

Strategies

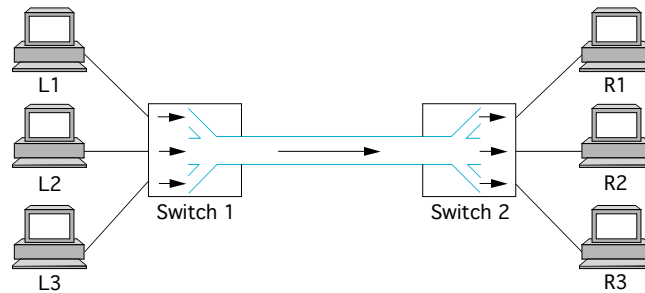
- Circuit switching: carry bit streams
 - original telephone network
- Packet switching: store-and-forward messages
 - Internet

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)



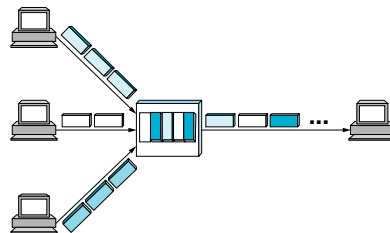
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Statistical Multiplexing

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



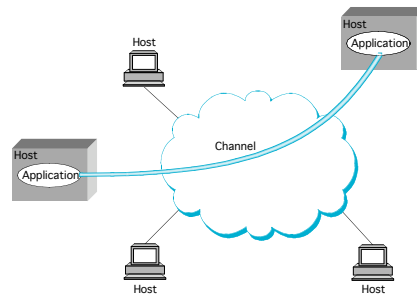
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Inter-Process Communication

- Turn host-to-host connectivity into process-to-process communication.
- Fill gap between what applications expect and what the underlying technology provides.



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IPC Abstractions

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

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What Goes Wrong in the Network?

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

- Packets are delayed
- Packets are delivered out-of-order
- Third parties eavesdrop

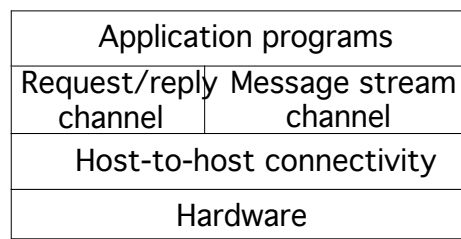
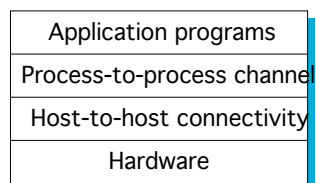
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Layering

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



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Protocols

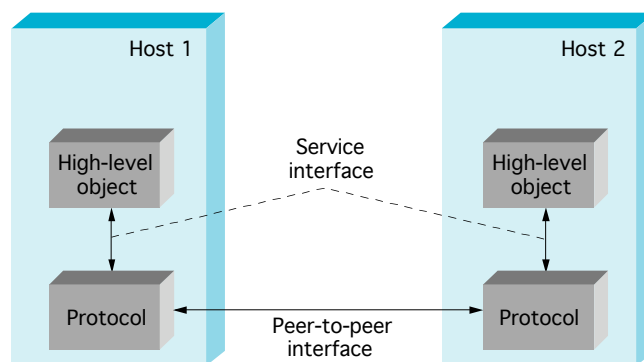
- Building blocks of a network architecture
- Each protocol object has two different interfaces
 - *service interface*: operations on this protocol
 - *peer-to-peer interface*: messages exchanged with peer
- Term “protocol” is overloaded
 - specification of peer-to-peer interface
 - module that implements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

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Interfaces



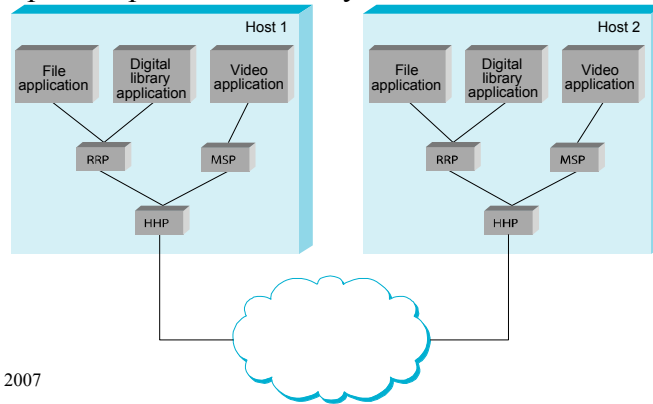
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Protocol Machinery

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

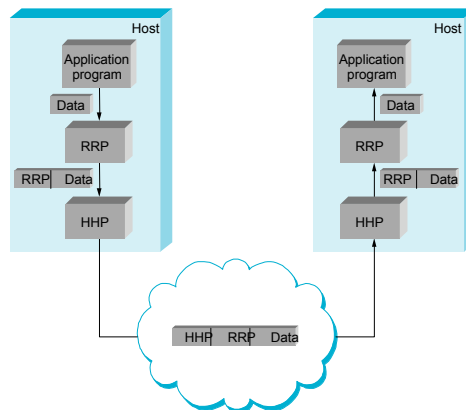


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Machinery (cont.)

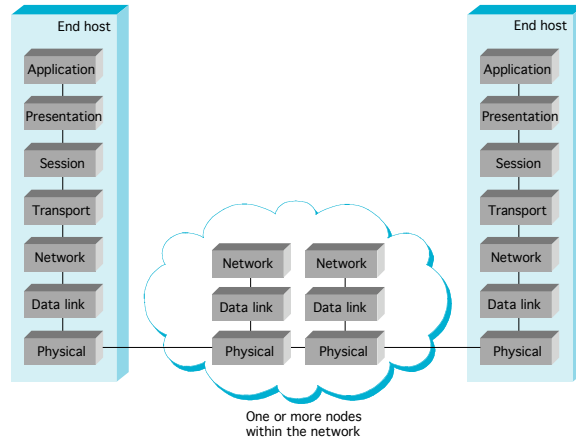
- Encapsulation (header/body)
- Multiplexing and Demultiplexing (demux key)



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OSI Architecture



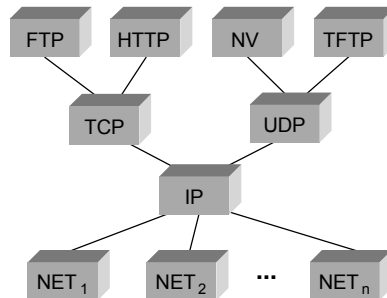
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Internet Architecture

- Defined by Internet Engineering Task Force (IETF)
- Hourglass Design
- Application vs Application Protocol (FTP, HTTP)



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Performance Metrics

- **Bandwidth (throughput)**
 - 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 / c
 - Transmit = Size / Bandwidth
- **Relative importance**
 - 1-byte: 1ms vs 100ms dominates 1Mbps vs 100Mbps
 - 25MB: 1Mbps vs 100Mbps dominates 1ms vs 100ms

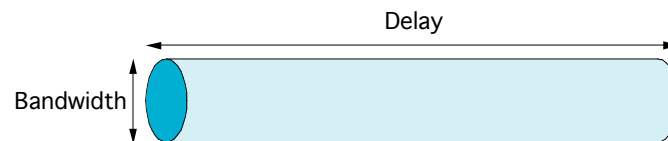
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Delay x Bandwidth Product

- Amount of data “in flight” or “in the pipe”
- Usually relative to RTT
- Example: $100\text{ms} \times 45\text{Mbps} = 560\text{KB}$



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