COMP 431
Internet Services & Protocols

A Whirlwind Introduction to the Internet
("Networking Nouns and Verbs")

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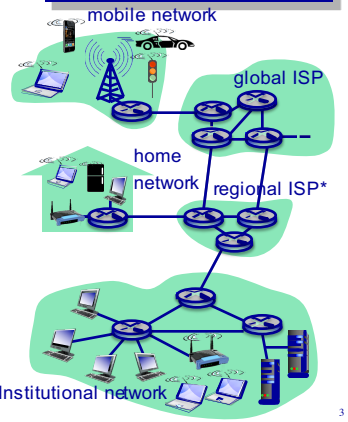
A Whirlwind Introduction to the Internet
Overview

Introduce the major nouns and verbs of networking!

- What's the Internet
- Network core
- Network edge
- Access nets, physical media
- Internet Structure & ISPs
- Performance: loss, delay
- Security
- Protocol layers, service models

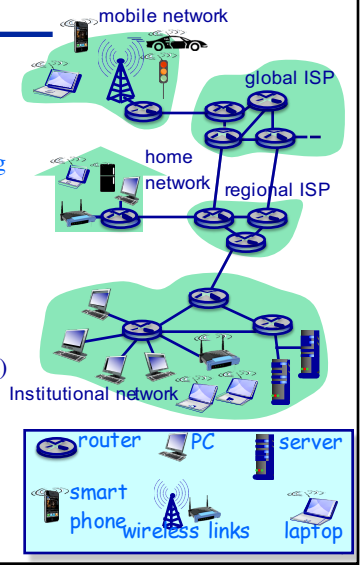


*Internet Service Provider

Some Definitions

The "nuts and bolts" view

- Billions of connected computing devices: hosts, **end-systems**
  - » PCs, laptops, servers
  - » Tablets, phones, e-readers, toasters running "network applications"
- Communication **links**
  - » 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)
- **Switches & Routers**:
  - » Forward "packets" of data though the network



Just What is the Internet?

Yes, there really are Internet toasters!

IP picture frame

Slingbox: watch, control cable TV remotely

Web-enabled toaster + weather forecaster

Tweet-a-watt: monitor energy use

Internet refrigerator

sensorized, bed mattress

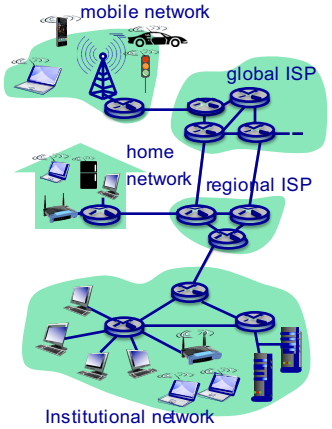
Internet phones

Internet is short-form for internetworking

Just What is the Internet?

The "nuts and bolts" view

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

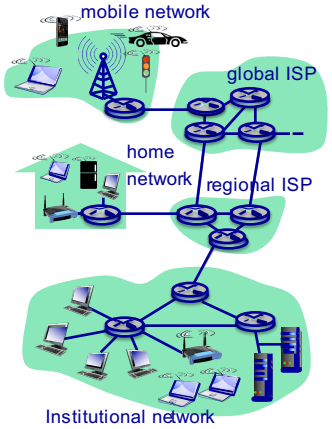


Internet is an infrastructure that is enabling a distributed structure

Some Definitions

The "services" view

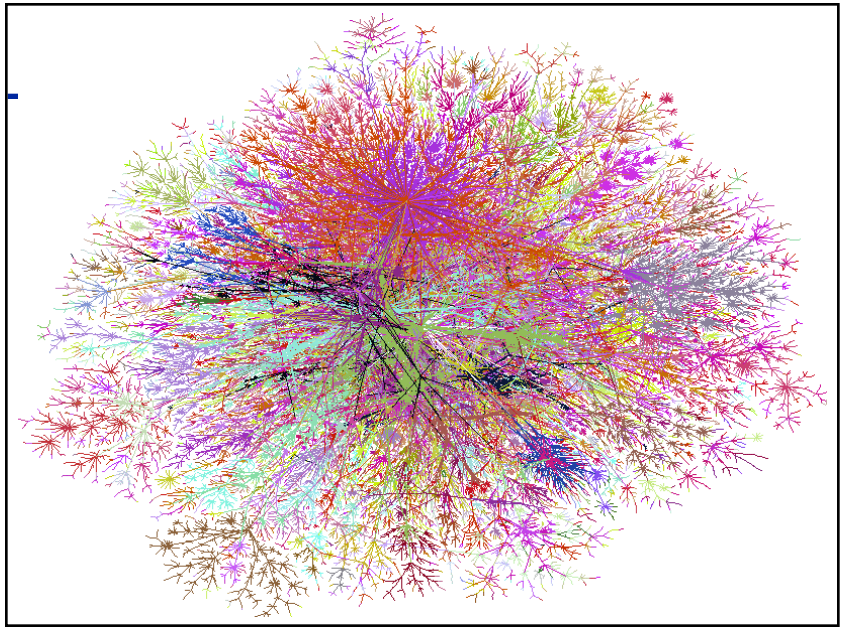
- Internet: A communication infrastructure enabling distributed applications
  - » WWW, email, games, e-commerce, database, voting, …
- Communication services provided:
  - » **Connectionless**:
    - ❖ No guarantees
  - » **Connection-oriented**:
    - ❖ Guarantees order and completeness



Network Maps

Just how big is the Internet…?

> 7.5 billion devices on the Internet



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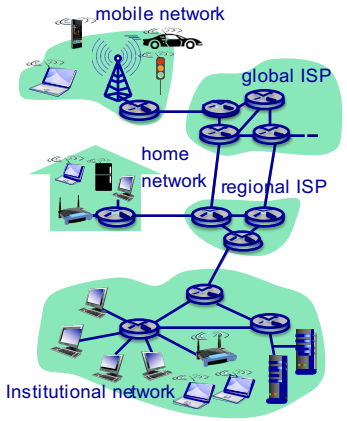
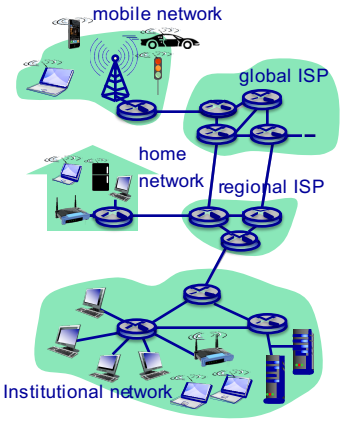


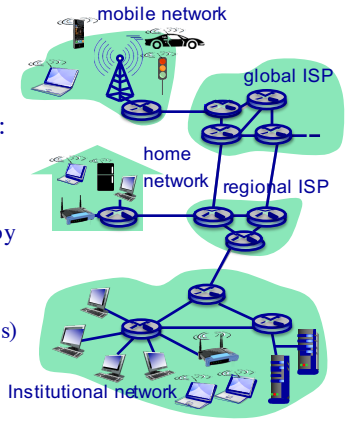
The Structure of the Internet
The physical makeup of the Internet

- Network core:
  - » Routers
  - » Network of networks
- Network edge:
  - » Applications running on hosts
    - ❖ "host" = "end system"
- In between: Access networks
  - » Physical media: communication links



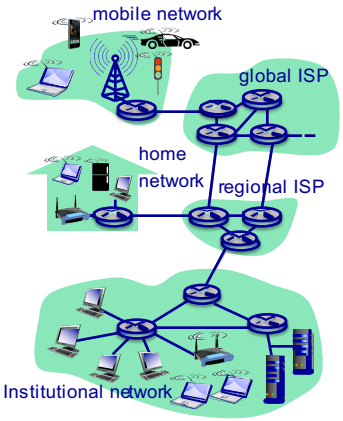
Network Structure
The network core

- A mesh of interconnected routers
- *The* fundamental architectural question:
  How is data forwarded through the network?
  - » *Circuit switching*: "telephone model"
    - ❖ dedicated circuit (path) per call used by all data
  - » *Packet switching*: "datagram model"
    - ❖ data sent in discrete "chunks" (packets)
    - ❖ each packet has a path chosen for it independently



The Network Core
Circuit Switching

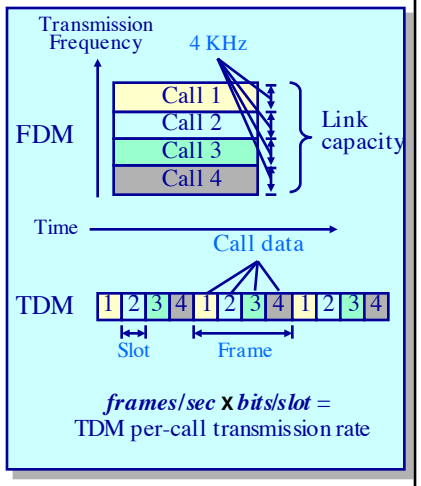
- Resources reserved *end-to-end* for the connection ("call")
  - » Resources:
    - ❖ Link bandwidth, switch processing capacity, memory buffers, *etc.*
  - » Reservation:
    - ❖ Dedicated fraction of available bandwidth, buffers, *etc.*
- ☺:
  - » Circuit-like (guaranteed) performance
- ☹:
  - » Call setup required
  - » Call rejection ("busy signal") possible



Circuit Switching

Allocating fractions of bandwidth — Multiplexing

- Network bandwidth divided into transmission "slots"
  - » Slots allocated to calls
  - » Slots are unused ("idle") if not used by owning call
  - » No sharing of slots!
- How to divide link bandwidth into slots?
  - » Frequency division multiplexing (FDM)
  - » Time division multiplexing (TDM)



The Network Core

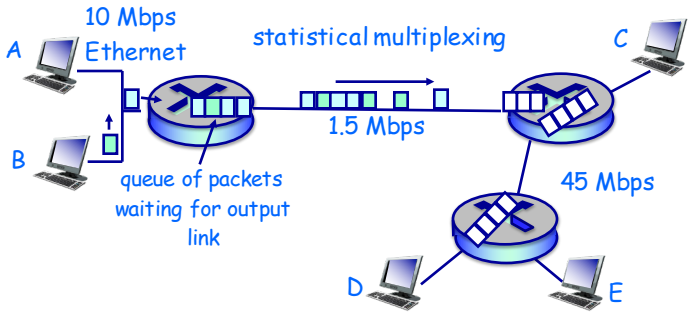
Packet Switching

- Each sender divides its messages into "*packets*" *(sequence of bits)*
  - » Each packet uses *full* link capacity until transmission completed
  - » Senders' packets *share (compete for)* network resources
  - » Resources allocated & used *as needed*

- But now we have resource contention!
  - » Aggregate resource demand can exceed amount available
  - » Congestion: packets queue, wait for link availability
- Also introduces **Store-and-Forward** delays:
  - » packets move one hop at a time
    - ❖ Routers receive complete packet over incoming link
    - ❖ Then transmit over outgoing link

Packet Switching

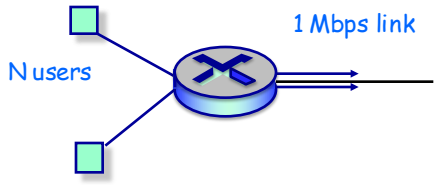
Statistical multiplexing



- Packet-switching versus circuit switching:
  - » Restaurant seating analogy
  - » Other familiar analogies?

The Network Core

Packet switching *v.* Circuit switching



Packet switching allows more users to use the network!

- Assume that on a 1 Mbps link:
  - » Each user consumes 100Kbps when "active"
  - » Each user active 10% of time
- Circuit-switching can support 10 users
- Packet switching can support 35 users
  - » With 35 users the probability of more than 10 users active simultaneously is less than 0.0004

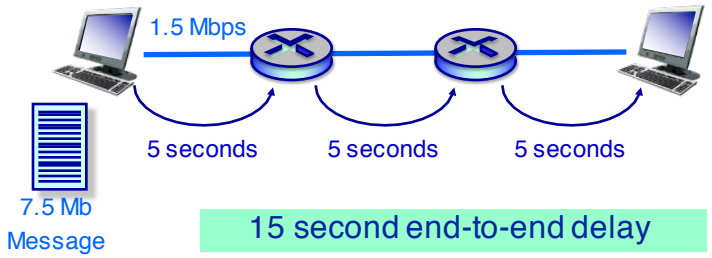
Packet Switching *vs.* Circuit Switching

Is packet switching a "no brainer"?

- ☺:
  - » Great for bursty data ☺
    - ❖ Resource sharing
  - » No call setup
  - » Light-weight fault recovery
- 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 (go to grad school!)

Packet Switching (Store and Forward)

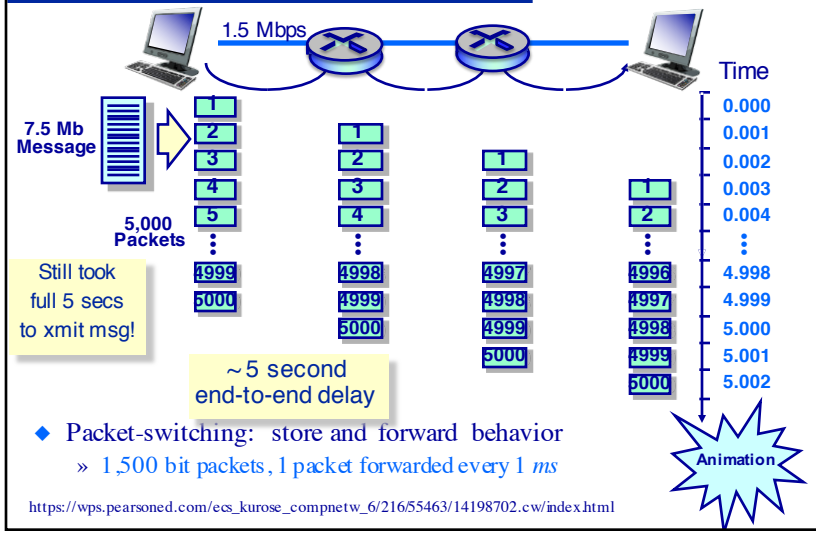
Why switch packets instead of entire messages?



- "Message switching" example
  - » Transmit a 7.5 Mb message over a network with 1.5 Mbps links
  - » What is the total elapsed transmission time?

Packet Switching (Store and Forward)

Why switch packets instead of entire messages?

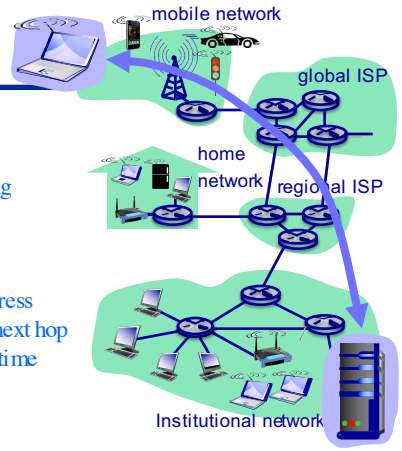


- Packet-switching: store and forward behavior
  - 1,500 bit packets, 1 packet forwarded every 1 *ms*

https://wps.pearsoned.com/ecs_kurose_compnetw_6/216/55463/14198702.cw/index.html

Packet Switching

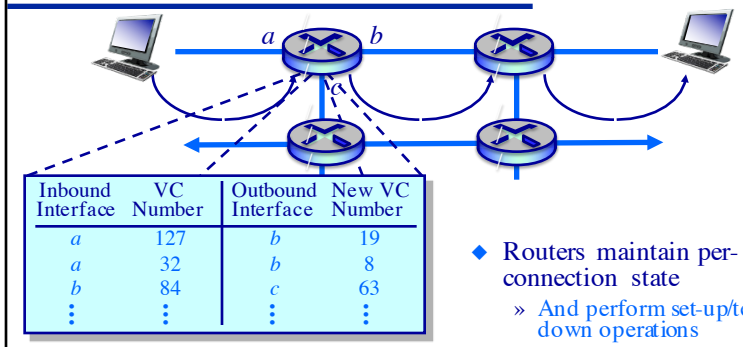
Forwarding



- Forwarding:
  - The process of moving packets among routers from source to destination
- Datagram network:
  - Each packet carries a destination address
  - Destination address used to look up next hop
  - Route (next hop) may change at any time
- Virtual circuit (path) network:
  - Packets carry a "tag" (virtual circuit ID) that determines the next hop
  - Path determined at call setup time & remains fixed throughout call
  - Routers maintain per-call path state

Forwarding in Packet Switched Networks

Virtual circuit forwarding



Inbound Interface	VC Number	Outbound Interface	New VC Number
a	127	*b*	19
a	32	*b*	8
b	84	*c*	63
⋮	⋮	⋮	⋮

- A (static) route is computed before any data is sent
- Packets contain a VC identifier
  - » Identifier replaced at every hop
- Routers maintain per-connection state
  - » And perform set-up/tear-down operations

(Why not choose a single VC identifier for the entire path and avoid replacing it at each hop?)

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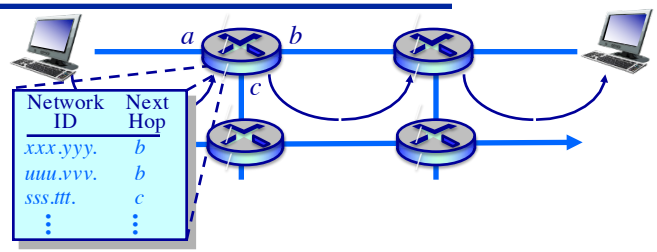
Forwarding in Packet Switched Networks

Datagram forwarding



Network ID	Next Hop
xxx.yyy.	*b*
uuu.vvv.	*b*
sss.ttt.	*c*
⋮	⋮

- Packets contain complete destination address
  - » Address specifies both a network and a host
- Each router examines the destination address
  - » And forwards packet to the next router closest to the destination network
    - ❖ Routers maintain a table of "next hops" to all destination networks
- Routers maintain no per-connection state

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Difference between circuit switching and virtual circuit forwarding:

circuit switching: all data is sent continuously
virtual circuit forwarding happens in the context of packet switching: things are sent in packets - broken up

the difference is taking advantage of statistical multiplexing to accommodate for more users

for a given router VCF vs DF
routing table is small

- router can receive packets out of order and force them to reorder although it is every unlikely for say the 20th packet to come before the first

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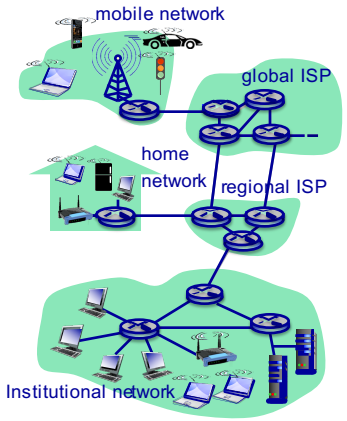
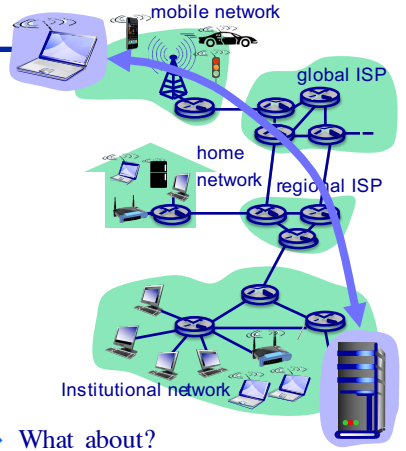


Network Structure

The network edge

- End systems (hosts)
  - » Live at the "edge of network"
  - » Run applications
- Interaction paradigms:
  - » Client/server model
    - ❖ Client requests, receives service from server
    - ❖ WWW browser/server; email client/server
  - » Peer-to-peer model:
    - ❖ Host interactions symmetric
    - ❖ File sharing (BitTorrent, Limewire, Kazaa, eMule, …)



- What about?
  - » Remote login?
  - » Newsgroups?
  - » Telephony?

- The internet is a network of networks

- When applications interact over the internet: they use client server or peer to peer (interaction is more symmetrical)

- Remote login: when you ssh it is a client server model, your terminal is the client and the server is in the CS department

- in peer to peer you should also be serving something in addition to requesting things

Transport Services @ The Network Edge
Connection-oriented service

- Connection-oriented service on the Internet:
  - » TCP - Transmission Control Protocol [RFC 793]
- Goal: Transfer data between end systems
  - » *handshaking:* setup data transfer ahead of time
    - ❖ "Hello, hello-back" human protocol
    - ❖ Set up "state" in two communicating hosts
  - » Transmit data
- TCP service model
  - » *reliable, in-order, byte-stream*
    - ❖ Losses detected and recovered from
  - » *flow control:*
    - ❖ Sender won't overwhelm receiver
  - » *congestion control:*
    - ❖ Senders "slow down sending rate" when network congested

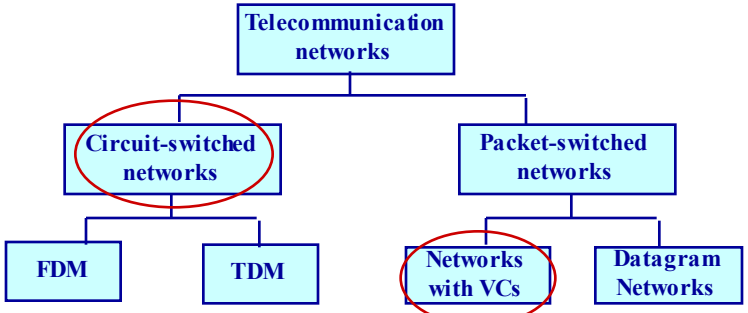
Each of the above services can be defined only in the context of a "connection"!

Transport Services @ The Network Edge
Connectionless service

- Connectionless service on the Internet:
  - » UDP - User Datagram Protocol [RFC 768]
    - ❖ Unreliable data transfer
    - ❖ No flow control
    - ❖ No congestion control
- Goal: Transfer data between end systems
  - » Same as before!
- Applications using TCP:
  - » HTTP (WWW),
  - » FTP (file transfer),
  - » Telnet (remote login),
  - » SMTP (email)
- Applications using UDP:
  - » DNS (name to address mapping),
  - » Streaming media (some),
  - » Teleconferencing,
  - » Internet telephony (VoIP)

- treat everything independently
- why use UDP instead of tcp because tcp gives reliability and semantics:
some applications don't care if packets get lost,
having a more timely experience is more important,

Network Taxonomy



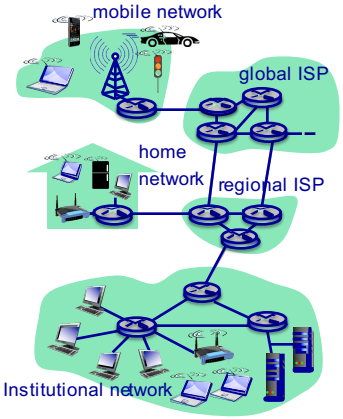
- The Internet
  - » Is a Datagram network
  - » Provides two types of services to applications:
    - ❖ Connectionless (UDP)
    - ❖ Connection-oriented (TCP)

How would you compare and contrast the 3 circled items

The Structure of the Internet

The physical makeup of the Internet

- Network core:
  - » Routers
  - » Network of networks
- Network edge:
  - » Applications and hosts
- In between: Access networks
  - » Physical media: communication links



Read the textbook and the rest of the slides after this point

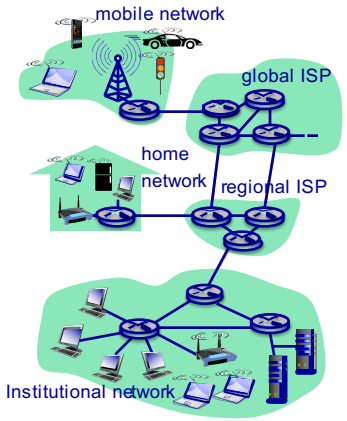
cables are known as guided materials

multipart propogation allows your phone to work while inside

Network Structure

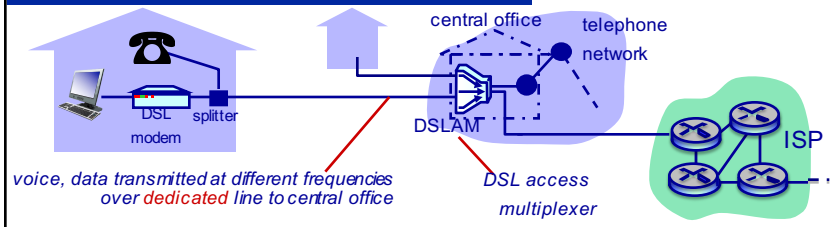
Access networks and physical media

- How to connect end-systems to the Internet (edge router)?
  - » Residential access nets
  - » Institutional/enterprise access networks
  - » Mobile access networks
- Differences/Issues:
  - » Transmission speed (bits per second) of access network?
  - » Shared or dedicated?



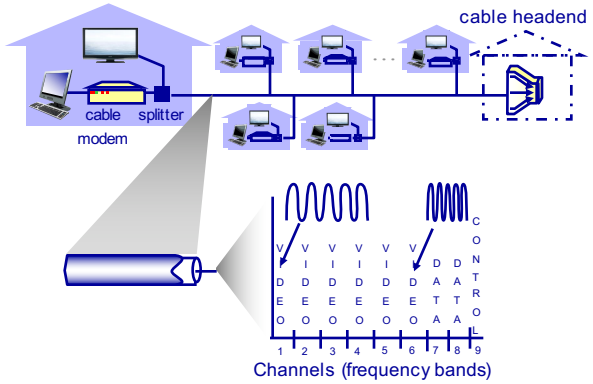
Access Networks

Example: Digital subscriber line (DSL)



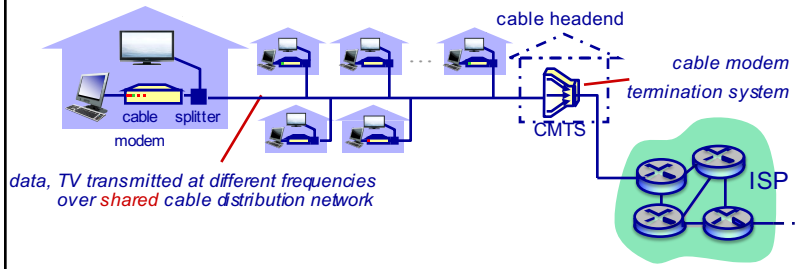
- Uses the existing telephone line to connect to the "central office" DSLAM
  - » Data sent over DSL phone line goes to Internet
  - » Voice sent over DSL phone line goes to telephone net
- Lots of flavors of DSL but common data rates are:
  - » A max of 2.5 Mbps upstream (typically < 1 Mbps)
  - » ~24 Mbps downstream (possibly up to 50 Mbps)

Access Networks
Example: Cable networks



- Cable relies on *frequency division* multiplexing (FDM)
  - » Different communication "channels" are transmitted in different frequency bands

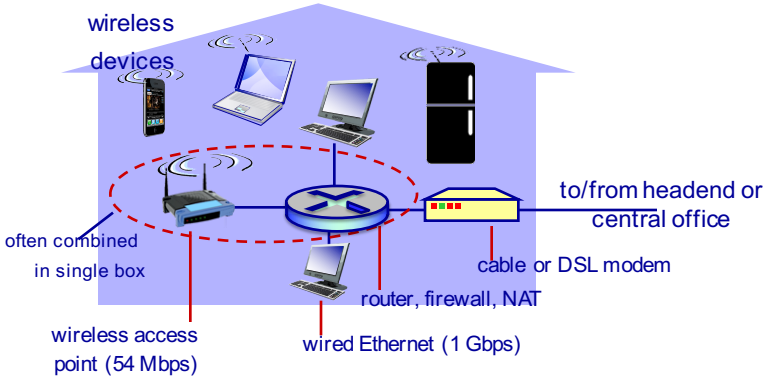
Access Networks
Example: Cable networks



- HFC: hybrid fiber coax
  - » Asymmetric: 10-300 Mbps downstream transmission rate, 2-10 Mbps upstream transmission rate
- Network of coax/fiber attaches homes to ISP router
  - » Homes share the access network to the cable headend (unlike DSL, which has dedicated access to central office)

Access Networks

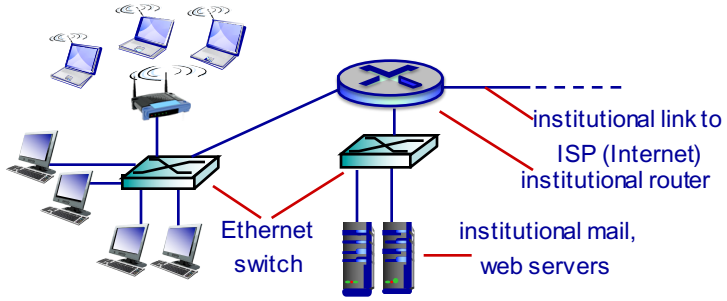
Example: Your home network!



- *Your* home network today is likely more complex than the entire UNC network was 25 years ago!
  - » And has a higher capacity!

Access Networks

Example: Enterprise access



- Ethernet (mostly wired) is the dominant medium
  - » Scalable (& symmetric): 10 Mbps, 100 Mbps, 1,000 Mbps (1 Gbps). 10,000 Mbps (10 Gbps)
  - » End-systems typically physically connect to an Ethernet switch

Access Networks

Example: Wireless access networks

wireless LANs:

- access point per room (100 ft.)
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate

wide-area wireless access

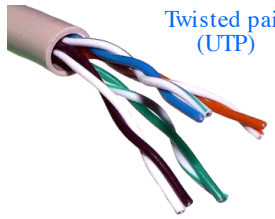
- provided by telco (cellular) operator, 10's km range
- between 1 and 10 Mbps
- 3G, 4G: LTE

- End-systems connect to router via a radio base station (an "access point")
  - » Inherently a shared transmission medium

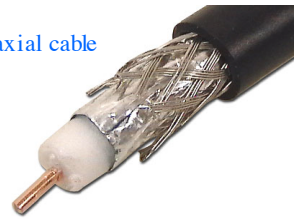
Physical Transmission Media

Transmitting the bits and bytes

Twisted pair (UTP)



Coaxial cable

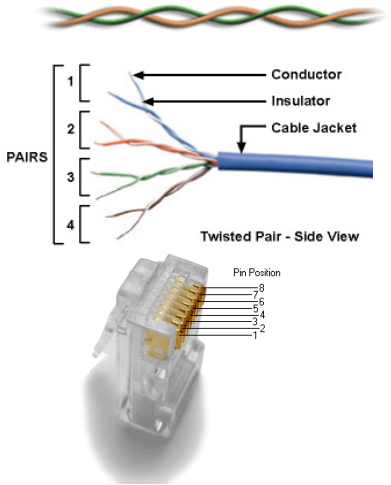


- Transmission is the propagation of an electromagnetic wave (or optical pulse) through a physical medium
- Media types
  - » Guided media — signals propagate in solid media (copper, fiber)
  - » Unguided media — signals propagate freely (radio, infrared)

Physical Transmission Media

Twisted pair copper wiring

- What do you use?
  - » Twisted Pair (UTP) — Two insulated copper wires
- Category 3 UTP:
  - » Traditional phone wires, 10 Mbps Ethernet
- Category 5/5e UTP:
  - » 100Mbps Ethernet
  - » Gigabit possible
  - » Distance limited (100 *m*)
- Category 6/6a UTP:
  - » 10Gbps Ethernet
  - » Distance limited (37-55 *m*)



Physical Transmission Media

Coaxial and fiber optic cable

- Coaxial cable
  - » Wire (signal carrier) within a wire (shield)
    - ❖ Baseband: single channel on cable
    - ❖ Broadband: multiple channels on cable
  - » Bi-directional transmission
  - » Largely used for cable TV

- Fiber optic cable
  - » Glass fiber carrying light pulses
  - » Higher-speed operation:
    - ❖ 100-1,000 Mbps Ethernet
    - ❖ High-speed point-to-point transmission (*e.g.*, 10 Gbps)
  - » Low signal attenuation – long distances
  - » Low error rate

Physical Transmission Media

Radio frequency ("RF")

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

- Radio link types:
  - » Microwave
    - ❖ Up to 45 Mbps channels
  - » LAN (*e.g.*, 802.11)
    - ❖ 2 Mbps, 11, 56 Mbps
  - » Wide-area (*e.g.*, cellular)
    - ❖ CDPD, 10's Kbps
    - ❖ 3G, 100's Kbps
    - ❖ 4G, 100's Kbps - 1-5 Mbps
    - ❖ LTE, 10-20 Mbps
  - » Satellite
    - ❖ Up to 50Mbps channel (or multiple smaller channels)
    - ❖ 270 msec end-end delay
    - ❖ Geosynchronous versus LEOS