Lecture 2: Basic Concepts and the Physical Layer

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**Basic Concepts**

- **Computer Network**: 2 or more computers interconnected by a computer network
- **Connectivity**: provided by a network
- **Link**: physical medium that interconnects 2 computers
  - Point to Point
  - Multiple access (broadcast)
- **Node**: computer (etc.) in the network
- **Switched Network**: nodes organized in a systematic way to forward data from a source node to a destination node.
  - **Circuit Switched**: used in telephony
  - **Packet Switched**: nodes send discrete blocks of data (called packets) among themselves
  - **Store and forward**: complete packet received, stored, fwd
Transmission Media

- Twisted Pair
  - Two insulated copper wires twisted together to reduce electrical interference (cat 3, cat 5)

- Coaxial Cable
  - Stiff copper wire surrounded by insulator and plastic sheath (p84) (50 ohm, 75 ohm)

- Fiber Optics (capable of 50-100 gbps)

- Wireless
  - VLF, LF, MF via groundwave
  - HF, VHF via ionosphere reflection
  - UHF, EHF directional
  - ...
Circuit Switching vs Store-and-Forward

- **Circuit Switching**
  - Connection is allocated a given transmission rate (r bps).
  - Path created (fixed) from transmission site to destination
  - Each comm link dedicates bandwidth r to this connection.
  - If no path can be found having r bps on all links, call is rejected.
Inefficient Link Utilization

\[ E(t_i) = \frac{1}{\lambda} \]

\[ E(X_i) = \bar{X} \]
Store-and-Forward

- Session setup without (necessarily) reserving bandwidth across network.
- One msg/pkt/cell transmitted on link at a time using full bandwidth of link.
- Packet waits in queue if needed to be transmitted on next link (disadvantage).
- Advantage is that each link is fully utilized when there is traffic to send.
Host: a node that uses the network (outside the network)

Switch: a node that implements the network (inside the network)

Internetwork: A set of independent networks that are interconnected

Router/Gateways: a node connected to two or more networks

Address: a byte string that identifies a node

Routing: a process of forwarding packets across a network based on source and destination addresses.

Unicast and Multicast Addresses: addresses assigned to single or multiple destinations.
End-to-end analog-digital-analog
But inside the network...
The Communication Link or Channel

Network Layer
Data Link Control
RS-232-C Interface
Modem

Communication Link

Network Layer
Data Link Control
RS-232-C Interface
Modem

Synchronous or Asynchronous
Unreliable bit-pipe
Digital Signal to Analog Waveform

Note: baud rate vs bit rate
Bandwidth of Channel

- In early 19th Century Fourier showed that most periodic functions having period T can be represented as a sum of sines and cosines (p78).
- The coefficients in such a series represent the "harmonics" of the signal.
  - Frequency domain representation
- Any communication channel passes a minimum and maximum frequency that limits the number of harmonics that can be recovered.
Important Channel Concepts

- Bandwidth: the difference between the highest frequency and lowest frequency that a channel can carry. It is directly related to the number of bits that can be transmitted over a network in a fixed time period.
Max Data Rate of Noisy Channel

- Nyquist (1924) and Shannon (1948) showed that the maximum data rate of a noisy channel whose bandwidth is $H$ Hz and whose signal-to-noise ratio is $S/N$, is given by:
  - $\text{max bits/sec} = 2H \log_2(1+S/N)$

- Example, a channel of 3kHz bandwidth and a signal to noise ratio of 30 dB can never transmit more than 30kbps
Important Channel Concepts (continued)

- **Bit Transmission Time**: the amount of time it takes to transmit one bit onto the channel.
- **Propagation Delay**: the amount of time it takes a bit to travel the length of the channel.
- **Throughput**: Generally refers to measured bps over the channel (as opposed to bandwidth, the theoretical max).
  - depends on statistical characteristics of input to the channel
  - has its own statistical distribution with mean usually indicated by lambda.
Important Channel Concepts (continued)

- Delay or Latency: the time it takes a packet to travel end-to-end across the network (or link).
- Roundtrip Time (RTT): the time it takes a packet to travel across the network (link) and back.
- Characteristic throughput-delay curve
Components of Delay

- Propagation Delay (Speed of Light)
  - $3 \times 10^8$ meters/sec in a vacuum
  - $2.3 \times 10^8$ m/s on a cable
  - $2.0 \times 10^8$ m/s on a fiber

- Transmission Time: packet length in bits divided by bps channel speed

- Queuing Delays: time spent waiting for service just like cars at a traffic light.
Delay x Bandwidth Product

- delay (secs) x bandwidth (bits/sec) = bits
- represents the number of bits that a channel can "hold" before the first bit transmitted gets to the destination.
  - Ex. a transcontinental channel with a one-way latency of 50 ms and a bandwidth of 45 mbps can hold: $50 \times 10^{-3}$ secs $\times$ $45 \times 10^6$ bits/sec = $2.25 \times 10^6$ bits or 280 kbytes (kB) of data.
End-to-end analog-digital-analog
Analog signals digitized in end-office producing 8-bit sample.

Codec samples 8000 per second at 125 microsec per sample (7-bits data + check bit each sample)

- 4 kHz bandwidth per channel (Nyquist)
- 64 kbps transmitted per channel
- 56 kbps data transmitted per channel

T1 carrier has 24 voice channels multiplexed together (1.544 mbps)
T1 Carrier and ATM

1 T1 frame (125 μsec)

Channel 1 gets exactly 1 byte at the start of each frame

(a)

There is no requirement about cell ordering

(b)

1 cell

(53 bytes)
Generic ATM Switch

Cells come in | Cells are switched | Cells go out

Switching fabric
PVC and SVC

Diagram showing network topology with nodes labeled A to H, and connections marked as Virtual circuit, Trunk, and Switch.
The Virtual bit-pipe

Network Layer

Data Link Control

Physical Interface

Synchronous or Asynchronous
Unreliable bit-pipe

Communication Link
Types of Bit-pipes

- Synchronous virtual bit pipe
  - DLC feeds the modem one bit each T secs
  - Idle fill

- Intermittent synchronous virtual bit pipe
  - Data bits fed synchronously and no idle bits
  - Receiving modem must detect 1,0 and idle

- Asynchronous characters
  - Bits go at fixed rate
  - Variable delay between characters
  - Generally low speed
Linear Time-Invariant Filter

- If input $s(t)$ yields output $r(t)$, then for any $u$, input $s(t-u)$ yields output $r(t-u)$
- If $s(t)$ yields $r(t)$, then for any real number $a$, $a*s(t)$ yields $a*r(t)$
- If $s_1(t)$ yields $r_1(t)$ and $s_2(t)$ yields $r_2(t)$, then $s_1(t)+s_2(t)$ yields $r_1(t)+r_2(t)$