ECE 333: Introduction to Communication Networks
Fall 2001

Lecture 3: Physical Layer I

- Overview
- Fundamental Limitations

Notes:

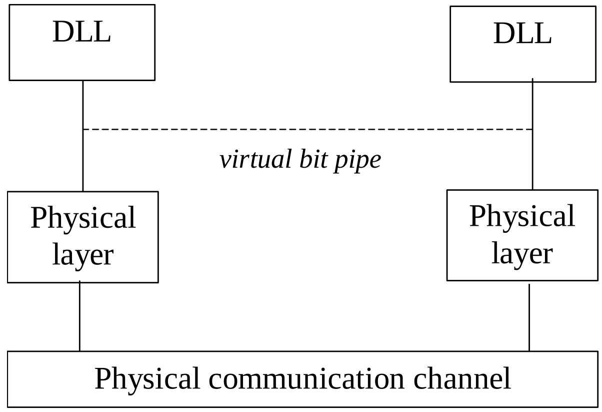
The last lecture introduced layered network architectures. Layering provides a hierarchical decomposition of a network into functional modules called layers. Each layer provides a ***service*** to the next higher layer.

In this lecture and the next, we focus on the lowest layer in most protocol stacks – **the physical layer.** Following the OSI architecture, we assume that the next layer above the physical layer is the Data Link Layer (DLL). The physical layer provides a "virtual bit pipe" service between two nodes in a network that are connected by a communication link (also called a communication channel). In other words, for two nodes connected by a communication channel, the physical layer is responsible for transporting sequences of bits from a DLL peer process at one node to the DLL peer process at the other node.

Basic characteristics of the bit pipe service provided by the physical layer include the ***bit rate*** (how many bits can be sent per second), the ***bit error rate*** (what is the probability a bit is received in eror), the ***delay*** from when a bit is sent until it is received, whether or not this bit pipe is ***synchronous,*** and if this pipe is ***full-duplex*** (two-way), ***half duplex*** (two way, but only one way at a time) or ***simplex*** (one way).

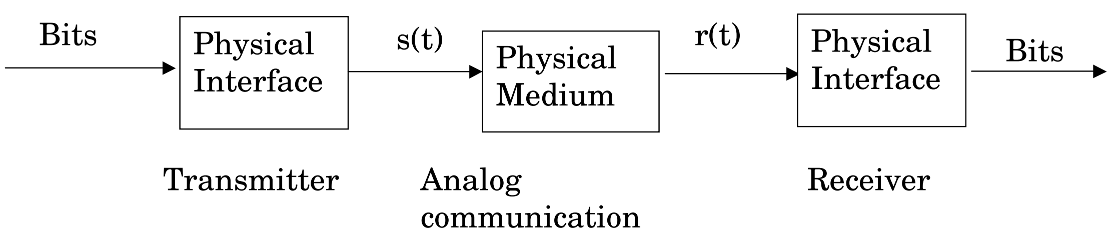
In a synchronous bit pipe, bits are sent and received at a fixed rate (e.g. 1 bit per T second). The sending DLL peer must supply bits at this rate even when it has no data to send and the receiving DLL peer will receive bits at this rate. In an asynchronous bit pipe, characters (groups of bits) are sent asynchronously whenever they are generated, and no bits are sent when no data is available. Asynchronous bit pipes are only used over short distances and for low data rates, for example a serial connection between a computer and a peripheral.

Service Characteristics



Charactersitics -

Communication channels



Transmitter: maps bits into **s(t).**

Receiver: map **r(t)** into bits

Want received bits = transmitted bits.

Notes:

We focus on the case where communication links are physical mediums through which electromagnetic waves can propagate. Common examples include copper wire, optical fiber and the atmosphere. (An example of a communication channel that does not utilize electromagnetic waves would be an underwater acoustic channel.)

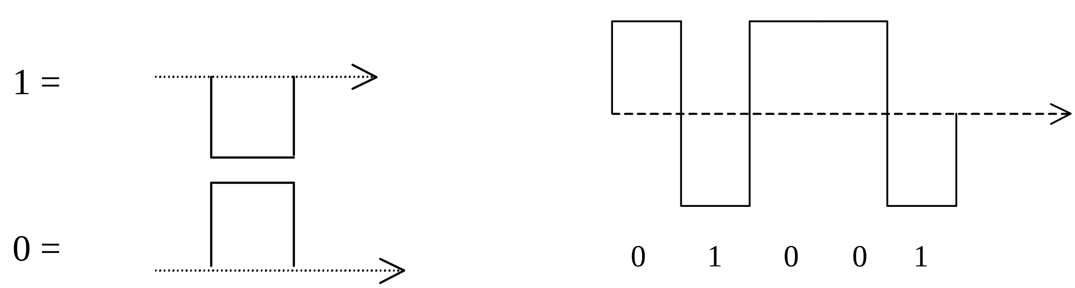
Information is conveyed over the channel by varying some physical property such as voltage or current. This property is represented as a single-valued function of time, ***s(t)***. A physical interface or transmitter converts the bit sequence into the channel input, ***s(t).*** The receiver tries to recover the original bit sequence from the channel output, ***r(t).*** Often the physical interface is called a modem (**mo**dulator/**dem**odulator).

A channel in which the input can be an arbitrary time function is called an ***analog communication channel***, all physical communication mediums are analog channels (However, in some cases, nodes in a network may be connected via another network, for example a leased line from the telephone company. In this case the physical layer for the first network is a ***digital communication channel***, i.e., a channel whose input is discrete-time and finite valued.)

Communication over analog channels is a large topic that lends itself to a thorough mathematical analysis. This is covered in depth in many other classes such as ECE 378, ECE 380, ECE 427, ECE 428,….

A through treatment of this subject requires a background in linear system theory and random processes, which are not a prerequisite for this course. We will spend two lectures on this broad topic. The goal is to provide an overview to those lacking background in this area and (hopefully) some perspective to those with more background.

Simple Example: (base-band signaling)



How to recover?

Timing?

Timing:

Asynchronous base-band communication (RS-232)

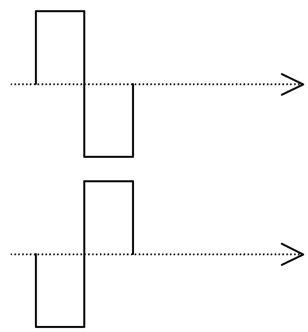
Send 7 bit characters, preceded by start bit (0). Always send -15V when inactive.

Synchronous links use ***self-synchronizing codes***, to keep timing:

Ex: Manchester code:

1 =

0 =



Impairments

The received signal, ***r(t)*** will not equal the transmitted signal ***s(t)*** due to channel impairments:

- Attenuation
- Distortion (filtering)
- Noise
- Dispersion

Attenuation

Electromagnetic waves loose energy as they propagate:

- In fiber and copper wire, energy is absorbed and converted into heat.
- In free space, waves spread out and loose energy per unit area.

Transmitted Signal → Channel → Received Signal

Power ≡ P_T Power ≡ P_R

Power Loss (Attenuation) ≡ L ≡ $P_T / P_R > 1$

Attenuation

Attenuation increases with transmission distance:

♦ For wire-line channels:

$$L = e^{2\alpha d} = 10^{0.868\alpha d}$$

♦ For wireless channels (with "line-of-sight")

$L = \beta\, d^2$ ($L = \beta d^\gamma$, $0<\gamma<5$, w/o line-of-sight)

d: transmission distance
α: attenuation coefficient determined by medium and signal frequency
β: a coefficient depending on signal frequency

Attenuation

Amplifiers can be used to compensate for the power loss

Input Signal → Amplifier → Output Signal

Power $\equiv P_i$ Power $\equiv P_o$

$$\text{Power Loss} \equiv L \equiv P_i / P_o < 1$$

Decibel Convention-

Power loss (gain) is usually expressed in decibels, i.e.,

$$\mathcal{L} = 10 \log_{10} L \quad \text{dB}$$

Example:

$$P_T = 5 \text{ W}, \ P_R = 5 \text{ mW}$$

$$\Rightarrow L = 1000 \quad = \ 30 \text{ dB} \quad \text{(a 30 dB power loss)}$$

A 30 dB transmission loss means that the power is weakened to 1/1000 of its original level.

Using decibels, the wire-line attenuation is

$$\mathcal{L} = 8.68 \ \alpha d \text{ dB}$$

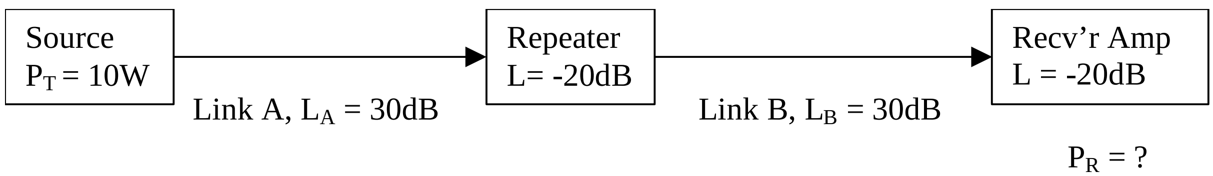
Thus

$$L/d = 8.68 \ \alpha \text{ dB/km} \quad \text{(if d is in km)}$$

Examples: Link Budget Analysis

Example 1:

Consider the following two-hop communication channel with a repeater in between. Find the received signal power following the receiver amplifier.



Example 2:

A broadcast station uses a transmitted power of 5 kW. The radio channel power attenuation is 10 dB per km. If the radio receiver has a sensitivity (i.e., minimum received power required) of 5 μW, what's the range of this radio station?

Notes

Slide 8: Distortion and noise will be addressed next time. One problem in next week's problem set will look at dispersion, this effect is important only in fiber optic transmission systems.

Slide 9: An element's (power) ***gain*** is equal to the inverse of the attenuation, thus amplifiers have gains greater than one. In dB the gain will be -1 times the attenuation.

Slide 13: The link budget is also called the link power budget; often other effects such as antenna gains are included in this type of analysis.

Example 1 solution:

$$\mathcal{L} = 30 \text{ dB} - 20 \text{ dB} + 30 \text{ dB} - 20 \text{ dB} = 20 \text{ dB}$$

$$\mathcal{L} = 20 \text{ dB} \quad \Longleftrightarrow \quad L = 100$$

Since $L = P_T / P_R$ and since $P_T = 10$ W, we have $P_R = 0.1$ W.

Example 2 solution:

On the edge of its range, the received power is 5 μW; this translates to a power loss of

$$L = 5\text{kW}/5\mu\text{W} = 10^9 \qquad \text{(This is the largest loss that can be tolerated)}$$

Or, in decibels,

$$\mathcal{L} = 10 \log_{10} L = 90 \text{ dB}$$

Therefore,

$$\text{Range} = (90 \text{ dB}) \div (10 \text{ dB/km}) = 9 \text{ km}$$