Lecture 4 - Ch2. BG

• Topic: point-to-point communication (WAN’s).
  (multiaccess later in Ch. 4 -> LAN’s)

• Covers layers 1-4

• We won’t discuss physical transmission. (Important, so please look at/skim sometime; we have no time in course)

• We will talk about physical channel terminology

• Most important topic: ARQ (Automatic Repeat Request) -> How DLC and Transport layers recover from errors.
• 2.2 Physical Layer Terminology

1) Analog vs. Digital Channels (p. 40, BG)

-- Digital Channels = bit pipe
   --- accepts a bit stream as input
   --- produces a bit stream as output

-- Analogue Channel:
   --- accepts waveform as input
   --- produces waveform as output
   --- waveform = any function of time

Bit Stream

--- Modem converts bit stream to waveform, waveform to bit stream.

- Examples: telephone system

-- Your home has an analog channel - 3kHz voice to telephone local loop
-- Backbone for most (all) long distance lines is digital channel (voice converted to bit stream, then to analog again)
-- Campus phones are digital (cost of stolen phone)
• Analog vs. Digital Channel (pp. 53-54)

  - Q: Because digital channel runs on analog medium, why distinguish digital vs. analog channel?
You

long distance - signal subject to exp. attenuation and noise

Me

Repeats

-- Analog channel: Repeater amplifies signal + noise. I receive accumulation of noise over entire path.

-- Digital channel: Repeater recovers digital signal, regenerates analog -> noise supressed at each stage.

-- Problem: cost of digital (modems)

-- Voice now uses digital channel just for noise suppression. This is important to stereo systems too!

Music company->Master DAT->CD->
->Copy your DAT->your amplifier
• (BG) page 51 [Held & Sarch pp. 116-117 has a good explanation, too]

- A bit stream is transmitted as an AC signal at some frequency.

- What is the highest data rate one could ever achieve given a certain maximum frequency that a medium could propagate?

Let $C =$ data rate (bits/sec), $W =$ max frequency (Hz), $V =$ # voltage levels used in coding

-- Answer 1: (1924) Nyquist theorem:
--- Ignoring noise, using binary encoding (i.e., 2 voltage levels)

$$C = 2W \log_2 V$$

--- So, for a $W=3000$ Hz voice line, with $V=2$ levels, $C = 6$ kbps
--- But if $V=8$, then $C=18$ kbps.
--- Why can’t we just use arbitrarily large $V$ to get build modem with super-high $C$?
Answer: As $V$ increases, differences between voltage levels shrinks, so signals are distorted in shape and receiver cannot recover signal.

-- Answer 2: (1948) Shannon then related encoding (e.g., value of $V$) to $C$:

$$C = W \log_2 (1 + (S/N))$$

where $S/N$ is signal to noise ratio
Note: S/N is in db:
\[10 \text{db}=10, \ 20 \text{db} = 10^2, \ 30 \text{db}=10^3\]

--- For a 3000 Hz voice line, and S/N = 30db,

\[C \ = \ (3 \times 10^3)(\log_2 (1+10^3))\]
\[= \ (3 \times 10^2)(10)\]
\[= \ 30 \text{kbps}\]

--- Today’s modems are close to theoretical limit. They also use compression to achieve higher data rates (e.g., a 24kbps modem with 4:1 compression can achieve 96 kbps).
• (BG) pp. 38 and 52

- 3 types of physical channels
  1) synchronous: transmit idle fill between frames
  2) intermittent synchronous
  3) character asynchronous: bits within a character are synchronous

- Note that sender and receiver must be synchronized during transmission of data. Hence, 1 works at highest speed and 3 at lowest speeds

- So:
  -- for a 2400 Hz voice line (over unshielded twisted pair) 2400bps is cut-off between 1 and 2
  -- for a coaxial cable with ethernet, 100Mbps is cut-off
Analog Channel - Synchronous vs. Asynchronous

- High speed modems require continuous transmission even if DLC has no frames to send.

- Low speed modems (<2400 bps on a voice grade 3kHz telephone line) can use intermittent synchronous or character asynchronous.

- Coaxial cable has higher bandwidth -> crossover point is higher. 10 Mbps ethernet is intermittent synchronous (problem: cannot have > 100Mbps ethernet because it fundamentally is intermittent synchronous mac).
• (BG) 2.2.6 FDM vs. TDM

Goal: multiple channels over one physical medium

- Examples:
  -- many voice calls over one transatlantic optical fiber
  -- many TV stations over cable
  -- ISDN: voice + data over one wire to your home

- FDM:
  -- Shift each channel in frequency by adding a different carrier frequency
  -- Split $W$ Hz medium into $m$ channels, each with approximately $W/m$ bandwidth. (< $W/m$ in practice - guard bands to reduce cross talk (surely you’ve heard this on your telephone!))

- TDM:
  -- Bandwidth = $W$ has greater data rate than BW $< W/m$
  -- Multiplex $m$ bit streams into one bit stream using bandwidth $W$
  -- Divide bit stream into frames:

```
Frame

1-8 bits

m slots

Extra bits to help receive and maintain synchronization
```
- In U.S.A.
  -- T1:
    --- 125 µsec for a 24x8+1 = 193 bit frame
    --- m = 24
    --- 8 bit slots -> 64kbps
    --- 1 bit extra for synchronization -> 1/8 x 64 = 8 kbps (contains 10101010 = sine wave @ 4000Hz)
    --- data rate = 1.544 Mbps  
      = 24 x 64 kbps + 1x8 kbps
  -- T3:
    --- data rate = 44.736 Mbps (internet backbone rate in U.S.A)
    --- multiplexes 28 T1 signals

- In Europe
  -- m = 32
  -- data rate = 2.048 Mbps
• Digital Channels (BG 2.2.8)

  - Should phone company/data carrier sell you a digital vs. analog phone? (hot debate in communications industry)

    -- One answer: simply a question of who buys modem

    -- Better answer: digital channels have higher data rates with lower error rates

    -- Current answer:
      --- local loop: analog
      --- backbone net: digital - TDM + T1

    -- Future answer from phone companies:
      --- digital local loop (plus expensive phone for customers, w/ modem)
      --- ISDN: Integrated Services Digital Network
      --- Sonet: (Synchronous Optical Network)
      -> STS-1 = 51.84 Mbps
      -> STS-n = n (51.84 Mbps)
      -> TDM, 125µs frame with large number of 64 kbps voice circuits with 1 byte per frame
• ISDN

- Re-use existing telephone wiring for data + voice

- "Integrated" means backbone + local loops are digital, and service can be voice, data, video

- Today’s local loop cannot carry voice + data together/simultaneously to your home

- Common offering:
  -- Basic service:
    --- "B" - 2 channels of 64 kbps (two voice or data channels)
    --- "D" - 1 channel of 16 kbps (network management, disconnecting calls, and low data-rate services)

  -- "2B + D" service
    --- You could use computer at home without losing phone calls
    --- Maybe "1B + D" is adequate
    --- Could use "B" channel as:
      -> Virtual circuit to one destination
      -> Access line to packet switched network

  -- Primary service: for businesses with PBX’s:
    --- A T1 link:
      -> 24 channels of 64 kbps (US, Japan)
      -> 31 channels of 64 kbps (Europe)
      -> one channel is D, rest are B
- ISDN limitations
  -- You need a digital phone for voice traffic
  -- What about
    --- TV service to home?
    --- Data transfer of images (10^9 bits)?