A Brief History of Networking

- Roots traced to public telephone network of the 60’s
  - How can computers be connected together?
- Three groups were working on packet switching as an efficient alternative to circuit switching
- L. Kleinrock had first published work in ‘61
  - Showed packet switching was effective for bursty traffic
- P. Baran had been developing packet switching at Rand Institute and plan was published in ‘67
  - Basis for ARPAnet
- First contract to build network switches awarded to BBN
- First network had four nodes in ’69

Basics

- Host vs Router
  - Router is a device with multiple interfaces and allows “data” forwarding between interfaces
  - Host may have multiple interfaces too
- IP address identifies an interface
- A trivial network: every host directly connected to every other host
  - Not a scalable construction
- Alternative: A hierarchical structure of hosts
  - Nodes (hosts or routers) grouped into network clouds
  - Network clouds are interconnected to form internetworks or internets
  - Internet (with capital I) refers to THE wide-area Internet we know today

History of the Internet contd.

- By ’72 network had grown to 15 nodes
  - Network Control Protocol - first end-to-end protocol (RFC001)
  - Email was first application – R. Tomlinson, ’72
- In ’73 R. Metcalfe invented Ethernet
- In ’74 V. Cerf and R. Kahn developed open architecture for Internet
  - TCP and IP
History of the Internet contd.

- By ’79 the Internet had grown to 200 nodes and by the end it had grown to over 100K!
  - Much growth fueled by connecting universities
  - L. Landweber from UW was an important part of this!
- Major developments
  - TCP/IP as standard
  - DNS
- In ’89 V. Jacobson made MAJOR improvements to TCP
- In ’91 T. Berners-Lee invented the Web
- In ’93 M. Andreesen invented Mosaic
- The rest should be pretty familiar…

Switched Networks

- A network can be defined recursively as...
  - two or more nodes connected by a link, or
  - two or more networks connected by nodes

Building Blocks

- Nodes: PC, special-purpose hardware...
  - hosts
  - Switches and routers
- Links: coax cable, optical fiber...
  - point-to-point
  - multiple access

Strategies

- Circuit switching: carry bit streams along determined paths
  - original telephone network
- Packet switching: store-and-forward messages
  - Internet
- Homework assignment: What is a Virtual circuit?
Multiplexing

- Resource sharing
- Analogous to CPU sharing among processes in

![Switch 1 and Switch 2 Diagram](CS640)

Statistical Multiplexing

- Simple example in class:
  - Each conversation has instantaneous load of 1 Mbps with 1/10 probability
  - No delay permissible: only 1 conversation
  - If some delay allowed: 5 simultaneous conversations
    - Delay on link about 6% of the time

![Bandwidth 1 Mbps Diagram](CS640)

Statistical Multiplexing

- Resources made available on-demand
- Packets from different sources interleaved on link
- Buffer packets that are *contending* for the link
- Buffer (queue) overflow is called *congestion*
  - Can lead to packet losses

![Packet Diagram](CS640)

Internet Goals

- Connectivity
  - Nodes, links, clouds

- Efficient resource sharing
  - Statistical multiplexing

- Services
  - Reliable channel
  - Request/reply or bit-stream channel
Performance Metrics

- Bandwidth: physical property of link
- Throughput: actual data transmitted per time unit
  - link versus end-to-end
    - notation
      - $KB = 2^{10}$ bytes
      - $Mbps = 10^6$ bits per second
- Latency (delay)
  - time to send message from point A to point B
  - one-way versus round-trip time (RTT)
  - components
    - Latency = Propagation + Transmit + Queue
    - Propagation = Distance / Speed (of light)
    - Transmit = Size / Bandwidth
- Actual delays on Internet is much greater than propagation

Layering

- Use abstractions to hide complexity
- Abstraction naturally lead to layering
- Alternative abstractions at each layer

<table>
<thead>
<tr>
<th>Application programs</th>
<th>Message stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Request/reply channel</td>
<td>Message stream</td>
</tr>
<tr>
<td>Host-to-host connectivity</td>
<td>Hardware</td>
</tr>
</tbody>
</table>

Bandwidth versus Latency

- Relative importance
- Assume propagation delay is 100 ms
- Transfer 1 Kb, bw 1 Mbps
  - Latency: $100 + 1$ (transmission delay) = 101 ms
- Transfer 1 Mb
  - Latency $100 + 1000$ (transmission delay) = 1100 ms

Protocols

- Building blocks of a network architecture
- Each protocol object has two different interface
  - service interface: operations on this protocol
  - peer-to-peer interface: messages exchanged with peer
- Term “protocol” is overloaded
  - specification of peer-to-peer interface
  - module that implements this interface
Interfaces

ISO Architecture

Machinery
- Multiplexing and Demultiplexing (demux key)
- Encapsulation (header/body)

Internet Architecture
- Defined by Internet Engineering Task Force (IETF)
  1. Application: interacts with user to initiate data transfers (Ln
     media player, command line)
  2. Transport: reliable, in-order delivery of data (TCP and UDP)
  3. Network: addressing and routing (IP)
  4. Data Link: defines how hosts access physical media (Ethernet)
  5. Physical: defines how bits are represented on wire (Manchester
     code)
- Information is passed between layers via encapsulation
  - Header information is attached to data passed down layers
- Multiplexing between layers
- Layers access other layers via API’s (eg. sockets)
- Communication at a specific layer is enabled by a protocol
Hourglass Design

- Single protocol at network level insures packet get from source to destination while allowing flexibility.

```
FTP  HTTP  NV  TFTP
   |      |    |
TCP  UDP  IP
       |    |
NET₁  NET₂  ...  NETₙ
```

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