EE3204/EE3204E- Computer Communication Networks I (part 1)

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Network Basics

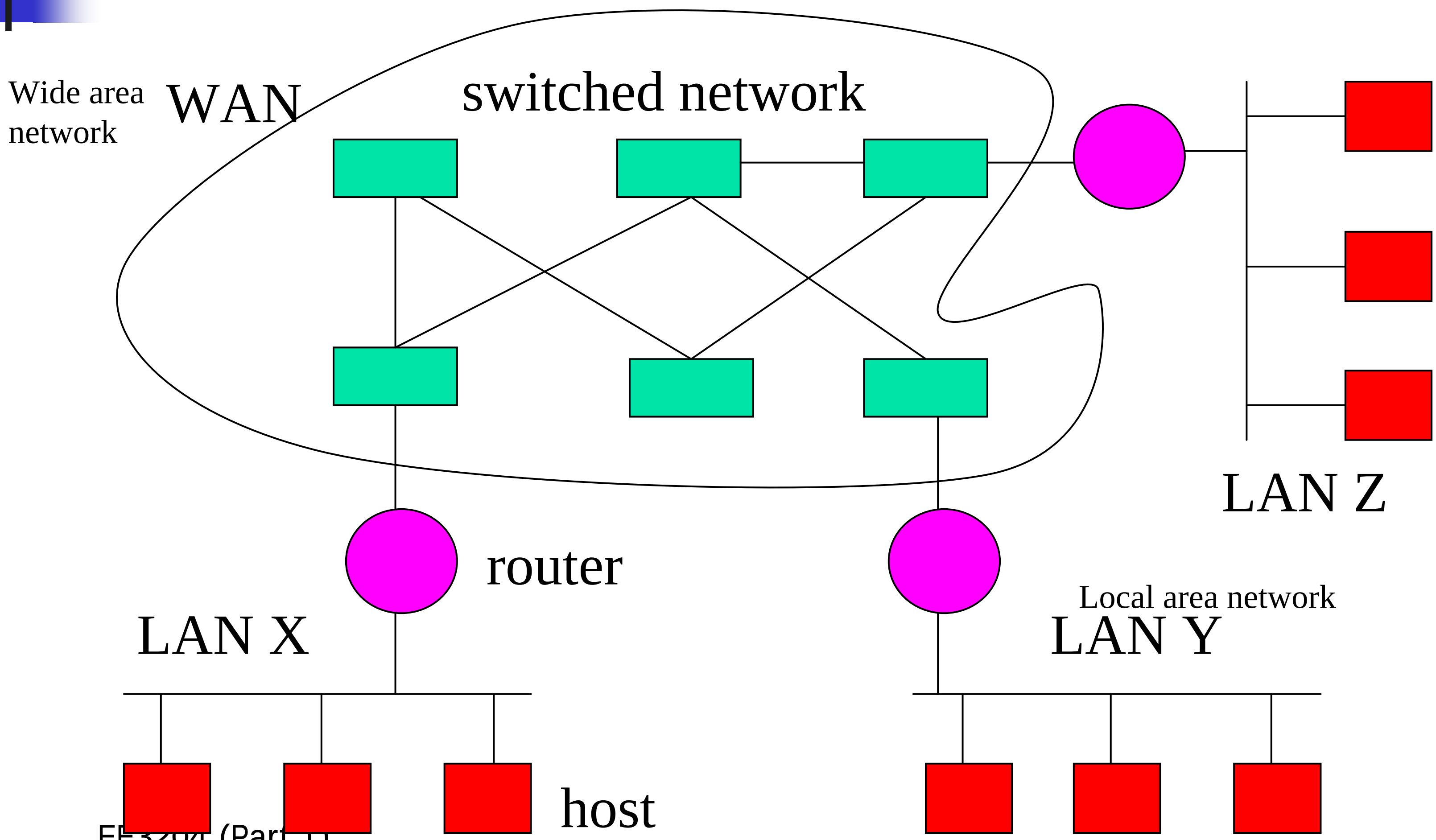
Networks: What? Why?

- A Network is a set of systems interconnected by communication links that is primarily used for information transfer
- System – computer, switch, router
- Different forms of information:
  - Text, voice, audio, video, picture, graphics, animation

Network Applications

1. World Wide Web (www)
2. E-mail, ftp
3. Video and audio streams
4. Voice over Packets
5. Distributed databases (banking, airline Transactions)

An Example Computer Network



Broadcast vs Point-to-Point Links

- Local area networks (LAN)
  - Host is a device where application runs; source/desination of a traffic; eg: computer, server, phone
  - Multiple hosts (nodes) connected by a broadcast link (also called multiple access or shared access link)
  - One node transmit; all nodes receive
  - Hosts can be connected by wireless LAN (not shown in the example-computer-network figure)
- Switched networks
  - Characterized by point-to-point links
  - Data traverses through one or switches and links
  - Data is forwarded from an input link to an output link within a switch (called switching)

Telephone Networks

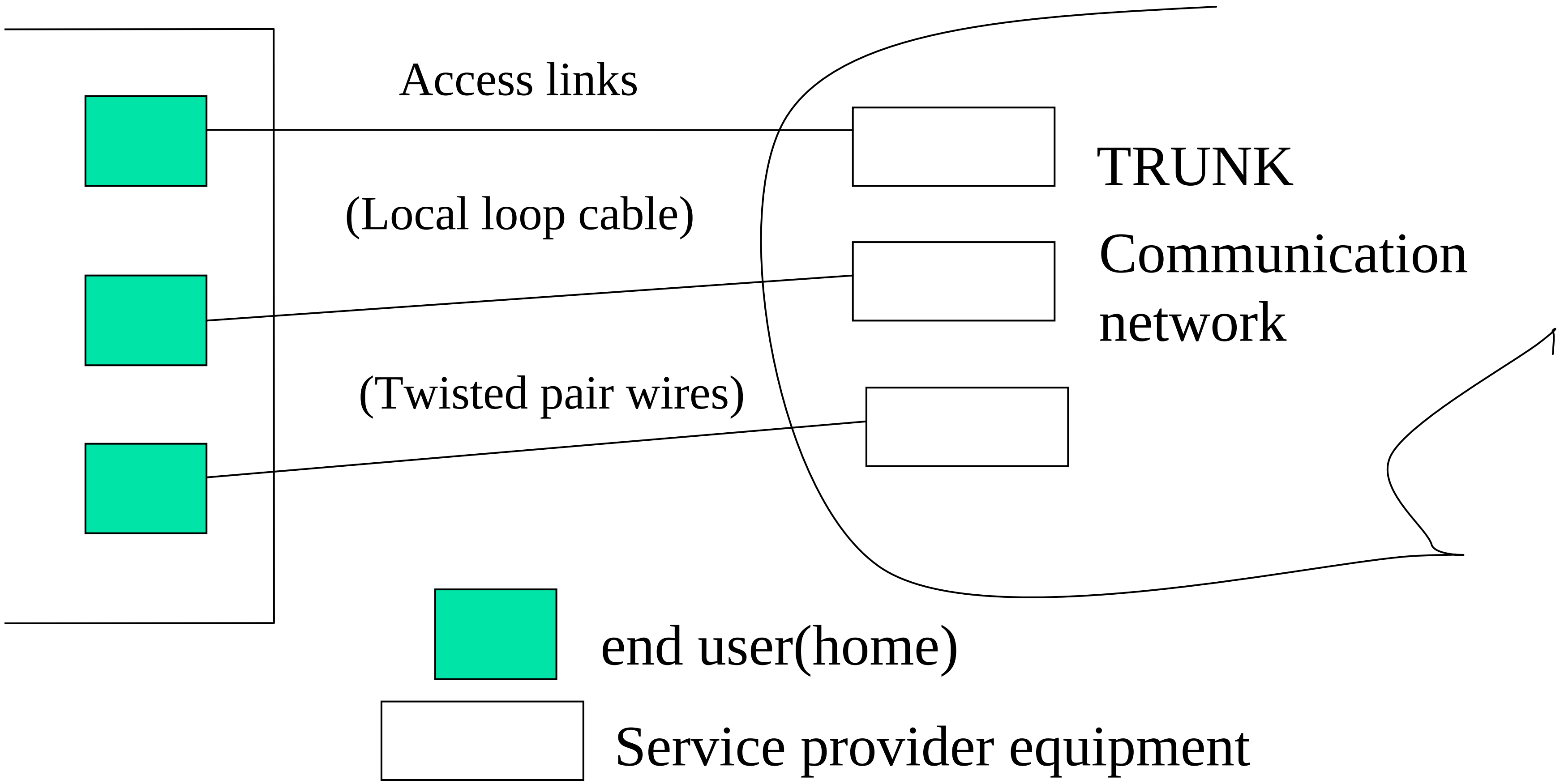
- Analog signal is converted to PCM (pulse code modulation) digital signal using CODEC (coder-decoder)
- Voice signal frequencies < 4 kHz
- Sampling theorem: sample at the rate of at least twice the maximum frequency to reconstruct the signal completely
  - 2x4000 = 8000 samples per second
  - 1 sample per 125 microseconds
  - 8000x8 = 64000 bits per second
  - data rate required for a voice signal is 64 Kbps, termed as DS0 (Digital Signal Level 0)

Some Definitions

- Bandwidth
  - Bandwidth of the transmitted signal as constrained by the transmitter and transmission medium, expressed in Hertz
- Data Rate
  - The rate in bits per second (bps) at which data can be communicated
- Channel Capacity
  - The maximum rate at which data can be transmitted over a communication path or channel under certain conditions such as SNR (signal-to-noise ratio)

- In the context of “computer communication networks” the terms bandwidth, data rate, and capacity are sometimes used interchangeably. Students should be able to distinguish them based on “unit” and “context”.

Telephone Network



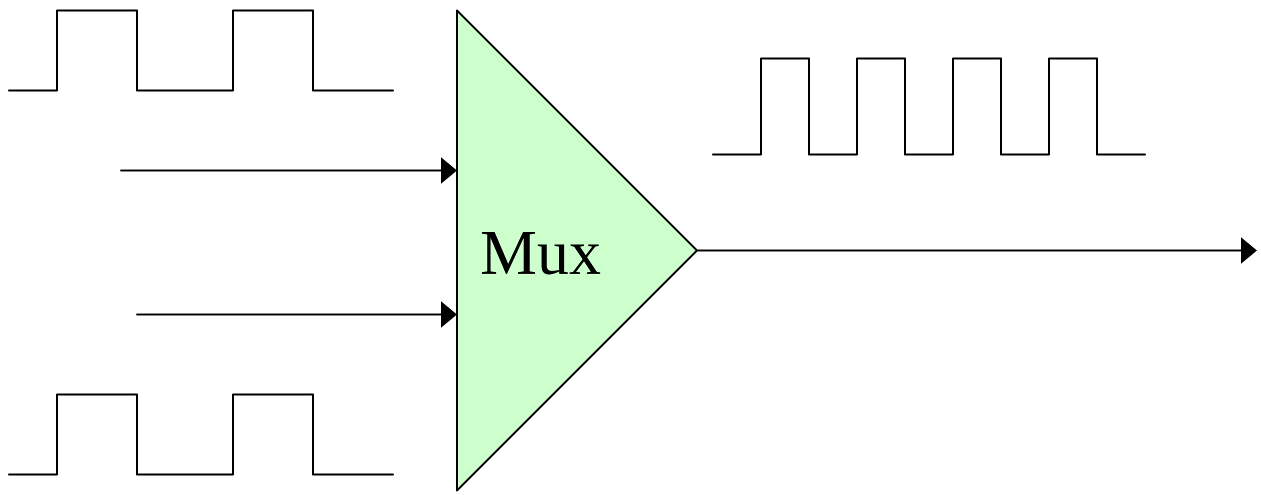
Multiplexing Hierarchy

- Multiplex several low rate signals into high rate signal
- Time division multiplexing
- Digital Signal (DS) hierarchy
- DS0, DS1, DS1c, DS2, DS3, and DS4
- DS2 (6.312 Mbps not widely used)
- Local loop: analog : up to 4 kHz
- Digital subscriber line (DSL) (1.544 to 7 Mbps and higher) over twisted pair copper wire

Time Division Multiplexing

- Consider a multiplexer with two input links and one output link
- Data rate of each input link is R bps requires the output link rate to be at least 2R bps
- If one byte is received at each input link for every T seconds, 2 bytes would be sent out at the output link for every T seconds

Time Division Multiplexing (illustration)



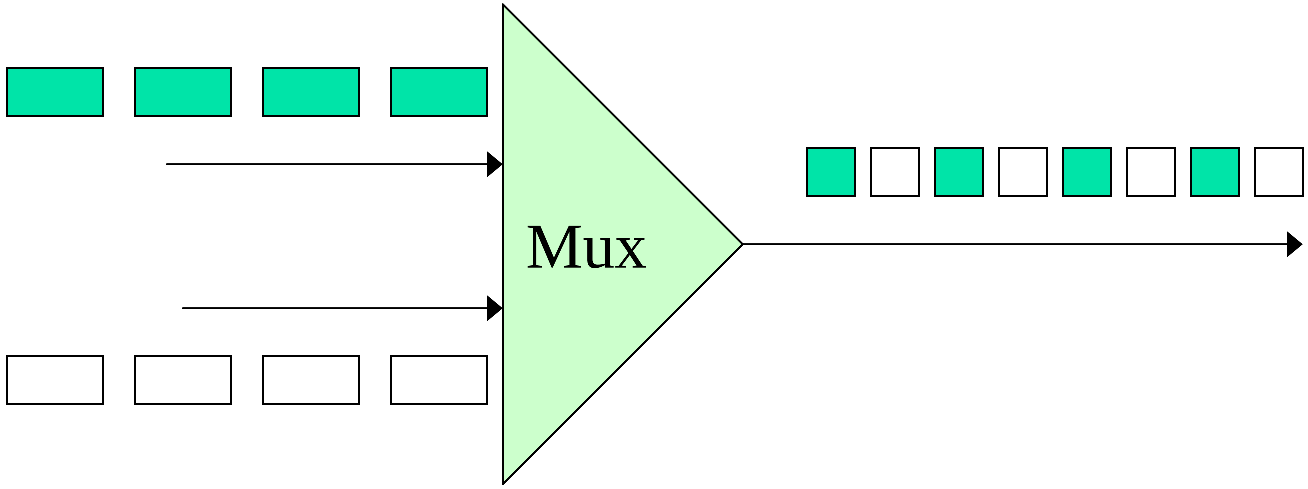
Digital Signal Hierarchy

Medium	signal	multiplex degree	# of DS0 circuits	Rate in Mbps
T1 pair	DS1	24 DS0	24	1.544
T1c pair	DS1c	2 DS1	48	3.152
T3 coax/ fiber	DS3	7 DS2	672	44.736
T4 coax/ fiber	DS4	6 DS3	4032	274.176

Time division multiplexing

- Fixed multiplexing
  - Fixed and dedicated bandwidth is reserved
  - Guaranteed service
  - Inefficient bandwidth utilization
- Statistical multiplexing
  - On Demand multiplexing
  - No fixed and dedicated bandwidth
  - No service guarantee
  - Efficient bandwidth utilization

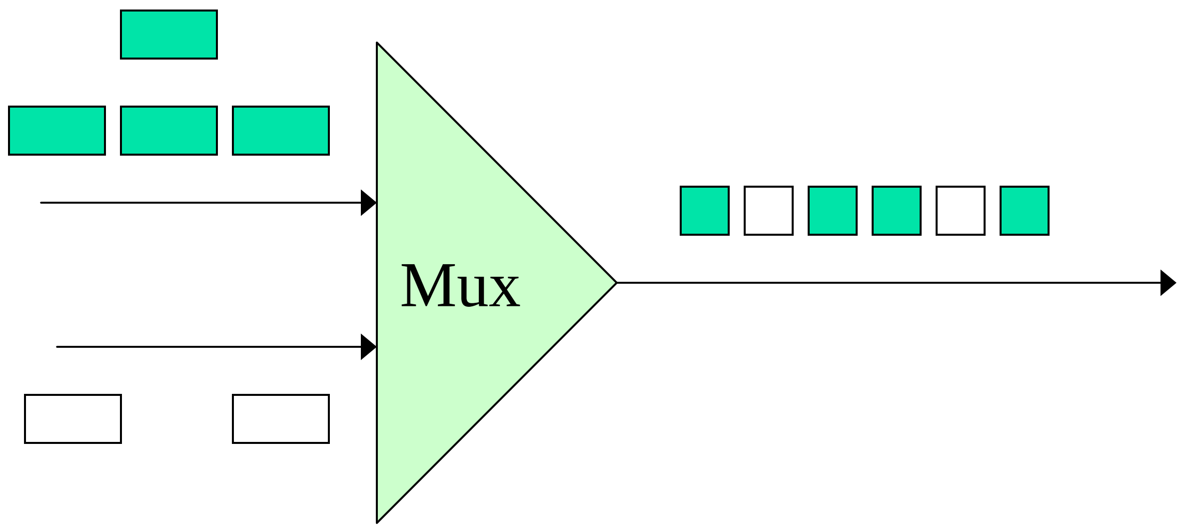
Fixed Time Division Multiplexing (FTDM)



FTDM (contd.)

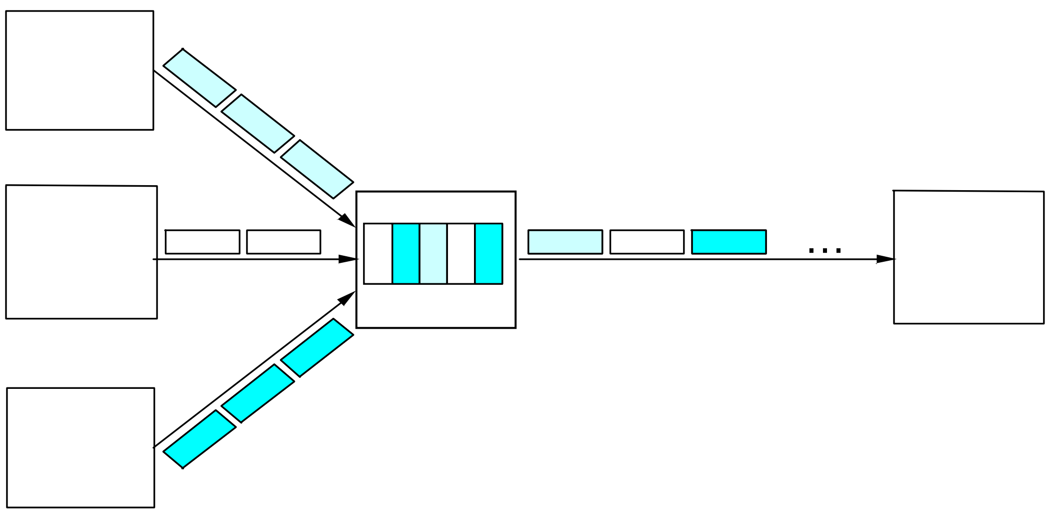
- For the example above, we can think of repeating frames sent on the output link.
  - Each frame carries two bytes (assuming byte interleaved multiplexing)
  - First byte comes from the top input link and second byte comes from the bottom input link

Statistical Time Division Multiplexing



Statistical Multiplexing in Networks

- On-demand time-division, better resource sharing
- 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*



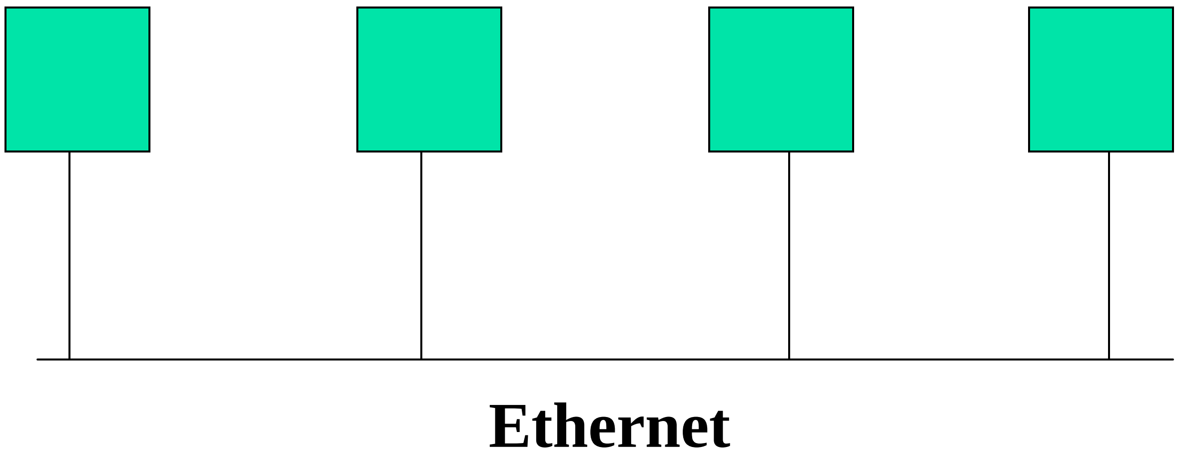
Computer Networks - Classification

- A computer network comprises nodes and links
- Nodes (computers, switches, routers, gateways)
- Links
  - Wired: twisted pair, coax cable, optical fiber
  - Wireless: microwave, spread spectrum radio, infrared
- Classification
  - Local area networks (LANs)
  - Metropolitan area networks (MANs)
  - Wide area networks (WANs)

Local Area Networks

- Small geographical area, e.g., campus
- Multiple access link, shared medium
- Medium access control
  - Ethernet (IEEE 802.3)
    - Broadcast medium
    - 10 Mbps, 100 Mbps
  - Token Ring (IEEE 802.5)
    - Token passing ring
    - 4 Mbps, 16 Mbps
  - Wireless (IEEE 802.11)

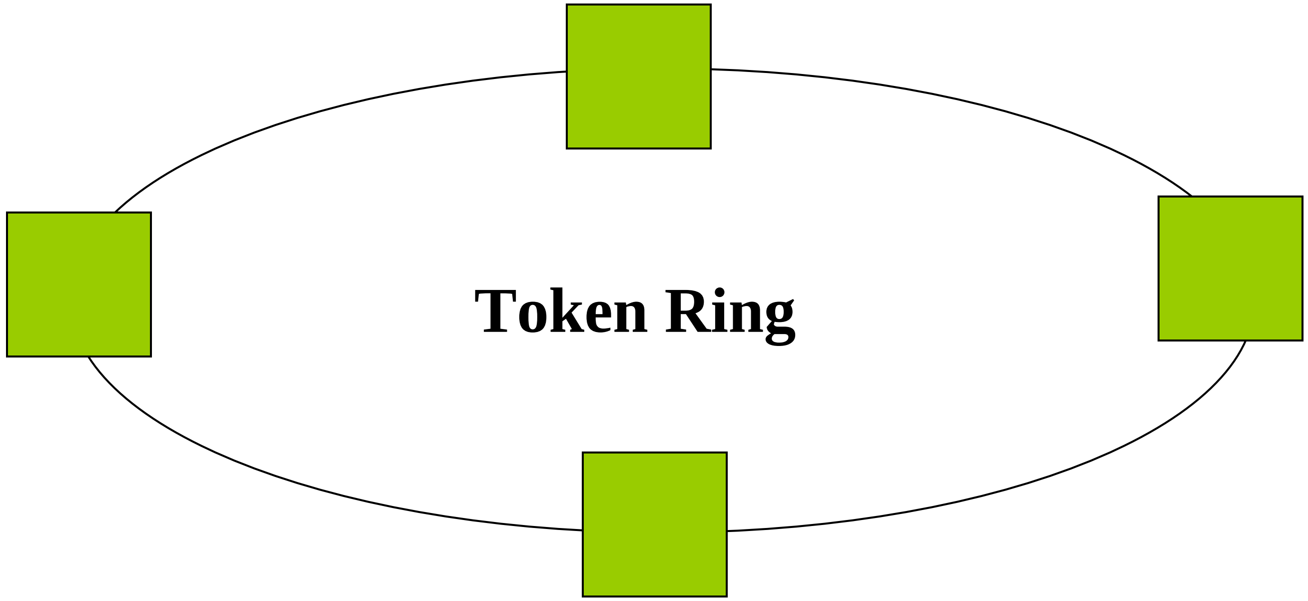
Local Area Networks - Ethernet



Ethernet –MAC -Principle

- Broadcast medium
  - Traffic transmitted by a host can be seen by every host
- Possibility of more than one host transmitting data frames at the same time leading to collisions
- Mechanisms for detecting a collision and retransmitting data in the event of a collision are used [Details are available in Lecture Notes-4 on Ethernet]

Local Area Networks – Token Ring



Token Ring – MAC - Principle

- Broadcast Medium
- No collision
- A special packet called Token is circulating around the ring
- A host waits for its turn; captures token; transmits traffic; passes token to the next host
- Packet makes one full round and is drained at the source

Metropolitan Area Networks

- Medium geographical area: city
- Fiber Distributed Data Interface
  - Token ring, 100 Mbps
- Synchronous Optical Network (SONET)
  - Fixed bandwidth allocation, > 51.84 Mbps
  - Fixed TDM
- Asynchronous Transfer Mode (ATM)
  - Flexible bandwidth allocation, statistical TDM

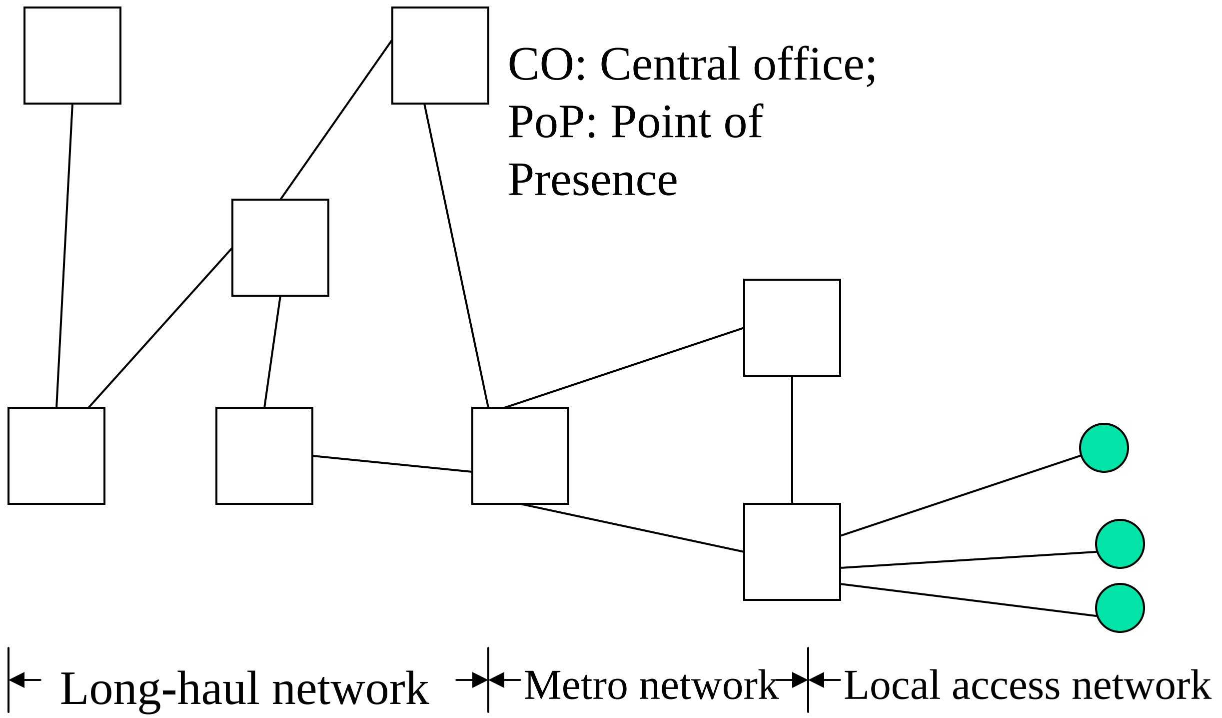
Wide Area Networks

- Large geographical area (country, continent, world)
- Irregular topologies, point-to-point links
- Interconnecting several LANs and MANs
- IP, SONET, ATM, WDM technologies
- IP is carried on SONET, ATM, WDM networks
  - IP – Internet Protocol
  - SONET – Synchronous Optical Networks
  - ATM – Asynchronous Transfer Mode
  - WDM - Wavelength Division Multiplexing (simultaneous transmission of messages on different wavelengths on a fiber each operating at the rate of a few Gbps)
- Moving from Gigabit networks to Terabit networks, e.g. WDM (wavelength division multiplexing) networks

Access Networks

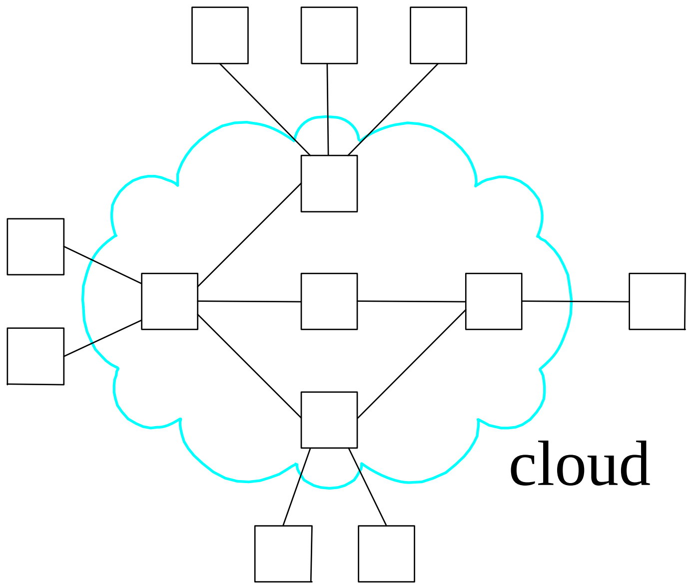
- Last Leg of telecom networks providing services to homes and small businesses
- Telephone network-based DSLs and Community Antenna/cable TV (CATV)-based Cable modems
- Offer downstream bandwidth of a few Mbps only
- Can be up to a few tens of Mbps with technology advances
  - have limitations on distance (from CO to subscriber) of up to 4km
- In CATV network channel bandwidth is shared, and at high loads the performance degrades
- Passive Optical Networks (PONs) are becoming popular solutions for access networks
- ATM PON (APON), Gigabit PON (GPON), Ethernet PON (EPON), WDM PON

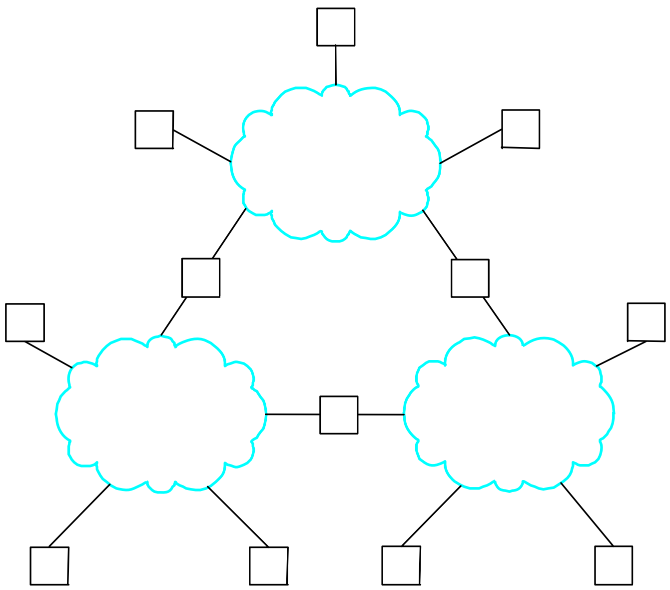
Telecommunication Networks



Switched Networks

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





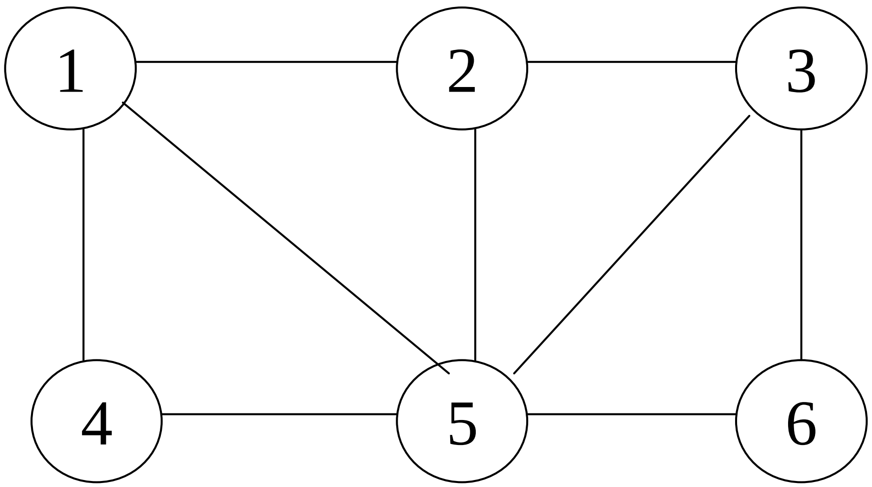
Network Services

- Connection-oriented service (eg. ATM, SONET, WDM)
  - Three phases: connection set up, message transmission and connection release
  - All packets in a message follow the same route
  - Packets are received in the order they were sent
  - Every node maintains connection state (id) information
  - Small header
  - Better support for Quality-of-Service (QoS)
    - QoS: delay, jitter, bandwidth, packet/cell loss rate
  - Connection setup/release overhead
  - Bandwidth utilization may not be efficient

Network Services (contd.)

- Connectionless service (Datagram service) (eg. IP)
  - packets in a message need not follow the same route
  - Packets may be received out of order
  - No connection state (id) information is maintained
  - large header (every packet carries source, destination information…)
  - No QoS guarantee (poor QoS support)
  - No Connection setup/release overhead
  - Bandwidth utilization is efficient

Connection-oriented and Connectionless Routing



Source: 1 destination: 6

Connection-oriented: 1-5-3-6 (all packets)

Connectionless: 1-4-5-6 (pkt1) 1-5-3-6 (pkt2) 1-5-6 (pkt3)

Switching Techniques

- Circuit switching
  - Link bandwidth (capacity) is divided into fixed-size circuits
  - eg: telephone network, SONET, WDM
  - 3 distinct phases: circuit setup, data transmission, and circuit release phases
  - Connection-oriented service
  - An application uses a fixed path to be used by all data
  - data arrive in sequence
  - fixed bandwidth (BW) circuits, low BW utilization
  - guaranteed service

Switching Techniques (contd.)

- Packet Switching
  - store and forward technique employed
  - switching entity is a packet. Statistical multiplexing is used.
  - High bandwidth utilization
  - Connectionless packet switching (eg. IP)
    - Different packets of the same message may traverse different routes
    - May result in out-of-order sequence of packet delivery
    - Difficult to provide guaranteed service, usually best-effort service
  - Connection-oriented virtual circuit switching, cell switching (eg. ATM)
  - Congestion can occur at a node when incoming traffic speed exceeds the outgoing link capacity and sufficient buffers are not available to hold the excess data

Addressing

- 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

Packet Transfer – A simplified example (Refer slide 5)

- A host (or router) has 4-byte IP address (format: x.y.z.w)
  - Hierarchical address; a part of address denotes network id (say,LAN), all hosts in a network has same network id
  - Host IP address from its ASCII name is obtained using DNS (Domain Name Server)
- A host (or router) has network interface card (nic) connecting to the cable
- A host has 6-byte Ethernet (or hardware or MAC address) hardwired at nic (format: a:b:c:d:e:f)
  - Non-hierarchical address; When a host sees a packet carrying its own h/w address, it copies the packet onto itself
  - Hardware address of IP address of each host on a LAN is known to host on the same LAN using ARP (Address Resolution Protocol)

Example (contd.) – Case 1

- Host A at LAN X wants to transfer a packet to Host B at LAN Z
- At host A: obtain IP address of host B using DNS and attach to the packet
- Compare Network id part of host A's IP address with B's. Since they differ, hardware address of router interface at LAN X is attached to the packet
- Broadcast the packet on LAN X
- Router at LAN X grabs the packet; uses IP address for routing the packet
- Packet reaches the router attached at LAN Z. Network id part of packet's IP address matches that of this router
  - This router knows the corresponding hardware address (using ARP)
  - Router attaches the hardware address of host B with the packet
  - Router broadcasts the packet on LAN Z
  - Host B finds a match with its hardware address
  - Host B copies the packet

Example (contd.) – Case 2

- Host A at LAN X wants to transfer a packet to Host C at the same LAN X
- At host A, obtain IP address of host C using DNS and attach to the packet
- Compare Network id part of host A's IP address with C's. Since they match, Hardware address of host C at LAN X is attached to the packet
    - Hardware address of host C is known to host A using ARP
- Broadcast the packet on LAN X
- Host C at LAN X takes the packet;

Bandwidth and Throughput

- Bandwidth, data rate, capacity
  - These terms might be used interchangeably as stated earlier
  - Number of bits that could be transmitted per time unit
  - link versus end-to-end
  - Bandwidth of a link (or end-to-end connection)
  - Notation: 1 Kbps bandwidth = 10^3 bits per second

- Throughput or Effective throughput
  - Number of bits transferred per unit time (measured quantity)
  - Ratio between message size and message transfer time
  - Notation: message size 1 KB = 2^{10} bytes

Message Transfer Time

- Transmission time (T_t)
  - Time to transmit (or pump) message bits on to the link
  - i.e time elapsed between the beginning of transmission of the first bit and the end of transmission of the last bit
  - Message size / Bandwidth
- Propagation time (T_p)
  - Time to traverse from node A to node B
  - Distance / Propagation speed
- Queuing time (T_q)
  - Time for which a message is waiting in the queue at a node before the start of transmission
- Message Latency T_t $+T_p$ + T_q for one-way unacknowledged message transfer
  - Time required to transfer a message from A to B

Acknowledged Message Transfer

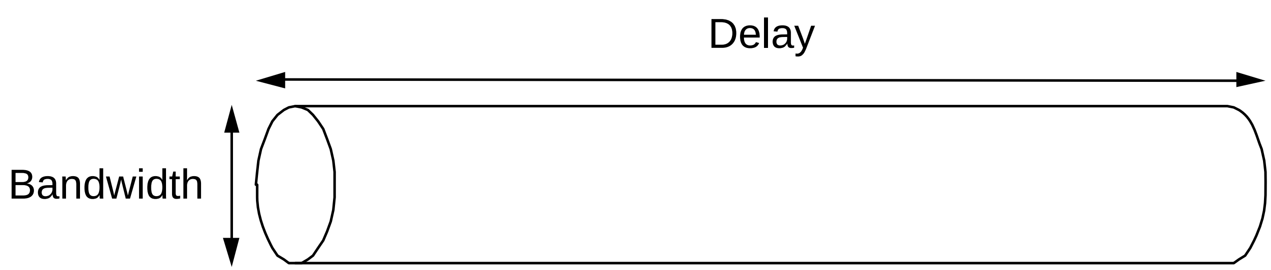
- Round-Trip Time (RTT)
  - Time taken by a message to traverse from A to B then back to A
  - Usually the transmission time is excluded

- RTT is usually used in acknowledged services wherein data is transmitted in one direction and ACK is transmitted in the reverse direction

- Message Latency $T_t + 2T_p + T_q$ for one-way acknowledged message transfer
  - Time required to transfer a message from A to B + Time required to transfer ACK from B to A

Delay x Bandwidth Product

- Here, delay refers to the propagation time on the link (pipe)
- Amount of data “in flight” or “in the pipe”
- Example: 100ms x 45Mbps = 4500 Kbits



Significance of DxB Product

- Upon receiving a bit, if the receiver sends a signal to the sender to stop transmission, then the sender would have transmitted DxB bits (D: Delay, B: Bandwidth)
- If the sender expects some signal (say acknowledgement) from the receiver before filling the pipe, then the bandwidth is underutilized

(Effective) Throughput

- Depends on RTT and transmission time
  - For unacknowledged one-way message transfer, one-way propagation time is used instead of RTT

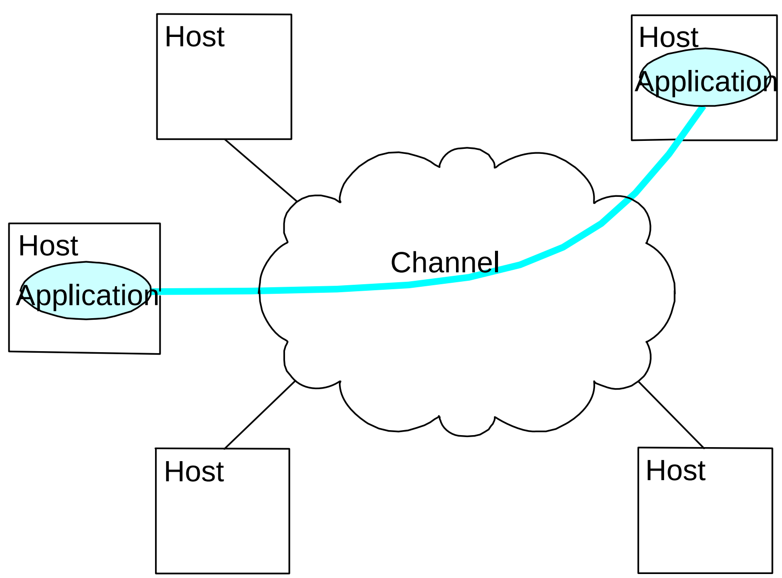
- It is desirable that the throughput is close to the bandwidth

- Case 1: RTT=10 ms, message size=1MB, b/w=10 Mbps
  - Transfer time= 10+(1MB/10Mbps)=849 ms
  - Eff. Throughput= 1MB/849ms = 9.88 Mbps

- Case 2: RTT=10 ms, message size=1MB, b/w=1 Gbps
  - Transfer time= 10+(1MB/1 Gbps)= 18.4ms
  - Eff. Throughput= 1MB/18.4ms = 456Mbps

Inter-Process Communication

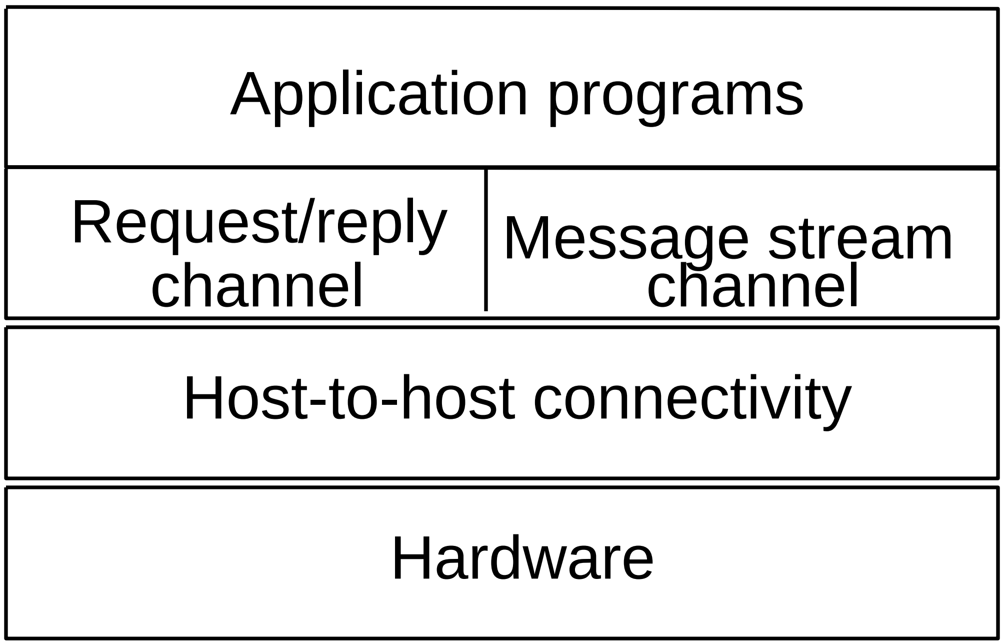
- Turn host-to-host connectivity into process-to-process communication.
- Fill gap between what applications expect and what the underlying technology provides.



Different Kinds of Channels

- Request/Reply
  - distributed file systems
  - digital libraries (web)
- Stream-Based
  - video: sequence of frames
    - 1/4 NTSC = 352x240 pixels
    - (352 x 240 x 24)/8=247.5KB
    - 30 fps = 60Mbps (approx)
  - video applications
    - on-demand video
    - video conferencing

Network Architecture - Layering



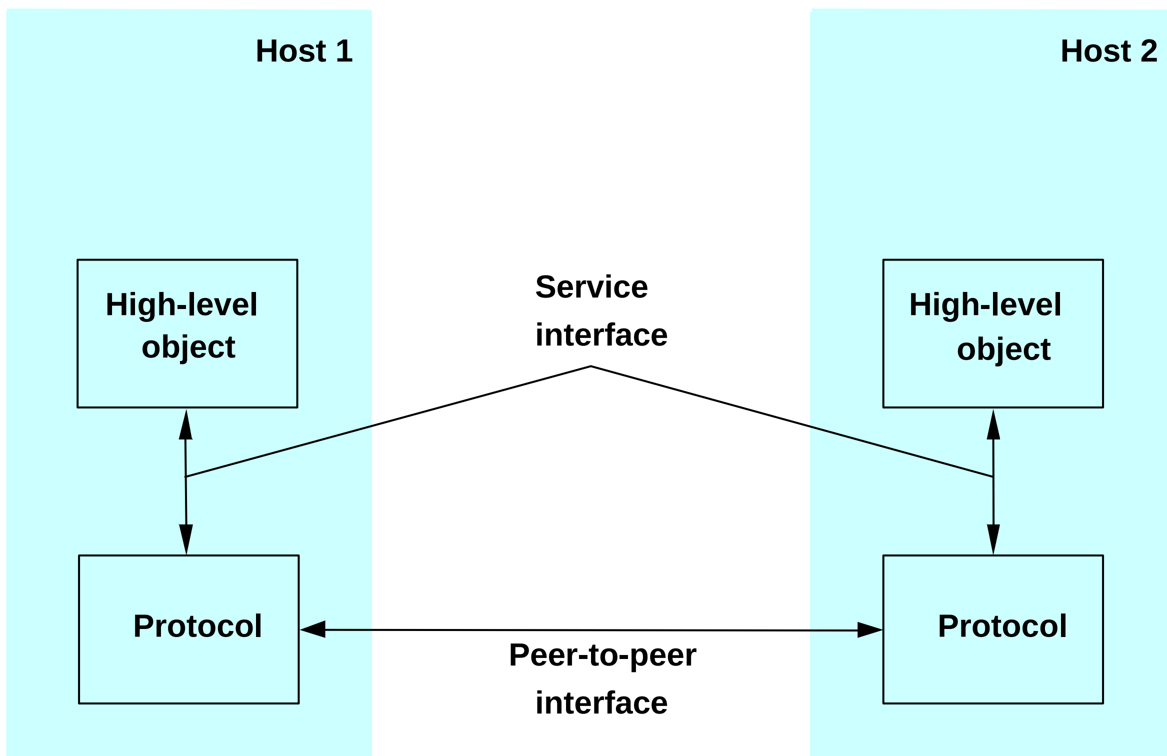
Advantages of Layering

- Use abstractions to hide complexity
- Abstraction naturally lead to layering
- Alternative abstractions at each layer
- Network design becomes easier as layering allows decomposing of the design problem into manageable components
- Layering aids modular design. New services can be added to a layer without modifying the functionality of other layers

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
    - pseudocode /state transition diagrams
  - module that implements this interface
    - may exist more than one implementation for the same specification (module interoperability)

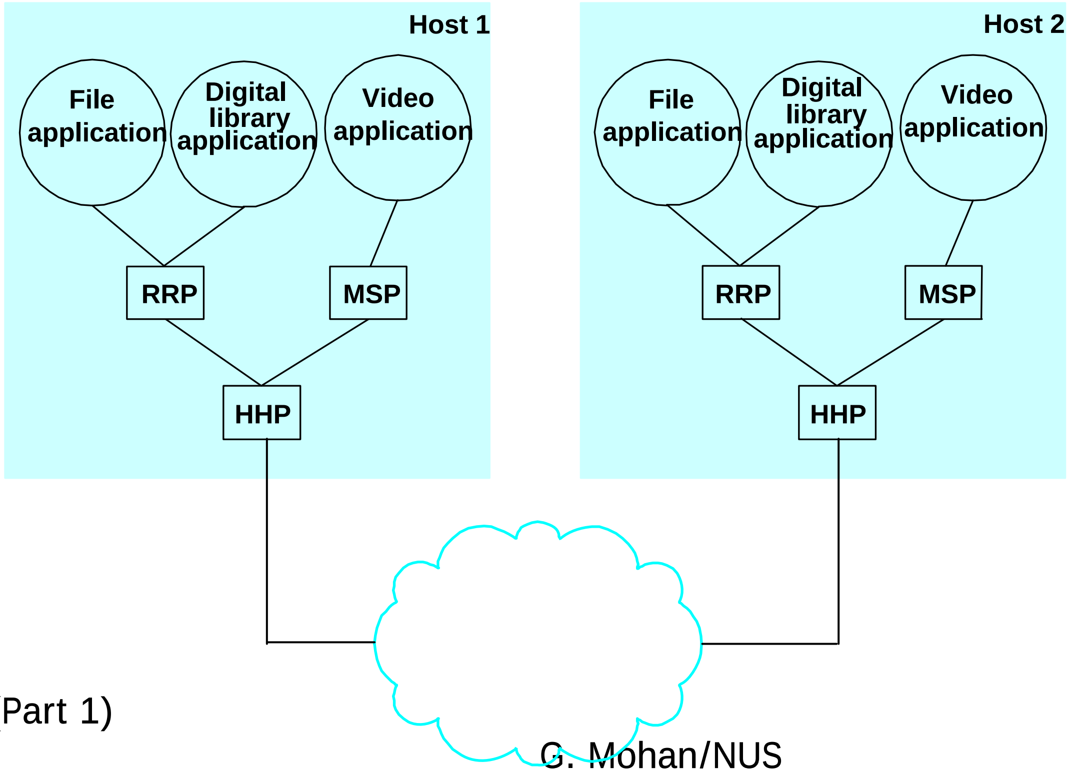
Interfaces



Host 1
Host 2
High-level object
High-level object
Service interface
Protocol
Protocol
Peer-to-peer interface

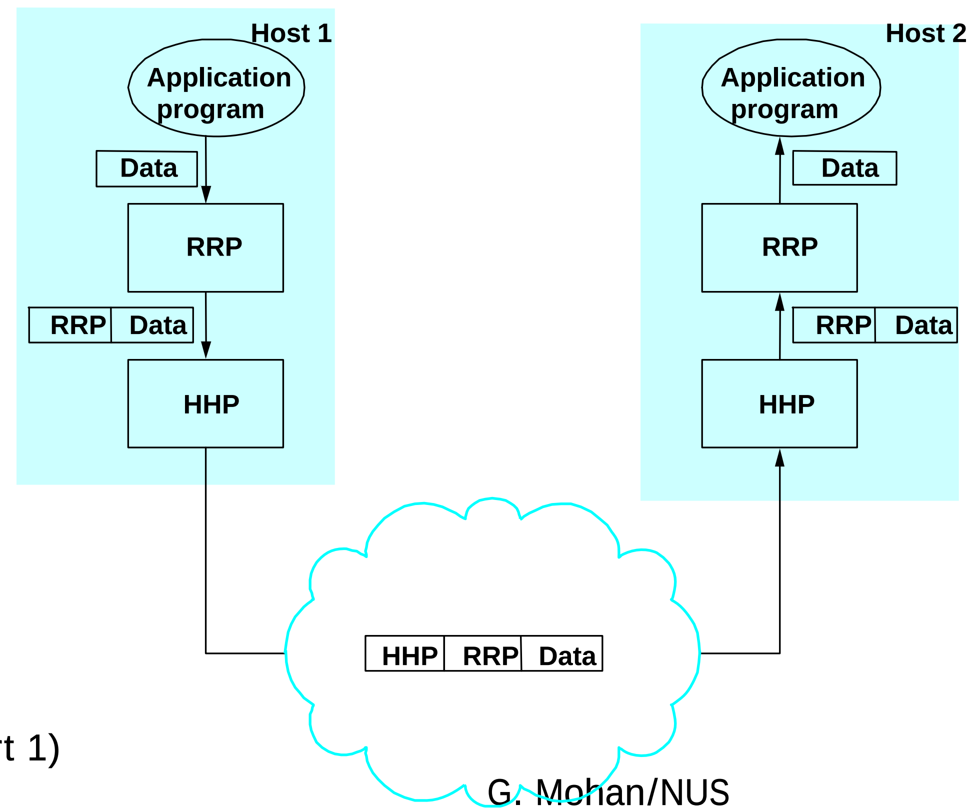
Protocol Machinery

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

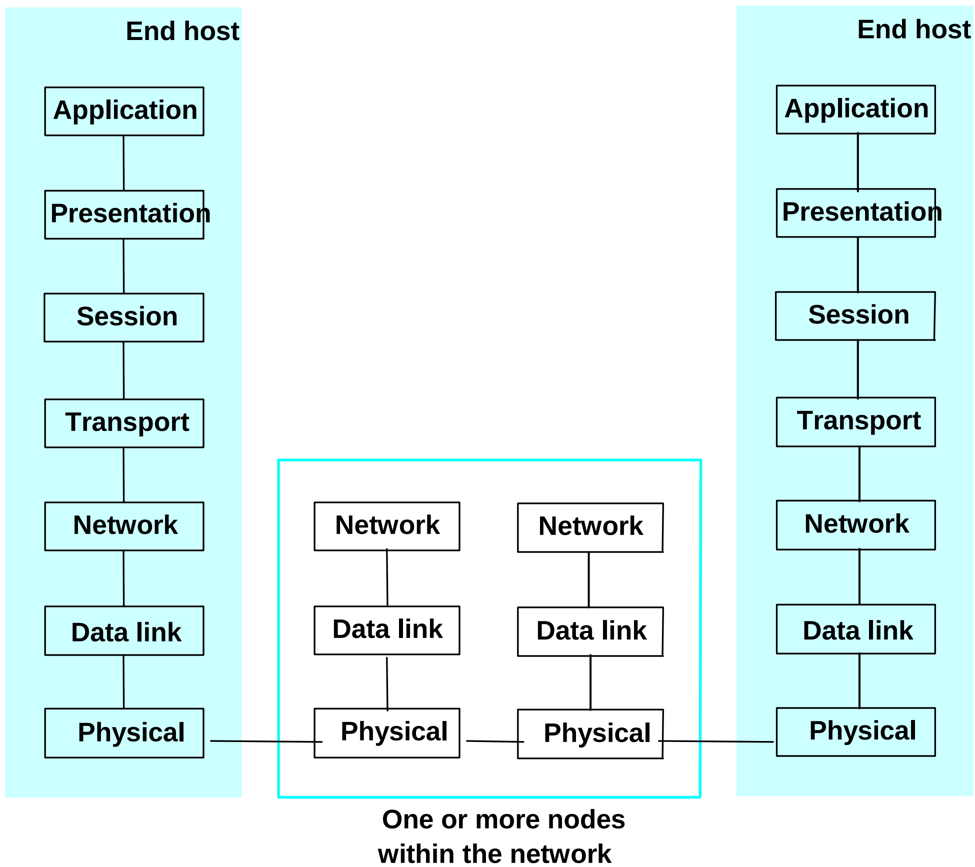


Protocol Machinery (cont)

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



ISO-OSI Architecture
Intl. Standards Organization-Open Systems Interconnection



Functions of Layers

- Physical layer (Layer 1, in short L1)
  - Transmission of raw bits over a communication link
  - Electrical characteristics: voltage levels, signal durations
  - Mechanical characteristics: pluggable connector specifications
- Data link layer (Layer 2)
  - Aggregation of bits into frames, error and flow control (optional)
  - Medium access control (MAC), e.g. Ethernet
- Network layer (Layer 3)
  - Routing packets between nodes, may do congestion control (IP routers do not do congestion control)
- Transport layer (Layer 4)
  - Handles messages Process-to-process channel, end-to-end layer, end-to-end message transfer, reliable message delivery, congestion control, flow control

Functions of Layers (contd.)

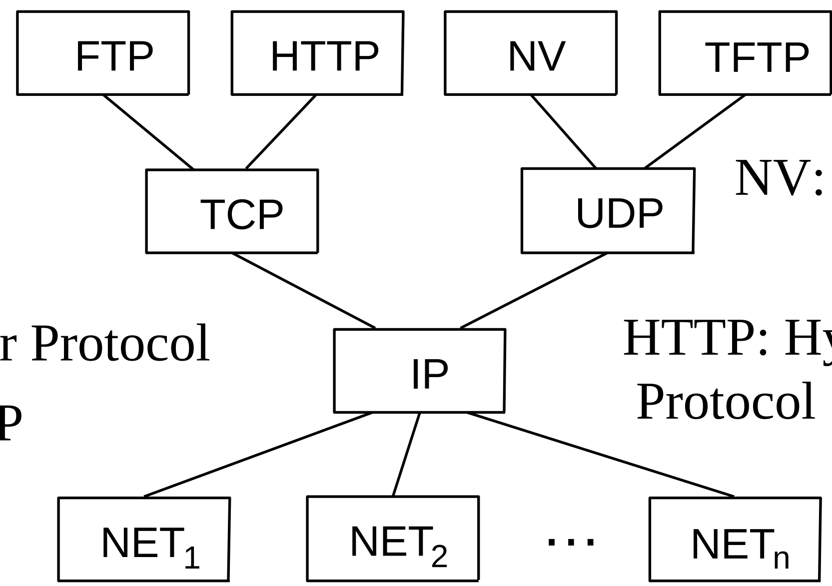
- Session layer
  - provide name space to collectively refer to different transport streams that are a part of a single application
  - eg. Video conferencing (audio and video streams)
- Presentation layer
  - data representation (integer, string)
  - how data is transmitted MSB first or LSB first.
  - Compression, encryption
- Application layer
  - Provides protocols to support different applications such as FTP, email/SMTP (Simple Mail Transfer Protocol)

Internet Architecture

- Five layer architecture
- Application Layer (L5, in ISO-OSI architecture, it is L7)
  - Present at the end systems (hosts)
- TCP or UDP layer (L4)
  - Present at the end systems (hosts); lowest end to end layer
  - TCP: Transmission Control Protocol
    - Reliable connection oriented transport service, guarantee for no errors, in-order delivery;
    - Flow control, error control, congestion control
  - UDP: User Datagram Protocol
    - Unreliable connectionless message transport service
- IP layer (L3)
  - Routing; does not do congestion
- Physical Network (Link layer (L2)and physical layer(L1))
  - Flexible to support any underlying wired or wireless networks
    - E.g. Ethernet, wireless LAN, SONET, ATM

Internet Architecture

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



NV: Networked Video

FTP: File Transfer Protocol

TFTP: Trivial FTP

HTTP: Hyper Text Transport Protocol

Protocol Data Units in the TCP/IP Architecture