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 eve 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 k today

History of the Internet contd.

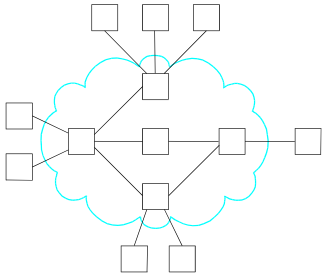
- By '72 network had grown to 15 nodes
  - Network Control Protocol - first end-to-end protocc (RFC001)
  - Email was first application – R. Tomlinson, '72
- In '73 R. Metcalfe invented Ethernet
- In '74 V. Cerf and R. Kahn developed open architecture for Internet
  - TCP and IP

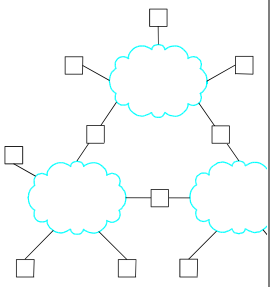
History of the Internet contd.

- By ’79 the Internet had grown to 200 nodes and by the en 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

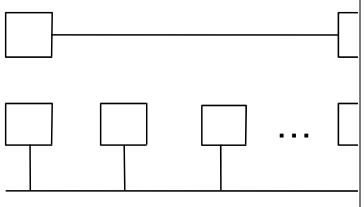
- A network can be defined recursively as...
  - two or more nodes connected by a link, or
  - two or more netw connected by nod





Building Blocks

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

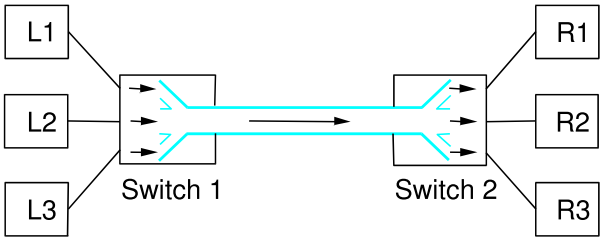


Strategies

- Circuit switching: carry bit streams along determined paths
  - original telephone network
- Packet switching: store-and-forward messages
  - Internet
- Homework assignment: What is aVirtual circui

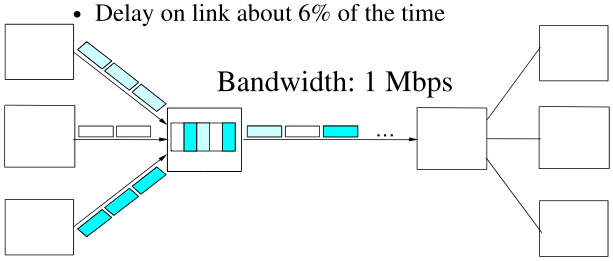
Multiplexing

- Resouce sharing
- Analogous to CPU sharing among processes in



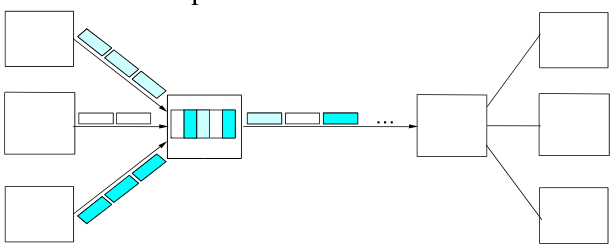
Statistical Multiplexing

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



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



Internet Goals

- Connectivity
  - Nodes, links, clouds
- Efficient resource sharing
  - Statistical multiplexing
- Services
  - Reliable channel
  - Request/reply or bit-stream channel

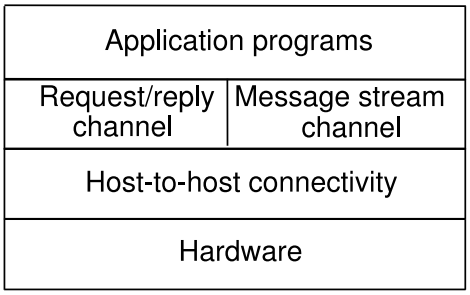
Performance Metrics

- 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



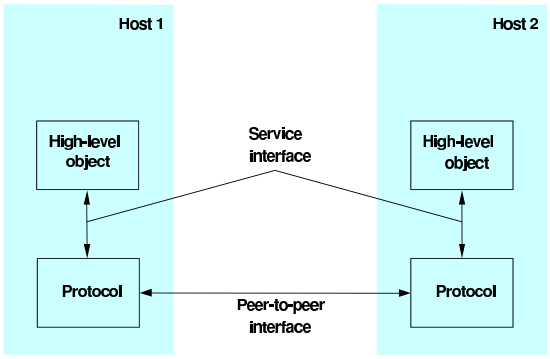
Bandwidth versus Latency

- 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

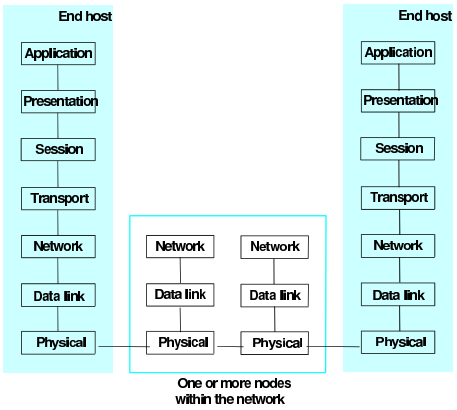
Protocols

- 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 pe
- Term "protocol" is overloaded
  - specification of peer-to-peer interface
  - module that implements this interface

Interfaces

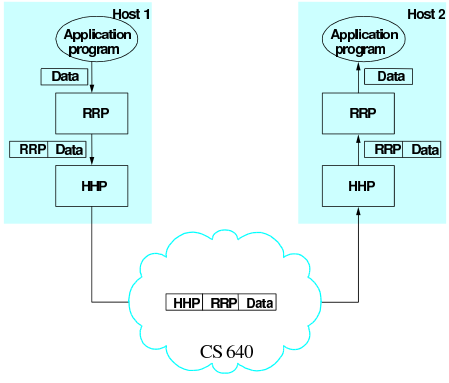


ISO Architecture



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 (bro 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 (Ethern
  5. Physical: defines how bits are represented on wire (Manches
- Information is passed between layers via encapsulatio
  - 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 pro

Hourglass Design

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