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


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 ≠ 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 message

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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

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**

“Cool” Appliances

- IP picture frame
- World’s smallest web server
  - [http://www.cs.c.uu.edu/~shri/Ipic.html](http://www.cs.c.uu.edu/~shri/Ipic.html)
- Web-enabled toaster+weather forecaster
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**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

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
  - 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
"Internetworking"?

- Internetwork - interconnection of networks - also called an "internet"
- Subnetwork - a constituent of an internetwork
- 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.

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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 …

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?

Layers, Protocols, Interfaces
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)

<table>
<thead>
<tr>
<th>OSI</th>
<th>TCP/IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Application</td>
</tr>
<tr>
<td>6</td>
<td>Presentation</td>
</tr>
<tr>
<td>5</td>
<td>Session</td>
</tr>
<tr>
<td>4</td>
<td>Transport</td>
</tr>
<tr>
<td>3</td>
<td>Network</td>
</tr>
<tr>
<td>2</td>
<td>Data link</td>
</tr>
<tr>
<td>1</td>
<td>Physical</td>
</tr>
</tbody>
</table>

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

```plaintext
layer 1 (physical)
   |    link
   |    network
   |    transport
   |    application
```

- 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

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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

**FDMA**
- Frequency division multiplexing
- Example: 4 users

**TDMA**
- Time division multiplexing

### 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

### 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 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)

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

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
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

Telecommunication networks
  - Circuit-switched networks
    - FDM
    - TDM
  - Packet-switched networks
    - Networks with VCs
    - Datagram 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
  - if queue is full, arriving packets dropped (Drop-Tail)

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

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

- A transmission
- B propagation
- nodal processing
- queueing

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

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

- \(d_{\text{proc}}\): processing delay
  - typically a few microseconds or less
- \(d_{\text{queue}}\): queuing delay
  - depends on congestion
- \(d_{\text{trans}}\): transmission delay
  - \(= L/R\), significant for low-speed links
- \(d_{\text{prop}}\): propagation delay
  - a few microseconds to hundreds of milliseconds

Queueing delay (revisited)

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

traffic intensity = \(La/R\)

- \(La/R \approx 0\): average queueing delay small
- \(La/R \to 1\): 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.

[Diagram showing traceroute process]
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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 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

- Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet
- Tier-2 ISP is customer of tier-1 provider
- Tier-2 ISPs also peer privately with each other, interconnect at NAP

Internet structure: network of networks

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

- Local and tier-3 ISPs are customers of higher tier ISPs connecting them to rest of Internet

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!