Physical Layer Outline (Part 1)

- Definitions
- Nyquist Theorem - noiseless
- Shannon’s Result - with noise
- Analog versus Digital
- Amplifier versus Repeater
- Advantages/Disadvantages of Analog vs Digital Transmissions
The Physical Layer is concerned with physical considerations and limitations.
The time required to transmit a character depends on both the encoding method and the signaling speed (i.e., the modulation rate - the number of times/sec the signal element changes).

- **baud (D)** - the number of signal elements per second.
- **bandwidth (H)** - the range of frequencies that is passed by a channel. The transmitted signal is constrained by the transmitter and the nature of the transmission medium in cycles/sec (hertz).
- **channel capacity (C)** - the rate at which data can be transmitted over a given channel under given conditions. (This is also referred to as data rate (R).)
Modulation Rate

modulation rate is doubled

Figure 5.5 A Stream of Binary Ones at 1 Mbps
Nyquist Theorem

(assume a noiseless channel)

If an arbitrary signal is run through a low-pass filter of bandwidth $H$, the filtered signal can be completely reconstructed by making $2H$ samples/sec.

This implies for a signal of $V$ discrete levels,

$$\text{Max. data rate \::\: } C = 2H \log_2(V) \text{ bits/sec.}$$

Note - a higher sampling rate is pointless because higher frequency signals have been filtered out.
(b) Maximum pulse transmission rate is $2H$ pulses/second

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Voice-grade Phone Line

Example 1. \{sampling rate\}

\[ H = 4000 \text{ Hz} \]

\[ 2H = 8000 \text{ samples/sec.} \]

\[ \rightarrow \text{sample every 125 microseconds!!} \]

Example 2. \{noiseless capacity\}

\[ D = 2400 \text{ baud} \quad \{\text{note } D = 2H\} \]

\[ V = \text{each pulse encodes 16 levels} \]

\[ C = 2H \log_2(V) = D \times \log_2(V) \]

\[ = 2400 \times 4 = 9600 \text{ bps}. \]
Signal Constellations

4 “levels”/ pulse
2 bits / pulse
2D bits per second

16 “levels”/ pulse
4 bits / pulse
4D bits per second
(a) QPSK.   (b) QAM-16.   (c) QAM-64.

Figure 2-25.

Tanenbaum
Signal to Noise Ratio (SNR)

High SNR

- Signal
- Noise
- Signal + Noise

Low SNR

- Signal
- Noise
- Signal + Noise

SNR = \frac{\text{Average Signal Power}}{\text{Average Noise Power}}

\text{SNR (dB)} = 10 \log_{10} \text{SNR}

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Shannon's Channel Capacity Result

{assuming only thermal noise}

For a noisy channel of bandwidth \( H \) Hz. and a signal-to-noise ratio \( \text{SNR} \), the max. data rate:

\[
C = H \log_2 (1 + \text{SNR})
\]

Regardless of the number of signal levels used and the frequency of the sampling.
Telephone channel (3400 Hz) at 40 dB SNR

\[ C = H \log_2 (1 + SNR) \text{ b/s} \]

SNR (dB) = 40 dB

40 dB = 10 \log_{10} (SNR)

4 = \log_{10} (SNR)

SNR = 10,000

\[ C = 3400 \log_2 (10001) = 44.8 \text{ kbps} \]
Analog and Digital correspond roughly to continuous and discrete, respectively. These two terms can be used in three contexts: data, signals, transmissions.

1. data:: entities that convey meaning (or information).
   - analog - voice and video are continuously varying patterns of intensity.
   - digital - take on discrete values (e.g., integers, ASCII text).

Data are propagated from one point to another by means of electrical signals.
## Analog and Digital Contexts: Data Signals Transmissions

### (a) Data and Signals

<table>
<thead>
<tr>
<th>Analog Data</th>
<th>Digital Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Signal</td>
<td>Two alternatives: (1) signal occupies the same spectrum as the analog data; (2) analog data are encoded to occupy a different portion of spectrum.</td>
</tr>
<tr>
<td>Digital Data</td>
<td>Digital data are encoded using a modem to produce analog signal.</td>
</tr>
</tbody>
</table>

### (b) Treatment of Signals

<table>
<thead>
<tr>
<th>Analog Transmission</th>
<th>Digital Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Signal</td>
<td>Is propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data.</td>
</tr>
<tr>
<td>Digital Signal</td>
<td>Not used</td>
</tr>
</tbody>
</table>
Analog and Digital Signaling

signals:: electric or electromagnetic representations of data.

2. signaling :: is the physical propagating of the signal along a suitable medium.

Analog signal - a continuously varying electromagnetic wave that may be propagated over a variety of medium depending on the spectrum (e.g., wire, twisted pair, coaxial cable, fiber optic cable and atmosphere or space propagation).
digital signal – a sequence of voltage pulses that may be transmitted over a wire medium.

Note – analog signals to represent analog data and digital signals to represent digital data are not the only possibilities.
Analog and Digital Signals

(a) Analog

(b) Digital

DCC 9th Ed. Stallings
Signals Details

- Means by which data are propagated.

- **Analog Signals**
  - Continuously variable
  - Various media
    - wire, fiber optic, space
  - Speech bandwidth 100Hz to 7kHz
  - Telephone bandwidth 300Hz to 3400Hz
  - Video bandwidth 4MHz

- **Digital Signals**
  - Use two DC components.
Digital data can be represented by analog signals using a modem (modulator/demodulator). The digital data is encoded on a carrier frequency.

Analog data can be represented by digital signals using a codec (coder-decoder).
User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by -5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).
Analog Signals: Represent data with continuously varying electromagnetic wave

Analog Data (voice sound waves) → Telephone → Analog Signal

Digital Data (binary voltage pulses) → Modem → Analog Signal (modulated on carrier frequency)
Digital Signals: Represent data with sequence of voltage pulses

Analog Signal → Codec → Digital Signal

Digital Data → Digital Transceiver → Digital Signal
Digital signaling is:

- Cheaper
- Less susceptible to noise interference
- Suffers more attenuation.
Attenuation of a signal:
the reduction or loss of signal strength (power) as it is transferred across a system.

Attenuation is an increasing function of frequency.

The strength of the received signal must be strong enough for detection and must be higher than the noise to be received without error.
Attenuation

FIGURE 2.1 Attenuation of Digital Signals
3. Transmissions :: communication of data by the propagation and processing of signals.

- Both analog and digital signals may be transmitted on suitable transmission media.
- [Stalling's argument] The way the signals are “treated” is a function of the transmission system and here lies the crux of the distinction between transmission types.
(a) **Analog transmission**: all details must be reproduced accurately.

- e.g. AM, FM, TV transmission

(b) **Digital transmission**: only discrete levels need to be reproduced.

- e.g. digital telephone, CD Audio
Analog Transmissions

- Analog transmission: a means of transmitting analog signals \textit{without regard to their content} (i.e., the signals may represent analog data or digital data).
  - Transmissions are attenuated over distance.

**Analog signal** - the analog transmission system uses \textit{amplifiers} to boost the energy in the signal.
Analog Transmissions

Amplifiers boost the energy this amplifies the signal and amplifies the noise.

The cascading of amplifiers distorts the signal.

Note – voice (analog data) can tolerate much distortion but with digital data, distortion introduces errors.
Digital transmissions: assume a binary content to the signal. Attenuation is overcome without amplifying the noise.

1. Analog signals \{assumes digital data\}:

With retransmission devices \{analog repeater\} at appropriate points the device recovers the digital data from the analog signal and generates a new clean analog signal.

*the noise is not cumulative!!*
2. digital signals - digital repeaters are used to attain greater distances.

The digital repeater receives the digital signal, recovers the patterns of 0's and 1's and retransmits a new digital signal.

The treatment is the same for analog and digital data.
Analog vs Digital Transmission

Analog Transmission

Source → Amplifier → Amplifier → Destination

Digital Transmission

Source → Repeater → Repeater → Destination
Analog Transmissions

Attenuated & distorted signal + noise

Recovered signal + residual noise

Amplifier

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Digital Transmissions

Amplifier Equalizer → Decision Circuit & Signal Regenerator → Timing Recovery

Repeater (digital signal)

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Digital Transmission Advantages

- Superior cost of digital technology
  - Low cost LSI/VLSI technology
  - Repeaters versus amplifiers costs

- Superior quality {Data integrity}
  - Transmit longer distances over lines with lower error rates

- Capacity utilization
  - Economical to build high bandwidth links
  - High degree of multiplexing easier with digital techniques
    - TDM (Time Division Multiplexing) is easier and cheaper than FDM (Frequency Division Multiplexing).
Digital transmission advantages

- Security & Privacy
  - Encryption techniques readily applied to *digitized* data.
- Integration
  - Can treat analog and digital data similarly.
  - Economies of scale come from *integrating* voice, video and data.

Analog transmission advantages

- Digital signaling not as versatile or practical (digital impossible for satellite and microwave systems).
- LAN star topology *reduces* the severity of the noise and attenuation problems.
Physical Layer Summary (Part 1)

- Definitions of bandwidth, capacity and modulation rate.
- Nyquist Theorem
  - noiseless channel, sampling rate
- Shannon’s Result
  - Channel with thermal noise, voice-grade line, SNR, constellations
Physical Layer Summary (Part 1)

- Analog versus Digital
  - Data, signals, transmissions
  - **Attenuation** of the signal as a function of transmission frequency.

- **Amplifier versus Repeater**
  - Effect of cascading amplifiers
  - Analog and digital repeaters

- Advantages/Disadvantages of Analog vs Digital Transmissions