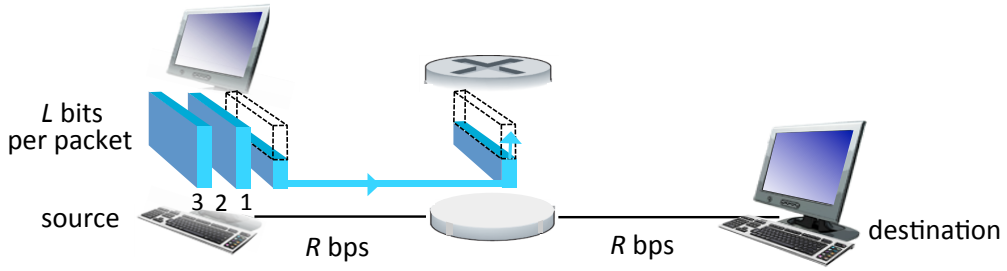


- Takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- Store and forward: entire packet must arrive at router before it can be transmitted on next link
- delay (for one packet) = $2L/R$ (assuming 0 propagation delay)

more on delay in part 2…

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

Store and Forward
Question

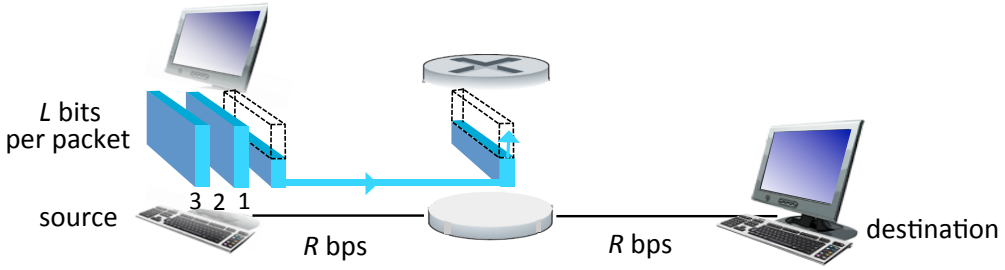


- How long until the destination receives all 3 packets?

- Reminder: L bits /R bps

Store and Forward

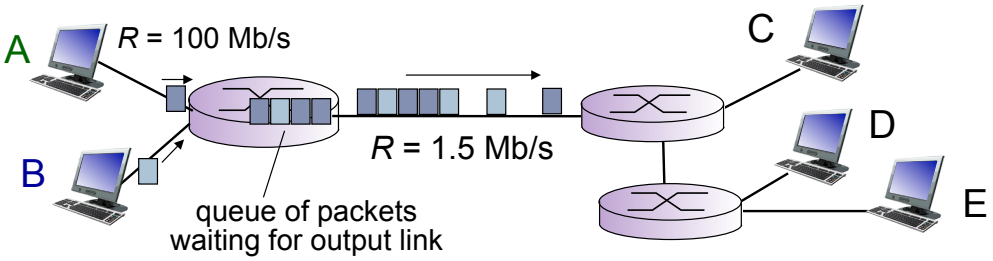
Thought Question For Next Time...



- What is the delay for P packets of length L sent over a series of N links?

Packet Switching

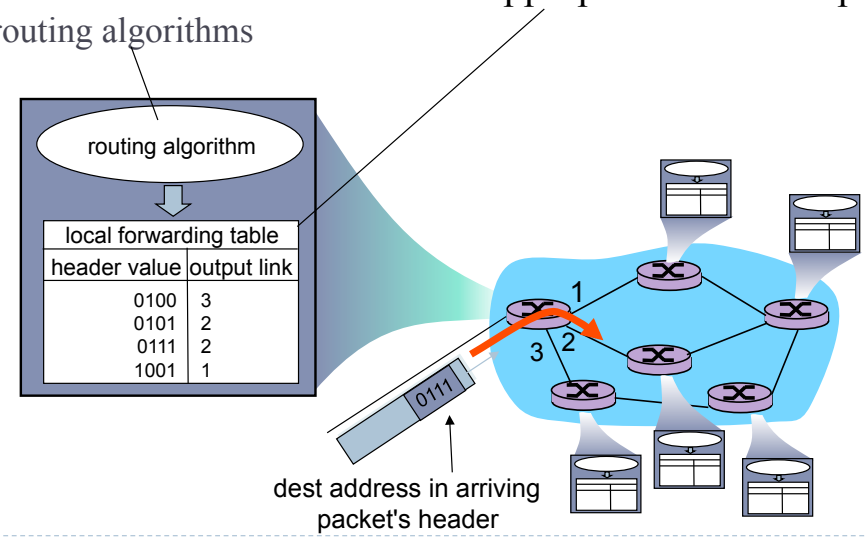
Queuing delay, loss



- 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

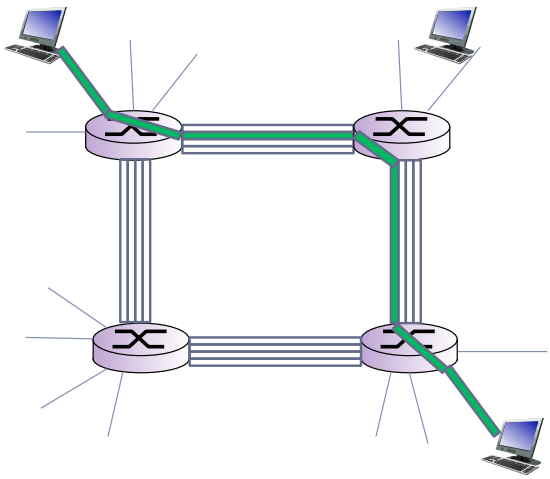
Network Core
Two Key Functions

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

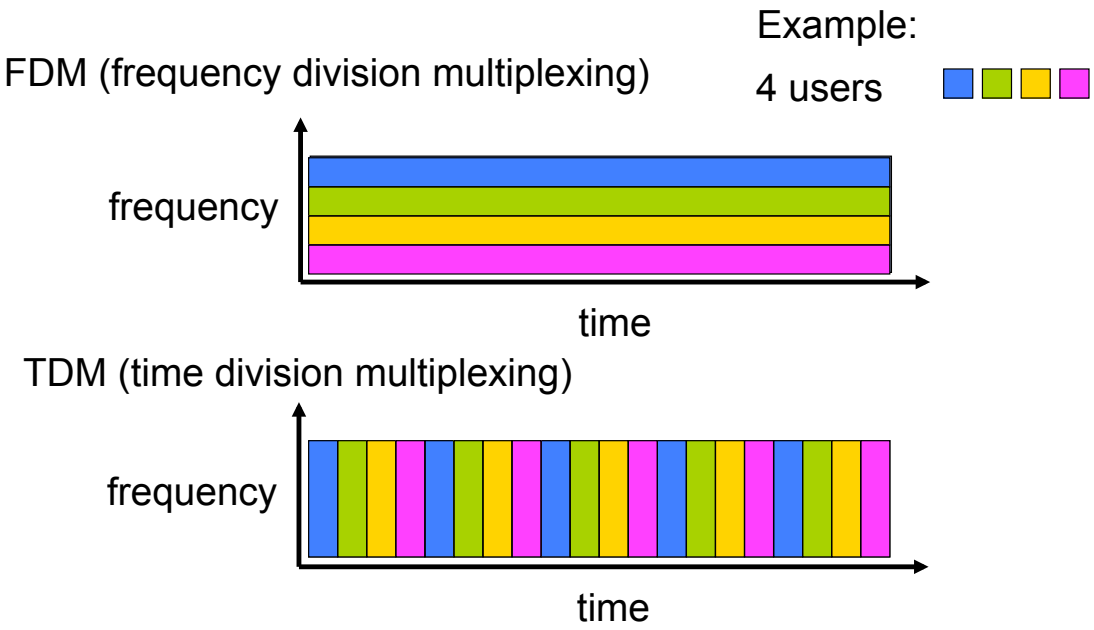


Network Core
Alternative: circuit switching

- 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
  - guaranteed performance
- Circuit segment idle if not used by call (no sharing)
- Commonly used in traditional telephone networks



Circuit Switching
FDM versus TDM



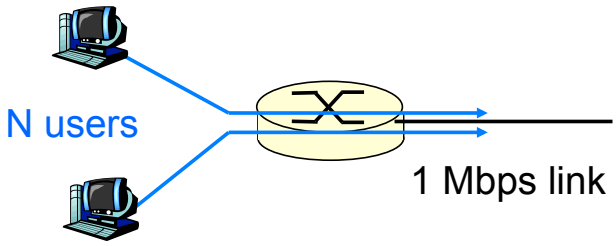
Circuit Switching
Example

- How long would it take to send a file of 640,000 bits from Host A to Host B over a circuit-switched network?
  - All links have a total bitrate of 1.536 Mbps
  - Links use TDM with 24 slots
  - Takes 500 ms to setup a circuit

Packet Switching vs. Circuit Switching
Example

- 1 Mbps link
- each user:
  - 100 kbps when "active"
  - active 10% of time
- circuit-switching:
  - 10 users
- packet switching:
  - with 35 users, probability that more than 10 are active at same time is less than 0.0004

Packet switching allows more users to use network!



Packet Switching vs. Circuit Switching
Is packet switching a "no brainer"?

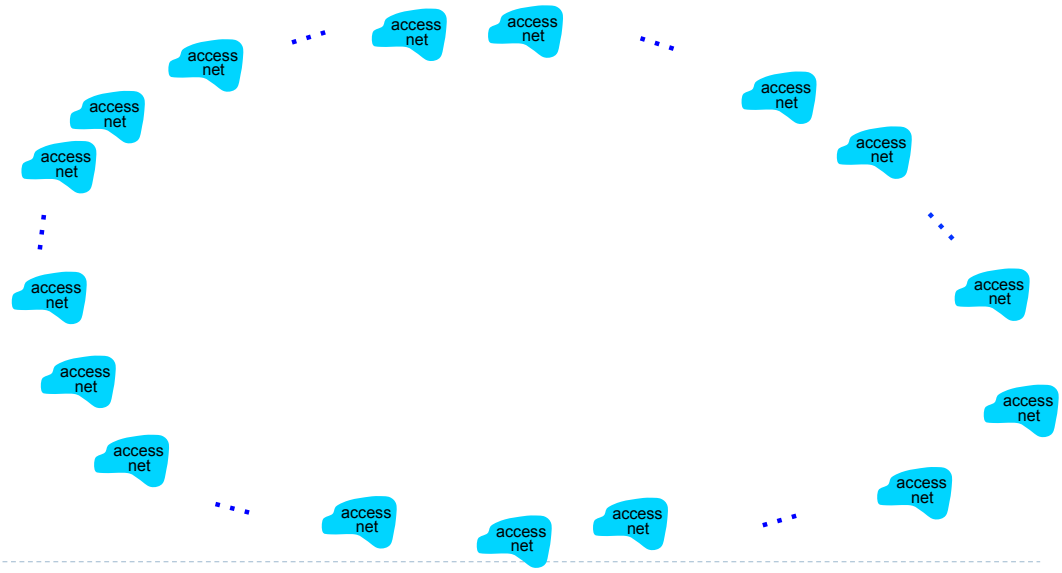
- Great for bursty data
  - Resource sharing
  - No call setup
- Excessive congestion: packet delay and loss
  - Protocols needed for reliable data transfer, congestion control
- How to provide circuit-like behavior?
  - Bandwidth guarantees needed for audio/video applications?
  - Still an unsolved problem (that's why we do research!)

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

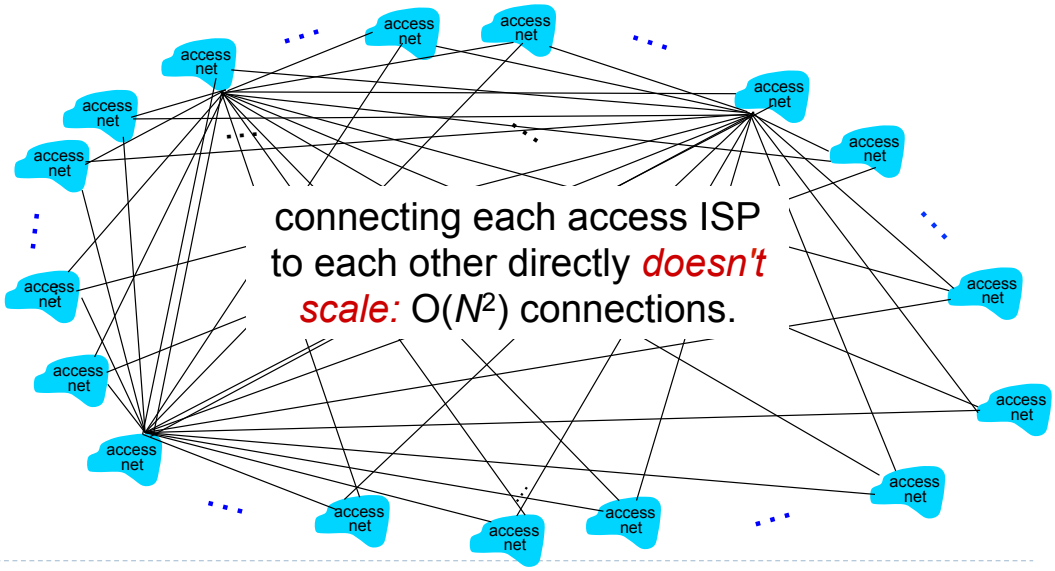
Internet Structure
Network of networks

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



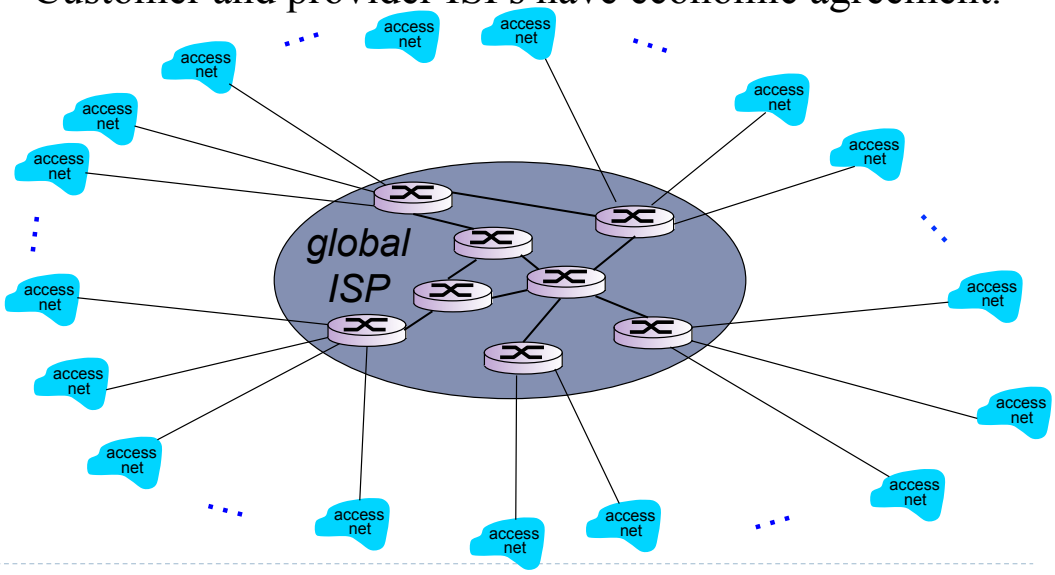
Internet Structure
Network of networks

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



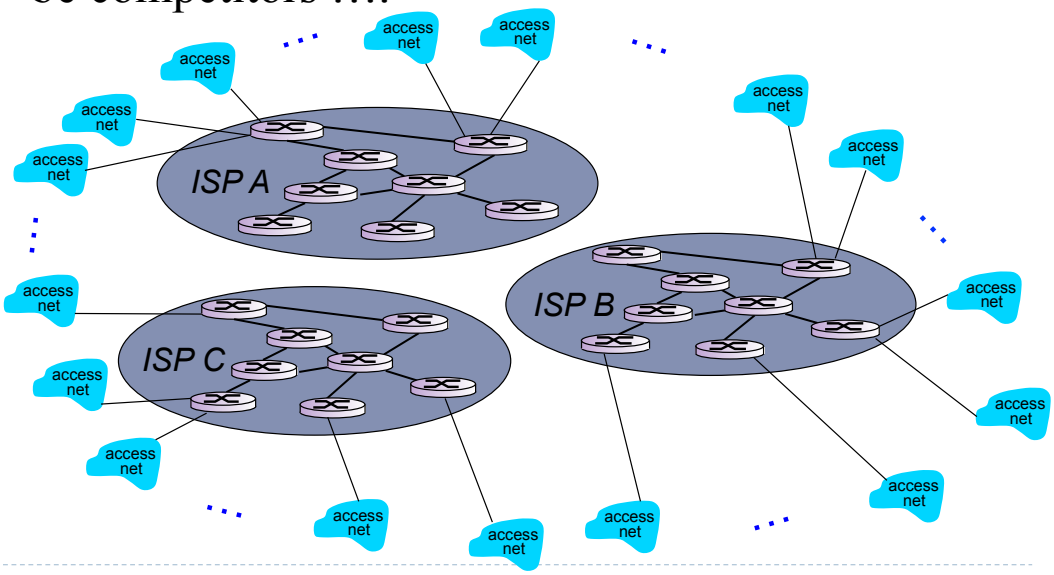
Internet Structure
Network of networks

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



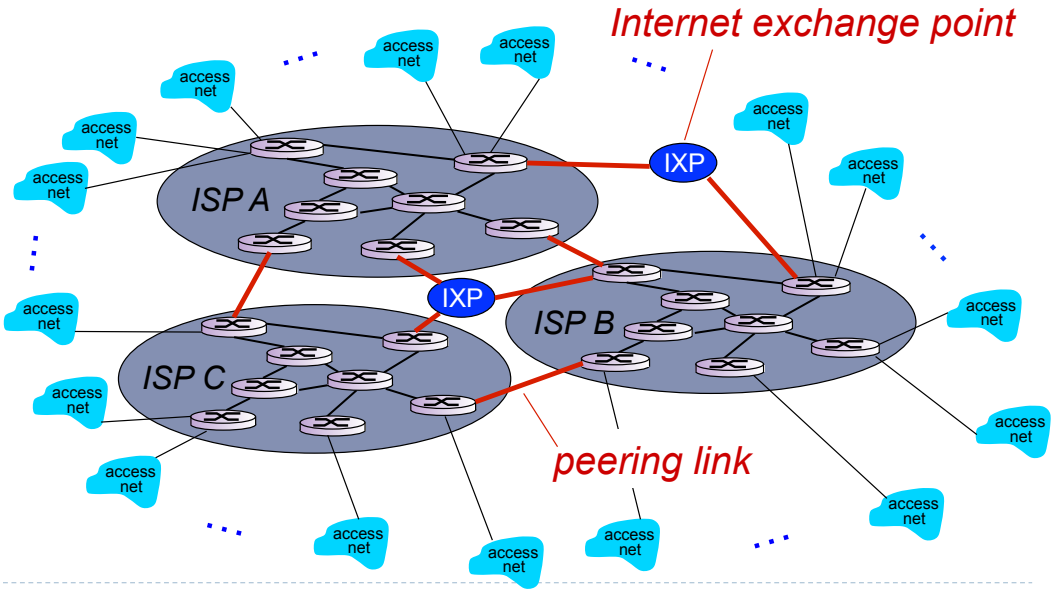
Internet Structure
Network of networks

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



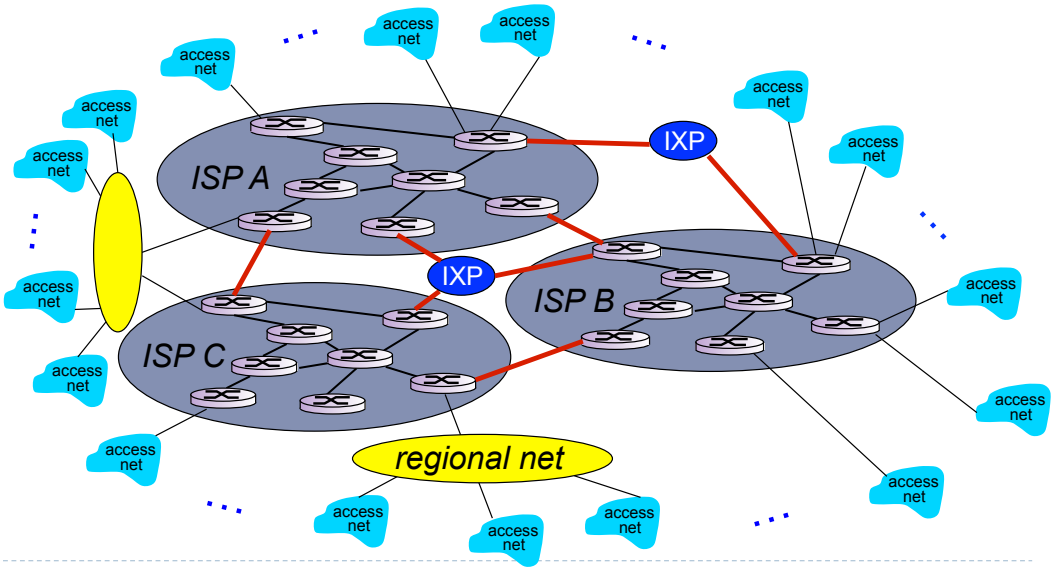
Internet Structure
Network of networks

- …. which must be interconnected



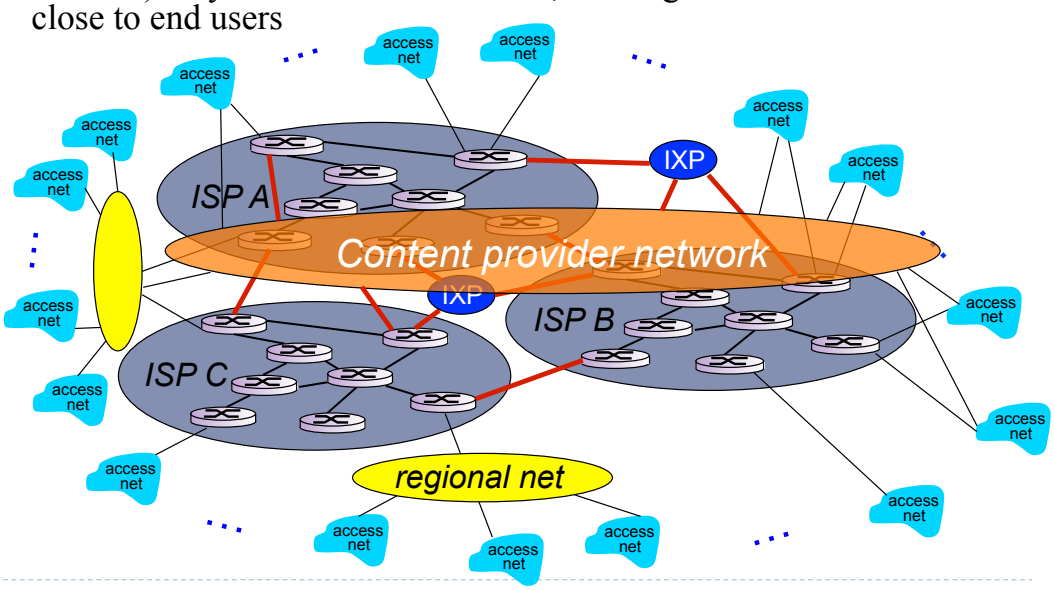
Internet Structure
Network of networks

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



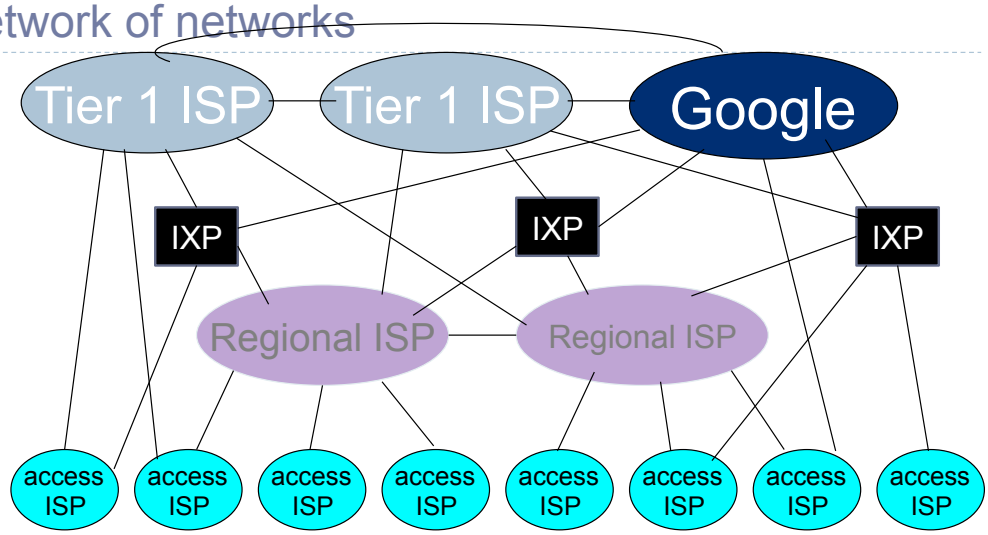
Internet Structure
Network of networks

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



Internet Structure

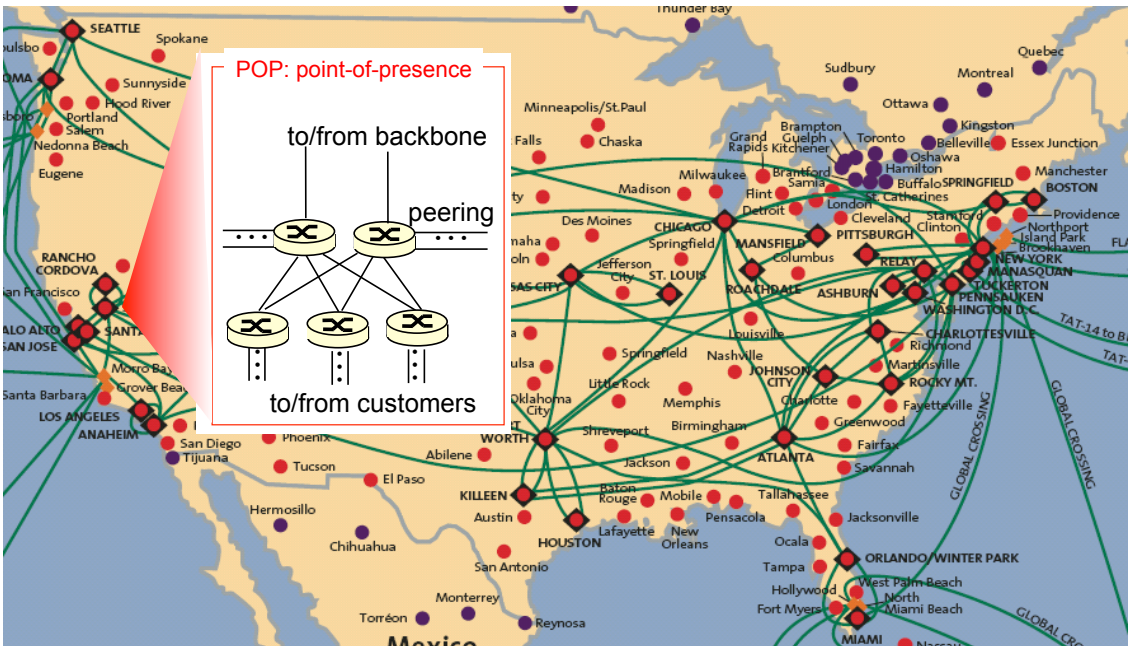
Network of networks



- 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 it data centers to Internet, often bypassing tier-1, regional ISPs

The Network Core

Sprint's Backbone Map



A Whirlwind Introduction to the Internet

Overview

- What's the Internet (KR 1.1)
- Network Edge (KR 1.2)
- Network Core (KR 1.3)
- Performance: Loss and Delay (KR 1.4)
- Protocol Layering (KR 1.5)
- Networks Under Attack (KR 1.6)
- History (KR 1.7)