RW354
Principles of Computer Networking

- Larry L. Peterson and Bruce S. Davie. Computer Networks: A Systems Approach (Fifth Edition). Morgan Kaufmann Publishers. ISBN 1-55860-577-0.
- Behrouz A. Forouzan. Data Communications and Networking. McGraw Hill. ISBN 007-123241-9.
- Alberto Leon-Garcia and Indra Widjaja. Communication Networks: Fundamental Concepts and Key Architectures. McGraw Hill. ISBN 0-07-119848-2.

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Expectations

This course IS about

- principles and concepts
- general-purpose computer networks
- the Internet perspective
- network software
- designing and building a system.

This course IS NOT about

- a survey of existing protocol standards
- specialized networks (CATV, telephone, . . .)
- the OSI perspective
- network hardware (we do survey)
- network performance using queuing theory models.

Perspective

The expectations that you have of a network depends upon your persepctive

- Network users: network services that user applications need e.g. a guarantee that each message that the application sends will be delivered without error within a certain amount of time.
- Network designers: cost-effective design e.g. network resources are efficiently utilized and fairly allocated to different users.
- Network providers: a system that is easy to administer and manage e.g. faults can easily be isolated and it is easy to charge for usage.

Characterizing Networks

Communication networks are divided into 2 basic types

- connection oriented: circuit switched
- connectionless: packet switched.

Packet switched networks fall into 3 classes

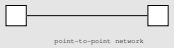
- WAN: a national/international network
- MAN: a network connecting several LANs
- LAN: a network connecting computers in a building or a campus.

Some networks are deliberately kept small in size.

The Internet is designed to grow to an arbitrarily large size (scale).

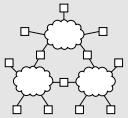
Connectivity

- network building blocks
  - links: coaxial cable, optical fibre, satellite . . .
  - nodes: routers
- direct links
  - point-to-point: one link connects two nodes



  - multiple access: many nodes share a link

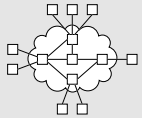
Indirect connectivity



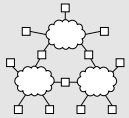
- nodes (switches) inside the cloud store & forward packets
- nodes (hosts) outside the cloud support users & applications
- routers (gateways) are connected to two or more networks.

Indirect connectivity

- switched networks



- internetworks



Switching strategies

A network can be defined recursively as

- two or more nodes connected by a physical link, or
- two or more networks connected by one or more nodes.

Networks use two switching methods

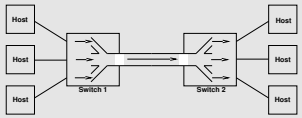
- circuit switching: dedicated circuits are used to send/receive a bit stream
- packet switching: store-and-forward is used to send/receive messages (packets).

Addressing & routing

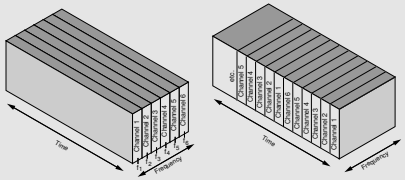
- an address is a byte string that identifies a node; usually unique
- routing is the process of determining how to forward a message towards the destination node based on its address
- there are several types of addresses
  - unicast: node-specific
  - broadcast: all the nodes in the network
  - multicast: some subset of the nodes in the network.

Cost-effective resource sharing

Networks must share (multiplex) network resources (nodes & links) among multiple users.



Common multiplexing strategies



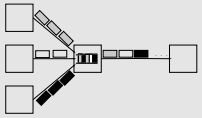
Frequency-division multiplexing Time-division multiplexing

- synchronous time-division multiplexing (STDM)
- frequency-division multiplexing (FDM)

Both STDM and FDM are inefficient.

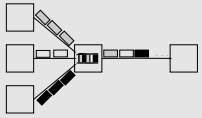
Statistical multiplexing

- TDM on demand rather than during a fixed time slot
- the link is rescheduled on a per-packet basis
- packets from different sources are interleaved on the link
- packets that contend for the link are buffered
- the packet queue is usually processed FIFO
- buffer overflow (dropped packets) is called congestion



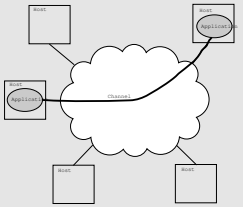
Statistical multiplexing

- the packet queue is usually processed FIFO, but not necessarily
  - packets from different flows are serviced in a round robin fashion
  - certain flows receive a certain portion of the link bandwidth
    - Quality of Service



Functionality

Application programs running on hosts connected to the network must be able to communicate in a meaningful way.



The network provides common process-to-process channels. Each channel provides a set of communication services.

Process-to-process channels

What functionality should the channels provide? Guaranteed/best effort delivery? Delivery in/out of order? Privacy? Constant/variable packet delivery rate?

- request/reply: for file access & digital libraries
- message stream: for video applications
  - video: sequence of frames
  - resolution: 1/4 TV-size image = 352×240 pixels
  - 24-bit color: frame = 352×240×24 / 8 = 247.5KB
  - frame rate: 30 fps = 7500KBps = 60Mbps
  - video on-demand vs video-conferencing

Network faults

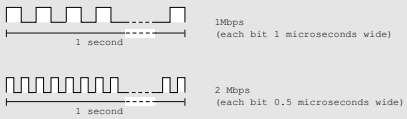
What can go wrong in the network?

- bit errors, burst errors: rare, error correction
- packet-level errors: usually caused by congestion
- link & node failures
- messages are delayed
- messages are delivered out-of-order
- third parties eavesdrop.

The key problem is to fill in the gap between what applications expect & what the underlying technology provides.

Performance: bandwidth (throughput)

- the amount of data that can be transmitted per time unit, for example 10Mbps
- link versus end-to-end performance
- notation: KB = 2^{10} bytes, Mbps = 10^6 bits per second
- bandwidth is related to "bit width"



Performance: latency (delay)

- latency: the time it takes to send a message from point A to point B
- the round-trip time (RTT): from A to B & back
- the components of latency
  - latency = propagation + transmission + queue
  - propagation = distance / C
  - transmit = size / bandwidth
- the speed of light C
  - 3.0×10^8 meters/second in a vacuum
  - 2.3×10^8 meters/second in a cable
  - 2.0×10^8 meters/second in a fiber

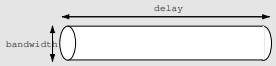
Performance: latency (delay)

Notes

- no queuing delays in direct link
- bandwidth is not relevant for the performance of small transfers
- bandwidth is relevant for the performance of large transfers
- process-to-process latency includes software overhead
- software overhead can dominate when distance is small

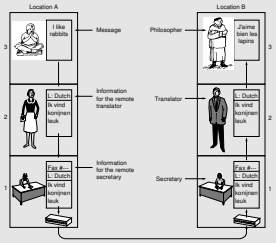
Delay-bandwidth product

- the relative importance of bandwidth & latency
  - small message (e.g. 1 byte): 1ms vs 100ms RTT dominates 1Mbps vs 100Mbps bandwidth
  - large message (e.g. 25 MB): 1Mbps vs 100Mbps bandwidth dominates 1ms vs 100ms RTT
- delay-bandwidth product: 100ms delay & 45Mbps bandwidth = 560 KB of data in the pipe



- application needs
  - bandwidth requirements: burst size vs peak rate
  - jitter: variance in latency (inter-packet gap)

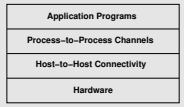
Network architecture: Layering



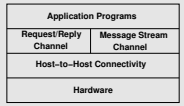
A protocol stack is a list of protocols used by a system, one protocol per layer.

Network architecture: Layering

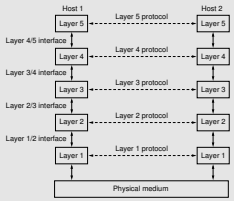
- abstractions are used to hide complexity
- abstraction naturally leads to layering



- alternative abstractions can be present at each layer



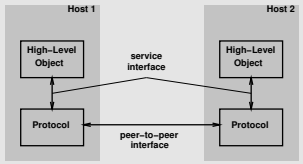
Network architecture: Layering



- the corresponding layers on different machines are called peers
- an interface is present between each pair of adjacent layers.

Network architecture: Protocols

- building blocks of a network architecture
- each protocol object has two different interfaces
  - the service interface: defines operations on this protocol
  - the peer-to-peer interface: defines messages exchanged with peer.



Network architecture: Protocols

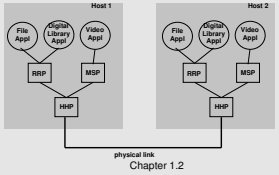
The term "protocol" is overloaded. It implies both

- *the specification of the peer-to-peer interface*
  - *textual, psuedo-code, state transition diagrams, pictures of packet formats*
- *the module that implements this interface.*

Network architecture: Protocols

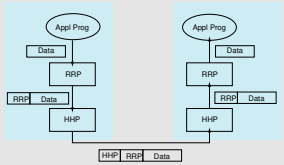
A protocol graph denotes a collection of protocols & their dependencies

- *nodes correspond to protocols*
- *edges correspond to dependencies*
- *most peer-to-peer communication is indirect*
- *peer-to-peer communication is direct only at hardware level.*



Network architecture: Protocols

- *multiplexing & demultiplexing: the demux key identifies the originating application*
- *encapsulation (header/body)*



The nodes in the network can inspect the HHP header – the payload is not inspected.

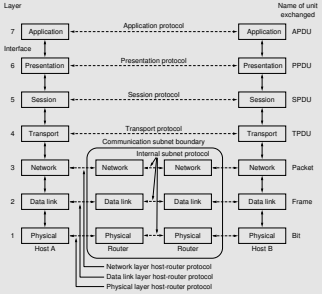
Standard architecture

Not the first network architecture

- *International Standards Organization (ISO)*
- *Open Systems Interconnect (OSI) Architecture*
- *International Telecommunications Union (ITU); formerly CCITT*
- *"X dot" series: X.25, X.400, X.500*

Standard architecture

The ISO OSI reference model

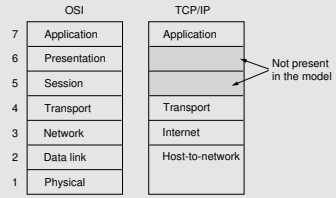


Standard architecture

- *the physical layer: the transmission of bits on the physical link*
- *the data link layer: correct transmission of a frame from one node to the next node*
- *network layer: correct transmission of a packet from source to destination*
- *the transport layer: correct transmission of a message from source to destination*
- *the session layer: manages different transport streams that are part of a single application*
- *the presentation layer: the format of the data exchanged between peers*
- *the application layer: the application*

Internet architecture

The Internet has a 4-layer model



Internet architecture

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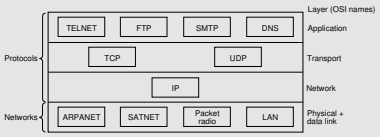
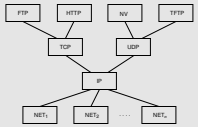


Internet architecture

The process of defining the Internet architecture is controlled by the Internet Engineering Task Force (IETF).



- *Application vs Application Protocol (FTP, HTTP)*
- *Features*
  - *does not imply strict layering*
  - *hourglass shape – IP is the focal point*
  - *design & implementation go hand-in-hand.*