Computer Networks（01）

An Introduction

lijt@fudan.edu.cn

Some slides from Jim Kurose

Introduction

Our goal:

- get "feel" and terminology
- more depth, detail *later* in course
- approach:
  - use Internet as example

Overview:

- what's the Internet
- what's a protocol?
- network edge
- network core
- access net, physical media
- Internet/ISP structure
- performance: loss, delay
- protocol layers, service models
- network modeling

Course Non-goals

- **Learn how to configure a Router**
  - That requires a class all by itself
  - Huawei/Cisco teaches those classes
  - Our perspective will be broader

- **Become "Internet Experts"**
  - The Internet will be our frequent ***motivating example***
  - ***Our perspective will be broader***
  - ***Focus on Internet, but understand important common issues and challenges***

Why *not* an "Internet class"?

- **Is there anything other than the Internet?**

  Give two examples ?

Course Goals

- **Think "the network way"**
  - Distributed coordination is hard
- **Learn how computer networks work**
  - Problems, approaches, protocols, software
- **Learn how to write network applications**
- **Hands-on understanding of network internals**
  - Course Projects

What Is a Network?

- Collection of nodes and links that connect them
- This is vague. Why? Consider different networks:
  - Internet
  - Social networks
  - Telephone
  - Others
    - – transport nets, sensor nets, cellular nets, …

What is a Computer Network

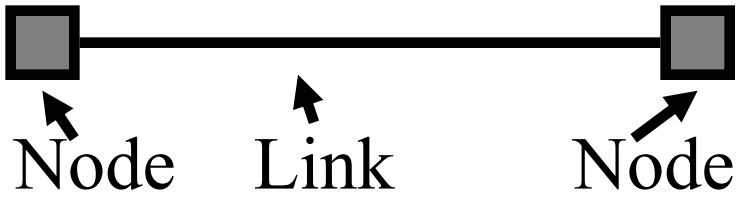
- Interconnected;
- Autonomous;
- Collection.

Abstraction:

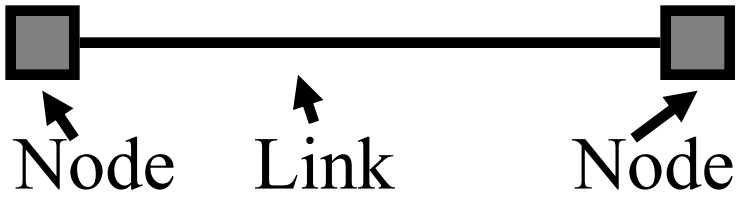
End system +Link +Switching node

Host + Link + Router (for Internet)

How to Draw a Computer Network



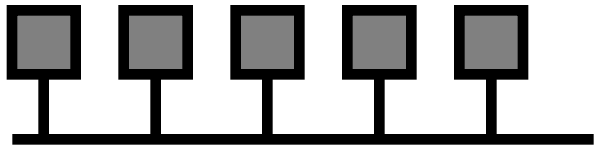
Building block: The Links



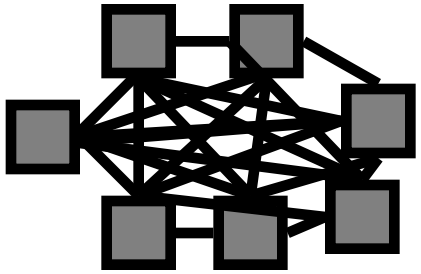
- Electrical questions
  - Voltage, frequency, …
  - Wired or wireless?
- Link-layer issues: How to send data?
  - When to talk – can everyone talk at once?
  - What to say – low-level format?
  - Stay tuned for Chapter 5

- Okay… what about more nodes?

- … But what if we want more hosts?



One wire

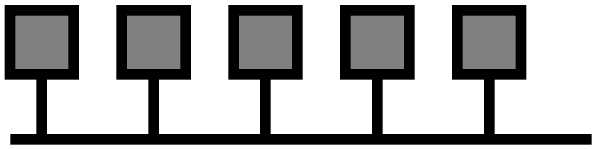


Wires for everybody!

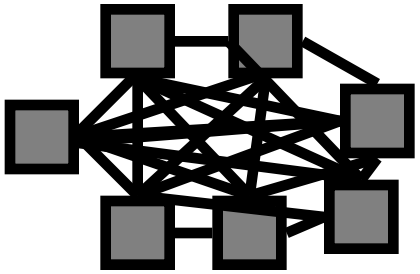
- Scalability?!

Scalability: how to solve ?

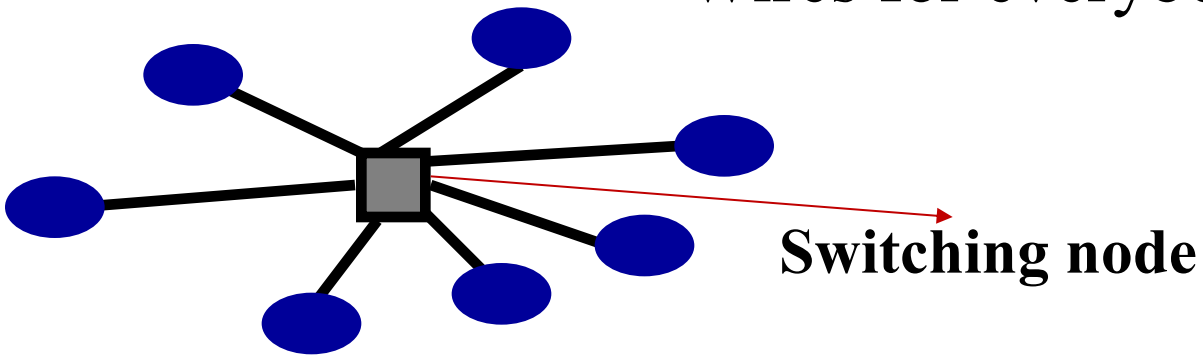
- … But what if we want more hosts?



One wire

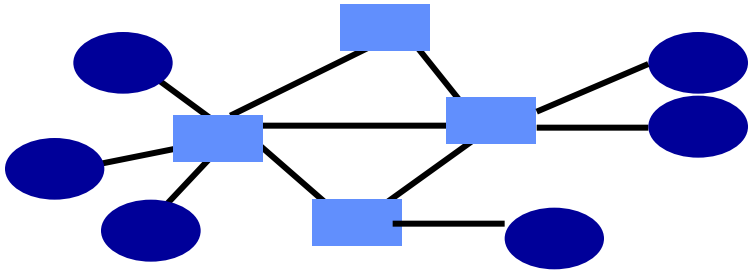


Wires for everybody!



Multiplexing!

- Need to share network resources

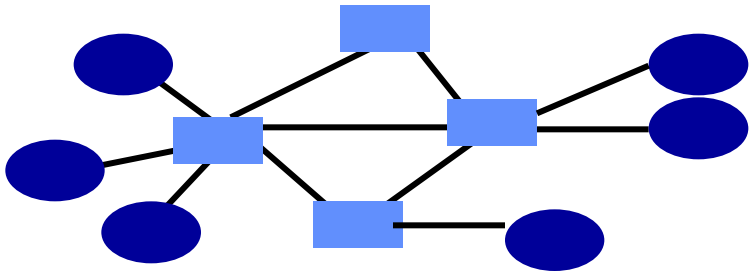


- How? Switched network
  - Party "A" gets resources sometimes
  - Party "B" gets them sometimes
- Interior nodes act as "Routers" or "Switches"
- What mechanisms can share resources?

Review:

- Layering
  - Abstraction
  - OSI vs. TCP/IP
- Control plane and Data Plane
  - Design considerations
- Basic Model for computer networks

End system +Link +Switching node



Networks Juggle Many Goals

- Efficiency – resource use; cost
- The "ilities":
  - Evolvability
  - Managability
  - Security (securability, if you must)
  - Ease of:
    - Creation
    - Deployment
    - Management
    - *Creating useful applications*
  - Scalability

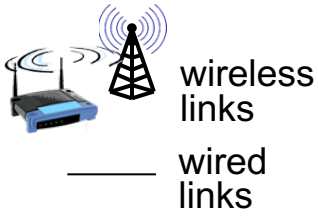
A Protocol for Packet Network Interconnection. Vinton Cerf and Bob Kahn
The Design Philosophy of the DARPA Internet Protocols. David D. Clark

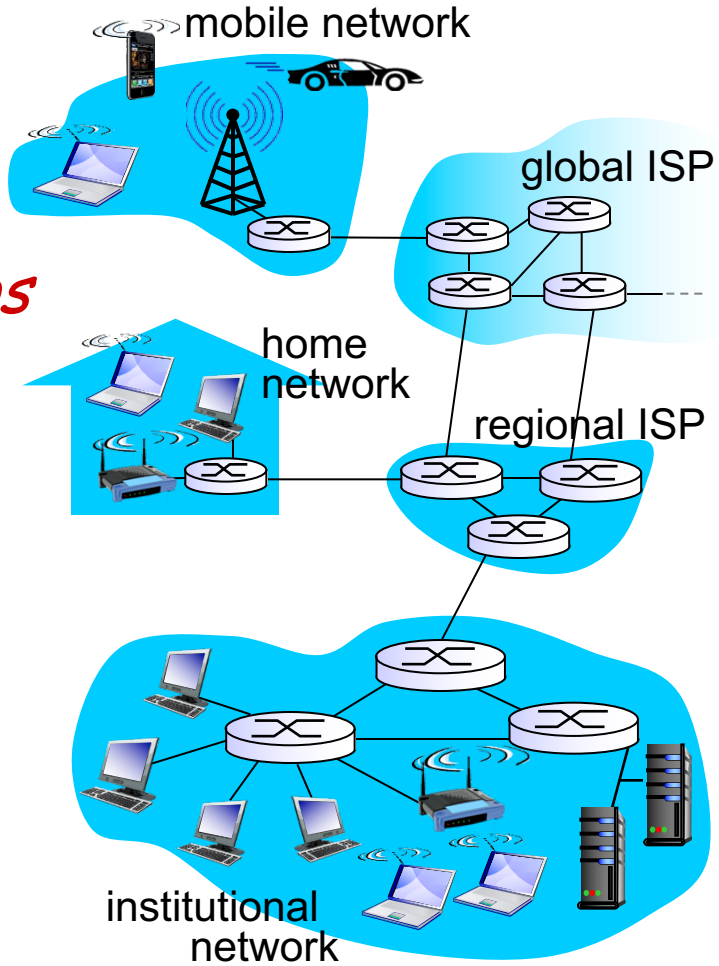
Roadmap

1.1 What *is* the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

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

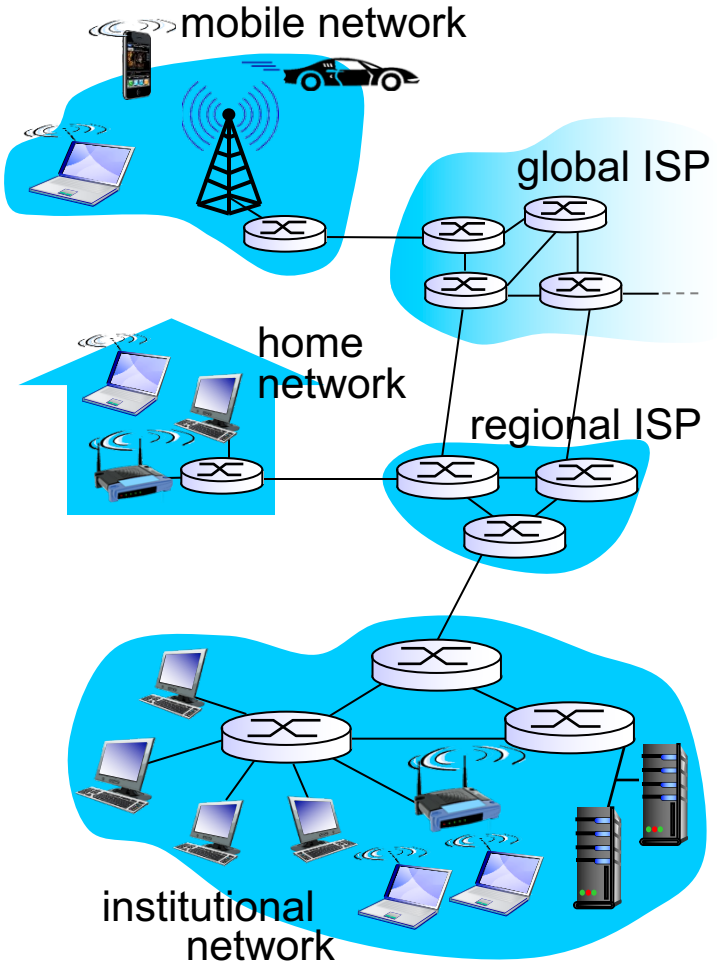
- millions of connected computing devices: *hosts*
  - running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: **bandwidth**
- *routers*: forward packets (chunks of data)





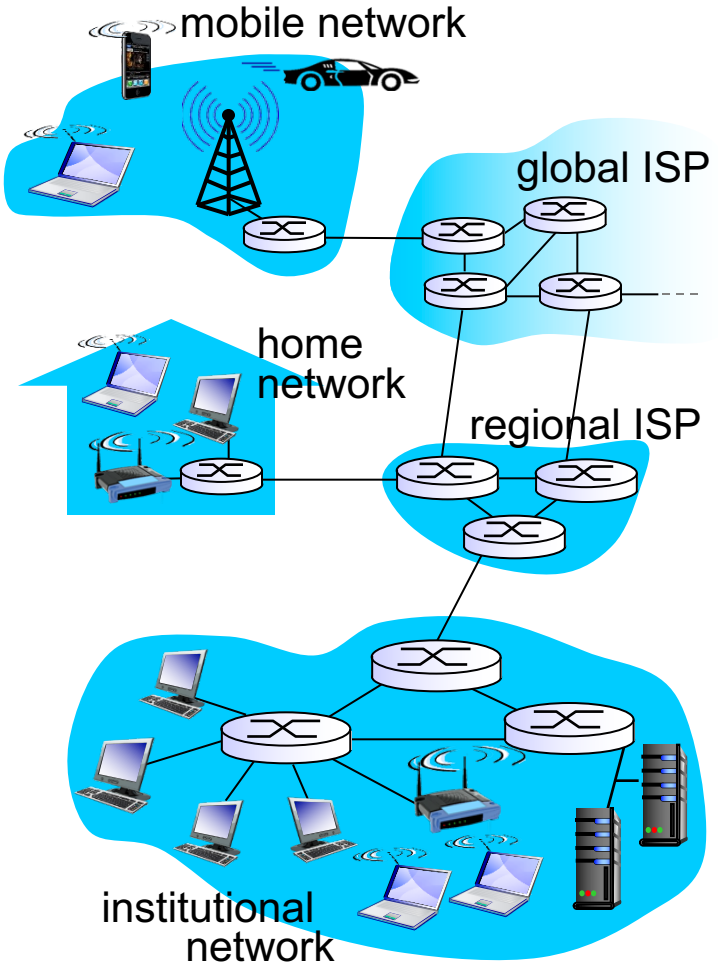
What's the Internet: "nuts and bolts" view

- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, Ethernet
- *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:
  - Web, VoIP, email, games, e-commerce, file sharing
- *communication services provided to apps:*
  - reliable data delivery from source to destination
  - "best effort" (unreliable) data delivery



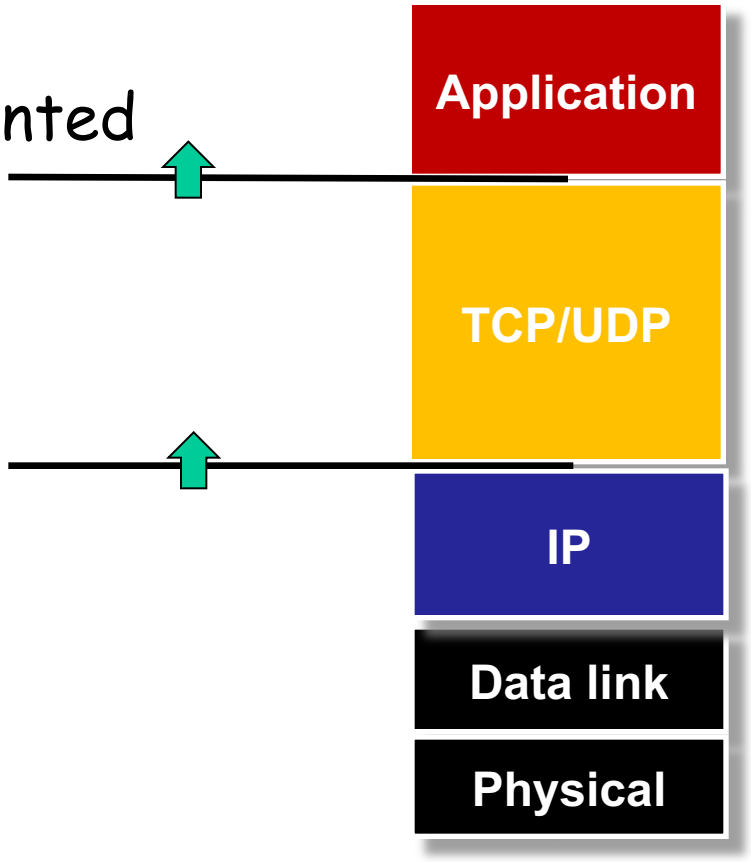
Connectionless unreliable vs. connection-oriented reliable

What's the Internet: a service view

Provided Service:

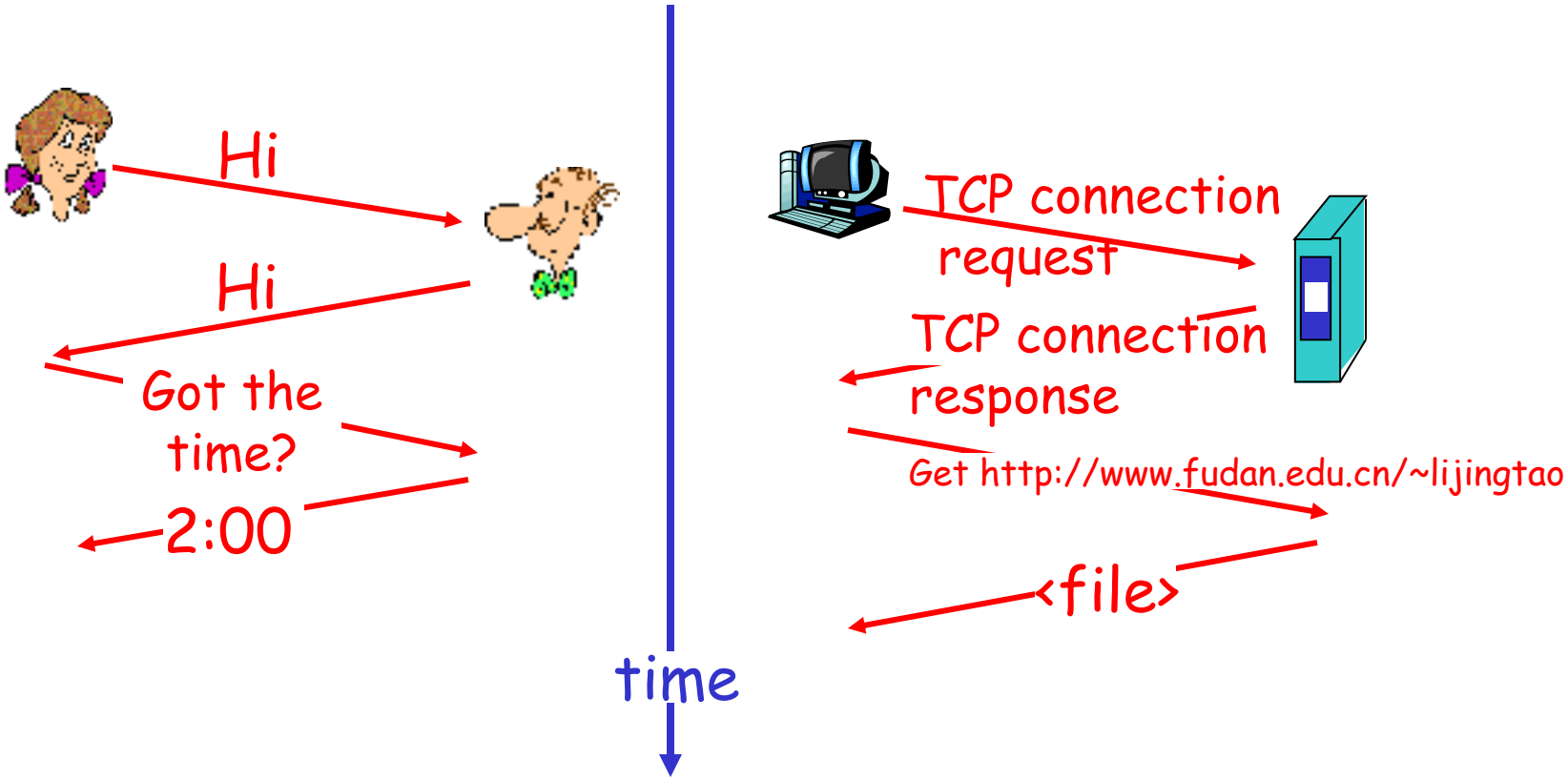
- TCP: connection-oriented
- UDP: conectionless

Provided Service: ?



What's a protocol?

a human protocol and a computer network protocol:



Q: Other human protocols?

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

Introduction: roadmap

1.1 What *is* the Internet?

1.2 Network edge

1.3 Network core

1.4 Network access and physical media

1.5 Internet structure and ISPs

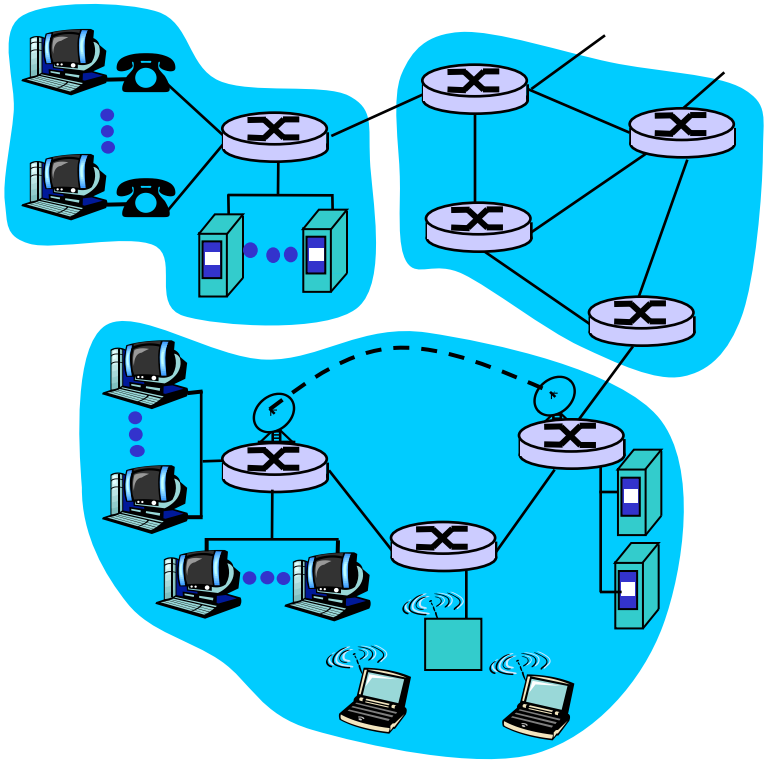
1.6 Delay & loss in packet-switched networks

1.7 Protocol layers, service models

1.8 History

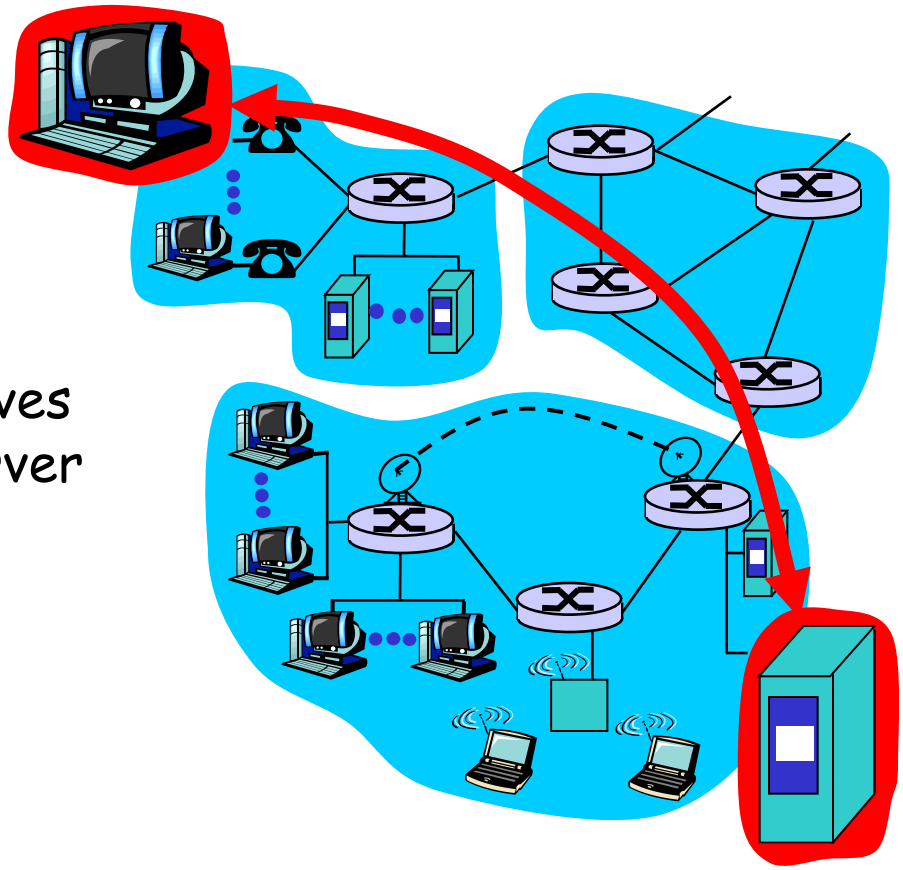
A closer look at network structure:

- network edge:
  applications and hosts
- network core:
  - routers
  - network of routers
- access networks, physical media:
  - communication links
  - routers



The network edge:

- 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
- peer-peer model:
  - minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent, KaZaA



Network edge: connection-oriented service

Goal: data transfer between end systems

- *handshaking:* 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]:
  - connectionless
  - unreliable data transfer
  - no flow control
  - no congestion control

App's using TCP:

- HTTP (Web), FTP (file transfer), Telnet (remote login), SMTP (email)

App's using UDP:

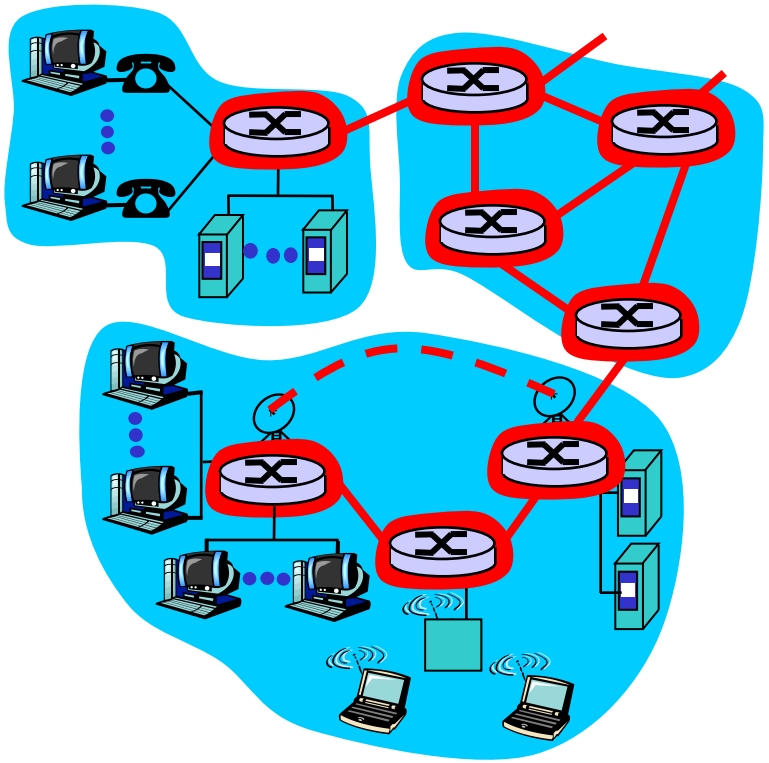
- streaming media, QQ, teleconferencing, DNS, Internet telephony

Introduction: roadmap

1.1 What *is* the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

The Network Core

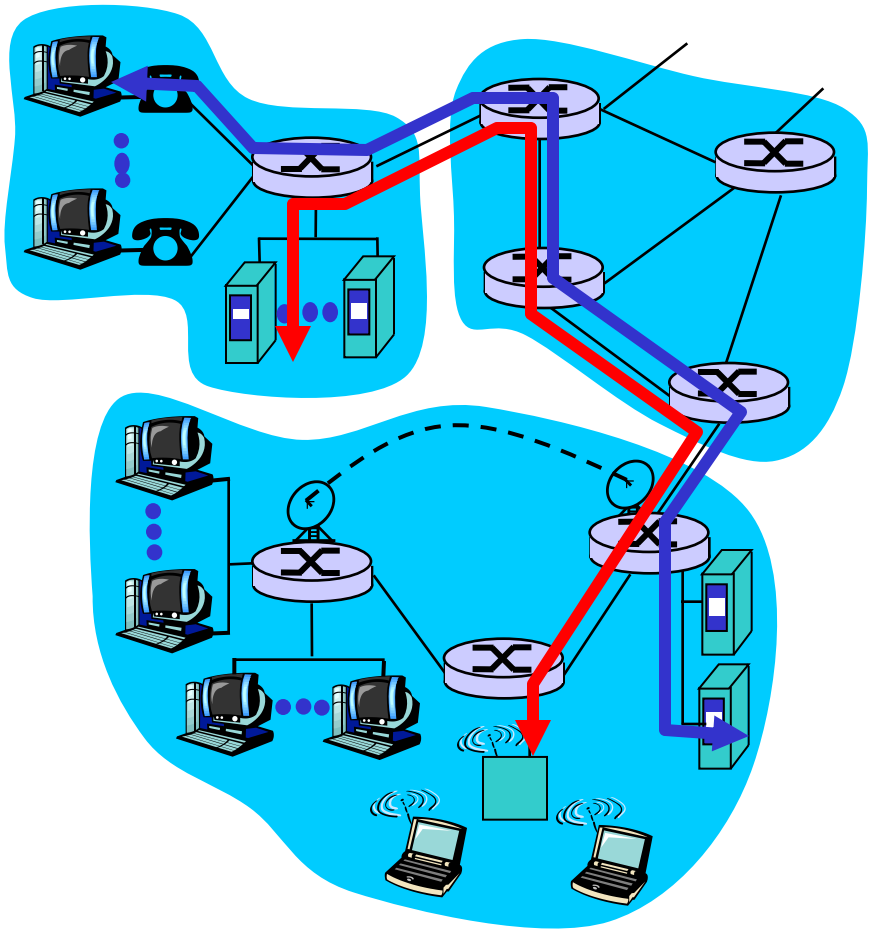
- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



Network Core: Circuit Switching

End-end resources reserved for "call"

- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required



Network Core: Circuit Switching

network resources (e.g., bandwidth) divided into "pieces"

- pieces allocated to calls
- resource piece *idle* if not used by owning call *(no sharing)*

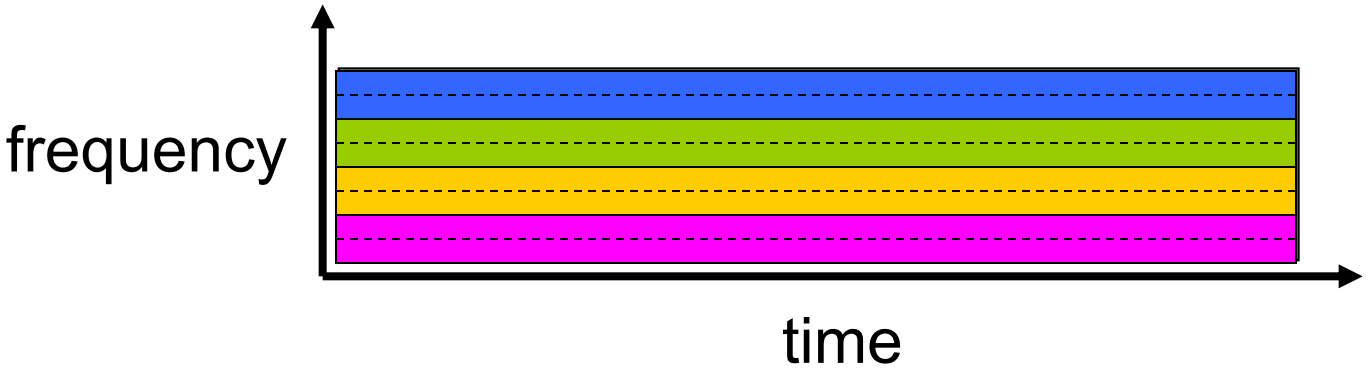
- dividing link bandwidth into "pieces"
  - frequency division
  - time division

Circuit Switching: FDM and TDM

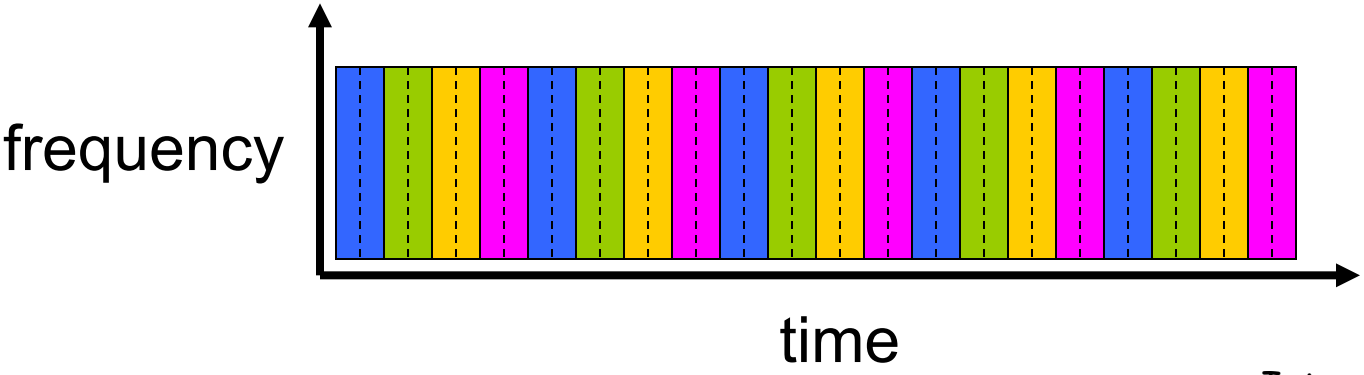
Example:

4 users

FDM



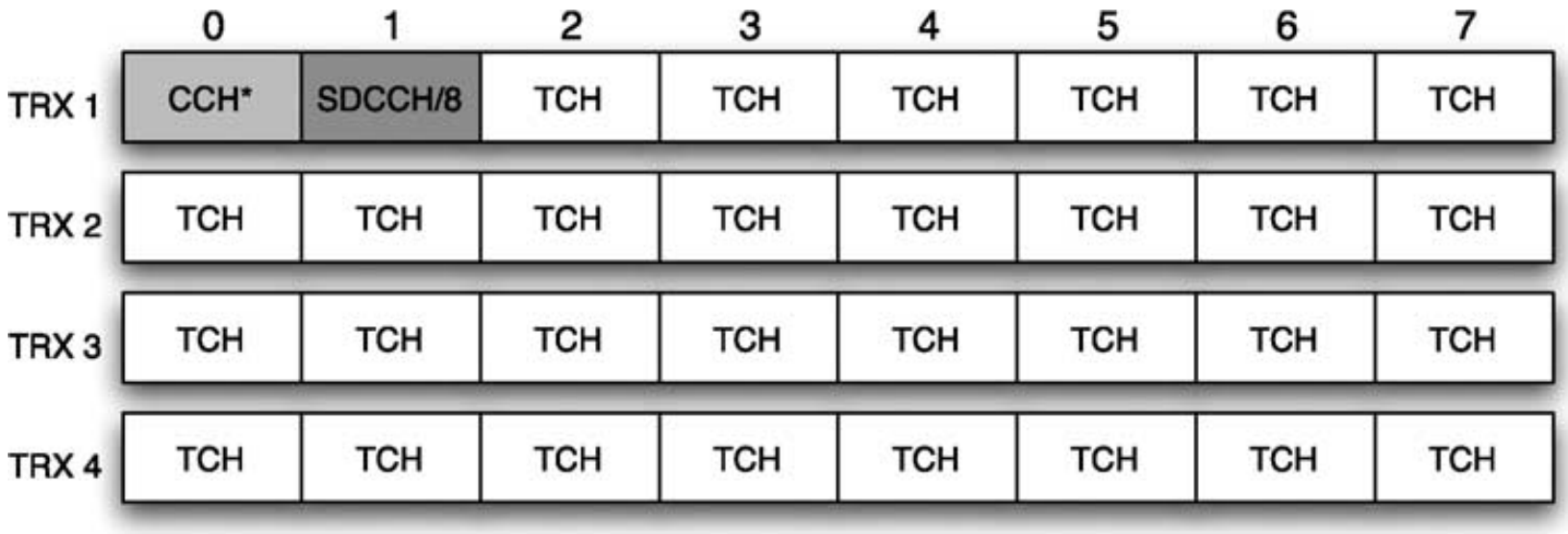
TDM



More Examples

GSM (a single cell)

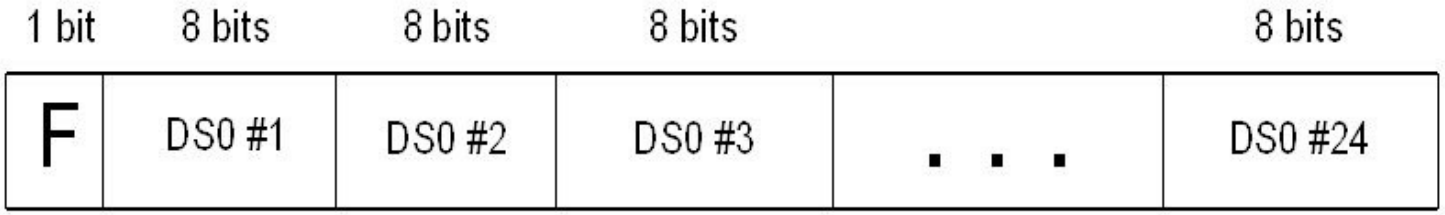
- 4 Carriers --FDM
- 8 time slots for each carrier --TDM



T1/DS1 (Digital Signal Designator)

- In the T1 system, voice or other analog signals are sampled 8,000 times a second and each sample is digitized into an 8-bit word.
- With 24 channels being digitized at the same time, a 192-bit/slot frame (24 channels each with an 8-bit word) is thus being transmitted 8,000 times a second.
- Each frame is separated from the next by a single bit, making a 193-bit block. The 192 bit frame multiplied by 8,000 and the additional 8,000 framing bits make up the T1's 1.544 Mbps data rate.

T1 Frame Format



- Each DS0 called a **time slot**
- 8000 frames/sec * 8 bits/slot = 64 Kbps
- 24 * 8 + 1 = 193 bits/frame
- 8000 frames/sec * 193 bits/frame = 1.544 Mbps
- 8000 Framing bits sent per second

Transmission Rates

Digital Signal Designator	Data Rate	DS0 Multiple	T-Carrier
DS0	64 Kbps	1	-
DS1	1.544 Mbps	24	T1
DS3	44.736 Mbps	672	T3
OC3	155.52 Mbps		Optical Carrier
OC12	622.08 Mbps		
OC192	10 Gbps		
OC256	13.271 Gbps		
OC768	40 Gbps		

Numerical example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Let's work it out!

Numerical example

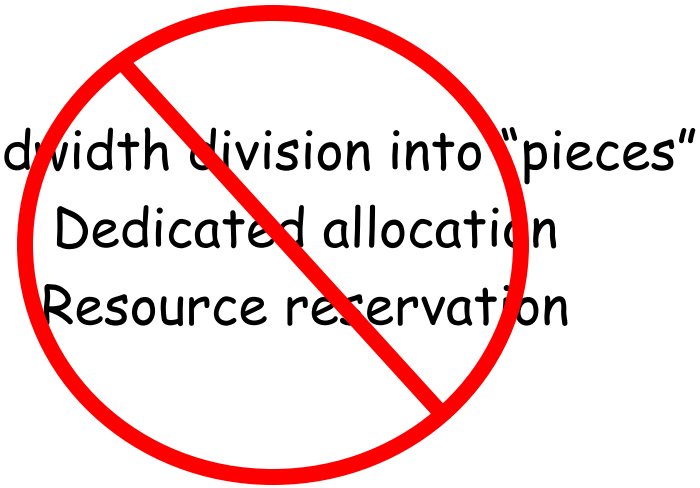
- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Let's work it out! (10.5sec)

Network Core: Packet Switching

each end-end data stream divided into *packets*

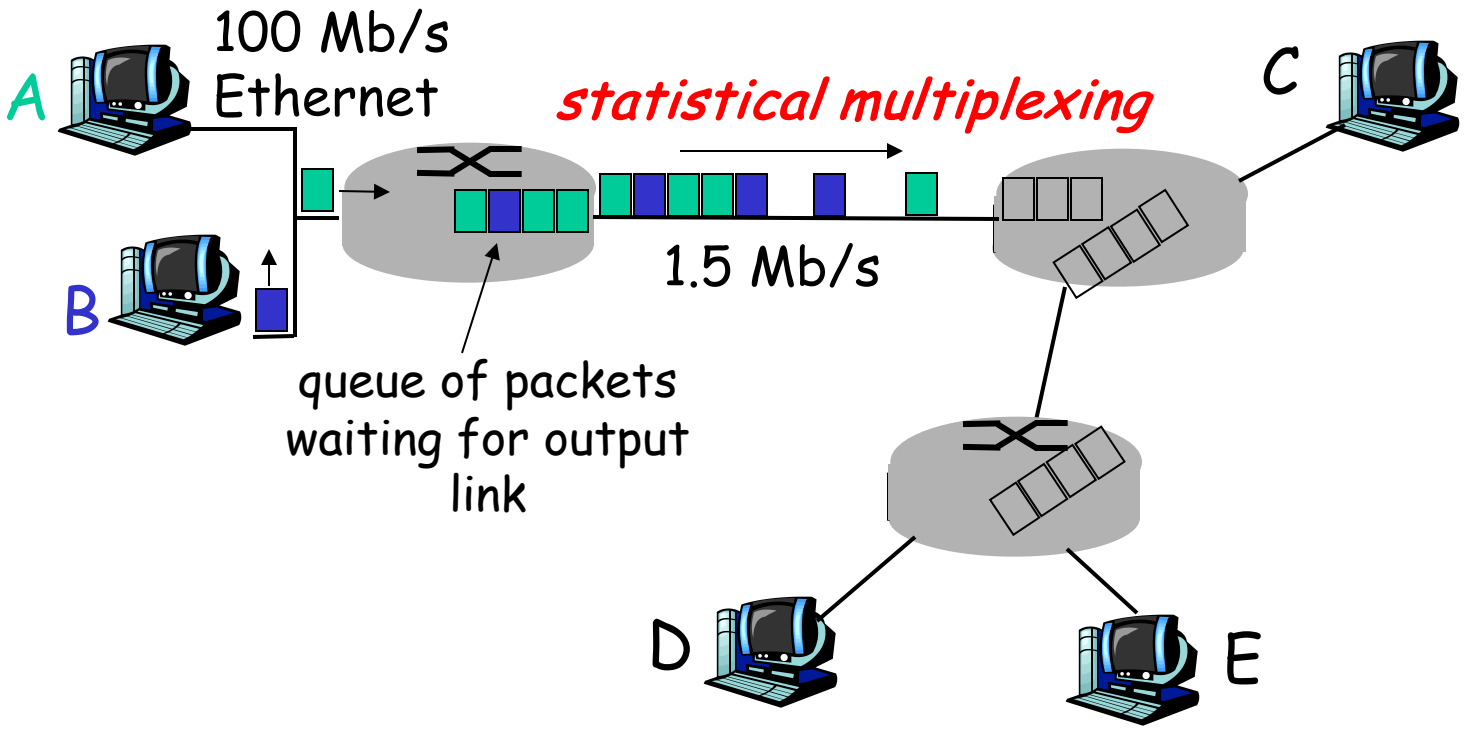
- user A, B packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*



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
  - Node receives complete packet before forwarding

Packet Switching: Statistical Multiplexing



Sequence of A & B packets does not have fixed pattern, shared on demand ➡ *statistical multiplexing*.

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

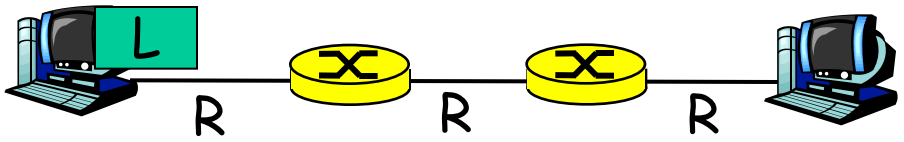
Packet switching versus circuit switching

Is packet switching a "winner?"

- Great for bursty data
  - resource sharing
  - simpler, no call setup
- 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 (known as "QoS")

Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

Packet-switching: store-and-forward



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

} more on delay shortly …

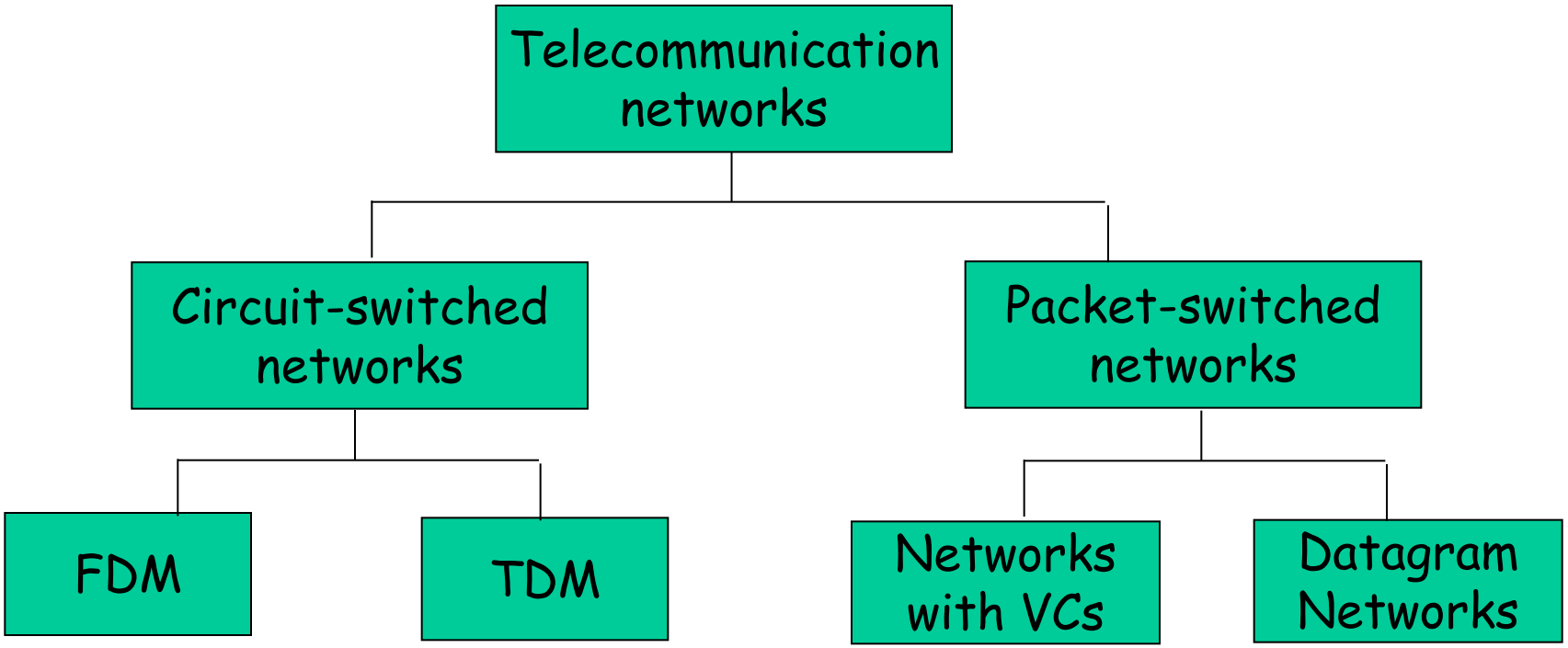
Example:

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

Packet-switched networks: forwarding

- *Goal:* move packets through routers from source to destination
  - we'll study several path selection (i.e. routing) algorithms (chapter 4)
- datagram network:
  - *destination address* in packet determines next hop
  - routes may change during session
  - analogy: driving, asking directions
- virtual circuit network:
  - each packet carries tag (virtual circuit ID), tag determines next hop
  - fixed path determined at *call setup time*, remains fixed thru call
  - *routers maintain per-call state*

Network Taxonomy



- Datagram network is *not* either connection-oriented or connectionless.
- Internet provides both connection-oriented (TCP) and connectionless services (UDP) to apps.

Introduction: roadmap

1.1 What *is* the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

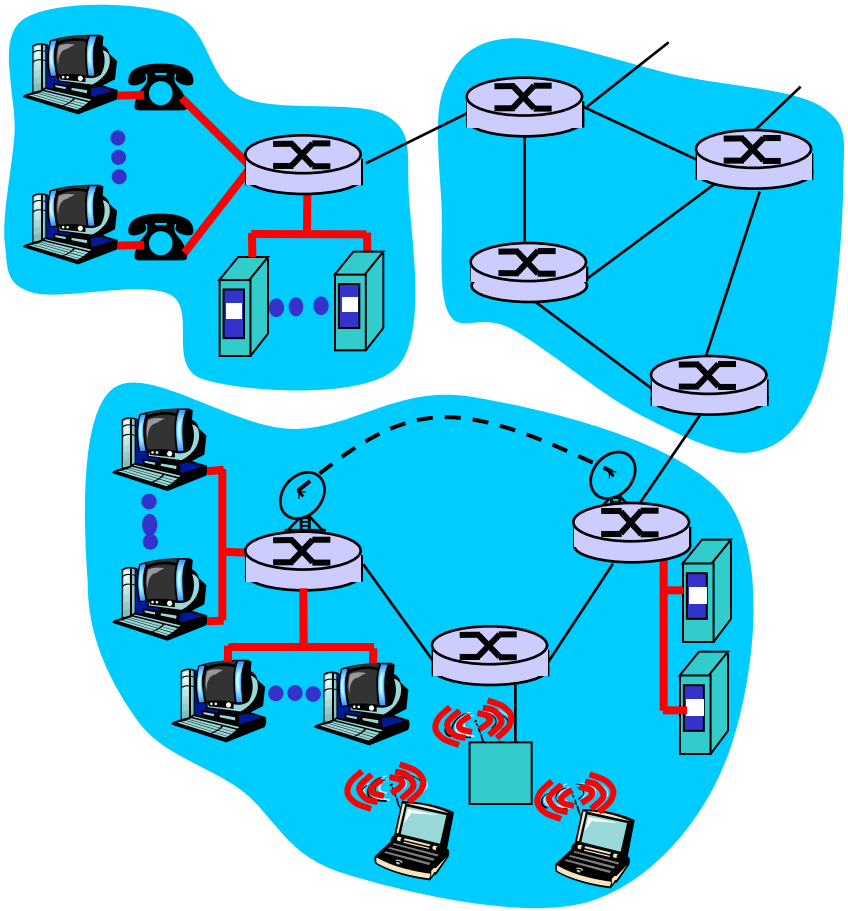
Access networks and physical media

Q: How to connect end systems to edge router?

- residential access nets
- institutional access networks (school, company)
- mobile access networks

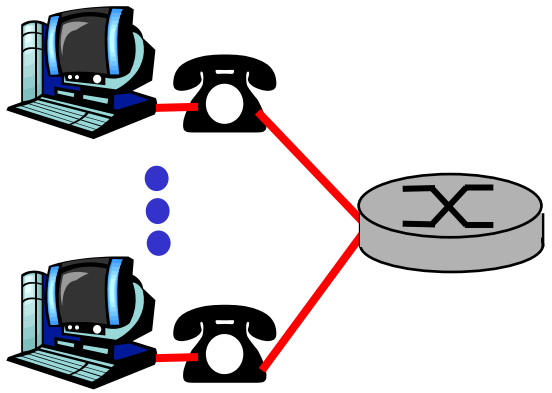
Keep in mind:

- bandwidth (bits per second) of access network?
- shared or dedicated?



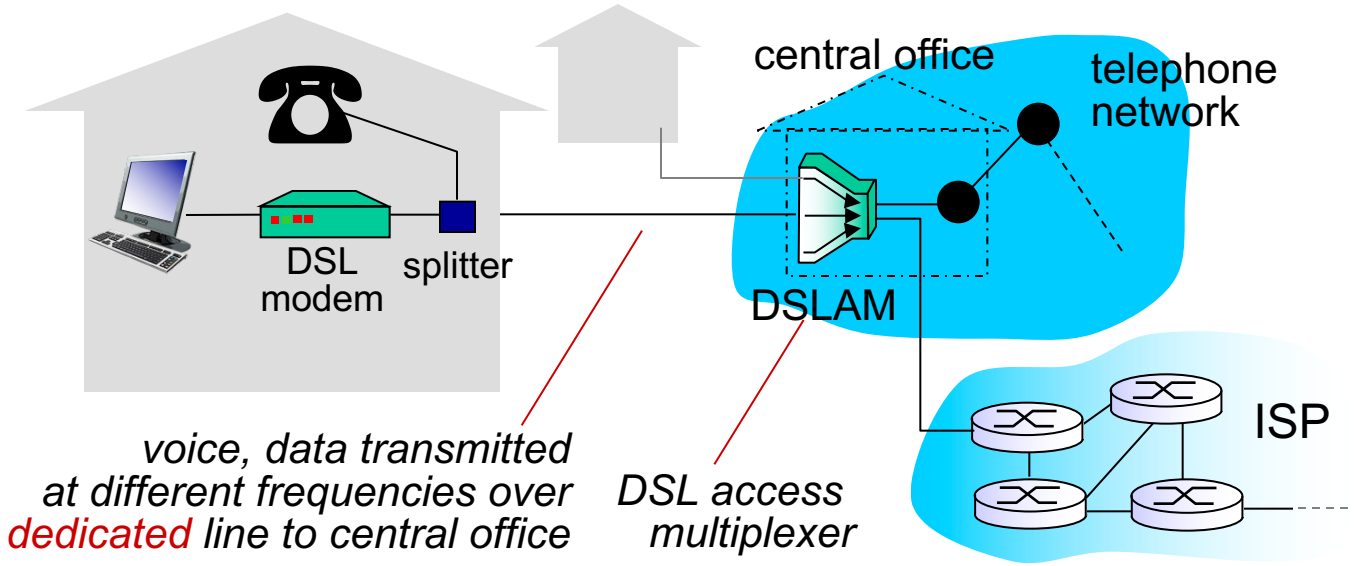
Residential access: point to point access

- Dialup via modem
  - up to 56Kbps direct access to router (often less)
  - Can't surf and phone at same time: can't be "always on"



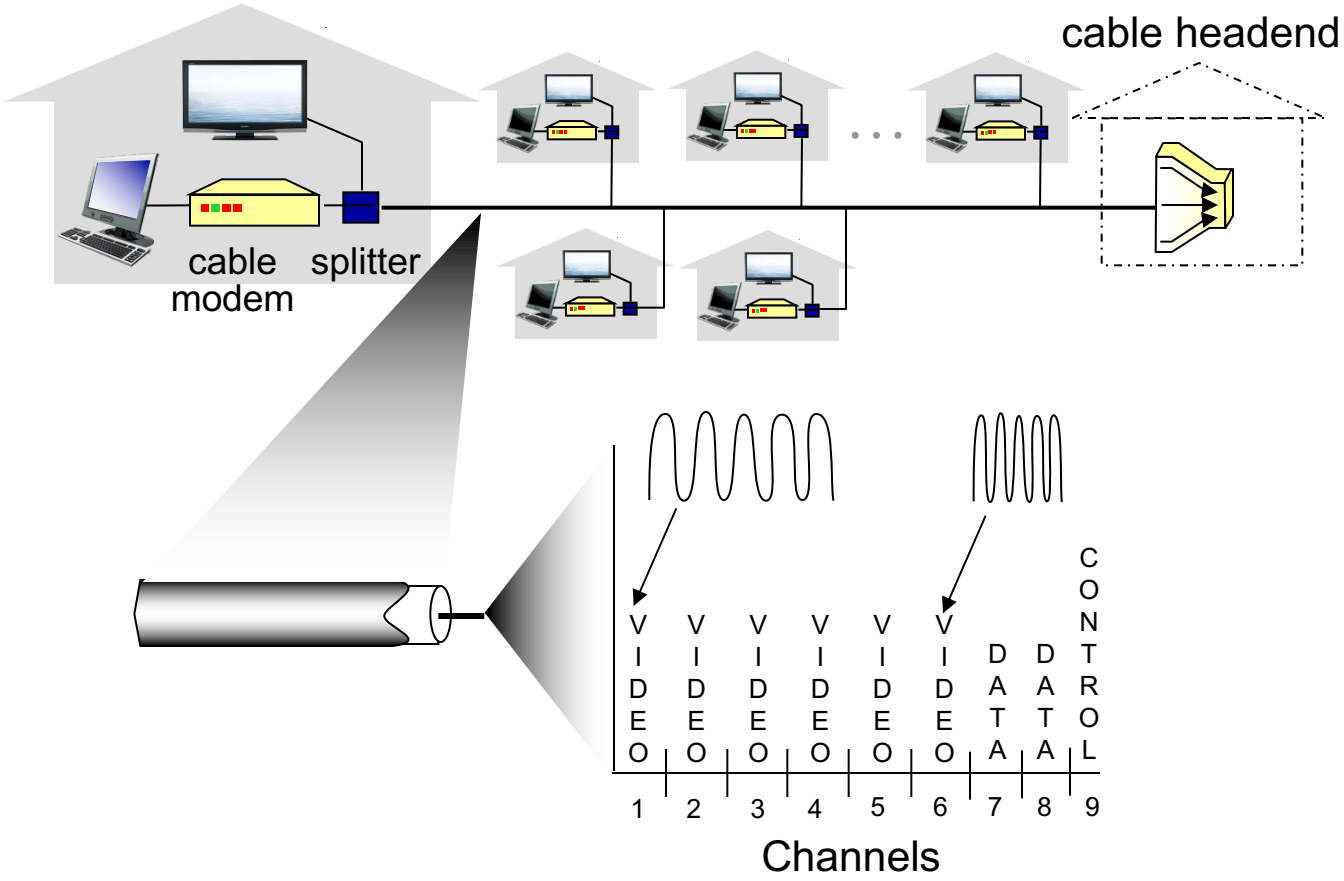
- ADSL: asymmetric digital subscriber line
  - FDM: 50 kHz - 1 MHz for downstream
    4 kHz - 50 kHz for upstream
    0 kHz - 4 kHz for ordinary telephone

Access net: 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 net: cable network



frequency division multiplexing: different channels transmitted in different frequency bands

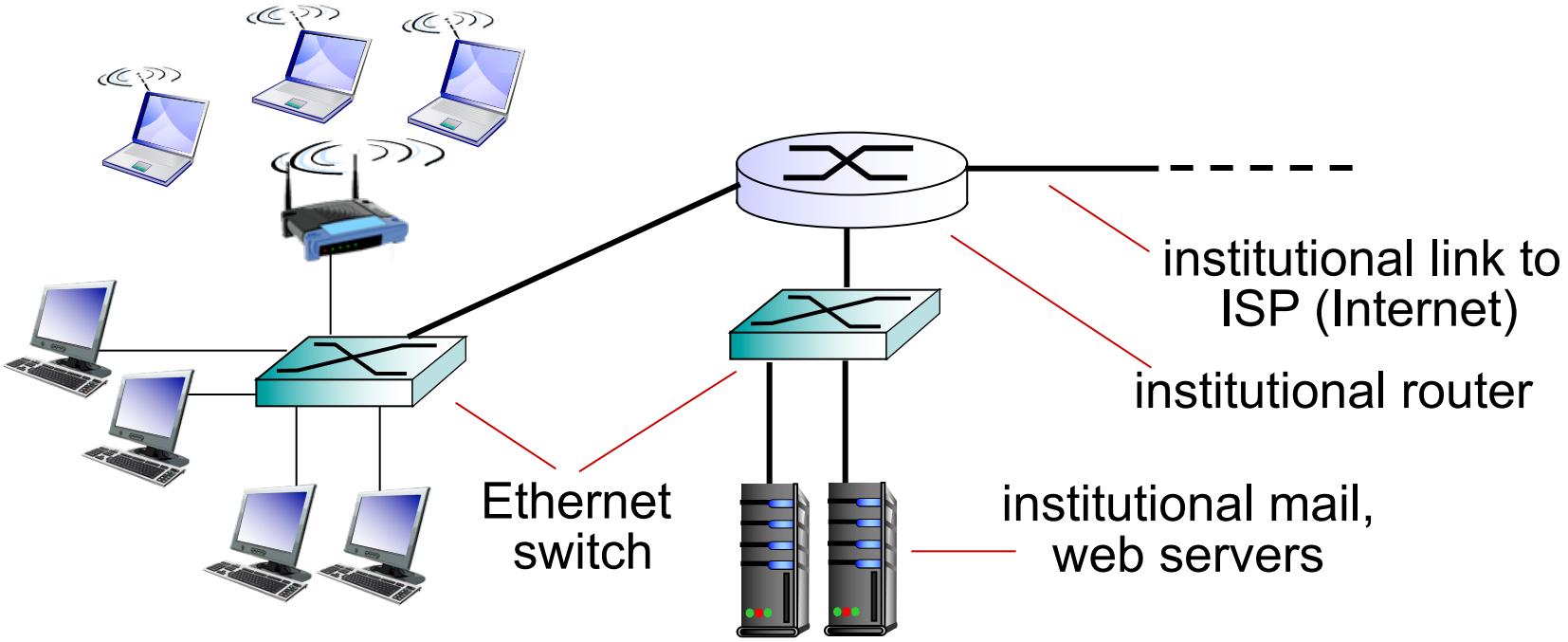
Residential access: cable modems

- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- network of cable and fiber attaches homes to ISP router
  - homes share access to router
- deployment: available via cable TV companies

Enterprise access nets: local area networks

- company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - shared or dedicated link connects end system and router
  - 10 Mbps, 100Mbps, Gigabit Ethernet

Enterprise access networks



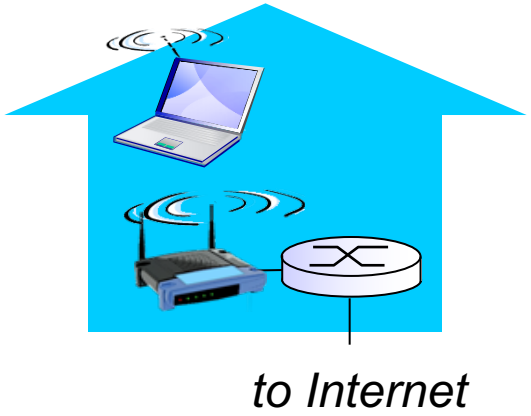
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

Wireless access networks

- shared *wireless* access network connects end system to router
  - via base station aka "access point"

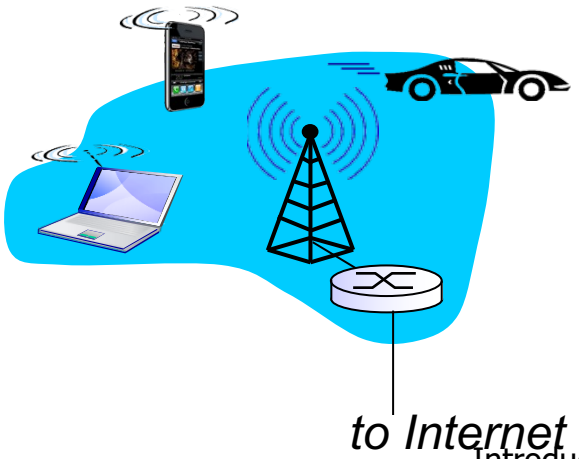
wireless LANs:

- within building (50 m)
- 802.11b/g/n (WiFi): 11, 54, 540Mbps transmission rate



wide-area wireless access

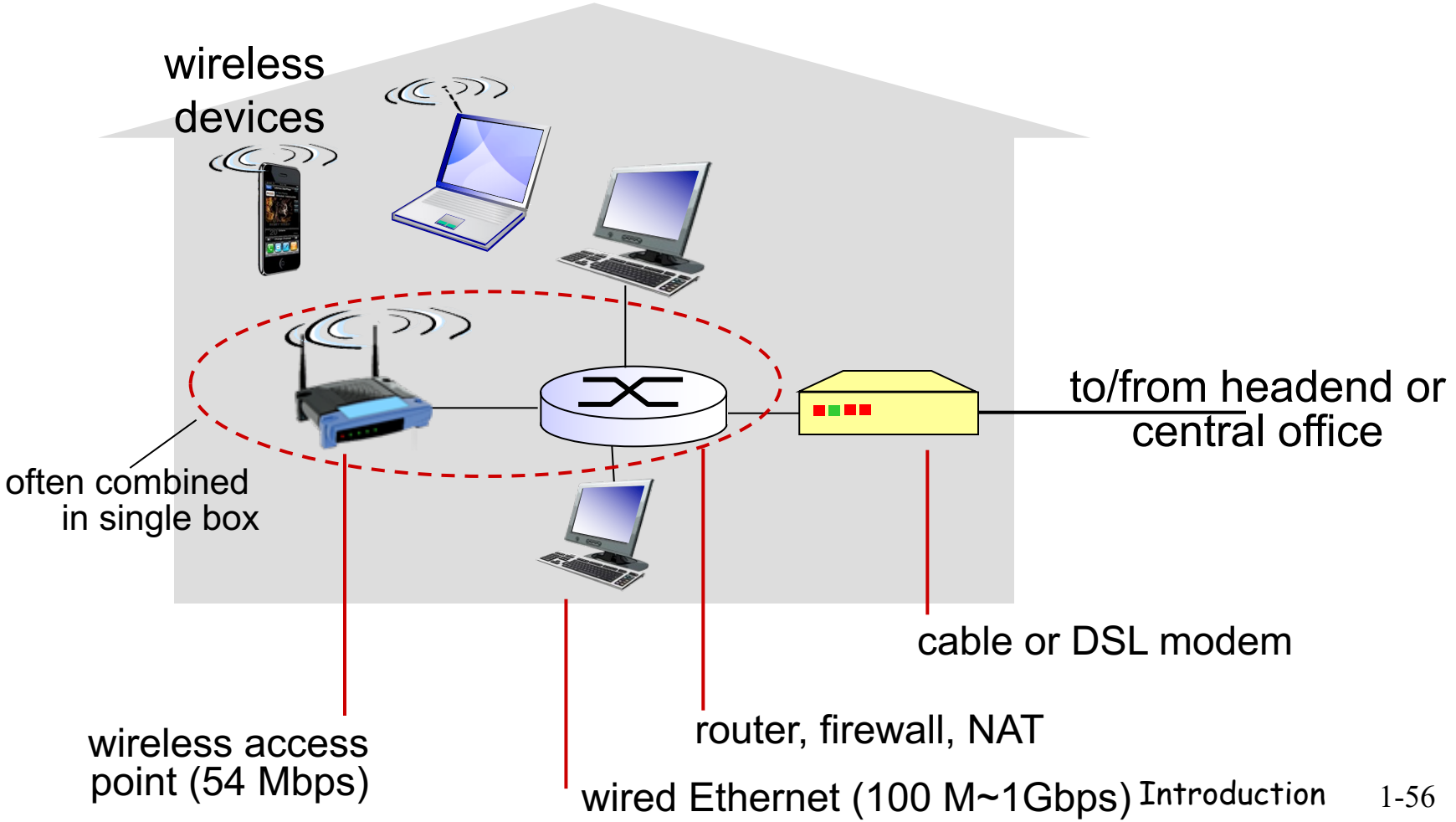
- provided by telco (cellular) operator, 10's Km
- between 1 and X00 Mbps
- 3G, 4G, LTE, WiMax



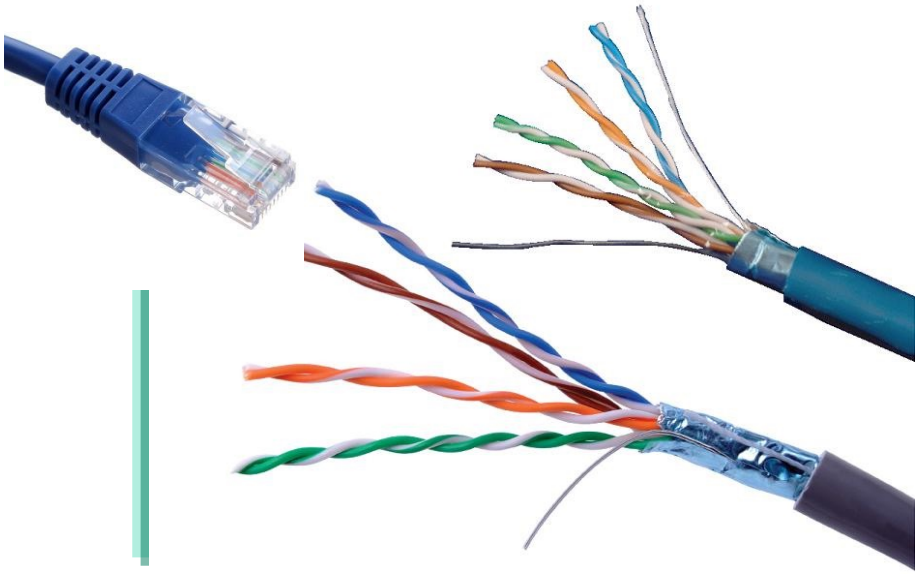
Home networks

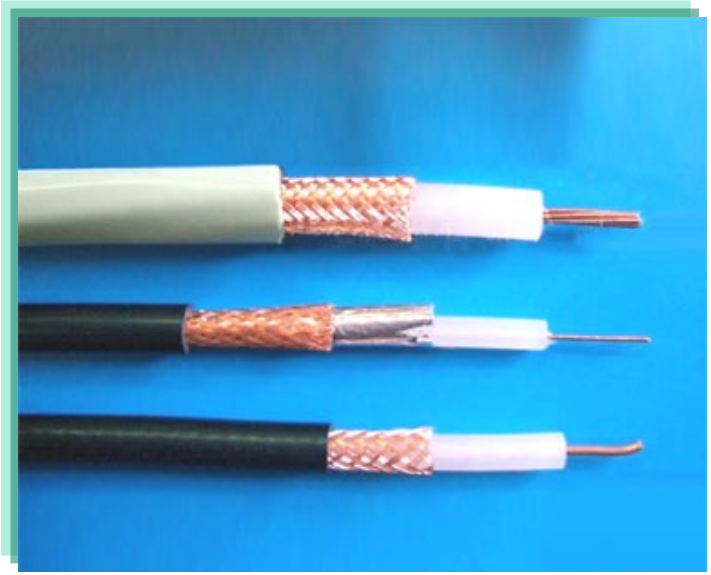
Typical home network components:

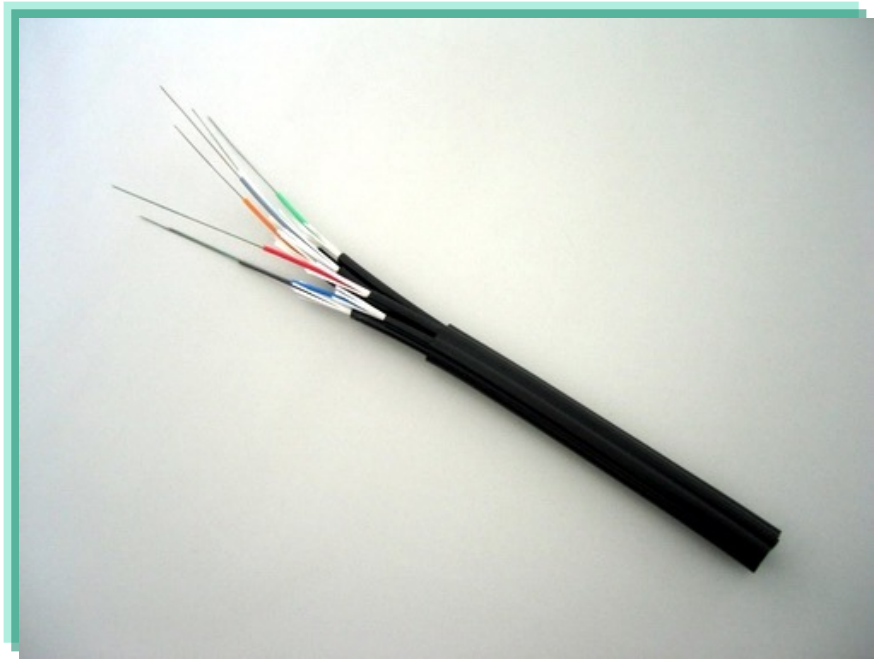
- ADSL, cable modem, or FTTH (eg. EPON)
- router/firewall/NAT
- Ethernet
- wireless access point



Physical Media







Physical Media

- Bit: propagates between transmitter/rcvr 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 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5: 100Mbps Ethernet

    1 Gpbs Ethernet
  - Category 6: 10Gbps

Physical Media: coax, fiber

Coaxial cable:

- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- broadband:
  - multiple channels on cable
  - HFC

Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gps)
- low error rate: repeaters spaced far apart ; immune to electromagnetic noise

Physical media: radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

Radio link types:

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., Wifi)
  - 11Mbps, 54 Mbps, 540Mbps…
- wide-area (e.g., cellular)
  - e.g. 3G: ~2Mbps; 4G: 1xxMbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude