CSE 422 Notes, Set 1


- Additional figures are repeated, with permission, from *Computer Networks*, 2nd through 4th Editions, by A. S. Tanenbaum, Prentice Hall.

- The remainder of the materials were developed by Philip McKinley at Michigan State University

Assignment:

**Read Chapter 1 of Kurose-Ross**
Goals of this section

- Introduce major concepts and terminology
- Describe how and why the Internet came to be
- Overview the operation of the current Internet
- Introduce network performance

Outline

- Major Internet components
- Network architecture and protocols
- Switching strategies
- Internet protocol stack, history
- Introduction to network performance
A “nuts and bolts” view of the Internet

- Millions of connected computing devices:
  - *hosts = end systems*
  - running network applications

- Communication links
  - fiber, copper wires
  - radio, satellite channels
  - transmission bit rate is proportional to *bandwidth*

- Switching elements:
  - forward packets (chunks of data)

Example Hosts

- Traditional desktop
- Cell phones
- IP picture frame
- E-puck microrobot
- Sensor nodes
- Computers on Aircraft Carrier
Types of Communication Links

- **Point-to-point**
  - Two endpoints (nodes)
  - May be unidirectional or bidirectional
  - Switches or routers (or hosts) connect point-to-point links

- **Broadcast channel**
  - Single channel shared by more than two nodes
  - One, some or all nodes may listen
  - Only one node at a time may transmit
  - Access control is a key issue
  - Examples: Legacy Ethernet, wireless LAN, satellite up link

A note about bit rate and memory size

- **Computer memory is measured in powers of 2**
  - 1 kilobyte = $2^{10} = 1024$ bytes
  - 1 megabyte = $2^{20} = 1024 \times 1024 = 1,048,576$ bytes
  - 1 gigabyte = $2^{30} = 1,073,741,824$ bytes
  - 1 terabyte = $2^{40} = 1,099,511,627,776$ bytes
  - Kbyte, Mbyte, Gbyte, Tbyte, and so on...

- **Similarly for bits of memory**
  - Kbit, Mbit, Gbit, Tbit...

- **Why powers of 2, and not powers of 10?**
On the other hand...

- Communication rate units are powers of 10
  - 1 kilobit/second (kbps) = $10^3 = 1000$ bits/second
  - 1 megabit/second (mbps) = $10^6 = 1,000,000$ bps
  - 1 gigabit/second (kbps) = $10^9 = 1,000,000,000$ bps

- And so on... Why?

- Note: Also (somewhat surprisingly) disk manufacturers typically measure disk capacity in powers of 10

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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
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 Gbps)
- low error rate: repeaters spaced far apart; immune to electromagnetic noise

Wireless media:
- signal carried in electromagnetic spectrum
- no physical “wire”
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

Example Radio links:
- terrestrial microwave
  - e.g. up to 45 Mbps channels
- WLAN (e.g., Wi-Fi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 4G: up to 1 Gbps, all IP-based
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay (!)
  - geosynchronous versus low altitude
Switching Elements

- Transfer data from one link to another
- Buffers some or all of the data in a “chunk”
- Examples:
  - Hubs: forward data on multiple links
  - Switches: switch data from one link to another based on hardware/software settings
  - Router: look up path in routing table, then forward data
- Primary functionality may not be for data
  - E.g., telecommunication switch

NOTE: Logical vs. Physical View

- Logically, hosts lie outside the “network”
- Physically, hosts might participate in providing network services, such as routing
Internet: A Network of Networks

- **Organization**
  - loosely hierarchical
  - public Internet versus private intranet

- **Protocols**
  - control sending, receiving of msgs
  - e.g., TCP, IP, HTTP

- **Internet standards**
  - Enable interoperation of networks
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force

Types of Networks

- **Local Area Networks (LANs)**
  - within a building or campus
  - usually based on broadcast channels
  - often connected via router to wide area network
  - major commercial success: Ethernet (1976)
  - Other examples: ARCNET, FDDI ring, ATM LANs, Fast Ethernet, Gigabit Ethernet, ...
  - Bit rates: 10 Mbps to 10 Gbps
LAN Topologies

- Ring (e.g. FDDI)
- Star (hub or switch)

Wireless LANs

- Has become pervasive in past 20 years.
- Fundamentally different than wired LANs
- How?
Types of Networks

- **Metropolitan Area Networks (MANs)**
  - Covers area of a city
  - Usually based on LAN technologies
  - Concept first realized in 1990s
  - Examples:
    - Data services on cable television networks
    - City-wide wireless infrastructure
      - Early adopters: Austin, TX, Alexandria, VA, …

- **Wide Area Networks (WANs)**
  - Earlier known as Long-Haul Networks
  - May cover continent or (this) planet
  - Most communication links are point-to-point
  - Switching elements are generically referred to as routers
  - Typically provides connections between multiple LANs and MANs
An Internetwork

- An internetwork, or internet, is a unified, cooperative interconnection of networks that supports a universal communication service.
  - Software hides the low-level network differences from the user and application program
  - the interconnected networks appear as a single large network
  - component networks may be LANs, MANs, or WANs
  - gateway nodes (routers) are used to interconnect different networks
  - A router has at least two addresses, one on each network
- The canonical example of an internet connects most major research institutions derived from the ARPANET and is usually called, simply, the Internet.
- The Internet employs the TCP/IP Protocol Suite, developed in the late 1970s by BBN and UC Berkeley with support from DARPA.

Protocols

human protocols:
- International Diplomacy
- Simple conversation
  - specific msgs sent
  - specific actions taken when msgs received, or other events

network protocols:
- Executed by machines rather than humans
- All communication activity in Internet is governed by protocols
  - protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt
**Example protocols**

a human protocol and a computer network protocol:

![Diagram showing human and computer communication protocols]

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**Network Architecture**

- A set of **layers and protocols**
- **Layer interaction**
  - each layer offers primitive operations and services to higher layers
  - the interface between each pair of adjacent defines these primitives and services
  - interfaces should be clean and well-defined
- **Peer processes**
  - the entities making up the corresponding layers on different machines
- **Protocol**
  - a set of rules governing the format and meaning of the information that is exchanged by the peer processes within the same layer

**Layered Network Architecture**

[Diagram showing a layered network architecture with layers 1 to 5 and interfaces between them.]
**Layering**

- Layers on the sending side may add headers, add trailers, or partition messages as they proceed down the stack.
- Layers on receiving sending side remove headers and trailers, and may combine segments as they proceed up the stack.

![Layering Diagram]

- Example information in headers?
- Example information in trailers?
- Why do some layers partition messages?
- Every layer requires a mechanism for connection establishment and termination, the former entailing some form of addressing.
Why layering?

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
- Disadvantages of layering?

Layer Design Issues

- Addressing and routing
- Rules for data transfer
  - simplex communication - data only in one direction
  - half duplex communication - data in one direction at a time
  - full-duplex communication - data concurrently in both directions
- Error detection and correction
- Ordered delivery (sequencing)
- Fragmentation and reassembly
- Flow control, congestion control
- Multiplexing and demultiplexing
  - Connection-oriented or connectionless service
Connection-oriented service

- **Operation**
  - establish connection, use it, disconnect

- **Real world example:** phone call

- **In the Internet:**
  - reliable connection-oriented service
    - examples: tcp connection, file transfer
  - unreliable connection-oriented service
    - example?

  - why unreliable?

Connectionless Service

- **Operation**
  - each message routed independently through system

- **real world example:** postal letter

- **Internet example?**

- **Flavors**
  - datagram service - no acknowledgement
  - acknowledged datagram service
  - Request-reply service - ack contains answer
Connections or Not

- Connection-oriented vs. connectionless service depends on the layer of the protocol stack under consideration.
- These services may be “mixed and matched” along the protocol stack.
- Example:
  - Non-persistent HTTP
  - over TCP,
  - over IP,
  - over Ethernet

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Switching Strategies

- Refers to how data is taken off one link and put on another
- Historically, the telephone network was based on circuit switching
  - Originally a copper connection between phones
  - Replaced by electro-mechanical switches (1930s)
  - Then replaced by electronic switches (1960’s)
- The TCP/IP Internet is based on a fundamentally different paradigm:
  - packet switching

Circuit Switching

Reserves capacity from source to destination for the “call”

- call setup/teardown required
- link bandwidth, switch capacity reserved along the path
- Those resources dedicated to the call, not shared
- circuit-like (guaranteed) performance, as in a physical copper connection
Circuit Switching

- How is capacity reserved across single physical wire (or fiber, or wireless channel)?
  - Capacity of the link (e.g., bandwidth, timeslot) divided into “pieces”
  - Different pieces allocated to different calls
  - Resource piece *idle* (wasted) if not used by the call for which it is allocated

Circuit Switching: FDM and TDM

Frequency Division Multiplexing

Example:
- 4 users

Time Division Multiplexing
Frequency Division Multiplexing

- Multiplexer combines inputs from $n$ inputs and transmits them on the single link.
- Demultiplexer separates the data according to channel.
- Different signals are carried simultaneously by modulating each onto a different carrier frequency.
- The carrier frequencies are sufficiently separated that the bandwidths do not overlap.
- Examples?

TDM Example

- Each channel is divided into frames.
- Frames are divided into timeslots.
- Each slot is dedicated to a particular “conversation.”
- Sample voice 8000 times per second, 8 bits/sample
- Data switched from one link to the next based on information stored at the switch.
Time and Switching

- Using static allocation with TDM implies **circuit** switching
- What if we divide resources in time, but allocate capacity (slots) dynamically?
- This is **packet** switching
- Each packet contains data and some control information, such as addressing
- How is this different from the data samples in CS?

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, bandwidth shared on demand ⇒ statistical multiplexing.
As opposed to TDM, where each host gets same slot in revolving TDM frame.

Packet switching versus circuit switching
Packet switching allows more users to use network!

- 1 Mb/s link
- each user:
  - 100 kb/s when “active”
  - active 10% of time

- circuit-switching:
  - 10 users

- packet switching:
  - with 35 users, probability > 10 active at same time is less than .0004
Packet switching versus circuit switching

Packet switching dominates the Internet, for now...

- **Great for bursty data**
  - Maximize resource sharing
  - simpler, no call setup
  - no call **blocking**, just longer delay

- **However**, congestion can lead to packet delay and loss
  - protocols needed for reliable data transfer, congestion control

- **Question: How to provide circuit-like behavior?**
  - bandwidth guarantees needed for audio/video apps
  - Stored video, live video, interactive video...