College of Computer Science
Northeastern University
Wireless Networks CS G250

Lecture 4
September 22 2008
Lecturer: R. Sundaram

Fading, Discrete Modulation of Analog Signals, Analog Modulation of Analog Signals

1 Fading

Transmissions vary in intensity over space and time due to mainly two reasons:

1. Multipath Effects
2. Mobility

1.1 Multipath

There exist 3 types of Multipath phenomena:

1. Reflection (Figure 1): The transmission encounters a surface bigger than the wavelength of the signal, which reflects a copy of the signal to the receiver. If there is LOS between sender and receiver, the latter may get a duplicated signal, slightly shifted in time, which may act as noise.

2. Diffraction (Figure 2): An edge may bend the signal towards the receiver. This may be the case in a metropolitan area, with buildings acting as edges. The obstacle is also larger than the wavelength.

3. Scattering (Figure 3): A particle of size comparable to the wavelength will scatter weaker copies of the signal in many directions, one of which may reach the receiver.

Multipath effects cause various copies of the signal (known as delay spread) to reach the receiver, which may be delayed or distorted. Commonly, this is measured by Average Delay Spread or Root Mean square delay spread.

It is very hard to design transmission systems that compensate for multipath effects because of the difficulty to model these effects. The simplest

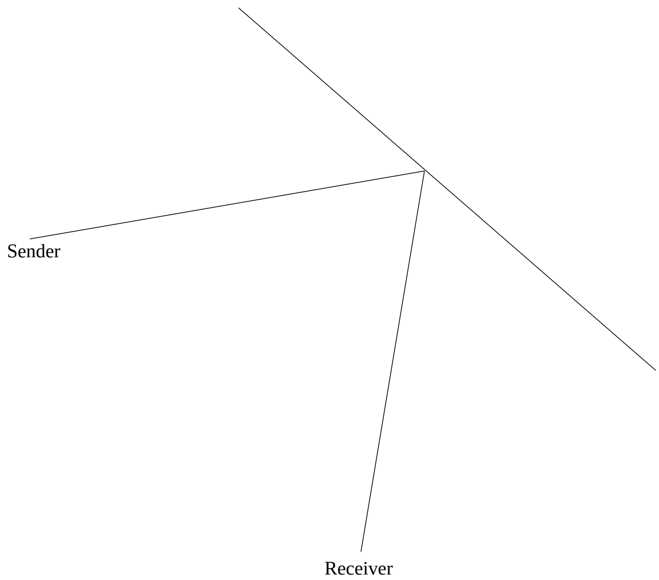

Figure 1: Reflection

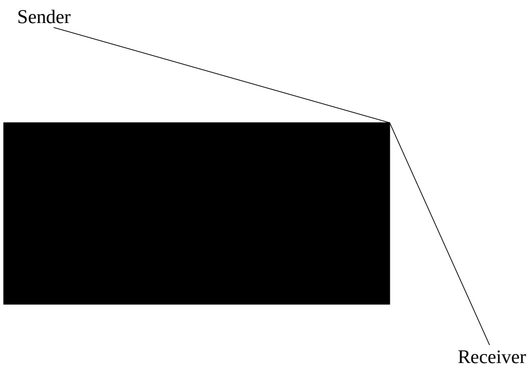

Figure 2: Diffraction

Figure 3: Scattering

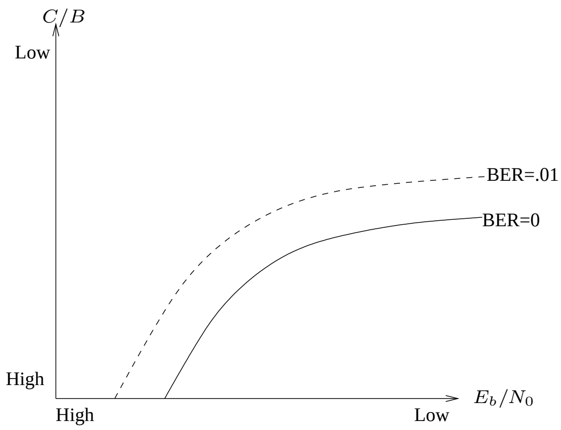

Figure 4: $\frac{C}{B}$ in terms of $\frac{E_b}{N_0}$

way to model is to take only AWGN into account. In practice, this is a good estimator for certain types of communications, like space communication or wired transmissions.

Rayleigh fading and Rician fading models are used for terrestrial communications. The channel models used describe a parameter K defined as:

$$K = \frac{\texttt{power in the dominant path}}{\texttt{power in the scattered paths}}$$

When there is no dominant path (e.g. an LOS path), that is $K = 0$, this is called a Rayleigh channel. AWGN is equivalent to having $K = \infty$. Recall the Capacity in terms of E_b/N_0 plot from previous chapters (Figure 4). The curve defines a maximum transmission rate with 0 error rate. It is possible however to achieve a higher rate by paying the price of having a higher error rate. So the plot becomes now a family of curves, each one of which defines a maximum error rate for areas below it.

If one were to plot the Bit Error Rate (BER) against E_b/N_0, the result would be Figure 5. It is clear that for higher values of K, the BER drops faster when the transmission energy increases; conversely, when having $K = 0$, the payoff is smaller.

1.2 Mobility

Mobility also produces fading similar to the Doppler Effect. Figure 6 illustrates the effect. If the sender transmits a signal with frequency f, the

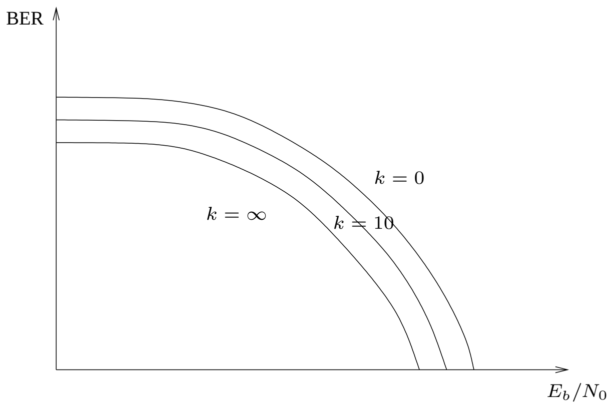

Figure 5: BER in terms of $\frac{E_b}{N_0}$ with different error rates

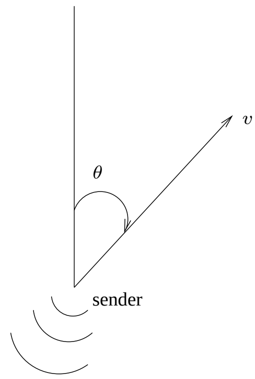

Figure 6: Doppler Effect

receiver will observe a shift of $\pm f_d = v \cos \theta / \lambda$, where v is the speed of the sender, and θ is the angle.

Fading can be classified as fast, slow, flat, or selective. Fast fading refers to rapid changes in signal strength over distances about one half of the wavelength. Slow fading refers to changes over greater distances (as landscape changes). When fading affects all frequencies equally, then it is said Flat Fading occurs. Contrast this to selective fading, in which certain frequency components of the signal are affected.

To deal with fading, several methods are used:

1. Forward error correction consists of adding redundant bits in the transmission to recover from errors

2. Adaptive equalization using training techniques, such as examining a known transmission and compensating for the observed corruption

3. Diversity techniques involve sending the message through multiple means (frequencies, amplitudes, times) to compensate for errors

2 Discrete Modulation of Analog Signals

In order to transmit a signal it is necessary to encode the digital signal (bits) on the "natural" signals for the medium over which the transmission is to take place. Recall that a signal has three components:

$$s(t) = A(t) \sin(2\pi f t + \phi)$$

, where the parameters are the amplitude $A(t)$, the frequency f, and the phase ϕ. We will refer to the digital data with $d(t)$.

In the context to data transmissions, it is useful to speak about signal elements instead of raw bits. For instance, a transmission that may send one of four different numbers is said to have 4 possible symbols or signal elements. In this context, the term baud refers to the number of signal elements per second in the transmission.

2.1 Amplitude-Shift Keying (ASK)

With this encoding, the digital data is multiplied with the carrier signal. The digital signal is a series of zeros and ones, so the resulting signal for each bit is either no transmission for 0 and the carrier wave for 1. This is shown in Figure 7.

2.2 Frequency-Shift Keying (FSK)

With this type of modulation, the frequency changes depending on the digital data. Two frequencies $\pm f_d$ centered around f_c are sent.

$$s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{if } d(t) = 1, f_1 = f_c - f_d \\ A\cos(2\pi f_2 t) & \text{if } d(t) = 0, f_2 = f_c + f_d \end{cases}$$

Figure 8 shows the shape of the signals involved.

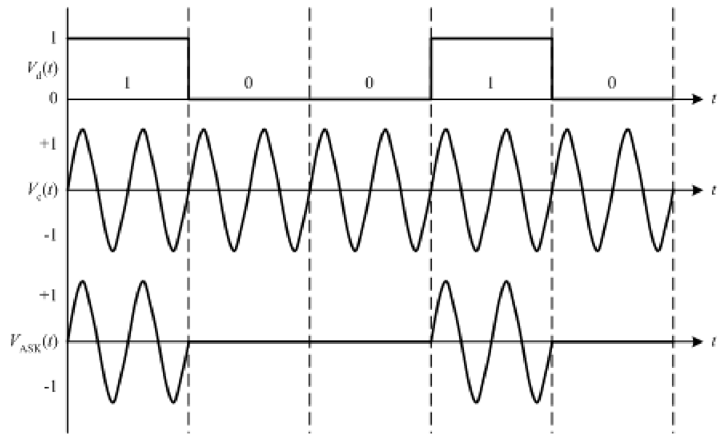

Figure 7: Amplitude Shift-Keying

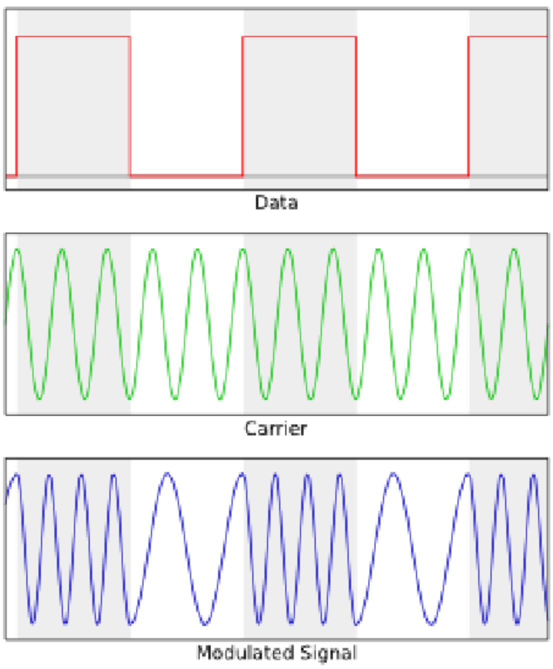

Figure 8: Frequency-Shift Keying

2.3 Multiple Frequency-Shift Keying (MFSK)

Instead of using 2 frequencies to encode a bit, we can generalize the scheme for signal elements of L bits, allowing us to send $M = 2^L$ signal elements. In MFSK, the signals are:

$$s_i(t) = Acos(2\pi f_i t)$$

where

$$\begin{aligned} f_i &= f_c + (2i - 1 - M)f_d \\ f_c &= \text{The center (or carrier) frequency} \\ f_d &= \text{The difference frequency} \end{aligned}$$

2.4 Phase-Shift Keying (PSK)

Phase-Shift keying modifies the phase. In the binary case, the signal looks like:

$$s(t) = A\cos(2\pi f_c t + \pi d(t))$$

Alternatively, DPSK or Differential Phase-Shift Keying transmits the signal in the same phase as the previous bit for 0 and changes the phase of the previous bit for 1. See Figure 9 for a graphic representation.

2.5 Quadrature Phase-Shift Keying

Instead of using a shift of π to represent a bit, it is possible to use multiples of $\pi/4$ to separate the possible phases:

$$s(t) = \begin{cases} A\cos\left(2\pi f_c t + \frac{\pi}{4}\right) & \text{for } 00 \\ A\cos\left(2\pi f_c t + \frac{\pi}{2}\right) & \text{for } 01 \\ A\cos\left(2\pi f_c t + \frac{3\pi}{4}\right) & \text{for } 10 \\ A\cos\left(2\pi f_c t + \pi\right) & \text{for } 11 \end{cases}$$

2.6 Quadrature Amplitude Modulation

This scheme uses odd and even bit positions as factors of a cosine and a sine terms:

$$\begin{aligned} d(t) &= d_o(t) + d_e(t) \\ s(t) &= d_o(t)\cos(2\pi f t) + d_e \sin(2\pi f t) \end{aligned}$$

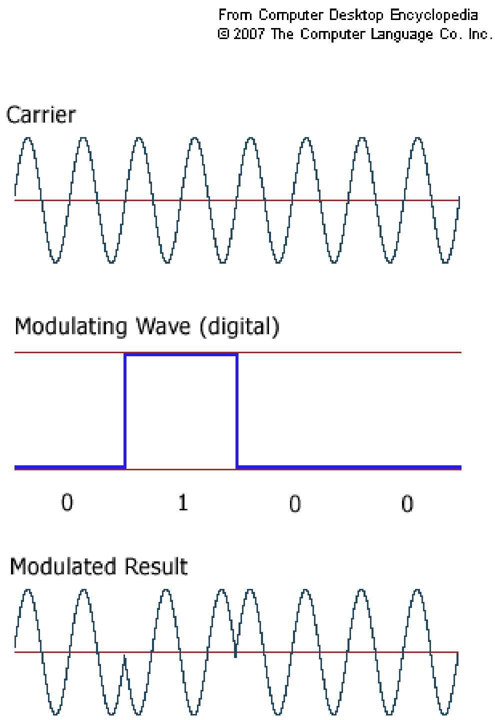

Figure 9: Phase-Shift Keying

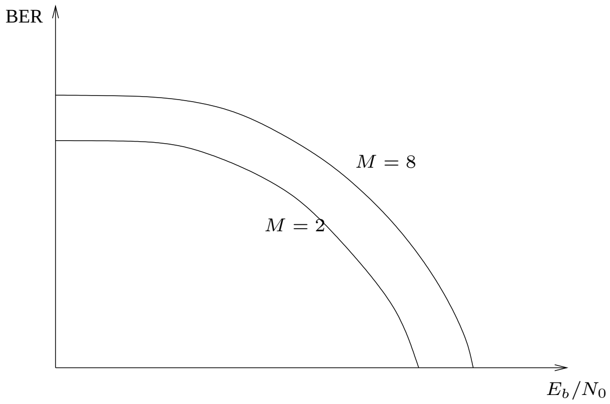

Figure 10: BER in terms of $\frac{E_b}{N_0}$ for MPSK

2.7 Bandwidth Efficiency

For ASK, BPSK, and BFSK, the transmission rate per bandwidth is

$$\frac{R}{B} = \frac{1}{1+r}$$

where $0 < r < 1$ and r is related to the modulation filters used.

For MPSK

$$\frac{R}{B} = \frac{\log_2 M}{1+r}$$

For MFSK

$$\frac{R}{B} = \frac{\log_2 M}{M(1+r)}$$

The Bit Error Rate plots for MPSK show that the Bit Error Rate decreases with lower values of M (Figure 10), while for MFSK, the inverse is true (Figure 11). The efficiency however, for bigger values of M decreases faster for MFSK than for MPSK.

3 Analog Modulation of Analog Signals

Why modulate analog data with analog signals?

1. The medium filters certain frequencies more than others

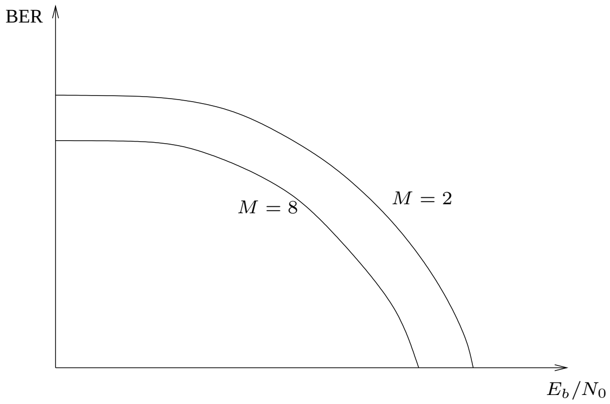

Figure 11: BER in terms of $\frac{E_b}{N_0}$ for MFSK

2. Certain types of transmissions with long wavelength would need impractically large antennas to be transmitted. Therefore, they are upshifted to make their emission possible.

3.1 Amplitude Modulation

$$s(t) = (1 + n_a m(t)) \cos(2\pi f t)$$

In this scheme, the factor n_a is the ratio of the amplitudes of the signal and the carrier. As long as $n_a < 1$, the envelope signal will not touch the x-axis and no information will be lost. In this scheme, the power varies over time. Figure

3.2 Angle Modulation

Frequency modulation and Phase modulation are special cases of Angle Modulation:

$$\begin{aligned} s(t) &= A\cos(2\pi f t + m(t)) \\ s(t) &= A\cos\left(2\pi f t + \int m(t)dt\right) \end{aligned}$$

In this scheme, power remains constant over time.

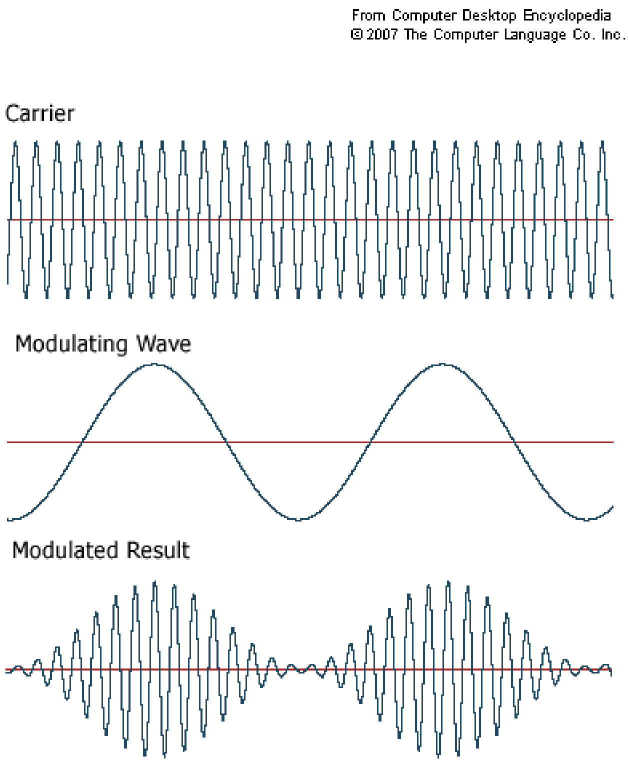

Figure 12: Amplitude modulation

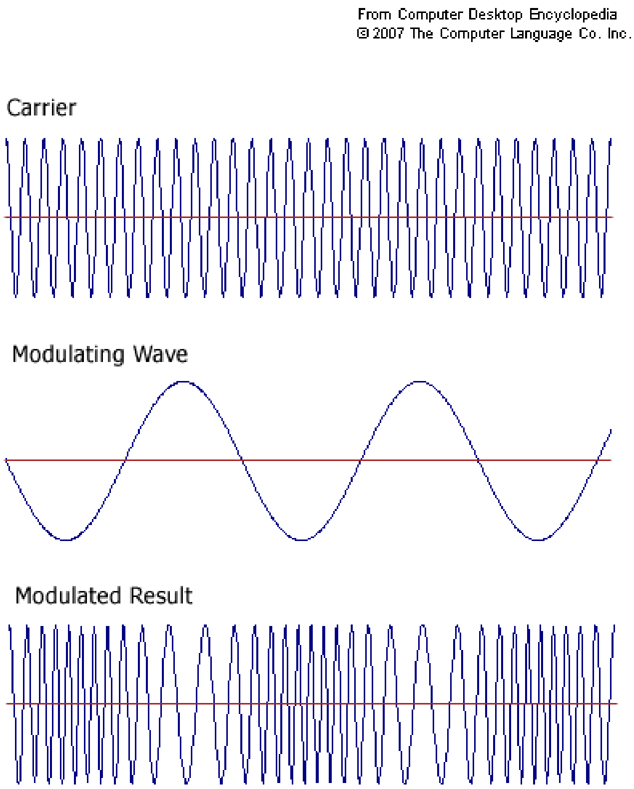

Figure 13: Angle modulation