

Fundamentals of Networks

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- What is a Network?
 - A collection of devices (aka nodes) interconnected by different types of links, which allow devices to communicate at a distance in order to support diverse applications
 - Devices:
 - * End systems or terminal nodes: computer (desktop, laptop), cell-phone, tablet, car, sensor, and virtually almost anything
 - * Intermediate nodes: modem, repeater, hub, switch, router, base station, etc.
 - Links:
 - * Wired links: fiber, copper, etc.
 - * Wireless links: electromagnetic waves (radio, microwave, terahertz band, infra-red, etc.), acoustic waves (ultra-sounds), etc.
 - Applications:
 - * E-mail, instant messaging, web browsing, multimedia streaming, etc.
- A wireless sensor network
 - Many applications:
 - * Military applications: battlefield surveillance, nuclear, biological, and chemical attack prevention, etc.
 - * Environmental applications: tracking birds, smart irrigation, earth monitoring, etc.
 - * Health applications: health telemonitoring, drug administration tracking, etc.
- Network Types (classified by size):
 - PAN (Personal Area Networks) — Bluetooth, USB, etc.

- * Range of a person
 - LAN (Local Area Networks) — WiFi, Ethernet, etc.
 - * Range of a single building: a home, office, or factory
 - MAN (Metropolitan Area Networks) — WiMax, cable, etc.
 - * Range of a city
 - WAN (Wide Area Networks) — Cellular, landline telephone, etc.
 - * Range of an entire country or continent
 - Satellite
- Thus, the internet is a “network of networks”
 - Billions of connected computing devices:
 - * Hosts = end systems
 - * Running network applications at Internet’s “edge”
 - Packet switches: forward packets (chunks of data)
 - * Routers, switches, etc.
 - Communication links
 - * Fiber, copper, radio, satellite
 - * Transmission rate: link capacity (bps)
 - Networks
 - * Managed by organization
 - Interconnected ISPs (Internet Service Providers)
 - Protocols are everywhere
 - Control sending, receiving of messages
 - Examples: HTTP (Web), streaming video, Skype, TCP, IP, WiFi, 4G, 5G, Ethernet
 - Internet Standardization
 - IETF: Internet Engineering Task Force
 - * RFC: Request for Comments
 - IEEE: Institute of Electrical and Electronics Engineers
 - * IEEE 802.3, IEEE 802.11
 - Infrastructure that provides services to applications:

- Web, streaming video, multimedia teleconferencing, e-mail, games, e-commerce, social media, interconnected appliances
- Provides programming interface to distributed applications:
 - “Hooks” allowing sending/receiving applications “connect” to, use Internet transport service
 - Provides service options, analogous to postal service
- Protocols
 - For humans, an example is language (we have phonetics, grammar, etc.)
 - All communication activity in Internet governed by protocols
 - Sample definition: Protocols define the format, order of messages sent and received among network entities, and actions taken on message transmission and receipt.
- A closer look at internet structure:
 - Edge of the network:
 - * Hosts: clients and servers
 - * Servers often in data centers
 - Access networks:
 - * Wired, wireless communication links
 - Network core:
 - * Interconnected routers
 - * Network of networks
- Physical Media
 - Bit: unit of information that is carried by the signal that propagates between transmitter and receiver
 - Physical link: what lies between transmitter and receiver
 - Types of media:
 - * Guided media: signals propagate solid media (e.g. copper, fiber, coaxial)
 - Twisted pair (TP) — Two insulated copper wires twisted together in a helical form (The signals are usually carried as the difference in voltage between the two wires in the pair to increase robustness against noise).
 - Coaxial cable — Two concentric copper conductors, with bidirectional capabilities. Longer distances at higher data transmission rates than twisted pairs. A broadband system; that is, multiple frequency channels on cable.

- Fiber optic cable — Glass fiber carrying light pulses, each pulse a bit. High-speed operation, with point-to-point transmissions ranging from 10's-100's Gbps. Very low error rate because it is immune to electromagnetic noise, with repeaters spaced far apart. Downside: expensive and fragile
 - * Unguided media: signals propagate freely (no physical wire, like a radio)
 - Signal can be carried in different ways — electromagnetic waves (most commonly used), acoustic waves (typically underwater), magnetic-induction (e.g. Near Field Communications)
 - Propagation environment effects — reflection, obstruction by objects, interference
- Network types classified by switching technology — there are two fundamental approaches to moving data through a network of links
 - Circuit Switching
 - * Resources needed along a path (e.g. link transmission rate) to provide for communication between hosts are reserved before the transmission starts
 - * This reservation defines the path followed by data and guarantees the communication
 - * The resources are reserved for the duration of the communication session between the hosts
 - Packet Switching
 - * A message is divided into smaller data units or packets, which are transmitted over the network using the resources demanded
 - * No reservation of resources
 - * Different packets in the same “information stream” may traverse different paths and suffer different delays
- The Network Core
 - The network core of the Internet is a mesh of interconnected packet switches
 - Thus, the Internet is a packet-switched network
 - Packet switching: hosts break host messages into packets
 - * Packets are forwarded from one router to the next across links on path from source to destination
 - * Each packet is transmitted at full link capacity in each link
 - * No reservation → A packet may have to wait (that is, queue on a router)
 - Host sending function
 1. Takes application message
 2. Breaks into smaller chunks or packets, of length L bits

3. Transmits packet into access network at transmission rate R (bits/sec)
 - * Full link transmission rate: link capacity (aka link bandwidth)
 4. Packet transmission delay = Time needed to transmit L -bit packet into link

$$= \frac{L}{R}$$
- Router Function
 - * Store and forward — entire packet must arrive at input link of router before it can be forwarded to output link and then transmitted on next link
 - * Transmission delay — takes L/R seconds to transmit (push out) L -bit packet into output link at R bps
 - * End-to-end transmission delay — $2L/R$, ignoring other types of delays (more on delay shortly)
 - Circuit Switching
 - End-to-end resources reserved for, and allocated to communication between source and destination
 - Commonly used in traditional telephone networks
 - Usually, the communication is referred to as a “call”
 - Before the sender can send the information, the network must establish a connection between the sender and the receiver (resource reservation)
 - * Switches on the path between the sender and receiver maintain connection state
 - Internet Structure
 - Hosts connect to Internet via access to Internet Service Provider (ISPs)
 - * Residential, enterprise (company, university, commercial) ISPs
 - Access ISPs in turn must be interconnected
 - * So that any two hosts can send packets to each other
 - Resulting network of networks is very complex
 - * Evolution was driven by economics and national policies
 - Nodal Delay
 - Four types — Nodal processing, transmission, queueing, and propagation
 - $d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$
 - Nodal Processing (d_{proc})
 - * Check bit errors, determine output link, ...
 - * Typically $< 1[\mu s]$ or less

- Queuing Delay (d_{queue})
 - * Time waiting at output link for transmission
 - * Depends on congestion level of router
 - * Can vary from packet to packet
 - * Each output link has its own buffer (aka queue)
 - * Buffers have finite memory space
 - * Arrival rate (bps) to output link in router exceeds transmission rate, R bps, of this link temporarily
- Transmission Delay (d_{trans})
 - * L packet length (bits)
 - * R link transmission rate (bps)
 - * $d_{trans} = L/R$
- Propagation Delay (d_{prop})
 - * d length of physical link
 - * s propagation speed ($2 \cdot 10^8$ to $3 \cdot 10^8$ meters per second)
 - * $d_{prop} = d/s$
- Packet Queuing Delay
 - R link capacity (bps)
 - L packet length (bits per packet)
 - a average packet arrival rate (packets per second)
 - The traffic intensity is $(La)/R$
 - * When $(La)/R \approx 0$, average queueing delay small
 - * When $(La)/R = 1$, average queueing delay large
 - * When $(La)/R > 1$, “work” arriving is more than can be serviced — average delay is infinite
- End-to-end Delay
 - Total delay from source to destination
 - Nodal delays in the source to destination path accumulate to give the end-to-end delay
 - There can also be additional delays in the end system, *e.g.*:
 - * Delays when transmitting a packet in shared links (more later)
 - * Packetization delay: typically present in real-time applications
 - Time that it takes to fill a packet with encoded real-time data before sending the packet

- Throughput
 - Throughput: rate (bits/time unit) at which the receiver receives the data from the sender (aka end-to-end throughput)
 - * Instantaneous — rate at given point in time
 - * Average — Rate over longer period of time