COMPUTER NETWORKS
CS 45201
CS 55201

CHAPTER 1
Network Foundation

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Fall 2001

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Perspective

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

History

- We have migrated from industrial revolution (18th century) to age of steam engine(19th century), and to information gathering, processing and distribution (20th century).
- In computer era, we have migrated from a single computer serving all organizations to computer networks.

Computer Networks vs. Distributed Systems

- In Distributed Systems, multiple computers are transparent.
  - Users are unaware of underlying structure
  - Mostly OS issue
  - Nodes are generally under one organization control
- In Computer Networks, autonomous computers are interconnected.
  - Users specify the location of resources
  - Nodes are autonomous
- Nevertheless, there are a lot of overlaps between them.

Network Goals

- Resource sharing: factory automation at different locations.
- High reliability: having alternative resources.
- Saving money: small computers have better price/performance.
- Flexibility: Adding more processors as load increases.
- Using network as communications medium.

Network Classifications

Processors Location	Distance	Example
Circuit-board	0.1m	Data flow machine
System	1m	multiprocessors
Desk	10m	DAN
Building	100m	LAN
Campus	1Km	LAN
City	10Km	MAN
Country	10Km	WAN (long haul)
Continent	1000Km	Long Haul
Planet	10,000Km	Long Haul

- Network exists whenever two or more elements interact with each other.
- A network is a set of nodes and links.
- Why networks
  - sharing resources such as databases or CPUs
  - interprocesses or interprocessor communications.
  - providing reliability using backup or redundancy (routing?)
  - distributed processing
  - furnishing central control (defense, inventory, sales)
  - to provide compatibility of dissimilar equipment
  - maximum performance at minimum cost.

- Topological classification
  - Static networks
    - 1-D (bus)
    - 2-D (tree, stars, rings, mesh, etc.)
    - multidimensional (cube, hypercubes)
  - Dynamic networks
    - one or more switches are used.
- Technological Classification
  - Circuit-switching networks
    - dedicated paths are used between source and destination.
    - no queuing
    - example: telephone systems.
  - Packet Switching
    - The message is divided into a number of slices called packets of certain fixed size.
    - Each packet has its destination address.
    - Queuing involved
    - Routing is needed
    - errors involved
  - Message Switching
    - The network receives the entire messages, stores them in a secondary storage and transmit them.
    - It provides long term storage even after the message has been delivered.

- Non-Switching Networks.
  - Broadcast networks
  - Single node, data processing(800).
  - Single node, data base management (library).
- Voice transmission is still the most common mode of communications.
- All projections indicate that voice will continue to be the heaviest communications.
- Telephone is still analog although it is extensively used for data transmission.
- Data signals must normally be converted to voice (analog) signals using modems.
- AT&T in early 1960s introduced digital carrier system T1
  - Consists of 24 channels at 64 Kbps per channel.
  - 1.544 Mbps.
  - US, Canada and Japan.
- CCITT has 30-voice channel at 2.048 Mbps (rest of the world).
- Many telephone carriers provide all digital transmission over selected portion of the network..
- the great interest is transmitting packetized voice in real time.
- Protocols are the building blocks (not buzzwords) of a complex system developed based on engineering principles.
- How these building blocks are glued together to construct a network?

- They are constantly being redefined, extended, and replaced.
- Why networks are designed the way they are?

Protocols

- Exponential growth of Internet in recent years
  - Software run on general purpose computers
  - Easy to develop new software
  - WWW is the popular application
- Massive computational power of the hosts.
  - A requirement to play back voice codes

Elements of a network (subnetworks)

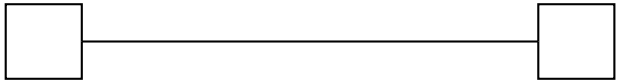
- Sources: terminals, information processors, or network processors.
- Switches: relaying nodes, terminal controlling nodes, or Interface Message Processors (IMPs).
- Destinations: remote terminals, computers, or network processors.

Applications

- FTP
- WWW
  - Synonymous with the Internet
  - Set of clients and servers using the same language: Hyper Text Transfer Protocol (HTTP).
  - Graphic client programs (Web browser) such as Mosaic and Netsacpe
  - URL (uniform resource locator) is function of a Web browser that opens a location on the Web
  - URL displays index.html
- Network Video
  - Synonymous with the Internet
  - Require a special hardware (frame grabber) to decode images for standard TV, $352 \times 240\ pixels \times 24$ bits

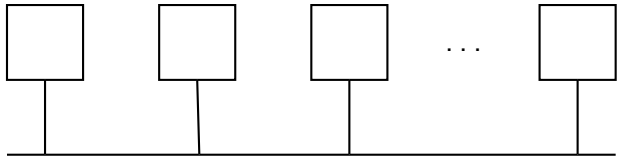
Connectivity

- Building Blocks
  - links: coax cable, optical fiber...
  - nodes: general-purpose workstations...
- Direct Links
  - point-to-point



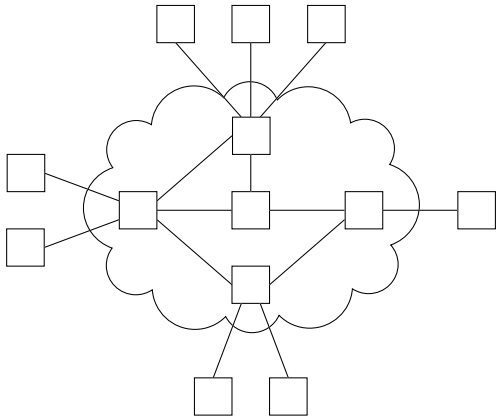
point-to-point network

  - multiple access

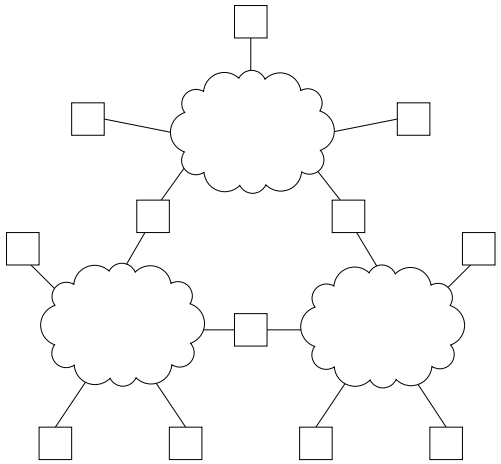


multiple access network

- Indirect Connectivity
  - switched networks



  - internetworks

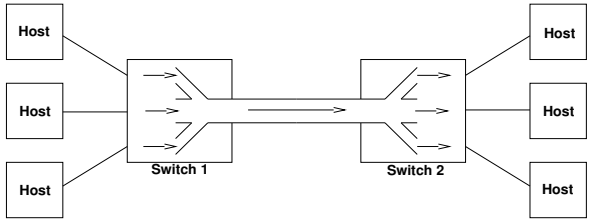


A network can be defined recursively as two or more nodes connected by a physical link, or by two or more networks connected by one or more nodes.

- Switching Strategies
  - circuit switching: dedicated circuit; send/receive a bit stream
  - packet switching: store-and-forward; send/receive messages (packets)
- Addressing and Routing
  - address: byte-string that identifies a node; usually unique
  - routing: process of determining how to forward messages towards 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

Cost-Effective Resource Sharing

Must share (*multiplex*) network resources (nodes and links) among multiple users.

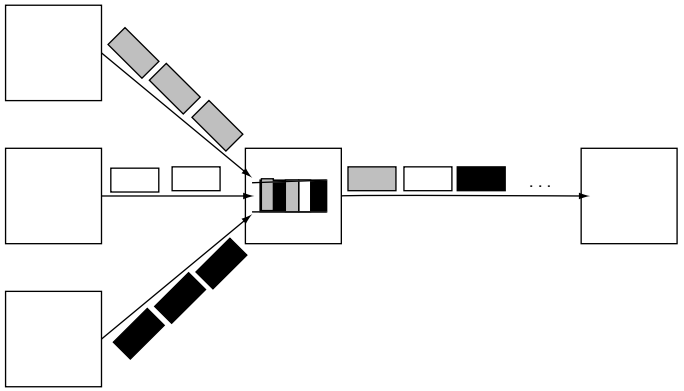


Common Multiplexing Strategies

- Time-Division Multiplexing (TDM) $\Longrightarrow$ TDMA
- Frequency-Division Multiplexing (FDM) $\Longrightarrow$ FDMA
- Code-Division Multiplexing (CDM) $\Longrightarrow$ CDMA
- Wave-Division Multiplexing (WDM) $\Longrightarrow$ WDMA

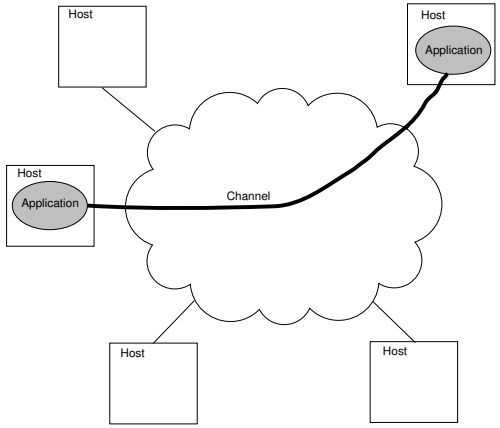
Statistical Multiplexing

- Time-division, but on demand rather than fixed
- Reschedule link on a per-packet basis
- Packets from different sources interleaved on the link
- Buffer packets that are *contending* for the link
- Packet queue may be processed FIFO, but not necessarily
- Buffer overflow is called *congestion*



Functionality

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



- Network supports common process-to-process channels; e.g.,
  - Request/Reply: for file access and digital libraries
  - Message Stream: for video applications
    - video: sequence of frames
    - resolution: 1/4 TV-size image = 352x240 pixels;
    - 24-bit color: frame = $(352 \times 240 \times 24)/8 = 247.5$KB;
    - frame rate: 30 fps = 7500KBps = 60Mbps
    - video on-demand versus video-conferencing

What Could Go Wrong in a Network?

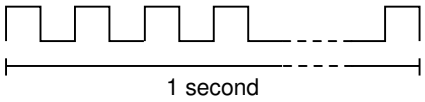
- Bit-level errors (electrical interference)
- Packet-level errors (congestion)
- Link and node failures

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

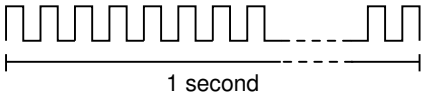
The key problem is to fill in the gap between what applications expect and what the underlying technology provides.

Performance

- Bandwidth (throughput)
  - Amount of data that can be transmitted per time unit
  - Example: 10Mbps
  - link versus end-to-end
  - Notation
    - KB $= 2^{10}$ bytes
    - Mbps $= 10^6$ bits per second
  - Bandwidth related to "bit width"



1Mbps
(each bit 1 microseconds wide)

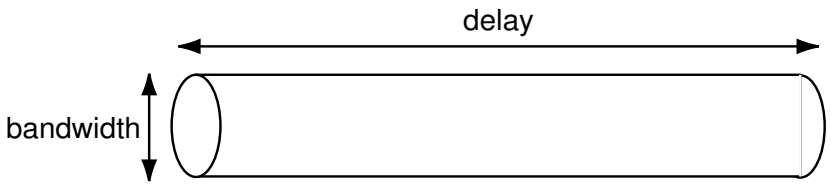


2 Mbps
(each bit 0.5 microseconds wide)

- Latency (delay)
  - Time it takes to send message from point A to point B
  - Example: 24 milliseconds (ms)
  - Sometimes interested in in round-trip time (RTT)
  - Components of latency

    Latency = Propagation + Transmit + Queue
    Propagation = Distance / SpeedOfLight
    Transmit = Size / Bandwidth
- Speed of light
  - 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
- Notes
  - no queuing delays in direct link
  - bandwidth not relevant if Size = 1 bit
  - process-to-process latency includes software overhead
  - software overhead can dominate when Distance is small
- Relative importance of bandwidth and latency
  - small message (e.g., 1 byte): 1ms vs 100ms dominates 1Mbps vs 100Mbps
  - large message (e.g., 25 MB): 1Mbps vs 100Mbps dominates 1ms vs 100ms

Delay × Bandwidth Product



- Example: 100ms RTT and 45Mbps Bandwidth = 560 KB of data
- Application Needs
  - bandwidth requirements: burst versus peak rate
  - jitter: variance in latency (inter-packet gap)

Network Architecture

- When two human engage in a dialog, Communication take pace at three levels.
  - Cognitive level: some level of understanding
  - Language level: no longer concern with the subject.
  - Transmission level: neither the concept nor the language is important (physical means).
- A network consists of a series of levels called layers.
- A protocol is the rule of conversation; each layer has its own protocol.
- An example in human speech is : don't interrupt when somebody speaks.
- Another example is return address on regular mail.
- Each computer and/or each application program in the computer may require a different communication access method and protocol.
  - setup a session through the network.
  - They must agree on the format.
  - Terminals must be able to regulate data rates
  - packets may arrive out of order.

Layered Architecture

- IBM SNA was one of first layered architecture, and ISO is rapidly becoming and International standard.
- Protocols must appear in every network node.
- The bottom 3 layers of ISO provide network services and the upper 4 layers provide services to the end users.

ISO/OSI Reference Model

Application	ftp, e-mail rlogin
Presentation	ASCII text, sound
Session	Establish/manage connection
Transport	End-to-end communication: TCP
Network	Routing, Addressing: IP
Datalink	Two part communication: Ethernet
Physical	How to transmit signal: Coding

1. Physical Layer
   - performs direct transmission of logical information into physical phenomena (electronic pulses).
   - modulators/demodulators are used at this layer.
2. Data Link Layer
   - makes sure that the message indeed reach the other end without corruption (signal distortion and noise).
   - acknowledgments
   - detect duplications.
   - timers for retransmission.
3. Network Layer
   - controls routes for individual message through the actual topology.
   - finds the best route.
   - finds alternate routes.
   - buffering and deadlock handling.
4. Transport Layer
   - locates the other party
   - creates a transport pipe between both end-users.
   - breaking the message into packets and reassembling them at the destination.
   - applies flow control to the packet stream.

5. Session Layer
   - is responsible for the relation between two end-users.
   - maintains the integrity and controls the data exchanged between the end-users.
   - the end-users are aware of each other when the relation is established (synchronization).
   - it uses naming and addressing to identify a particular user.
   - makes sure that the lower layer guarantees delivering the message (flow control).
6. Presentation Layer
   - it translates the language used by the application layer.
   - it makes the users as independent as possible, then they can concentrate on conversation.
7. Application Layer(end users)
   - where they process information that is being exchanged.
   - the users don't want to be aware of the mechanism of the network.
   - The users shouldn't be bothered by each other's language.

Advantages of Layered Architecture

- Any given layer can be modified or upgraded without effecting the other layers.
- Modulazition by means of layering simplifies the overall design.
- Different layers can be assigned to different standards, committees, and design teams.
- Different mechanisms (packet-switching, circuit-switching) may be used without effecting more than one layer.
- Different machines may be plugged in at different layers.
- The relation between different control functions can be better understood.
- Common lower levels may be shared by different higher levels.
- Functions (especially at lower levels) may be removed from software to hardware and microcodes.
- Increases the compatibility of different machines.

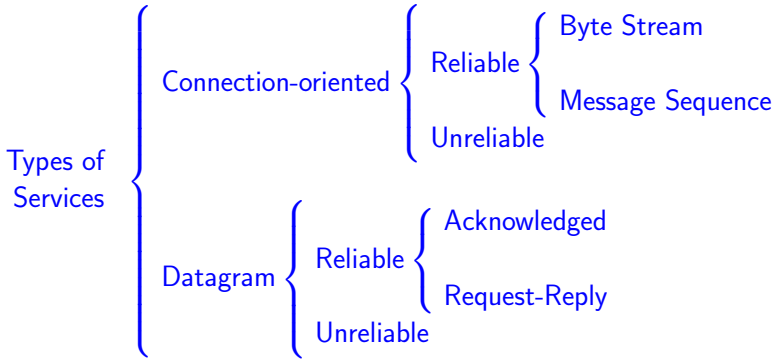
Disadvantages of Layered Architecture

- Total overhead is higher.
- Two communicating machines may have to use certain functions which they could do without layers.
- As technology changes, the functions may not be in the most cost-effective layer.

OSI Terminology

- *Entities*: active elements in each layer is called entities:
  - software: such as a process
  - software: such as I/O chips
- *Peer Entities*: entities in the same layer on different machines.
- Entities in layer N implement a service used by layer $N+1$. Layer N is called service provider, and layer $N+1$ is called service user.
- Services are available at Service Access Points (SAPs)
  - SAPs in telephone systems are sockets
  - SAP addresses are the telephone numbers of these sockets.
  - SAP addresses in postal service are P.O. box numbers.
  - In Berkeley UNIX, SAPs are sockets, and SAP addresses are socket numbers.
- At a typical interface (SAP point) between layer N and layer $N+1$
  - layer $N+1$ passes an IDU (Interface Data Unit) to layer N entity through the SAP
  - IDU consists of ICI (Interface Control Information) and SDU(Service Data Unit).
  - In order to transfer the SDU, layer N may have to fragment it to several pieces, each with a header called PDU (protocol Data Unit)

Types of Services



- Byte stream: user message boundaries are not preserved
- Request-reply: The reply serves as an acknowledgement as well
- Message oriented or byte oriented approach can be used for unreliable connection-oriented communication

Service Orientations

- Connection-oriented services
  - the sender pushes objects in at one end and the receiver collects them in the same order at the other end.
  - it was modeled after the telephone system.
- Connectionless-oriented services
  - it was modeled after the postal service
  - packet could take independent routes
  - packet could be received out of order collects them in the same order at the other end.
  - datagrams
- Request-Reply services
  - sender transmits a single datagram containing a request, the reply contains the answer.

Quality of Services

- Some reliable services use acknowledgments and hence overheads.
- File Transfer is a reliable connection oriented service.
- Reliable connection-oriented service has two variations:
  - message sequence : message boundaries are preserved.
  - byte streams: no message boundary are preserved.
- In some connection-oriented services the delay introduced by the ACKs are unacceptable (digitized voice traffic). Some level of noise is tolerable.

Service Primitives (operations)

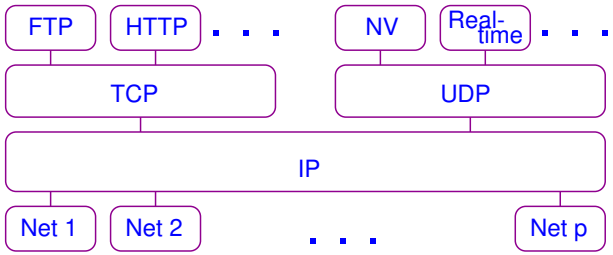
- The primitives tell to perform some action or report on an action taken by a peer entity.
- OSI primitives can be divided into four classes
  1. *request*: An entity wants the service to do some work.
  2. *indication*: An entity is to be informed about an event.
  3. *response*: An entity wants to respond to an event.
  4. *confirm*: An entity is to be informed about its request.
- Services and protocols are distinct concepts:
  - services are set of primitives that a layer provide to the layer above it.
  - services relate to an interface between two layers.
  - services are abstract data types.
  - protocols are set of rules governing the format and meaning of the frames, packets or messages.
  - protocols are implementations of the services data types.
  - entities use protocols in order to implement services.
- Unfortunately, OSI does not distinguish between these two.

Network Standardization

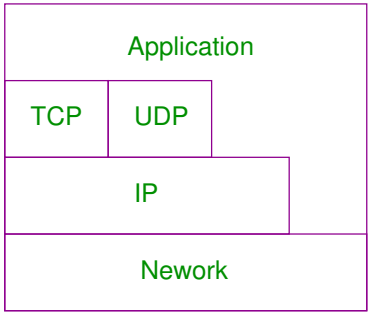
- In the early days, different vendors had different networks.
- Standards fall into two categories:
  - De facto standard
    - have just happened without formal plan.
    - IBM PC, UNIX, DOS.
  - De Jure standard (by law)
    - formal legal standards
- De Jure standards are two classes.
  - those established by treaty among national governments,
  - voluntary non-treaty organizations.

Internet Architecture

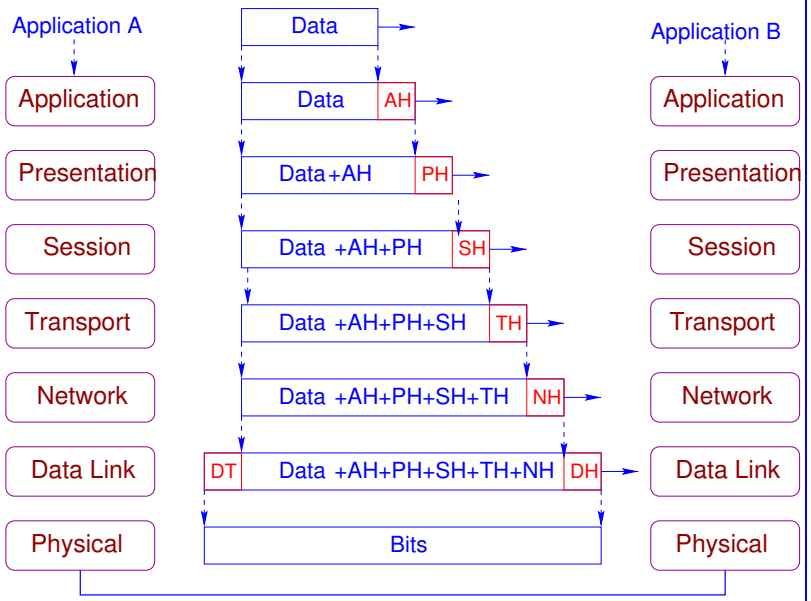
- Defined by Internet Engineering Task Force (IETF)



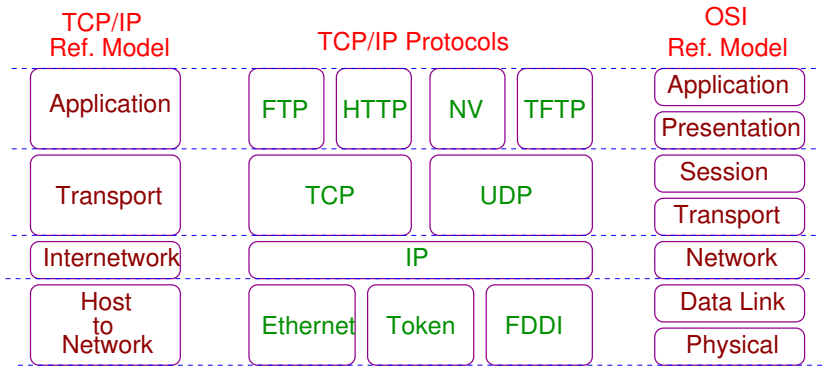
- Another view



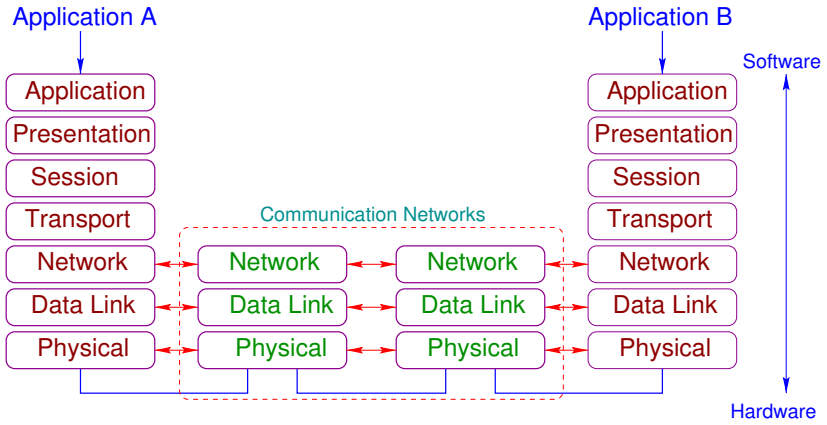
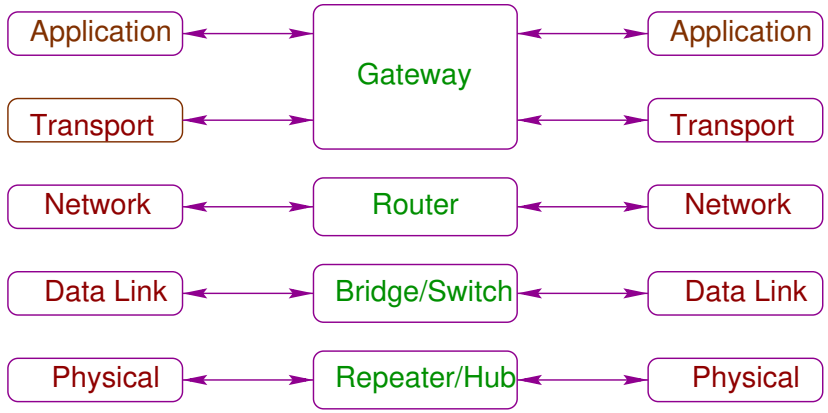
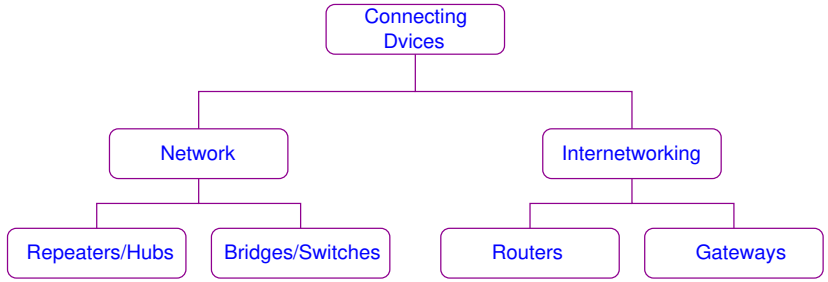
ISO Architecture



TCP vs. OSI



Internetworking



Network Interconnections