CPSC 441: Computer Communications

Instructor: Anirban Mahanti
Office: ICT 745
Email: mahanti@cpsc.ucalgary.ca
Class Location: ICT 121
Lectures: MWF 12:00 – 12:50

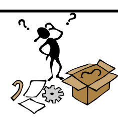
Notes derived from "*Computer Networking: A Top Down Approach Featuring the Internet*", 2005, 3rd edition, Jim Kurose, Keith Ross, Addison-Wesley.

Slides are adapted from the companion web site of the book, as modified by Anirban Mahanti (and Carey Williamson).

Roadmap

- What is a Computer Network?
- Applications of Networking
- Classification of Networks
- Layered Architecture
- Network Core
- Delay & loss in packet-switched networks
- Internet Structure
- Transmission Media (tutorial)
- History (tutorial)

Computer Network?

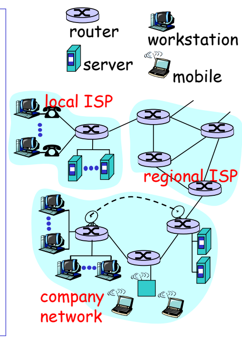


- "interconnected collection of autonomous computers connected by a *single* technology" [Tanenbaum]
- What is the Internet?
  - "network of networks"
  - "collection of networks interconnected by routers"
  - "a communication medium used by millions"
  - Email, chat, Web "surfing", streaming media
- Internet $\neq$ Web

The "nuts and bolts" view of the Internet

- millions of connected computing devices: *hosts, end-systems*
  - PCs workstations, servers
  - PDAs phones, toasters

  running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
  - Links have different ***bandwidth***
- *routers:* forward packets
- Packet: a piece of messg.

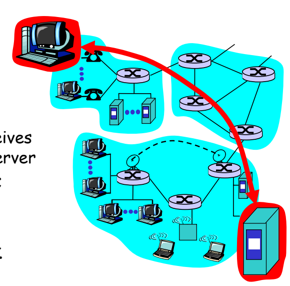


Roadmap

- What is a Computer Network?
- Applications of Networking
- Classification of Networks
- Layered Architecture
- Network Core
- Delay & loss in packet-switched networks
- Internet Structure
- Transmission Media (Wednesday tutorial)
- History (Monday tutorial)

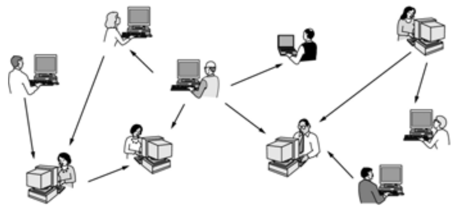
Applications (1)

- end systems (hosts):
  - run application programs
  - e.g. Web, email
  - at "edge of network"
- client/server model
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- Client/server model is applicable in an *intranet*.



Applications (2)

- peer-peer model:
  - No fixed clients or servers
  - Each host can act as both client & server
- Examples: Napster, Gnutella, KaZaA



CPSC 441: Introduction 1-7

Applications (3)

- WWW
- Instant Messaging (Internet chat, text messaging on cellular phones)
- Peer-to-Peer
- Internet Phone
- Video-on-demand
- Distributed Games
- Remote Login (SSH client, Telnet)
- File Transfer

CPSC 441: Introduction 1-8

"Cool" Appliances

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

World's smallest web server
http://www-ccs.cs.umass.edu/~shri/iPic.html

Web-enabled toaster+weather forecaster

CPSC 441: Introduction 1-9

Roadmap

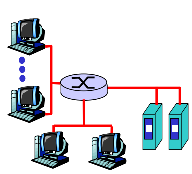
- What is a Computer Network?
- Applications of Networking
- Classification of Networks
- Layered Architecture
- Network Core
- Delay & loss in packet-switched networks
- Internet Structure
- Transmission Media (Wednesday tutorial)
- History (Monday tutorial)

A Classification of Networks

- Local Area Network (LAN)
- Metropolitan Area Network (MAN)
- Wide Area Network (WAN)
- Wireless LANs & WANs
- Home Networks

Local Area Network (LAN)

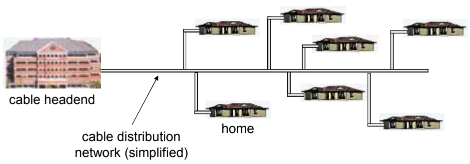
- company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - shared or dedicated link connects end system and router
  - 10 Mbs, 100Mbps, Gigabit Ethernet
- deployment: institutions, home LANs happening now
- LANs: chapter 5



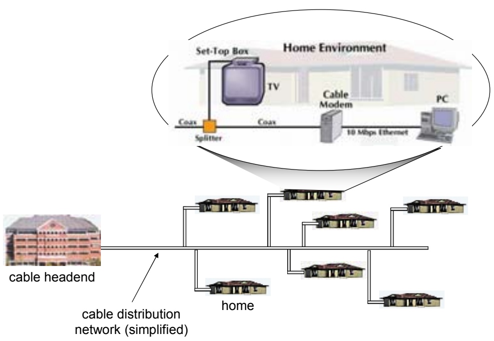
Metropolitan Area Network (MAN)

A Cable TV Network is an example of a MAN

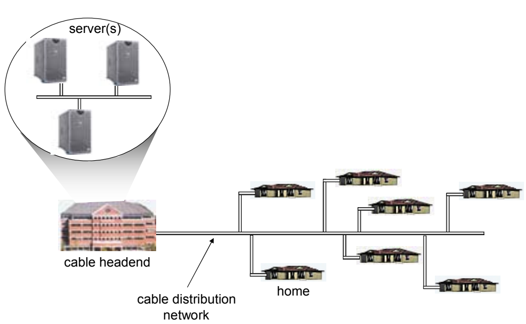
Typically 500 to 5,000 homes



Cable Network Architecture: Overview

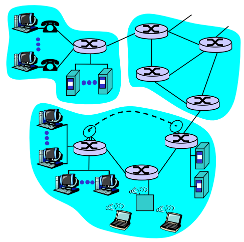


Cable Network Architecture: Overview



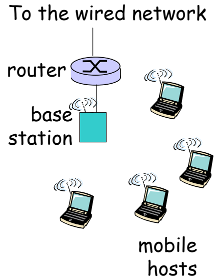
Wide Area Network (WAN)

- Spans a large geographic area, e.g., a country or a continent
- A WAN consists of several transmission lines and routers
- Internet is an example of a WAN



Wireless Networks

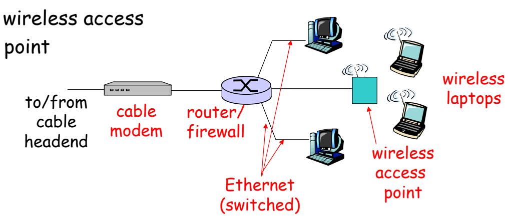
- shared *wireless* access network connects end system to router
  - via base station aka "access point"
- wireless LANs:
  - 802.11b (WiFi): 11 Mbps
- wider-area wireless access
  - provided by telco operator
  - 3G ~ 384 kbps
    - Will it happen??
  - WAP/GPRS in Europe



Home networks

Typical home network components:

- ADSL or cable modem
- router/firewall/NAT
- Ethernet
- wireless access point



"internetworking"?

- internetwork – interconnection of networks – also called an "internet"
- Subnetwork – a constituent of an internet
- Intermediate system – a device used to connect two networks allowing hosts of the networks to correspond with each other
  - Bridge
  - Routers
- Internet is an example of an internetwork.

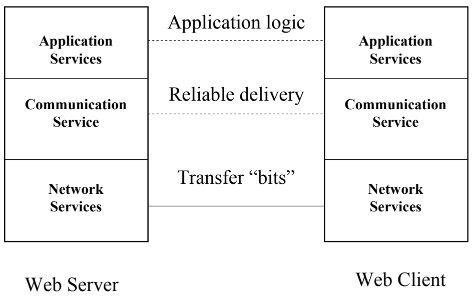
Roadmap

- What is a Computer Network?
- Applications of Networking
- Classification of Networks
- Layered Architecture
- Network Core
- Delay & loss in packet-switched networks
- Internet Structure
- Transmission Media (tutorial)
- History (tutorial)

Layered Architecture: Why?

- Networks are complex with many pieces
  - Hosts, routers, links, applications, protocols, hardware, software
- Can we organize it, somehow?
- Let's consider a Web page request:
  - Browser requests Web page from server
  - Server should determine if access is privileged
  - Reliable transfer page from server to client
  - Physical transfer of "bits" from server to client

Motivation Continued …



CPSC 441: Introduction 1-22

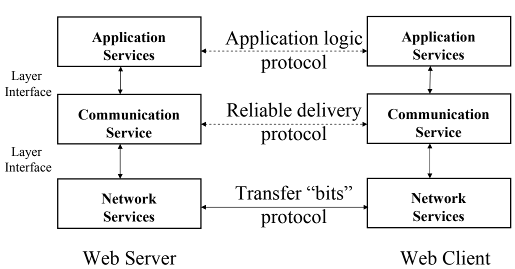
Motivation Continued …

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 doesn't affect rest of system
- layering considered harmful?

CPSC 441: Introduction 1-23

Layers, Protocols, Interfaces



CPSC 441: Introduction 1-24

Layered Architecture (Review 1/2)

- Networks organized as a stack of layers?
  - The purpose of a layer is to offer services to the layer above it using an interface (programming language analogy: libraries hide details while providing a service)
  - Reduces design complexity
- Protocols: peer-to-peer layer-n conversations
- Data Transfer: each layer passes data & control information to the layer below; eventually physical medium is reached.

Review (2/2)

- A set of layers & protocols is called a Network Architecture. These specifications enable hardware/software developers to build systems compliant with a particular architecture.
  - E.g., TCP/IP, OSI

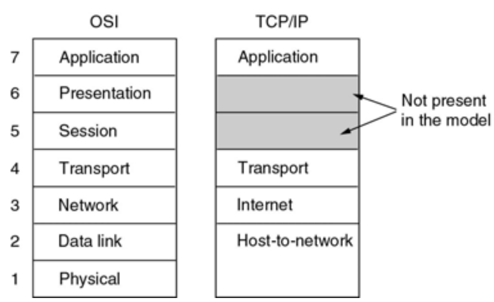
Layering: Design Issues

- Identify senders/receivers?
  - Addressing
- Unreliable physical communication medium?
  - Error detection
  - Error control
  - Message reordering
- Sender can swamp the receiver?
  - Flow control
- Multiplexing/Demultiplexing

Reference Models

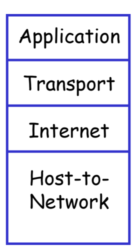
- Open Systems Interconnection (OSI) Model
- TCP/IP Model

Reference Models (2)



TCP/IP Model: History

- Originally used in the ARPANET
- ARPANET required networks using leased telephone lines & radio/satellite networks to interoperate
- Goals of the model are:
  - Seamless interoperability
  - Wide-ranging applications
  - Fault-tolerant to some extent



The Application Layer

- Residence of network applications and their application control logic
- Examples include:
  - HTTP
  - FTP
  - Telnet
  - SMTP
  - DNS

The Transport Layer

- Concerned with end-to-end data transfer between end systems (hosts)
- Transmission unit is called segment
- TCP/IP networks such as the Internet provides two types of services to applications
  - "connection-oriented" service – Transmission Control Protocol (TCP)
  - "connectionless" service - User Datagram Protocol (UDP)

TCP: Connection-oriented Service

- Handshaking between client & server programs
  - Parameters for ensuing exchange
  - Maintain connection-state
- Packet switches do not maintain any connection-state;
  - hence "connection-oriented"
- Similar to a phone conversation
- TCP is bundled with reliability, congestion control, and flow control.

UDP: Connectionless Service

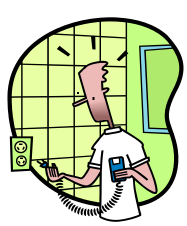
- No handshaking
- Send whenever and however you want
- A "best effort" service
  - No reliability
  - No congestion & flow control services
- Why is it needed?

The Internet Layer

- End systems inject datagrams in the networks
- A transmission path is determined for each packet (routing)
- A "best effort" service
  - Datagrams might be lost
  - Datagrams might be arrive out of order
- Analogy: Postal system

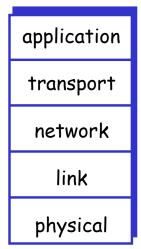
The Host-to-Network Layer

- Somehow, host has to connect to the network and be able to send IP Datagrams
- How?



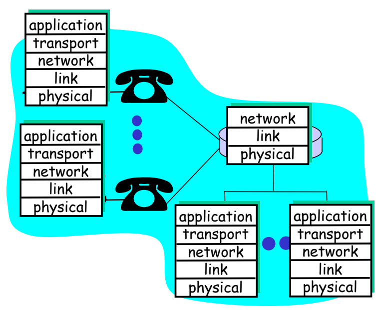
Internet protocol stack

- application: supporting network applications
  - FTP, SMTP, STTP
- transport: host-host data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - PPP, Ethernet
- physical: bits "on the wire"



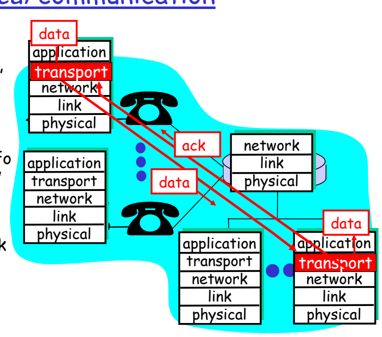
Layering: logical communication

Each layer:
- distributed
- "entities" implement layer functions at each node
- entities perform actions, exchange messages with peers

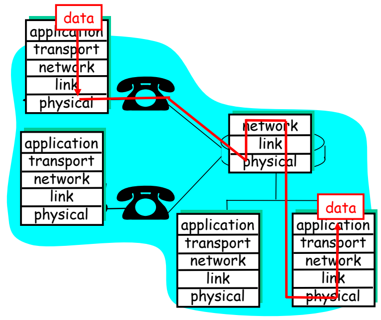


Layering: *logical* communication

- take data from app
- generate "segment" according to transport protocol
- add addressing, reliability check info to form "datagram"
- send datagram to peer
- wait for peer to ack receipt



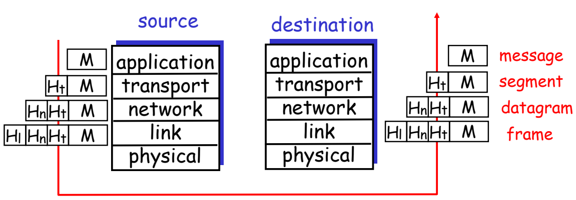
Layering: physical communication



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

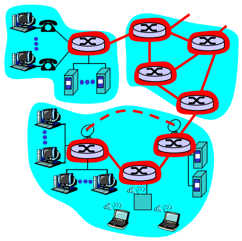


Roadmap

- What is a Computer Network?
- Applications of Networking
- Classification of Networks
- Layered Architecture
- Network Core
- Delay & loss in packet-switched networks
- Internet Structure
- Transmission Media (Wednesday tutorial)
- History (Monday tutorial)

The Network Core

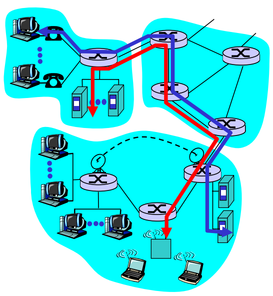
- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



Network Core: Circuit Switching

End-to-end resources reserved for "call"

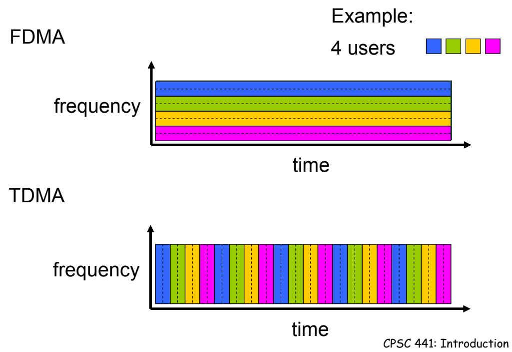
- Link bandwidth, switch capacity
- Dedicated resources with no sharing
- Guaranteed transmission capacity
- Call setup required
- "Blocking" may occur



Network Core: Circuit Switching

- Capacity of medium exceeds the capacity required for transmission of a single signal
  - How can we improve "efficiency"? Let's multiplex.
- Divide link bandwidth into "pieces":
  - frequency division - FDMA
  - time division – TDMA

Circuit Switching: FDMA and TDMA



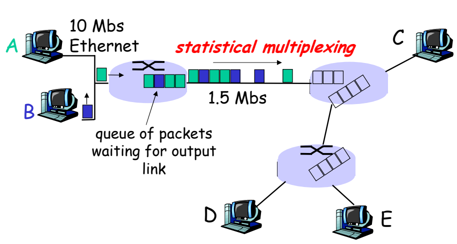
CPSC 441: Introduction 1-46

Network Core: Packet Switching

- "store-and-forward" transmission
- source breaks long messages into smaller "packets"
- packets *share* network resources
- each packet uses full link bandwidth
- resource contention
  - aggregate resource demand can exceed amount available
  - congestion: packets queue, wait for link use

CPSC 441: Introduction 1-47

Packet Switching: Statistical Multiplexing



Sequence of A & B packets does not have fixed pattern ➔ ***statistical multiplexing***.

In TDM each host gets same slot in revolving TDM frame.

CPSC 441: Introduction 1-48

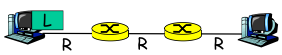
Packet switching versus circuit switching

Is packet switching a "slam dunk" winner?

- Great for bursty data
  - resource sharing
- Excessive congestion: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- Q: How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 6)

CPSC 441: Introduction 1-49

Packet-switching: store-and-forward

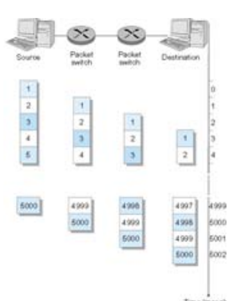


- Takes L/R seconds to transmit (push out) packet of L bits on to link or R bps
- Entire packet must arrive at router before it can be transmitted on next link: *store and forward*
- delay = 3L/R

Example:
- L = 7.5 Mbits
- R = 1.5 Mbps
- delay = 15 sec

CPSC 441: Introduction 1-50

Packet Switching: Message Segmenting



Now break up the message into 5000 packets

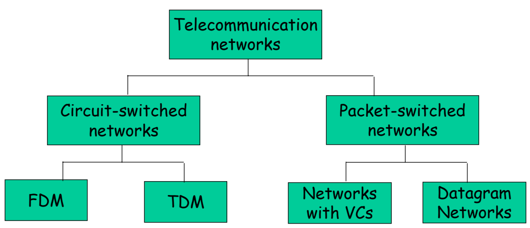
- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- *pipelining:* each link works in parallel
- Delay reduced from 15 sec to 5.002 sec

CPSC 441: Introduction 1-51

Packet-switched networks: forwarding

- datagram network:
  - *destination address* in packet determines next hop
  - routes may change during session (flexible?)
  - no "per flow" state, hence more scalable
- virtual circuit network:
  - each packet carries tag (virtual circuit ID), tag determines next hop
  - fixed path determined at *call setup time*
  - path is **not** a dedicated path as in circuit switched (i.e., store & forward of packets)
  - *routers maintain per-call state*
- datagram networks need per packet routing.

Network Taxonomy



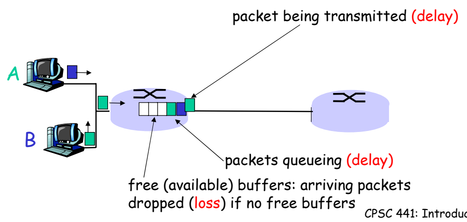
Roadmap

- What is a Computer Network?
- Applications of Networking
- Classification of Networks
- Layered Architecture
- Network Core
- Delay & loss in packet-switched networks
- Internet Structure
- Transmission Media (Wednesday tutorial)
- History (Monday tutorial)

How do loss and delay occur?

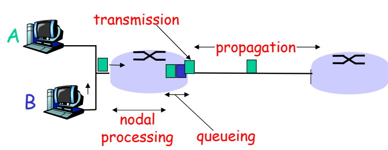
packets *queue* in router buffers

- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn
- if queue is full, arriving packets dropped (Drop-Tail)



Four sources of packet delay

- 1. nodal processing:
  - check bit errors
  - determine output link
- 2. queueing
  - time waiting at output link for transmission
  - depends on congestion level of router

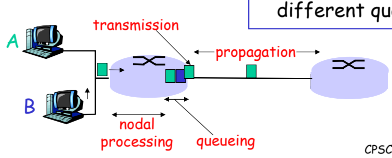


Delay in packet-switched networks

3. Transmission delay:
- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

4. 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!



Nodal delay

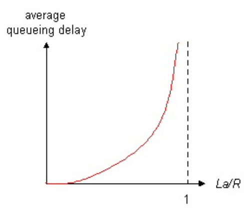
$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay
  - depends on congestion
- d_{trans} = transmission delay
  - = L/R, significant for low-speed links
- d_{prop} = propagation delay
  - a few microsecs to hundreds of msecs

Queueing delay (revisited)

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

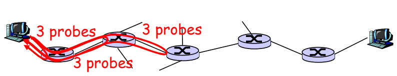
traffic intensity = La/R



- 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!

"Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- `Traceroute` program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i*:
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.

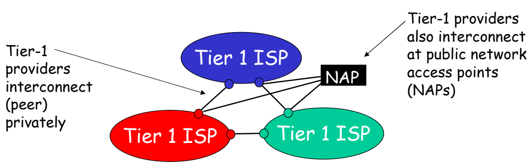


Roadmap

- What is a Computer Network?
- Applications of Networking
- Classification of Networks
- Layered Architecture
- Network Core
- Delay & loss in packet-switched networks
- Internet Structure
- Transmission Media (Wednesday tutorial)
- History (Monday tutorial)

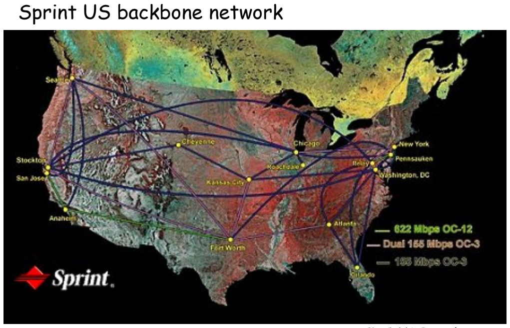
Internet structure: network of networks

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



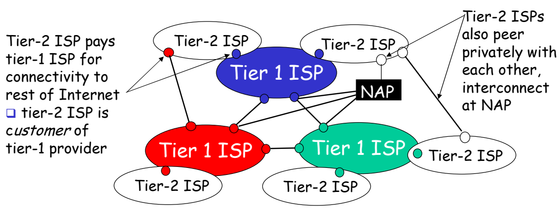
Tier-1 ISP: e.g., Sprint

Sprint US backbone network



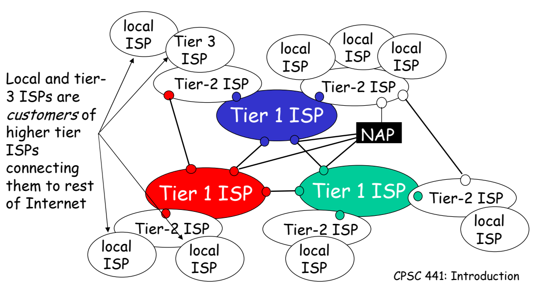
Internet structure: network of networks

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



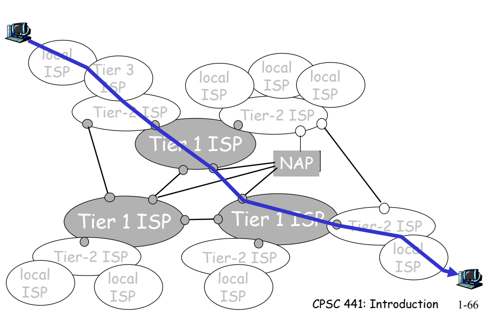
Internet structure: network of networks

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



Internet structure: network of networks

- a packet passes through many networks!



Introduction: Summary

Covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
- Internet/ISP structure
- performance: loss, delay
- layering and service models
- history (which you will be reading on your own)

You now have:

- context, overview, "feel" of networking
- more depth, detail *to follow!*