Line-of-Sight Transmission

Dr. Ansuman Bhattacharya

Indian Institute of Technology, Dhanbad

Winter Semester 2017-18

Outline I

Line-of-Sight Transmission I

- With any communications system, the signal that is received will differ from the signal that is transmitted, due to various transmission impairments.
- For analog signals, these impairments introduce various random modifications that degrade the signal quality.
- For digital data, bit errors are introduced: A binary 1 is transformed into a binary 0, and vice versa.

Line-of-Sight Transmission II

- For *LOS* wireless transmission the most significant impairments are :
  - Attenuation and attenuation distortion
  - Free space loss
  - Noise
  - Atmospheric absorption
  - Multipath
  - Refraction

Attenuation I

- The strength of a signal falls off with distance over any transmission medium.
- For guided media, this reduction in strength, or attenuation, is generally exponential and thus is typically expressed as a constant number of decibels per unit distance.
- For unguided media, attenuation is a more complex function of distance and the makeup of the atmosphere.

Attenuation II

- Attenuation introduces three factors for the transmission engineer.
  1. A received signal must have sufficient strength so that the electronic circuitry in the receiver can detect and interpret the signal.
  2. The signal must maintain a level sufficiently higher than noise to be received without error.
  3. Attenuation is greater at higher frequencies, causing distortion.

Attenuation III

- The first and second factors are dealt with by attention to signal strength and the use of amplifiers or repeaters.
- For a point-to-point transmission (one transmitter and one receiver), the signal strength of the transmitter must be strong enough to be received intelligibly, but not so strong as to overload the circuitry of the transmitter or receiver, which would cause distortion.
- Beyond a certain distance, the attenuation becomes unacceptably great, and repeaters or amplifiers are used to boost the signal at regular intervals.
- These problems are more complex when there are multiple receivers, where the distance from transmitter to receiver is variable.
- The third factor is known as attenuation distortion.

Attenuation IV

- Because the attenuation varies as a function of frequency, the received signal is distorted, reducing intelligibility.
- Specifically, the frequency components of the received signal have different relative strengths than the frequency components of the transmitted signal.
- To overcome this problem, techniques are available for equalizing attenuation across a band of frequencies.
- One approach is to use amplifiers that amplify high frequencies more than lower frequencies.

1 Line-of-Sight Transmission
- Attenuation
- Free Space Loss
- Noise
  - The Expression E_b/N_o
- Atmospheric Absorption
- Multipath
- Refraction

Free Space Loss I

- For any type of wireless communication the signal disperses with distance.
- Therefore, an antenna with a fixed area will receive less signal power the farther it is from the transmitting antenna.
- For satellite communication this is the primary mode of signal loss.
- Even if no other sources of attenuation or impairment are assumed, a transmitted signal attenuates over distance because the signal is being spread over a larger and larger area.
- This form of attenuation is known as free space loss, which can be express in terms of the ratio of the radiated power P_t to the power P_r, received by the antenna or, in decibels, by taking 10 times the *log* of that ratio.

Free Space Loss II

- For the ideal isotropic antenna, free space loss is

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2} \qquad (1)$$

where,
P_t = signal power at the transmitting antenna
P_r = signal power at the receiving antenna
λ = carrier wavelength
f = carrier frequency
d = propagation distance between antennas
c = speed of light (3×10^8 m/s)
where d and λ are in the same units (e.g., meters).

Free Space Loss III

- This can be recast as:

$$\begin{aligned} L_{dB} &= 10\log\frac{P_t}{P_r} = 20\log\frac{(4\pi d)}{\lambda} \\ &= -20\log(\lambda) + 20\log(d) + 21.98dB \end{aligned} \tag{2}$$

$$\begin{aligned} L_{dB} &= 10\log\frac{P_t}{P_r} = 20\log\frac{(4\pi fd)}{c} \\ &= 20\log(f) + 20\log(d) - 147.56dB \end{aligned} \tag{3}$$

Free Space Loss IV

- For other antennas, we must take into account the gain of the antenna, which yields the following free space loss equation:

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{G_t G_r \lambda^2} = \frac{(\lambda d)^2}{A_r A_t} = \frac{(cd)^2}{f^2 A_r A_t} \tag{4}$$

where,

G_t = gain of the transmitting antenna

G_r = gain of the receiving antenna

A_t = effective area of the transmitting antenna

A_r = effective area of the receiving antenna

Free Space Loss V

- The third fraction is derived from the second fraction using the relationship between antenna gain and effective area defined in Equation.
- We can recast this equation as:

$$\begin{aligned} L_{dB} &= 20\log(\lambda) + 20\log(d) - 10\log(A_t A_r) \\ &= -20\log(f) + 20\log(d) - 10\log(A_t A_r) + 169.54dB \end{aligned} \tag{5}$$

Free Space Loss VI

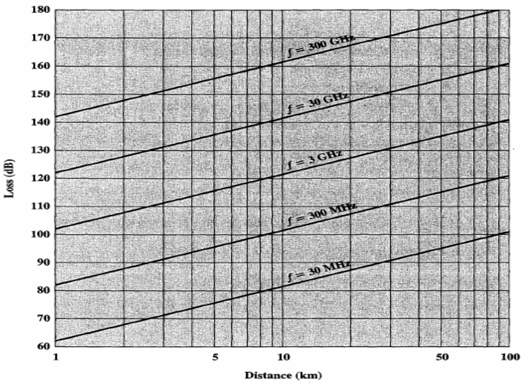
- Thus, for the same antenna dimensions and separation, the longer the carrier wavelength (lower the carrier frequency f), the higher is the free space path loss.
- It is interesting to compare Equations 3 and 5.
- Equation 3 indicates that as the frequency increases, the free space loss also increases, which would suggest that at higher frequencies, losses become more burdensome.
- However, Equation 5 shows that we can easily compensate for this increased loss with antenna gains.
- In fact, there is a net gain at higher frequencies, other factors remaining constant.
- Equation 3 shows that at a fixed distance an increase in frequency results in an increased loss measured by $20\log(f)$.

Free Space Loss VII

- However, if we take into account antenna gain, and fix antenna area, then the change in loss is measured by $-20 \log f$, i.e., there is actually a decrease in loss at higher frequencies.

Free Space Loss VIII

Free Space Loss



Noise I

- For any data transmission event, the received signal will consist of the transmitted signal, modified by the various distortions imposed by the transmission system, plus additional unwanted signals that are inserted somewhere between transmission and reception.
- These unwanted signals are referred to as noise. Noise is the major limiting factor in communications system performance.
- Noise may be divided into four categories:

  1. Thermal noise
  2. Intermodulation noise
  3. Crosstalk
  4. Impulse noise

Thermal noise I

- Thermal noise is due to thermal agitation of electrons.
- It is present in all electronic devices and transmission media and is a function of temperature.
- Thermal noise is uniformly distributed across the frequency spectrum and hence is often referred to as white noise.
- Thermal noise cannot be eliminated and therefore places an upper bound on communications system performance.
- Because of the weakness of the signal received by satellite earth stations, thermal noise is particularly significant for satellite communication.

Thermal noise II

- The amount of thermal noise to be found in a bandwidth of 1 Hz in any device or conductor is

$$N_o = kT(W/Hz) \tag{6}$$

Where, N_o = noise power density in watts per 1 Hz of bandwidth
k = Boltzmann's constant = $1.38 \times 10^{-23}\ J/K$
T = temperature, in kelvins (absolute temperature)

- The noise is assumed to be independent of frequency.
- Thus, the thermal noise in watts present in a bandwidth of B Hz can be expressed as $N = kTB$ or, in decibel-watts,

$$\begin{aligned} N &= 10\log k + 10\log T + 10\log B && (7)\\ &= -228.6dBW + 10\log T + 10\log B && (8)\end{aligned}$$

Intermodulation noise I

- When signals at different frequencies share the same transmission medium, the result may be intermodulation noise.
- Intermodulation noise produces signals at a frequency that is the sum or difference of the two original frequencies or multiples of those frequencies.
- For example, the mixing of signals at frequencies f_1 and f_2 might produce energy at the frequency $f_1 + f_2$.
- This derived signal could interfere with an intended signal at the frequency $f_1 + f_2$.
- Intermodulation noise is produced when there is some nonlinearity in the transmitter, receiver, or intervening transmission system.
- Normally, these components behave as linear systems; that is, the output is equal to the input times a constant.

Intermodulation noise II

- In a nonlinear system, the output is a more complex function of the input.
- Such nonlinearity can be caused by component malfunction, the use of excessive signal strength, or just the nature of the amplifiers used.
- It is under these circumstances that the sum and difference frequency terms occur.

Crosstalk I

- Crosstalk has been experienced by anyone who, while using the telephone, has been able to hear another conversation; it is an unwanted coupling between signal paths.
- It can occur by electrical coupling between nearby twisted pairs or, rarely, coax cable lines carrying multiple signals.
- Crosstalk can also occur when unwanted signals are picked up by microwave antennas; although highly directional antennas are used, microwave energy does spread during propagation.
- Typically, crosstalk is of the same order of magnitude as, or less than, thermal noise.
- However, in the unlicensed *ISM* bands, crosstalk often dominates.

Impulse noise I

- All of the types of noise discussed so far have reasonably predictable and relatively constant magnitudes.
- Thus it is possible to engineer a transmission system to cope with them.
- Impulse noise, however, is noncontinuous, consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude.
- It is generated from a variety of causes, including external electromagnetic disturbances, such as lightning, and faults and flaws in the communications system.
- Impulse noise is generally only a minor annoyance for analog data.

Impulse noise II

- For example, voice transmission may be corrupted by short clicks and crackles with no loss of intelligibility.
- However, impulse noise is the primary source of error in digital data transmission.
- For example, a sharp spike of energy of 0.01 *s* duration would not destroy any voice data but would wash out about 560 bits of data being transmitted at 56 *kbps*.

The Expression E_b/N_o I

- There is a parameter related to *Signal-to-Noise Ratio* (*SNR*) that is more convenient for determining digital data rates and error rates and that is the standard quality measure for digital communication system performance.
- The parameter is the ratio of signal energy per bit to noise power density per *Hertz*, E_b/N_o.
- Consider a signal, digital or analog, that contains binary digital data transmitted at a certain bit rate R.
- Recalling that $1\ watt = 1\ J/s$, the energy per bit in a signal is given by $E_b = ST_b$, where S is the signal power and T_b is the time required to send one bit.
- The data rate R is just $R = 1/T_b$.

The Expression E_b/N_o II

- Thus,

$$\frac{E_b}{N_o} = \frac{S}{N_o R} = \frac{S}{kTR} \tag{9}$$

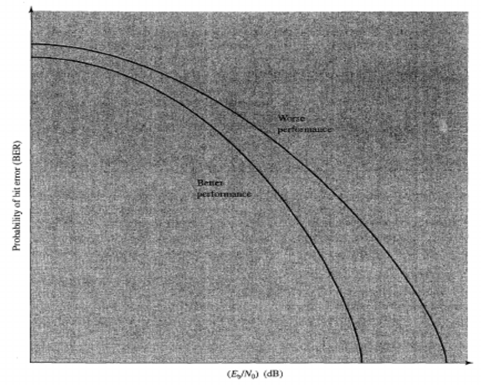
or, in decibel notation,

$$\begin{aligned}\left(\frac{E_b}{N_o}\right)_{dB} &= S_{dBW} - 10\log R - 10\log k - 10\log T \\ &= S_{dBW} - 10\log R + 228.6dBW - 10\log T \quad (10)\end{aligned}$$

- The ratio E_b/N_o is important because the *Bit Error Rate* (*BER*) for digital data is a (decreasing) function of this ratio.

The Expression E_b/N_o III

General Shape of *BER* Versus E_b/N_o Curves



The Expression E_b/N_o IV

- Figure illustrates the typical shape of a plot of *BER* versus E_b/N_o.
- For any particular curve, as the signal strength relative to the noise increases (increasing E_b/N_o), the *BER* performance at the receiver decreases.
- This makes intuitive sense. However, there is not a single unique curve that expresses the dependence of *BER* on E_b/N_o.
- Instead the performance of a transmission/reception system, in terms of *BER* versus E_b/N_o, also depends on the way in which the data is encoded onto the signal.
- Thus, Figure show two curves, one of which gives better performance than the other.
- A curve below and to the left of another curve defines superior performance.

The Expression E_b/N_o V

- Given a value of E_b/N_o needed to achieve a desired error rate, the parameters in Equation (5.4) may be selected.
- Note that as the bit rate R increases, the transmitted signal power, relative to noise, must increase to maintain the required E_b/N_o.
- The signal here is digital, but the reasoning would be the same for an analog signal.
- In several instances, the noise is sufficient to alter the value of a bit.
- If the data rate were doubled, the bits would be more tightly packed together, and the same passage of noise might destroy two bits.
- Thus, for constant signal and noise strength, an increase in data rate increases the error rate.

The Expression E_b/N_o VI

- The advantage of E_b/N_o compared to SNR is that the latter quantity depends on the bandwidth.
- We can relate E_b/N_o to SNR as follows.
- We have
$$\frac{E_b}{N_o} = \frac{S}{N_o R} \tag{11}$$
- The parameter N_o is the noise power density in $watts/hertz$.
- Hence, the noise in a signal with bandwidth B_T is $N = N_o B_T$.
- Substituting, we have
$$\frac{E_b}{N_o} = \frac{S B_T}{N R} \tag{12}$$
- Another formulation of interest relates to E_b/N_o spectral efficiency.

The Expression E_b/N_o VII

- Recall, Shannon's result that the maximum channel capacity, in bits per second, obeys the equation

$$C = B\log_2(1 + S/N) \tag{13}$$

where, C is the capacity of the channel in bits per second and B is the bandwidth of the channel in *Hertz*.

- This can be rewritten as:

$$\frac{S}{N} = 2^{C/B} - 1 \tag{14}$$

- Using Equation (5.5), and equating B_T with B and R with C, we have

$$\frac{E_b}{N_o} = \frac{B}{C}(2^{C/B} - 1) \tag{15}$$

The Expression E_b/N_o VIII

- This is a useful formula that relates the achievable spectral efficiency C/B to E_b/N_o.

Atmospheric Absorption I

- An additional loss between the transmitting and receiving antennas is atmospheric absorption.
- Water vapor and oxygen contribute most to attenuation.
- A peak attenuation occurs in the vicinity of 22 GHz due to water vapor.
- At frequencies below 15 GHz, the attenuation is less.
- The presence of oxygen results in an absorption peak in the vicinity of 60 GHz but contributes less at frequencies below 30 GHz.
- Rain and fog (suspended water droplets) cause scattering of radio waves that results in attenuation.
- This can be a major cause of signal loss.

Atmospheric Absorption II

- Thus, in areas of significant precipitation, either path lengths have to be kept short or lower-frequency bands should be used.

Multipath I

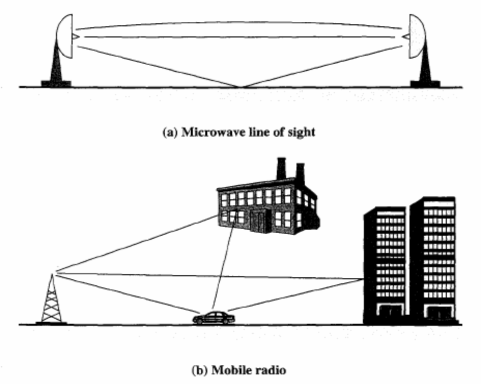
- For wireless facilities where there is a relatively free choice of where antennas are to be located, they can be placed so that if there are no nearby interfering obstacles, there is a direct line-of-sight path from transmitter to receiver.
- This is generally the case for many satellite facilities and for point-to-point microwave.
- In other cases, such as mobile telephony, there are obstacles in abundance.
- The signal can be reflected by such obstacles so that multiple copies of the signal with varying delays can be received.
- In fact, in extreme cases, the receiver my capture only reflected signals and not the direct signal.

Multipath II

- Depending on the differences in the path lengths of the direct and reflected waves, the composite signal can be either larger or smaller than the direct signal.
- Reinforcement and cancellation of the signal resulting from the signal following multiple paths can be controlled for communication between fixed, well-sited antennas, and between satellites and fixed ground stations.
- One exception is when the path goes across water, where the wind keeps the reflective surface of the water in motion.
- For mobile telephony and communication to antennas that are not well sited, multipath considerations can be paramount.

Multipath III

Examples of Multipath Interference



(a) Microwave line of sight

(b) Mobile radio

Multipath IV

- Figure illustrates in general terms the types of multipath interference typical in terrestrial, fixed microwave and in mobile communications.
- For fixed microwave, in addition to the direct line of sight, the signal may follow a curved path through the atmosphere due to refraction and the signal may also reflect from the ground.
- For mobile communications, structures and topographic features provide reflection surfaces.

Refraction I

- Radio waves are refracted (or bent) when they propagate through the atmosphere.
- The refraction is caused by changes in the speed of the signal with altitude or by other spatial changes in the atmospheric conditions.
- Normally, the speed of the signal increases with altitude, causing radio waves to bend downward.
- However, on occasion, weather conditions may lead to variations in speed with height that differ significantly from the typical variations.
- This may result in a situation in which only a fraction or no part of the line-of-sight wave reaches the receiving antenna.