Chapter 1: roadmap

- What is the Internet?
- Protocols
- Network Structure
- Network Types
- Network topologies
- Network edge
- Network core, transmission types
- Network access and physical media
- Internet structure and ISPs
- Delay & loss in packet-switched networks
- Protocol layers, service models
- History

The Network Core, Transmission Types

- 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: FDMA and TDMA

FDMA
- Example:
  - 4 users

TDMA
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

Bandwidth division into pieces
- Dedicated allocation
- Resource reservation

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.

Packet-switched networks: forwarding

- Goal: move packets through routers from source to destination
  - We’ll study several path selection (i.e., routing) algorithms
- 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
Transmission techniques comparison

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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"

- DSL: asymmetric digital subscriber line
  - up to 1 Mbps upstream (today typically < 256 kbps)
  - up to 8 Mbps downstream (today typically < 1.5 Mbps)
  - FDM: 50 kHz - 1 MHz for downstream
  - 4 kHz - 50 kHz for upstream
  - 0 kHz - 4 kHz for ordinary telephone

Residential access: cable modems

- HFC: hybrid fiber coax
  - asymmetric: up to 10Mbps downstream, 1 Mbps upstream
- network of cable and fiber attaches homes to ISP router
  - shared access to router among homes
  - issues: congestion, dimensioning
- deployment: available via cable companies, e.g., Charter, CommCast, MediaOne

Diagram: http://www.cabledatacomnews.com/cmic/diagram.html
Cable Network Architecture: Overview

Typically 500 to 5,000 homes
Cable Network Architecture: Overview

Cable Network Architecture: Overview

Company access: 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 Mbs, 100Mbps, Gigabit Ethernet
- deployment: institutions, home LANs happening now rapidly
- LANS

Wireless access networks
- shared wireless access network connects end system to router
  - via base station aka "access point"
  - wireless LANs:
    - 802.11b/g (WiFi): 11 Mbps
- wider-area wireless access
  - provided by telco operator
  - 36 – 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

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 TP: 100 Mbps Ethernet

**Coaxial cable**
- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- broadband:
  - multiple channel 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., 5 Gbps)
- 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., WaveLAN)
  - 2 Mbps, 11 Mbps
- wide-area (e.g., cellular)
  - e.g. 3G: hundreds of kbps
- satellite
  - up to 50 Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus LEOS

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

Tier-1 providers also interconnect at public network access points (NAPs)
**Tier-1 ISP: e.g., Sprint**

Sprint US backbone network

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**Internet structure: network of networks**

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

![Diagram of Internet structure showing tier-1 and tier-2 ISPs]

- Tier-2 ISPs also peer privately with each other, interconnect at NAP

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**Internet structure: network of networks**

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

![Diagram of Internet structure showing tier-3 and local ISPs]
Internet structure: network of networks

- a packet passes through many networks!

![Diagram of Internet structure: network of networks]

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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

![Diagram showing packet delay and loss]

- packet being transmitted (delay)
- packets queuing (delay)
- free (available) buffers: arriving packets dropped (loss) if no free buffers

WMU-CS, Dr. Gupta
Four sources of packet delay:

1. 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:
   - \( R = \text{link bandwidth (bps)} \)
   - \( L = \text{packet length (bits)} \)
   - Time to send bits into link = \( L/R \)

4. Propagation delay:
   - \( d = \text{length of physical link} \)
   - \( s = \text{propagation speed in medium (~2x10^8 m/sec)} \)
   - Propagation delay = \( d/s \)

Note: \( s \) and \( R \) are very different quantities!

Caravan analogy:

- Cars "propagate" at 100 km/hr
- Toll booth takes 12 sec to service a car (transmission time)
- Car-bit, caravan ~ packet
- Q: How long until carrot is lined up before 2nd toll booth?

- Time to "push" entire caravan through toll booth onto highway = \( 12*10 = 120 \text{ sec} \) (transmission delay)
- Time for last car to propagate from 1st to 2nd toll booth:
  \[ 100\text{km} / (100\text{km/hr}) = 1 \text{ hr} \] (prop delay)
- A: 62 minutes
Caravan analogy (more)

- Cars now "propagate" at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?

Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.

1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!