College of Computer & Information Science
Northeastern University
CSG250: Wireless Networks

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Handout 3
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Transmission Fundamentals

1 Antennas

An antenna is an electrical conductor or a system of conductors that radiates/collects (transmits or receives) electromagnetic energy into/from space. An idealized isotropic antenna radiates equally in all directions. The directivity of an antenna is captured by its beam width; it is the angle within which power radiated is at least half of that in the most preferred direction (that is, half of the maximum power).

Antenna gain is the power output, in a particular direction, compared to that produced in any direction by an idealized omnidirectional antenna. If f is the carrier frequency and A_e is the effective area of the antenna, then the antenna gain is given by

$$G = \frac{4\pi A_e f^2}{c^2},$$

where c is the speed of light. The effective area of an antenna depends on the size and shape of the antenna. The effective area of an idealized isotropic antenna is 1, by definition.

2 Propagation modes

Wireless transmissions propagate in three modes: ground-wave, sky-wave, and line-of-sight. Ground wave propagation follows the contour of the earth, while sky wave propagation uses reflection by both earth and ionosphere. Finally line of sight propagation requires the transmitting and receiving antennas to be within line of sight of each other. Which of these propagation modes dominates depends on the frequency of the underlying signal.

Examples of ground wave and sky wave communication are AM radio and international broadcasts such as BBC. Above 30 MHz, neither ground wave nor sky wave propagation operates and the communication is through line of sight.

If h is the height of a transmitting (resp., receiving) antenna in meters, then the distance to the receiver (resp., transmitter) for line-of-sight transmission should be at most

$$d = 3.57\sqrt{h} \text{ kms.}$$

This can be proved using elementary geometry. Since microwaves are bent or refracted by the atmosphere, the "effective" line of sight is, in fact, larger than the true line of sight. We introduce an adjustment factor K to capture the refraction effect and obtain

$$d = 3.57\sqrt{Kh} \text{ kms.}$$

If the two antenna have heights h_1 and h_2 meters, then the distance between them for LOS propagation should be at most

$$3.57\sqrt{K}(\sqrt{h_1} + \sqrt{h_2}) \text{ kms.}$$

3 Transmission limitations

There are four classes of limitations that affect electromagnetic wave transmissions.

Attenuation. The strength of signal falls with distance over transmission medium. The extent of attenuation is a function of distance, transmission medium, as well as the frequency of the underlying transmission. Even in free space, with no other impairment, the transmitted signal attenuates over distance simply because the signal is being spread over a larger and larger area. For an ideal isotropic antenna, the ratio between the transmitted power P_t and the received power P_r for a separation distance of d is given by

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

where λ, f, and c are the wavelength, frequency, and the speed of the signal.

One can express the above ratio in terms of antenna gains and effective areas of the antennas by applying the appropriate formulae.

Distortion. Since signals at different frequencies attenuate to different extents, as the above formula indicates, a signal comprising of components over a range of frequencies gets distorted; i.e., the shape of the received signal changes. A standard method of resolving this problem (and recovering the original shape) is to amplify higher frequencies and thus equalize attenuation over a band of frequencies.

Dispersion.

Noise. The most pervasive form of noise is thermal noise, which is often modeled using an additive Gaussian model. Thermal noise is due to thermal agitation of electrons and is uniformly distributed across the frequency spectrum. The thermal noise to be found in 1 Hz of bandwidth is

$$N_0 = kT \text{ W/Hz},$$

where T is the absolute temperature of the medium (conductor) and k is Boltzmann's constant (1.3803×10^{-23} Joules/Kelvin). The amount of thermal noise in B Hz of bandwidth is simply $N_0 B$.

Other forms of noise: intermodulation noise, crosstalk, and impulse noise.

The effect of noise on the achievable information rate is best captured by Shannon's capacity theorem which we derived last week, which relates the capacity to the signal-to-noise ratio. A more convenient form of this equation is in terms a different ratio, referred to as the E_b/N_0 term. Here E_b refers to the energy per bit of the signal and N_0 is the noise power density introduced above. The bit error rate achieved by a given signal encoding technique over a communication medium is a function of the E_b/N_0 term.

In terms of the signal power P and the information rate R, we can write E_b as P/R. Noting that $N = N_0 B$, we obtain $E_b/N_0 = (P/N)(B/R)$, where B is the bandwidth. Thus, the E_b/N_0 value

needed to achieve the capacity of a channel must satisfy the following equation.

$$C = B \log_2 \left(1 + \frac{E_b}{N_0}\frac{C}{B}\right) \rightarrow \frac{E_b}{N+0} = \frac{B}{C}(2^{C/B} - 1).$$

Bit-error rate and E_b/N_0 ratio.

4 Fading

Multipath propagation.

Different kinds of fading.

Delay spread: We send a probing pulse from a location and measure the received signal at the recepient location as a function of time. The signal power of the received signal spreads over time due to multipath propagation and the resulting spread in delays of the arriving signals. The pdf of the delay can be obtained, and the average delay and root mean square delay spread can be calculated.

Doppler spread: measure of spectral broadening caused by the time rate of change of the mobile radio channel. Caused by either relative motion between the mobile and base station or by movement of objects in the channel. When a pure sinusoid of frequency f is transmitted the received signal spectrum, the Doppler spectrum, is the range $[f - f_d, f|f_d]$, where f_d is referred to as the Doppler spread, given by

$$f_d = \frac{v}{\lambda}\cos\theta,$$

where v is the relative velocity of the mobile and θ is the angle formed by the direction of the motion and that of the signal, and λ is the wavelength of the carrier.

Flat fading: BW of signal ¡ BW of channel; Delay spread ¡ Symbol period;

Frequency selective fading: BW of signal ¿ BW of channel; Delay spread ¿ Symbol period;

Fast fading: Channel variations faster than baseband signal variations; high Doppler spread.

Slow fading: Channel variations slower than baseband signal variations; low Doppler spread.