Communication Systems (Lecture 1)

* Go through class outline - 10 min

Block diagram of a communication system

* Purpose of communication system - send information generated by the information source to one or more destinations.

* Information generated by the source - not suitable for direct transmission. For example, it may be in the form of voice, music, image, ...

* The information generated by the source is transformed into a signal by an element called transducer. Signals are used as carriers of information in an electronic communication system. Typical examples: microphone, camera, keyboard, ...

* Communication system transfers the information by manipulating electronic signals.

* At the end of the system, the signals are presented to an element called transducer. The transducer performs signal conversion into a form understandable by the information sink.

The heart of any electronic communication system are three elements:

1. Transmitter
2. Receiver
3. Channel
Transmitter - converts the signal into a form suitable for electronic transmission through physical channel.

Depending on the type of communication system, the transmitter may perform many tasks. Some of the tasks are listed as follows:

4. Filtering
   - Bandpass
   - Bandstop
   - Equalization
   - Amplification

5. Frequency Translation
   - In the case of digital transmission:
     - Sampling
     - Coding
     - Encrypting, etc.

Channel - physical medium used to send signal from TX to RX. There are several types of communication channel. A simple classification may be provided as follows:

- Wireless
  - Electrical (twisted pair, coax, cable, waveguide)
  - Optical (optical fiber)
  - Radio Frequency
  - Acoustic

- Closed channel (signal)
Channel disturbances can be:
1) additive
2) non-additive

Typical additive disturbances:
- Thermal noise and interference

Non-additive disturbances:
- Specular reflection (scattering), conductor
- absorption, interference products, ...

In general, the type of channel is one of the most important dependencies of the communication system. Large portion of the system design is dictated by the channel type.

Receiver - RX receives the transmitted signal after it has passed through the channel. Some of the receiver blocks may be listed as:

1) Frequency translation
2) matching matrix filtering
3) demodulation
4) decoding
5) in the case of digital transmission
   - decoding
   - de-ciphering
   - re-multiplexing, etc.

Mathemical model of a communication channel

Different physical channels have different mathematical models.

Within this course we will consider two types of channels:

1) The additive noise channel
2) linear time invariant channel
1) Additive noise channel

\[ s(t) \xrightarrow{\text{channel}} n(t) \]

- \( s(t) \): Transmitted signal
- \( n(t) \): Additive noise
- \( r(t) \): Received signal
- \( a \): Channel attenuation

\[ r(t) = a \cdot s(t) + n(t) \]

- Channel introduces two types of signal distortion:
  1. Attenuation
  2. Additive noise

In the special case when the noise \( n(t) \) is Gaussian, the channel is referred to as \( AWGN \).

2) Linear time invariant channel

\[ s(t) \xrightarrow{\text{channel}} r(t) \]

- \( s(t) \): Transmitted signal
- \( r(t) \): Received signal
- \( n(t) \): Noise
In this case

\[ r(t) = s(t) \ast d(t) + n(t) \]

\( d(t) \) - impulse response of the channel

\( \ast \) - indicates an operation known as convolution

Impulse: The impulse response of the channel stays unchanged over the communication period.

\[ r(t) = \left( \int_0^\infty h(t - \tau) d\tau + n(t) \right) \times \frac{d(t)}{h(t)} \]

Convolution integral

Convolution integral

**Definition: Convolution**

\[ x(t) \quad \text{LTI} \quad y(t) = x(t) \ast h(t) \]

LTI - linear time invariant system

\( h(t) \) - delta pulse

\[ h(t) = \begin{cases} \infty, & t = 0 \\ 0, & \text{else} \end{cases} \]

Two properties of delta function (impulse)

1. \[ \int_{-\infty}^{\infty} h(t) dt = 1 \]

Linear time invariant system is completely characterized by its impulse response.
Define the output of the system to a signal with a step function. The system's response to a step input is given by:

\[ y(t) = \begin{cases} 0 & \text{for } t < 0 \\ \frac{1}{t} & \text{for } t \geq 0 \end{cases} \]

The Laplace transform of the step function is:

\[ Y(s) = \frac{1}{s} \]

The system's transfer function is:

\[ H(s) = \frac{1}{s} \]

The system's response to the step input is:

\[ x(t) = u(t) \]

For the output of the system, apply the function:

\[ y(t) = \int_0^t x(t) \, dt \]

The Laplace transform of the output is:

\[ Y(s) = \frac{1}{s^2} \]

The system's stability is determined by the poles of the transfer function. The poles are found at:

\[ s = 0 \]

The system is stable.
1° \ y(t) = x(t) \cdot h(t) = \int_{-\infty}^{t} x(\tau) h(t-\tau) \, d\tau - \text{write the convolution expression}

2° Determine the integral bounds.

\[ \begin{align*}
\text{for } t < T & : \quad 0 \leq \tau \leq 2t \\
\text{for } t > T & : \quad t-2T \leq \tau < 0
\end{align*} \]

a) \ y(t) = \int_{0}^{t} x(\tau) h(t-\tau) \, d\tau \quad \text{for } t < T

b) \ y(t) = \int_{0}^{T} x(\tau) h(t-\tau) \, d\tau \quad \text{for } t > T

3° Evaluate integrals.

a) \ y(t) = \left[ t \cdot \exp \left( 1 - \frac{t}{\alpha} \right) \right] \bigg|_{t=0}^{t} = \alpha \exp \left( \frac{t}{\alpha} \right) \bigg|_{t=0}^{t} = \alpha \exp \left( \frac{t}{\alpha} \right) \bigg|_{0}^{t} = \alpha \left[ \exp\left( \frac{t}{\alpha} \right) - \exp\left( \frac{0}{\alpha} \right) \right] \quad t < T

b) \ y(t) = \left[ t \cdot \exp \left( 1 - \frac{t}{\alpha} \right) \right] \bigg|_{t=0}^{t} = \alpha \left[ \exp\left( \frac{T}{\alpha} \right) - \exp\left( \frac{t}{\alpha} \right) \right] \quad t > T

= \alpha \cdot \exp\left( \frac{T}{\alpha} \right) \left[ 1 - \exp\left( -\frac{t}{\alpha} \right) \exp\left( -\frac{T}{\alpha} \right) \right], \quad t > T