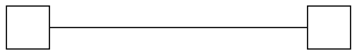
Introduction

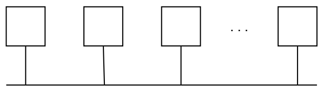
- Outline
  - Statistical Multiplexing
  - Inter-Process Communication
  - Network Architecture
  - Performance Metrics

Building Blocks

- Nodes: PC, special-purpose hardware...
  - hosts
  - switches
- Links: coax cable, optical fiber...
  - point-to-point

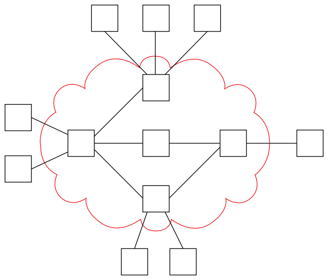


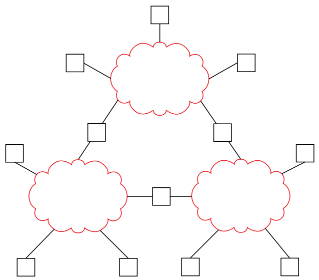
  - multiple access



Switched Networks

- A network can be defined recursively as two or more nodes connected by a physical link, or by two or more networks connected by one or more nodes.
- Strategies
  - circuit switching: carry bit streams
  - packet switching: store-and-forward messages



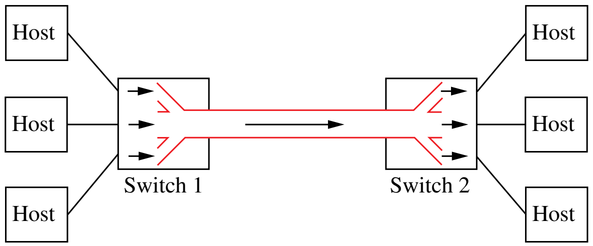


Addressing and Routing

- Address: byte-string that identifies a node; usually unique
- Routing: process of forwarding messages to the destination node based on its address
- Types of addresses
  - unicast: node-specific
  - broadcast: all nodes on the network
  - multicast: some subset of nodes on the network

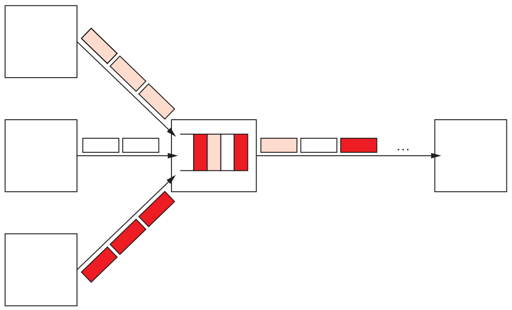
Multiplexing

- Time-Division Multiplexing (TDM)
- Frequency-Division Multiplexing (FDM)



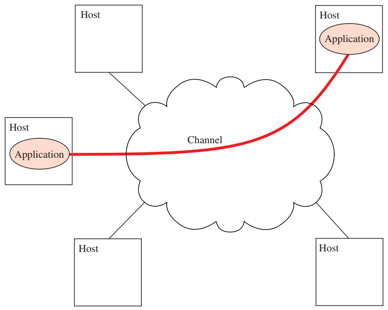
Statistical Multiplexing

- On-demand time-division
- Schedule link on a per-packet basis
- Packets from different sources interleaved on the link
- Buffer packets that are *contending* for the link
- Buffer (queue) overflow is called *congestion*



Inter-Process Communication

- Turn host-to-host connectivity into process-to-process communication.



- Fill in the gap between what applications expect and what the underlying technology provides.

IPC Abstractions

- Request/Reply
  - distributed file systems
  - digital libraries (web)
- Stream-Based
  - video data: sequence of frames
    - ∗ 1/4-size TV image = 352x240 pixels
    - ∗ $(352 \times 240 \times 24)/8 = 247.5$KB
    - ∗ 30 fps = 7500KBps = 60Mbps
  - video applications
    - ∗ on-demand video
    - ∗ video conferencing

What Goes Wrong in the Network?

- Bit-level errors (electrical interference)
- Packet-level errors (congestion)
- Link and node failures

- Messages are delayed
- Messages are deliver out-of-order
- Third parties eavesdrop

Layering

- Use abstractions to hide complexity
- Abstraction naturally leads to layering

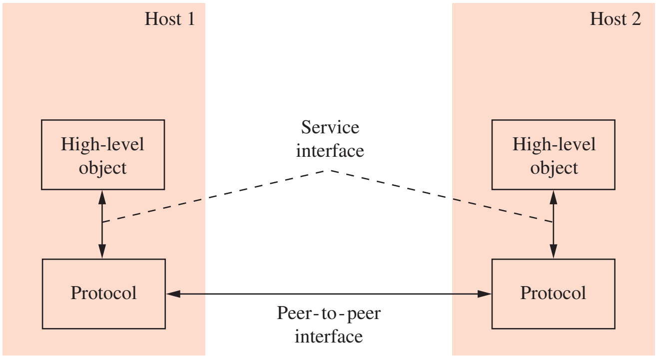
Application programs
Process-to-process channels
Host-to-host connectivity
Hardware

- Can have alternative abstractions at each layer

Application programs	
Request/reply channel	Message stream channel
Host-to-host connectivity	
Hardware	

Protocols

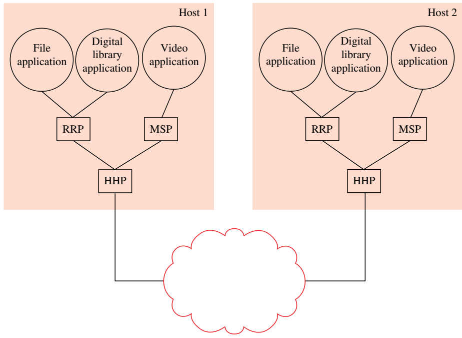
- Building blocks of a network architecture
- Each protocol object has two different interfaces
  - *service interface*: operations on this protocol
  - *peer-to-peer interface*: messages exchanged with peer



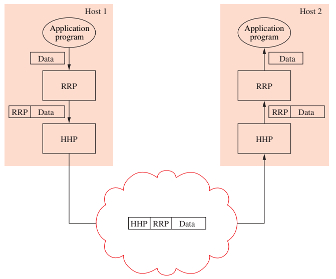
- Term "protocol" is overloaded
  - specification of peer-to-peer interface
  - module that implements this interface

Protocol Machinery

- Protocol Graph
  - most peer-to-peer communication is indirect
  - peer-to-peer is direct only at hardware level

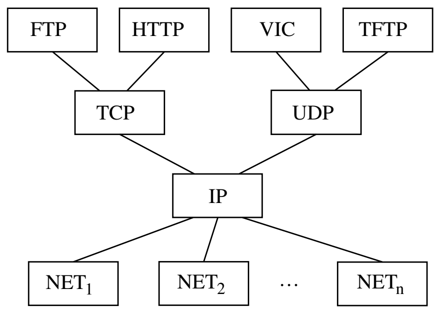


- Multiplexing and Demultiplexing (demux key)
- Encapsulation (header/body)



Internet Architecture

- Defined by Internet Engineering Task Force (IETF)



- Hourglass Design
- Application vs Application Protocol (FTP, HTTP)

Performance Metrics

- Bandwidth (throughput)
  - data transmitted per time unit
  - link versus end-to-end
  - notation
    - $\ast$ KB = 2^{10} bytes
    - $\ast$ 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 / SpeedOfLight
Transmit = Size / Bandwidth

Bandwidth versus Latency

- Relative importance
  - 1-byte: 1ms vs 100ms dominates 1Mbps vs 100Mbps
  - 25MB: 1Mbps vs 100Mbps dominates 1ms vs 100ms
- Infinite bandwidth
  - RTT dominates

    Throughput = TransferSize / TransferTime

    TransferTime = RTT + 1/Bandwidth x TransferSize
  - 1-MB file to 1-Gbps link as 1-KB *packet* to 1-Mbps link
- Delay × Bandwidth Product
  - amount of data "in flight" or "in the pipe"
  - example: 100ms RTT and 45Mbps Bandwidth = 560KB