Computer Networks and Internet

- Overview of computer networks and Internet
- Network edge, end systems, links, networks
- Network core, switch, router, network structure
- Network performance, delay, loss, throughput
- Protocols, layered structure, TCP/IP, OSI
- Network security
- History

Many of the slides are adapted from those associated with the text book by J.F. Kurose and K.W. Ross

Components in Internet

- **Computer network, hosts connected by links and routers/switches**
- **Internet, collection of computer networks connected by routers/switches**
- **Protocols, rules for communication, control send/receive messages**

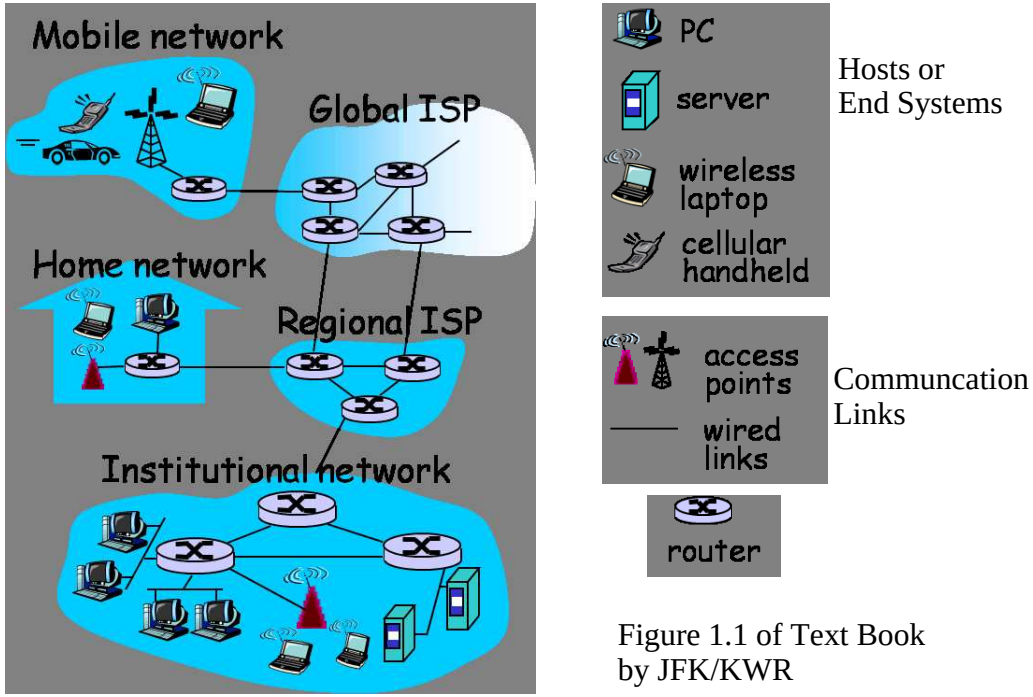


Figure 1.1 of Text Book
by JFK/KWR

Internet Services

- **Internet provides data transfer services for many distributed applications, email, Web, VoIP, online games, etc.**

  Those applications run on end-systems and transfer data via the Internet.

- **Application Programming Interface (API) is used by an application software on an end-system to send/receive data to/from the Internet.**

- **Data transfer in Internet**

  Reliable data delivery

  Best effort (unreliable data delivery)

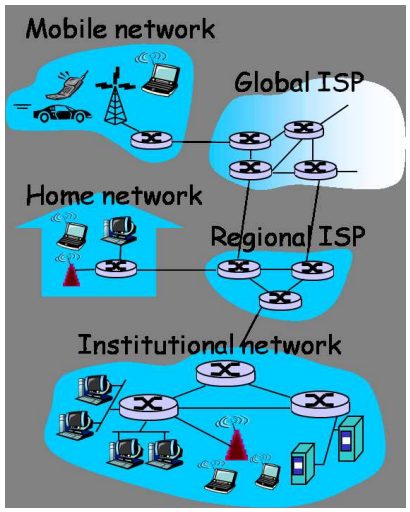
Protocols

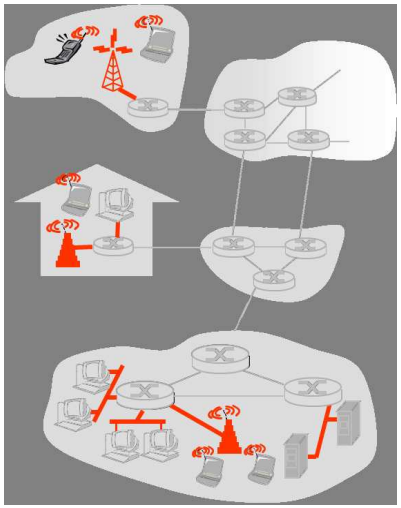
- **Rules for communication**
- **Specify message format**
- **Specify order of sending/receiving message**
- **Specify actions taken on messages transmission**
- **Examples, TCP, IP, HTTP, DNS**

Network Edge

- **Network edge, connect users to backbone**
- **End-systems (hosts), run applications (email, Web etc)**

  Applications may use client/server model or peer-to-peer model.
- **Access networks and links, connect end-systems to edge-routers which connect network edge to backbone**





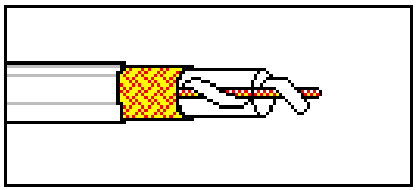
Figures of Text Bookby JFK/KWR

Access Networks

- **Dial-up modem, telephone lines, low data rate**
- **Digital subscriber line (DSL), telephone line, high data rate**
- **Cable modem, TV cables, high data rate**
- **Optical connection, optical fibers, very high data rate**
- **Ethernet, typically shared by multiple end-systems and used in offices, different data rate for different standards.**
- **Wireless access networks, wireless LAN, mobile phone**

Physical Links

- **Cable links, twisted pair (TP), coaxial cable, optical fiber**
- **Radio links, terrestrial microwave, wireless LAN, mobile phone, satellite.**



Network Classification

- **Broadcast networks, a common communication medium is shared by all end-systems attached to it. Examples, Ethernet, wireless networks.**
- **Switched networks, end-systems are connected by point-to-point links and switches/routers. Examples, telephone networks.**
- **Local area networks (LAN), a network covers a small area like a building, a campus, etc.**
- **Wide area network (WAN), a network covers a large geographical area. WANs are switched networks.**

Internet Backbone

- **Switched networks**
- **Wide area networks**
- **Networks of interconnected routers**
- **Basic technologies for data transfer between two end systems**

  Circuit switching, a dedicated path per connection

  Packet switching, data are transferred in packets

Circuit Switching

- **A dedicated path connects source and destination.**

  Three phases for a communication session:

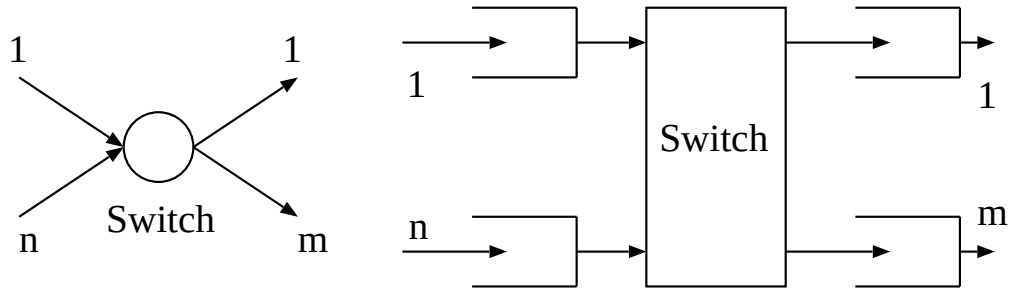
  - **Connection set-up, by signals on an auxiliary network or a routing prob message.**
  - **Message transmission, messages transferred on the path in the first-in-first-out order.**
  - **Connection termination, by signals on an auxiliary network or the last part of message.**

- **Circuit switching may be time consuming for connection set-up but has a small delay in data transfer.**

  An entire path is reserved for a connection, may waste resources.

Store and Forward Routing

- **A header with the routing info is attached to a message. The message is stored at a switch and then forwarded to an output link based on the routing info.**
- **Performance depends on link capacities, buffer sizes, switch processing capabilities, and traffic patterns.**
- **The queuing model is used for performance analysis.**



Packet Switching

- **Packet switching is based on store-and-forward routing.**

  A message is partitioned into packets of uniform size. Each packet is attached a header and delivered by store-and-forward routing. Each packet is transmitted independently.

- **Performance also depends on packet size. A larger packet requires a larger buffer size but introduces a smaller overhead traffic (the ratio of header/data is smaller) and vice versa.**

Internet Backbone Structure

- **Network of networks with hierarchical structure**
- **Tier1 networks, small number of large networks (ISPs)**

  National and international coverage

  Large content distributors

  Peer networks, no charge from one to another
- **Tier2 networks, usually regional networks (ISPs).**

  Customers of tier1 ISPs.
- **Tier3 networks, local ISPs**

  Customers of tier1/tier2 ISPs, last hop to end systems

Performance of Networks

- **Performance of a connection**
  - **Latency (delay)**

    Time to deliver data from source to destination, connection set-up time and data delivery delay.
  - **Throughput**

    Number of bits can be delivered from source to destination per unit time
  - **Error rate**

    Number of error bits per unit of data.
- **Performance of network**

  Aggregate or average performance of all connections in the network.

Delay in Packet Switching (1)

Four factors of delay from one router to another

- d_{proc}**: nodal processing delay, time for checking error, decide the output link.**
- d_{queue}**: queuing delay, time waiting at queue of the output link for transmission.**
- d_{trans}**: transmission delay, time for transmitting packet from queue to link.** $d_{trans} = L/R$**,** L **is packet size (bits) and** R **is throughput (bits per second, bps).**
- d_{prop}**: propagation delay, time for signal propagation from one router to another.** $d_{prop} = d/s$**,** d **is the length of link and** s **is propagation speed.**

Delay in Packet Switching (2)

- **Delay from one router to another**

$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}.$$

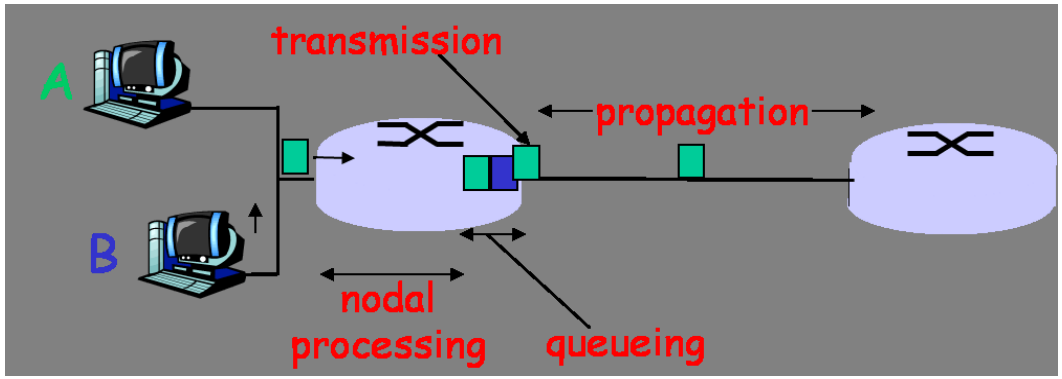


Figure from JFK/KWR

Queuing Delay

- R: **link bandwidth (bps)**

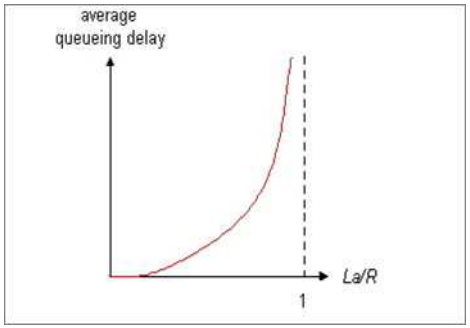
  L: **packet size (bits)**

  a: **average packet arrival rate (number of packets per second)**

- $\frac{L \times a}{R} \sim 0$, **average queuing delay small**

  $\frac{L \times a}{R} \to 1$, **average queuing delay large**

  $\frac{L \times a}{R} > 1$, **delay infinite and packets loss**



Figures from JFK/KWR

Packet Loss

- **Output link queue has finite size**
- **Packet arriving at a full queue is discarded.**
- **In Internet, router inform source for a discarded packet or a warning message before the queue full.**
- **Source may re-send the discarded packet.**

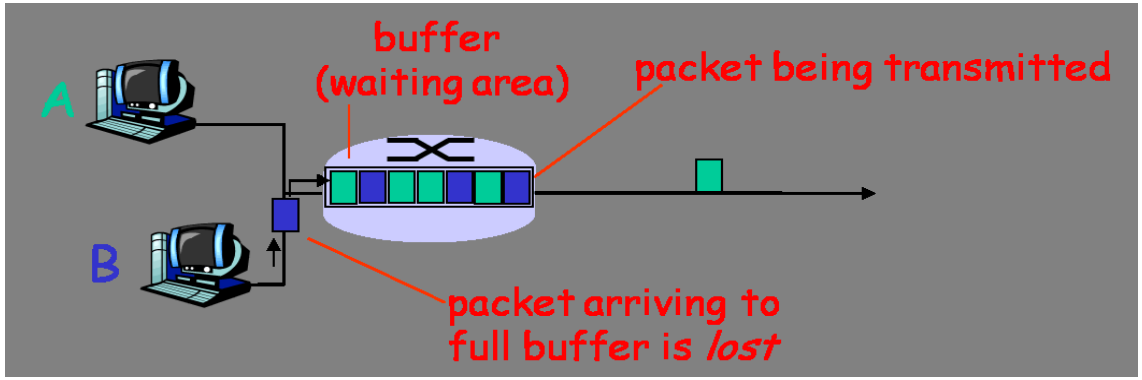


Figure from JFK/KWR

Throughput

- **Rate (bits per time unit) at which data transferred from sender to receiver.**

  Average throughput, average rate over a long time.

  Instantaneous throughout, rate at a specific time point.

- **Bottleneck link, a link with the minimum throughput in a path.**

- **Throughput betweeen two hosts in Internet,** $\min\{R_S, R_C, R/N\}$

  R_S**, throughput of link from sender to Internet core**

  R_C**, throughput of link from Internet core to receiver**

  R**, throughput of Internet core**

  N**, number of connections sharing Internet core**

Protocols

- **Rules for communication**

  Protocols to communication is similar as algorithms to computation

- **Layered structure**

  Functions of network are organized into layers. Services of layer n are realized by protocols at layer n using services of layer $n-1$.

- **Layered structure gives a clear identification and relation of complex network components.**

- **Layered structure makes maintenance and updating of systems easier, change of one layer may not affect other layers.**

- **Protocol standards for internet, TCP/IP, OSI**

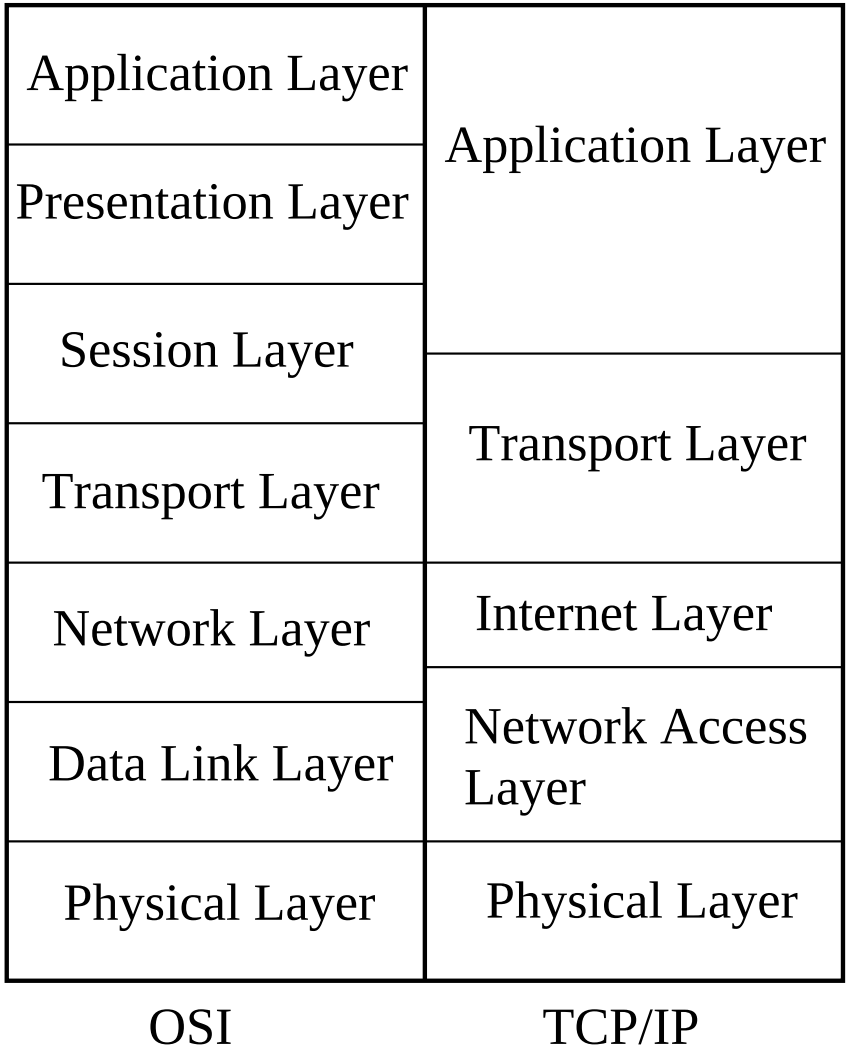
TCP/IP

- **TCP/IP has five layers, a de facto standard for internet.**
  - **Application layer, supporting network applications, HTTP, FTP.**
  - **Transport layer, process-to-process data transfer, TCP, UDP.**
  - **Internet layer, route data packets (IP datagrams) over multiple physical networks, IP.**
  - **Network access layer, route data packets over a same physical network, Ethernet.**
  - **Physical layer, specification of signal transfer on media/network.**

Open System Interconnection

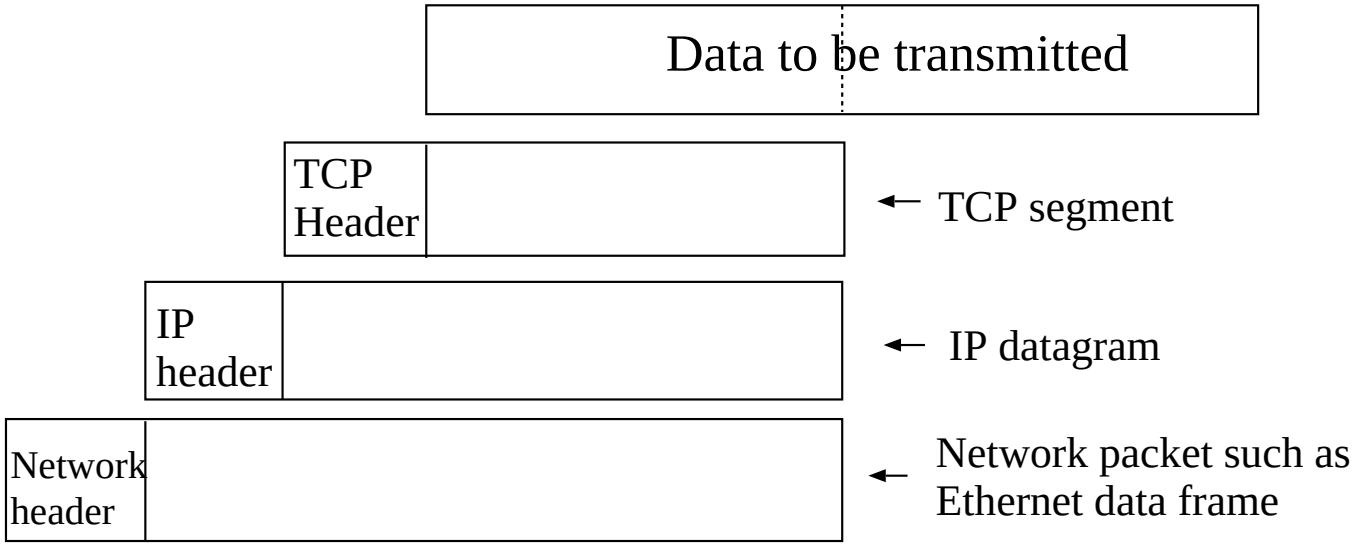
- **OSI has seven layers, a de jure reference model.**
  - **Application layer, supporting network applications, HTTP, FTP.**
  - **Presentation layer, interpret meaning of data, e.g., machine specific conventions.**
  - **Session layer, handle multiple sessions in a same host.**
  - **Transport layer, process-to-process data transfer, TCP, UDP.**
  - **Network layer, route data packets (IP datagrams) over multiple physical networks, IP.**
  - **Link layer, route data packets over a same physical network, Ethernet.**
  - **Physical layer, specification of signal transfer on media/network.**

Layered Structures of TCP/IP and OSI



Data Packets

- **A data packet consists of data and a packet head. Packets at different layers have different names but are generally called *protocol data unit PDU* .**



Protocol data units (PDU) in TCP/IP model

Network Security

- **Users in Internet are under attacks**

  Put malware into host via Internet.

  Denial of service (DoS), make resources unavailable to legitimate access with bogus accesses.

  Packet sniffing, read packets transmitted

  IP spoofing, change the IP addresses in data packets.

- **How to defend networks against the attacks.**

Internet History

- **Packet switching techniques, Kleinrock 1961, Baran 1964**
- **ARPANET, 1969 first node, 1972 public demonstration**
- **TCP/IP (1970s)**

  Allow LANs to use long-haul networks

  Internet protocol version 4 (IPv4, 1978)
- **Others**

  UNIX 4.2BSD support TCP/IP (1983)

  NSFNET, from NSF (1986)

  Hypertext Transfer Protocol, HTTP (1990)

  Commercial Internet Exchange, CIX (1991)

  Internet protocol version 6 (IPv6, 1998)

Internet Groups and Documents

- **Internet Society (ISOC), parent of other Internet boards and task forces,** `www.isoc.org`
- **Internet Architecture Board (IAB), parent for standard making and research groups,** `www.iab.org`
- **Internet Engineering Task Force (IETF), group for official Internet standards,** `www.ietf.org`
- **Internet Research Task Force (IRTF), group for research and development for future topics,** `www.irtf.org`
- **Internet Societal Discussion Forum (ISDF), forum on societal issues,** `www.isoc.org/members/discuss/isdf.shtml`
- **Internet Corporation for Assigned Names and Numbers (ICANN), manages domain name, IP address, etc,** `www.icann.org`
- **Request for Comments (RFC), technical reports on Internet protocols**

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