EE 122: Networks & Protocols
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http://inst.eecs.berkeley.edu/~ee122/
(Materials with thanks to Vern Paxson, Jennifer Rexford, and colleagues at UC Berkeley)

Welcome our New TA

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- Discussion section: TBA

Goals for Today’s Class

- Type of Networks
  - And the key concept of multiplexing
- What’s a Protocol?

What Global (non-digital) Communication Network Do You Use Every Day?
Roughly speaking, how does it work?

What’s Another Such Network That You Use Every Day?

Taxonomy of Communication Networks

- Communication networks can be classified based on the way in which the nodes exchange information:
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**Broadcast Communication Networks**
- Information transmitted by any node is received by every other node in the network
  - Examples?
    - Usually in LANs (Local Area Networks)
      - E.g., Ethernet (classical), WiFi
      - E.g., lecture!
  - What problems does this raise?
    - Problem #1: limited range
    - Problem #2: privacy of communication
    - Problem #3: coordinating access to the shared communication medium (Multiple Access Problem)

**Switched Communication Networks**
- Information transmitted along a path of intermediary nodes (“switches” or “routers”)
  - Basic issue: how the switches figure out the next hop along the path

**Taxonomy of Communication Networks**
- Communication networks can be classified based on the way in which the nodes exchange information:

**Circuit Switching (e.g., Phone Network)**
- Establish: source creates circuit to destination
  - Nodes along the path store connection info
  - Nodes generally reserve resources for the connection
  - If circuit not available: “Busy signal”
- Transfer: source sends data over the circuit
  - No destination address, since nodes know path
- Teardown: source tears down circuit when done
Circuit Switching
- Node (switch) in a circuit switching network

How does the node connect the incoming link to the outgoing?

Telephone Network
- Almon Brown Strowger (1839 - 1902)
  - 1889: Invents the “girl-less, cuss-less” telephone system – the mechanical switching system

Timing in Circuit Switching
- Circuit Establishment
- propagation delay
- time

Circuit Switching With Human Operator
Timing in Circuit Switching

Circuit Establishment

Propagation delay between Host 1 and Switch 1

Transmission delay time

Node (switch) in a circuit switching network

Incoming links

Node

Outgoing links

How do the black and red circuits share the outgoing link?

Circuit Switching
Circuit Switching: Multiplexing a Link

- Time-division
  - Each circuit allocated certain time slots
- Frequency-division
  - Each circuit allocated certain frequencies

Time-Division Multiplexing/Demultiplexing

- Time divided into frames; frames into slots
- Relative slot position inside a frame determines to which circuit data belongs
  - E.g., slot 0 belongs to red circuit
- Requires synchronization between sender and receiver—surprisingly non-trivial!
- In case of non-permanent circuits
  - Need to dynamically bind a slot to a circuit
  - How to do this?
  - If sender does not send data the circuit’s capacity is lost!

Packet Switching

- Data sent as chunks of formatted bit-sequences (Packets)
- Packets have following structure:
  - Header and Trailer carry control information (e.g., destination address, checksum)
  - Each packet traverses the network from node to node along some path (Routing) based on header info
  - Usually, once a node receives the entire packet, it stores it (hopefully briefly) and then forwards it to the next node (Store-and-Forward Networks)

Taxonomy of Communication Networks

- Communication networks can be classified based on the way in which the nodes exchange information:
  - Switched Communication Network
  - Broadcast Communication Network
  - Circuit-Switched Communication Network
  - Packet-Switched Communication Network
Packet Switching: Multiplexing/Demultiplexing

- Data from any flow can be transmitted at any given time
  - Single flow can use the entire link capacity if it is alone
- How to tell them apart?
  - Use meta-data (header) to describe data
- Note: for packet switching we use flow (instead of circuit) to denote packets sent by a sender to a receiver

Taxonomy of Communication Networks

- Communication networks can be classified based on the way in which the nodes exchange information:

  - Switched Communication Network
  - Broadcast Communication Network
  - Circuit-Switched Communication Network
  - Packet-Switched Communication Network
  - Datagram Network

Datagram Packet Switching

- Each packet is independently switched
  - Each packet header contains full destination address
  - No resources are pre-allocated (reserved) in advance
  - Leverages "statistical multiplexing" (or statistical-muxing)
    - Essentially: “chances are good that packets from different flows won’t all arrive at the same time, so we can get by without enough capacity for all of them at their peak transmission rate”
    - Assuming independence of traffic sources, can compute probability that there is enough capacity
  - Example: IP networks; postal system

Timing of Datagram Packet Switching

- Host 1
- Node 1
- Node 2
- Host 2

- Packet 1
- Transmission delay of Packet 1 at Host 1
- Propagation delay between Host 1 and Node 1
- Processing delay of Packet 1 at Node 2
- Node 1
- Packet 1
- Node 2
- Packet 1
- Host 2
- Host 1
Timing of Datagram Packet Switching

Datagram Packet Switching

Taxonomy of Communication Networks

Advantages of Circuit Switching

- Guaranteed bandwidth
- Predictable communication performance
- Simple abstraction
- Reliable communication channel between hosts
- No worries about lost or out-of-order packets
- Simple forwarding
- Forwarding based on time slot or frequency
- No need to inspect a packet header
- Low per-packet overhead
- Forwarding based on time slot or frequency
- No IP (and TCP/UDP) header on each packet
Disadvantages of Circuit Switching

- Wasted bandwidth
  - Bursty traffic leads to idle connection during silent period
  - Unable to achieve gains from “statistical multiplexing”
- Blocked connections
  - Connection refused when resources are not sufficient
  - Unable to offer “okay” service to everybody
- Connection set-up delay
  - No communication until the connection is set up
  - Unable to avoid extra latency for small data transfers
- Network state
  - Network nodes must store per-connection information
  - Unable to avoid per-connection storage and state
  - This makes failures more disruptive!

Packet-Switching vs. Circuit-Switching

- Critical advantage of packet-switching over circuit switching: **Exploitation of statistical multiplexing**
- Another: since routers don’t know about individual flows, when a router or link fails, it’s: **Easy to fail over to a different path**
- A third: easier for different parties to link their networks together because they’re not promising to reserve resources for one another
- However, packet-switching must handle congestion:
  - More complex routers
  - Harder to provide good network services (e.g., delay and bandwidth guarantees)
- In practice, sometimes combined, e.g., IP over SONET

What Is A Protocol?

- A protocol is an agreement on how to communicate
- Includes
  - **Syntax**: how a communication is specified & structured
    - Format, order messages are sent and received
  - **Semantics**: what a communication means
    - Actions taken when transmitting, receiving, or when a timer expires

Examples of Protocols in Human Interactions

- **Telephone**
  1. (Pick up / open up the phone.)
  2. Listen for a dial tone / see that you have service.
  3. Dial.
  4. Should hear ringing …
  5. Caller: “Hello?”
  6. Caller: “Hi, it’s Alice …”
     Or: “Hi, it’s me” (= what’s that about?)
  7. Callee: “Hey, do you think … blah blah blah …” **pause**
  8. Callee: “Yeah, blah blah blah ...” **pause**
  9. Caller: Bye
  10. Callee: Bye
  11. Hang up

Examples of Protocols in Human Interactions

- Asking a question
  1. Raise your hand.
  2. Wait to be called on.
  3. Or: wait for speaker to **pause** and vocalize

Questions?
Example: The Internet Protocol (IP)

- Problem:
  - Many different network technologies
  - e.g., Ethernet, Token Ring, ATM, Frame Relay, etc.
  - How can you hook them together?
    - n x n translations?
- IP was invented to glue them together
  - n translations
  - Minimal requirements (datagram)
- The Internet is founded on IP
  - "IP over everything"

Example: Transmission Control Protocol (TCP)

- Communication service
  - Ordered, reliable byte stream
  - Simultaneous transmission in both directions
- Key mechanisms at end hosts
  - Retransmit lost and corrupted packets
  - Discard duplicate packets and put packets in order
  - Flow control to avoid overloading the receiver buffer
  - Congestion control to adapt sending rate to network load

Protocol Standardization

- Ensure communicating hosts speak the same protocol
  - Standardization to enable multiple implementations
  - Or, the same folks have to write all the software
- Standardization: Internet Engineering Task Force
  - Based on working groups that focus on specific issues
  - Produces “Request For Comments” (RFCs)
  - Promoted to standards via rough consensus and running code
  - IETF Web site is [http://www.ietf.org](http://www.ietf.org)
  - RFCs archived at [http://www.rfc-editor.org](http://www.rfc-editor.org)
- De facto standards: same folks writing the code
  - P2P file sharing, Skype, <your protocol here>...

Example: IP Packet

<table>
<thead>
<tr>
<th>4-bit Version</th>
<th>4-bit Header Length</th>
<th>8-bit Type of Service (TOS)</th>
<th>16-bit Total Length (Bytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-bit Identification</td>
<td>3-bit Flags</td>
<td>13-bit Fragment Offset</td>
<td>8-bit Time to Live (TTL)</td>
</tr>
<tr>
<td>8-bit Protocol</td>
<td>16-bit Header Checksum</td>
<td>32-bit Source IP Address</td>
<td>32-bit Destination IP Address</td>
</tr>
<tr>
<td>Options (if any)</td>
<td>Payload</td>
<td>20-byte header</td>
<td></td>
</tr>
</tbody>
</table>

IP: “Best-Effort” Packet Delivery

- Datagram packet switching
  - Send data in packets
  - Header with source & destination address
- Service it provides:
  - Packets may be lost
  - Packets may be corrupted
  - Packets may be delivered out of order

Summary

- Types of communication networks
  - Broadcast, circuit-switched, packet-switched
  - Advantages & disadvantages of each
- Protocols: agreement on how to communicate
  - For networks, often requires formal standardization
Next Lecture

- Architecture, Layering, and the “End-to-End Principle”
- Read 1.4 & 1.5 of Kurose/Ross
- Pick up class computer account forms
- Take the survey (http://tinyurl.com/5rsdx5) ASAP and join the mailing list if you haven't already