Introduction

Computer Network. Interconnected collection of autonomous computers that are able to exchange information

- No master/slave relationship between the computers in the network

Data Communications. Transmission of signals in a reliable and efficient manner

Networking. Technology and architecture of communications networks used to interconnect communicating devices

A Communications Model

- Purpose of a communications system
  - Exchange of data between two entities
- Key elements of the model
  - Source
    - Entity that generates data
    - Person who speaks into the phone, or computer sending data to the modem
  - Transmitter
    - Device to transform/encode the signal generated by the source
    - The transformed signal is actually sent over the transmission system
    - Modem transforms digital data to analog signal that can be handled by telephone network
  - Transmission system
    - Medium that will allow transport of signal from one point to another
    - Telephone network for our computer/modem example
  - Receiver
    - Device to decode the received signal for handling by destination device
    - Modem converts the received analog data back to digital for use by the computer
  - Destination
    - Entity that finally uses the data
    - Computer on the other end of receiving modem
- Tasks to be accomplished in the model
  - Transmission system utilization
    - Efficient use of transmission network typically shared among a number of communicating devices
    - Multiplexing is used to share the total capacity of network among a number of consumers
    - Congestion control to ensure that the system does not get overwhelmed by excessive transmission network demand
  - Interface
    - Point of interaction or communication between two entities, such as a device and the transmission system
    - Communication is achieved through *signal generation*
    - Properties of signal
      - Possible to propagate through the transmission system
      - Possible to interpret as data by the receiver
  - Synchronization

    * Operation of transmitter and receiver in unison
    * Receiver must be able to determine when a signal begins to arrive and when it ends
    * Receiver must also know the duration of each signal element
  - Exchange management
    * Need for cooperation between two entities for bidirectional data transfer
    * Conventions or protocols to decide whether data is transferred simultaneously by more than one entity in a network connection or whether they take turns
    * Other things to worry about are the amount of data to be transferred, data format, and error detection/correction capabilities
  - Error detection/correction
    * Signal may get distorted during transmission
    * Cannot afford to alter the contents of data being transmitted
    * Imagine if this file gets some bits changed in every sentence while you download it, and does so in different locations for every download
  - Flow control
    * Collection of techniques used in serial communications to stop the sender sending data until the receiver can accept it
    * Receiver typically has a fixed size buffer into which received data is written as soon as it is received; when the amount of buffered data exceeds a "high water mark," the receiver will signal to the transmitter to stop transmitting until the process reading the data has read sufficient data from the buffer that it has reached its "low water mark," at which point the receiver signals to the transmitter to resume transmission
  - Addressing/Routing
    * Source must identify the identity of intended destination in a shared network
    * Transmission system must ensure that only the intended destination receives the data
    * The transmission system may choose any of the various available routes to deliver the data; it may even send data in parts with each part taking a different route
  - Recovery
    * In the event of transmission interruption, should the transmitter resend entire data, or send the remaining data only from the point of interruption
  - Message formatting
    * Preestablished patterns of signals between transmitter and receiver
  - Security
    * Safe delivery of data to intended recipient only
    * Data should not get modified during transmission
    * Data must be authenticated to be from the sender only
  - Network management
    * Configure the system
    * Monitor system status
    * React to failure and overload
    * Plan for future growth

Data Communications

- Where is data while it is traveling between different entities within the communications model, and what form is it in?

  - It could be in the form of a sequence of bits, or sequence of voltage shifts, or a signal suitable for transmission
  - Email example
    * Keyboard receives data and puts it in computer memory as a sequence of bits g
    * Data goes from memory to modem over local communications bus of the computer, and is denoted by $g(t)$ during this transition phase
    * It is picked up by modem (transmitter) and converted to sequence of voltage shifts (digital-to-analog conversion) which are sent over the network (communications medium); data are now denoted by $s(t)$
    * Finally, the signal reaches the destination (receiver) as $r(t)$ because it may get modified during the transmission by addition of noise
    * Receiver attempts to recover the signal $g(t)$ from $r(t)$ and produces a sequence of bits $g'(t)$
    * The final message m' should generally be as close to m as possible, ideally an exact copy of m
- Other aspects of data communications are data flow control, error detection and correction, and multiplexing for transmission efficiency

Network hardware and transmission technology

- Broadcast networks
  - Single communication channel shared by all machines on the network
  - Short messages, or *packets*, are sent from one machine and received by all machines
  - Address field within the packet specifies intended destination
  - Packet not intended for a machine is ignored by that machine
  - Multicasting
    * Transmission is sent only to a subset of machines
    * Possible by reserving one bit in the address field to indicate the presence of multicasting, with remaining bit holding a group number
    * A machine can *subscribe* to one or more groups
    * Packet sent to a group is delivered to all machines in that group
  - Typically used for smaller localized networks
- Point-to-point networks
  - Many connections between individual pairs of machines
  - Packet may visit intermediate nodes on its way to the destination
  - Routing algorithms are important for deciding a route in these networks
  - Typically used for large networks

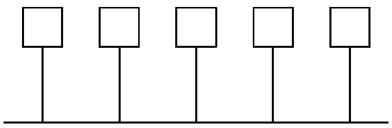
Data Communication Networking

- Impractical to connect every pair of communicating devices directly as point-to-point connection
  - Any pair of devices may be very far apart, making it expensive to have multiple dedicated links
  - A set of devices may require a link to many other devices at different times, for example telephones in an organization (all telephones at UMSL
- Problem can be solved by attaching each device to a communication network
  - Most networks can be categorized into one of the two classes: wide area networks and local area networks

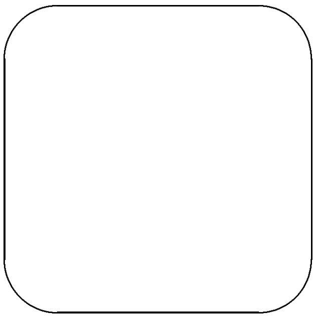
- Internetwork
  - Connection of two or more networks
  - Exemplified by internet
- **Wide Area Networks** or WANs
  - Generally spread over a large geographic area, from across the city to across the continent (100-1000 km)
  - Require crossing public area and may rely on circuits provided by a common carrier
  - Typically is made up of a number of interconnected switching nodes
  - Transmission from one device goes through internal nodes of the network to a specified destination device
  - Nodes are not concerned with the contents of the message but just bounce the message to the next node towards the destination
  - Implemented using circuit switching, packet switching, frame relay, or ATM
  - Circuit switching
    - A dedicated communication path is established between source and destination through the network nodes
    - Path is a connected sequence of physical links between nodes
    - On each link, a logical channel is dedicated to the connection
    - Data from the source is transmitted through the dedicated link as fast as possible
    - No delay between reception and retransmission of data at each node
    - Best example is the telephone network
  - Packet switching
    - No dedicated transmission capacity along a path
    - Data are sent in terms of packets
    - Packets travel through the network from node to node
    - At each node, packet is received and stored briefly before being transmitted to the next node
    - Commonly used for computer-to-computer communications
    - Considerable amount of overhead to compensate for errors
    - Additional bits to add redundancy and extra processing at each node for error detection and correction
    - Average data rate of about 64kbps
  - Frame relay
    - Removes the disadvantage of extra overhead in packet switching
    - Takes advantage of high transmission speed and low error rates in modern networks
    - Uses variable length packets called frames
    - Most of the overhead is stripped with error control
    - Operates efficiently to about 2Mbps
  - Asynchronous transfer mode or ATM
    - Also known as cell relay
    - Commercial state-of-the-art networks
    - Uses fixed length packets called cells to reduce the processing overhead
    - Provides little overhead for error control, depending on inherent reliability of transmission network and higher order logic at stations for error detection and recovery
    - Works in the order of 10–100Mbps range and may even achieve Gbps range
    - ATM vs. circuit switching
      - Circuit switching allows only fixed-data-rate circuits for the end systems
      - ATM allows multiple virtual channels with data rates that are dynamically defined at the time of creation of virtual channel

            - ATM is efficient due to the use of small fixed-size cells allowing it to offer a constant data rate channel while using packet switching
            - Data rate on each channel in the system can be dynamically set on demand
    - ISDN and Broadband ISDN
        - Integrated services digital network
        - Designed to replace existing public telecom network while delivering a wide range of services
        - Multiple networks within national boundaries with a single, unified view dictated by user interface standards
        - First generation or *narrowband* ISDN
            - Uses 64kbps channel with circuit switching and frame relay
        - Second generation or *broadband* ISDN
            - Supports high data rates at 100s of Mbps with packet switching and ATM

- **Local Area Networks** or LANs
    - Smaller scope compared to WANs, typically a single building or campus (10m – 1km)
    - Distinguished from other networks by size, transmission technology, and topology
    - Small size restriction binds the worst-case transmission time and simplifies network management
    - Internal data rates on LANs are much greater than those of WANs
    - Make use of a broadcast network approach rather than a switching approach
        - No intermediate switching nodes
        - Transmitter/receiver at each node communicates over a medium shared by other nodes
        - Transmission from any station is received by every other station
        - Data are transmitted in packets, allowing only one station to transmit at any given time
    - Generally use a single cable for transmission to which all machines are attached
    - Traditional speed is 10-100 Mbps, with low delay (10s of μs), with fewer errors
    - LAN topologies



Bus



Ring

        - Bus or linear cable network
            - At any point of time, one machine becomes master and transmits
            - Other machines cannot transmit at the same time
            - Conflicts, when two machines want to transmit at the same time, are resolved by some arbitration mechanism
            - Best example is Ethernet (IEEE 802.3), with decentralized control operating at 10-100Mbps
            - If nodes on Ethernet collide in packet transmission, each node waits for random time and tries again
        - Ring

- Each bit propagates around the network, without concern for rest of the packet
- Each bit may go around the ring even before the entire packet is transmitted
- Best example is IBM token ring (IEEE 802.5) operating at 4 and 16 Mbps

Protocols and protocol architecture

- In addition to data path, we need to account for other factors in communication network
  - Source must identify the destination to the network
  - Source must make sure that destination is prepared to accept data
  - Security must be accounted for; data should go to the intended user on the receiver
  - Incompatible file formats may need to be translated
- Computer communication
  - Exchange of information between computers for cooperative action
- Protocol
  - Set of rules governing the transfer of data between entities
  - Used for communication between entities in different systems
  - For two entities to communicate, they must speak the same language
  - Communication must follow some mutually acceptable conventions, referred to as protocol
  - Key elements of a protocol

    Syntax. Data formats and signal levels

    Semantics. Control information for coordination and error handling

    Timing. Speed matching and sequencing
- Protocol architecture
  - Cooperation between computers is broken into a number of tasks, with each task implemented separately
- **Three-Layer Model**
  - Communications can be abstracted in terms of three agents: applications, computers, and networks
  - File transfer operation

Application ⇒ Computer ⇒ Network ⇒ Computer ⇒ Application

  - Organize the communications task into three relatively independent *layers*
    1. Network access layer
       * Lowest layer in the communications network
       * Concerned with exchange of data between computer and network
       * Source computer must provide the address of destination computer to enable the network to route the data
       * Source computer may invoke some special services such as priority
       * Different standards for type of networks (circuit switching, frame relay, LAN)
       * The communications software above the network access layer need not know about the type of network
    2. Transport layer
       * Data must be exchanged reliably, and in the same order in which it is sent
       * This layer contains mechanisms for reliable data transportation

3. Application layer
    * Logic needed to support various user applications
    * Separate application dependent module

- Three computers connected to a network

  * Modules are at the same level and communicate through a network
  * Application at one machine hands a message to transport layer through its service access point to be transmitted over the network to the service access point of another application at a specified machine
  * Transport layer sends the data only to another machine and not to the service access point
  * The specifics of the address are encapsulated into the message
    · Data from next higher layer and the control information is known as *protocol data unit* or PDU
    · Header in each transport PDU contains control information to be used by peer transport protocol at destination
  * Examples of items in PDF

    Destination SAP. Address information for destination transport layer for data delivery

    Sequence Number. Allows assembly of messages from packets that arrive out of order

    Error-detection code. Extra information embedded by the transmitting transport entity to allow receiver to perform error detecting and correction
  * Transport layer hands over each PDU to the network layer, with instructions to send it over to destination
    · Network access protocol must present data to network with a transmission request
    · Network access protocol appends a network access header to the data received from transport layer, creating a network access PDU
    · Items in the network access header may include

      Destination computer address. Where to deliver the data

      Facilities requests. Extra facilities like priority

- **TCP/IP Protocol Architecture**
  - Most widely used interoperable structure
  - Organizes the communications task into five layers
    1. Physical layer
        * Physical interface between transmitter and network
        * Specifies the characteristics of transmission medium, nature of signals, data rate, and related matters
    2. Network access layer
        * Exchanges data between end system and network

    * Transmitter must provide the address of destination to the network for proper routing
    * Transmitter may invoke certain network services such as priority
    * Different standards are used for circuit switching, packet switching (X.25), LANs (Ethernet)
    * Mainly concerned with access and routing data between two computers connected to the same network
  3. Internet layer
    * Used to transfer data between devices attached to different networks
    * Data may have to traverse multiple interconnected networks
    * Uses **Internet Protocol** to route data across multiple networks
    * Protocol is implemented both in end systems as well as in routers
      · Router connects two networks and relays data from one network to the other
  4. Transport (host-to-host) layer
    * Ensures data reliability and packet order
    * Most common protocol in this layer is the *transmission control protocol* or TCP
  5. Application layer
    * Contains logic to support various user applications
    * Separate module for each application (such as `ftp`)

- **OSI Model**
  - Standard model for classifying communications functions
  - Contains seven layers
    1. Physical layer
       * Transmits unstructured bit stream over transmission medium
       * Mechanical, electrical, functional, and procedural characteristics to access the medium
    2. Data link layer
       * Reliable transfer of information across physical layer
       * Sends blocks/frames with synchronization, error control, and flow control
    3. Network layer
       * Separates data transmission and switching technologies from upper layers
       * Establishes, maintains, and terminates connections
    4. Transport layer
       * Reliable and transparent transfer of data between end points
       * End-to-end error recovery and flow control
    5. Session layer
       * Control structure for communicating between applications
       * Establishes, maintains, and terminates connections (sessions) between cooperating applications
    6. Presentation layer
       * Makes applications independent from differences in data representation
    7. Application layer
       * Access to the OSI environment
       * Distributed information services

Standards

- Essential for managing physical, electrical, and procedural characteristics of communications equipment
- Advantages

  - Large market for hardware/software; translates to lower cost
  - Intercommunication in products from different vendors
- Disadvantages
  - Technology freeze
  - Multiple/conflicting standards