Public Switched Telephone System

- Structure of the Telephone System
- The Local Loop: Modems, ADSL

Structure of the Telephone System

(a) Fully-interconnected network.
(b) Centralized switch.
(c) Two-level hierarchy.
A typical circuit route for a medium-distance call.

**Major Components of the Telephone System**

- **Local loops**
  - Analog twisted pairs going to houses and businesses
- **Trunks**
  - Digital fiber optics connecting the switching offices
- **Switching offices**
  - Where calls are moved from one trunk to another
The Local Loop: Modems, ADSL, and Wireless

The use of both analog and digital transmissions for a computer to computer call. Conversion is done by the modems and codecs.

Analog Signalling

- Analog signalling consists of varying a voltage with time to send information
- If the transmission media was perfect → No problem
- Transmitted signal ≠ Received Signal
- Three major problems
  - **Attenuation** - Loss of energy as the signal propagates (db in km)
    - Depends on frequency -- Different Fourier components attenuate differently
  - **Distortion** – different Fourier components propagate at different speeds
  - **Noise** – Unwanted energy from sources other than the transmitter
    - Thermal noise
    - Cross talk
    - Impulse noise
Modems

(a) A binary signal
(b) Amplitude modulation
(c) Frequency modulation
(d) Phase modulation

Different amplitudes to represent 0 and 1
Different frequencies are used
Wave is shifted systematically 0 or 180 degrees at uniformly spaced intervals.
45, 135, 225, 315 can be used to send 2 bits

Modems (2)

- To have higher speeds we cannot increase the sampling rate
- Nyquist theorem
  - Max data rate = $2H \log_2 V$ bits/sec
  - $H$ – bandwidth (Hz)
  - $V$ – discrete levels of signal
- If you have 3000 Hz perfect channel – do not sample faster than 6000 Hz
- The number of samples per second is **baud**
- During each baud a symbol is sent
**Modems (3)**

- n-baud line transmits n symbols/sec
- 2400 baud line sends one symbol about every 416.667 μsec
- If the symbol consists of 0 and 1 volts for 0 and 1 the bitrate is 2400 bps
- If each symbol consists of 2 bits
  - 2400 baud line transmits 2400 symbols/sec at a data rate of 4800 bps
  - Modulation is used to increase the number of bits/symbol

**Modems (4)**

- Transmit 9600 bps over a 2400 baud line

(a) QPSK (Quadrature Phase Shift Keying)
(b) QAM-16 (Quadrature Amplitude Modulation)
(c) QAM-64.
Modems (5)

- Each modem standard has its own constellation diagrams
- When we have more points even a small noise can result in errors
- To reduce the chance of error use error correction by adding extra bits to each sample
  - Trellis Coded Modulation (TCM)

Modems (6)

(a) V.32 for 9600 bps.
(b) V32 bis for 14,400 bps. (QAM-128)
6 data + 1 parity bit
Modems (7)

- V.34 – 28.800 bps at 2400 baud with 12 bits/symbol
- V.34 bis – 33.600 bps at 2400 baud with 14 bits/symbol
- Modems test the line before sending to adjust speed
- All modems allow traffic in both directions at the same time – full duplex
  - Half duplex
  - Simplex
- Shannon limit for telephone system is about 35 kbps
  - Determined by the average length of the local loops
- Maximum number bits/sec = \( H \log_2 (1+S/N) \)

Maximum data rate achievable is 70 kbps
Where does 56K modem come from?

- Nyquist theorem

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Digital Subscriber Lines

- Modems – 56Kbps
- Cable TV – 10 Mbps
- Satellite – 50 Mbps
- Sthg competitive needed – broadband
- xDSL (Digital Subscriber Line)
- Asymmetric DSL (ADSL)
- Do not filter out below 300Hz and above 3400Hz – effectively use 4000Hz
- Connect to a different switch
- The capacity is bounded by
  - Length
  - Thickness
  - General quality
Digital Subscriber Lines

If you want 50 Mbps you need to move closer to the end office.

Using mini end points EXPENSIVE!

Bandwidth versus distanced over category 3 UTP for DSL.

Digital Subscriber Lines

• xDSL design goals
  • The services must work over the existing category 3 twisted pair local loops
  • They must not affect customers’ existing telephones and fax machines
  • They must be much faster than 56Kbps
  • They should be always on, with just a monthly charge instead of per-minute charge
Digital Subscriber Lines

- DMT (Discrete MultiTone)
- Divide the spectrum available (1.1 Mhz) into 256 independent channels of 4312.5 Hz each
- Channel 0 is used for POTS
- Channels 1-5 are not used – separate voice and data channels from interfering
- 1 channel is used for upstream and downstream control
- 249 are used for data
- %80-90 are for downstream and remaining for upstream → Asymmetric

Operation of ADSL using discrete multitone modulation.
Digital Subscriber Lines

- ADSL allows 8Mbps downstream and 1Mbps upstream
- Within each channel a modulation scheme similar to V.34 is used but the sampling rate is 4000 baud instead of 2400 baud.
- Different channels may have different data rates
- Example
  - QAM modulation with 15 bits per baud
  - 224 downstream channels
  - \(4000 \times 15 \times 224 = 13.44\) Mbps
- In practice, SNR is never good enough but 8Mbps is possible on short runs over high quality loops.

Digital Subscriber Lines

A typical ADSL equipment configuration.