Exercises, module 3 week 39

Radio communication theory

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2 Theoretical elements of radio communication

2.1 Radio wave propagation

Radio propagation is the behavior of radio waves as they travel, or are propagated, from one point to another, or into various parts of the atmosphere. As a form of electromagnetic radiation, like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization, and scattering.

2.2 Radio frequency spectrum

The radio frequency spectrum is formed by a virtually infinite set of discreet frequencies characterized as waves with wavelengths corresponding to the frequencies. Their relation is shown in the following equation in vacuum:

$$f = \frac{c}{\lambda} \tag{1}$$

2.3 Antennas, gain, reciprocity

In electromagnetics, an antenna's power gain or simply gain is a key performance number which combines the antenna's directivity and electrical efficiency. In a transmitting antenna, the gain describes how well the antenna converts input power into radio waves headed in a specified direction. In a receiving antenna, the gain describes how well the antenna converts radio waves arriving from a specified direction back into electrical power.

2.3.1 Isotropic

An isotropic antenna (also known as an omnidirectional antenna) emits the signal uniformly in all directions. In other words, at distance d from the antenna, in any direction, the transmitted signal power is the same.

2.3.2 Half Wave Dipole

The half wave dipole is formed from a conducting element which is a wire or metal tube with a distance of $\frac{\lambda}{2}$. The half wave dipole is normally fed in the middle where the impedance falls to its lowest. In this way, the antenna consists of the feeder connected to two quarter wavelength elements in line with each other. It should be remembered that the length of the half wave dipole is an electrical half wavelength for the wave travelling in the antenna conductors.

2.3.3 Quarter wave ground-plane

As the name suggests the quarter wave vertical antenna consists of a quarter wavelength vertical element. The antenna is what is termed "un-balanced" having one connection to the vertical element and using an earth connection or simulated earth connection to provide an image for the other connection.

2.3.4 Yagi-Uda

The Yagi antenna or Yagi-Uda antenna is a particularly popular form of antenna where directivity and gain are required. The gain and directivity of the Yagi antenna enable improved reception by enabling better levels of signal to noise ratio to be achieved, and by reducing interference levels by only picking up signals from a given direction. This yields better use of the available power because it is possible to focus the transmitted power on areas where it is needed.

2.4 Feed lines and connector attenuation

1. In a radio antenna, the feed line (feedline), or feeder, is the cable or other transmission line that connects the antenna with the radio transmitter or receiver. In a transmitting antenna, it feeds the radio frequency (RF) current from the transmitter to the antenna, where it is radiated as radio waves.
2. Optical loss (for connectors), sometimes called attenuation, is simply the reduction of optical power induced by transmission through a medium such as a pair of fiber optic connectors. Return loss is the amount of light reflected from a single discontinuity in an optical fiber link such as a connector pair.

2.5 Path loss, inverse square law, near field obstacles, Fresnel zones, polarization

1. The signal path loss is essentially the reduction in power density of an electromagnetic wave or signal as it propagates through the environment in which it is travelling. This affects all radio communication, broadcast and wireless communication systems.
2. As electromagnetic radiation leaves its source, it spreads out, traveling in straight lines, as if it were covering the surface of an ever-expanding sphere. This area increases proportionally to the square of the distance the radiation has traveled. In other words, the area of this expanding sphere is calculated as $4\pi r^2$, where R is the distance the radiation has travelled, that is, the radius of the expanding sphere.
3. While installing a wireless communication system, it is important to keep an elliptical region between the transmit antenna and the receive antenna free from any obstruction for the proper functioning of the system. This 3D elliptical region between the transmit antenna and the receive antenna is called the Fresnel Zone.
4. Polarization (also polarisation) is a property applying to transverse waves that specifies the geometrical orientation of the oscillations. In a transverse wave, the direction of the oscillation is perpendicular to the direction of motion of the wave.

2.6 Radio Link Budget

A link budget is an accounting of all of the power gains and losses that a communication signal experiences in a telecommunication system; from a transmitter, through a medium (free space, cable, wave guide, fiber, etc.) to the receiver.

3 Practical Exercises

3.1 Radio Link Budget

3.1.1 Unit conversion mW and dBm

The equation used for unit conversion between mW and dbm are calculated with the following formula:

$$P_{dBm} = 10 \cdot \log_{10} P_{mW} \tag{2}$$

mW	dBm
100	20
500	26.99
1000	30

Table 1: Tabel of conversions

Table 1 shows the effect and the corresponding values in dBm.

3.1.2 Free space basic transmission loss

Free space transmission loss (FSPL) is attenuation of radio signal on a path between two antennas, the attenuation of the signal does not take into account power loss in the signal, and the signal is traveling in a line of sight path thru free space. Another assumption is that the polarization of the antennas is the same, and that there is not matter between them. The physical property that contributes to the loss of energy in the signal is that it disperses as a sphere thou space.

The FSPL can be calculate like so:

$$FSPL = -27.55 + \log_{10} f + \log_{10} d \tag{3}$$

3.1.3 Radio Link Budget

The radio link budget for a 433 MHz telemetry link is calculated with the following equation:

$$margin = TX_{Power} + Link_{Loss} - RX_{Sensitivity} \tag{4}$$

The result can be seen in table 2 along with the radio link budgets for 2.4 GHz C2 link and 5.8 GHz video downlink:

Link	Ant. Gain	Dist	Link Loss	TX Power	RX Sensitivity	Margin
433 [MHz]	20 [dBi]	19.5 [km]	-111 [dB]	40 [dBm]	-101 [dBm]	30.02 [dB]
2.4 [GHz]	20 [dBi]	3.4 [km]	-111 [dB]	40 [dBm]	-101 [dBm]	30.32 [dB]
5.8 [GHz]	20 [dBi]	1.45 [km]	-111 [dB]	40 [dBm]	-101 [dBm]	30.05 [dB]

Table 2: Radio Link Budgets

3.2 Near field absorption and Fresnel zones

3.2.1 Near field absorptions

If one places a receiving antenna very close to another antenna whose pattern one wants to measure, a coupling between these antennas may alter the pattern due to mutual impedances. Non-radiative 'near-field' behaviors dominate close to the antenna or scattering object, while electromagnetic radiation 'far-field' behaviors dominate at greater distances. The boundary between these two fields is generally accepted as $D \approx \frac{2L^2}{\lambda}$ (L being largest dimension of the antenna), although many specialized antennas do not follow this rule of thumb. For Yagi-Uda antennas, the coupling can actually be useful to purposely shape the radiated pattern.

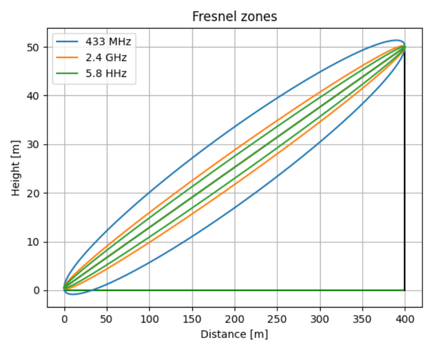

Figure 1: Fresnel zones

3.2.2 Fresnel zones

The Fresnel zone is an ellipsoid region of space between a transmitter and receiver. The important part about the Fresnel zone is that it should be free from any obstacles. This is important for the links between the drone operator and the drone, when flying will behave the best when the Fresnel zone are clear of any obstacles.

In figure 1, one can see the Fresnel zones of a transmitter at about 0.5m height and a drone 400m away at 50m height. Notice how the 5.8 GHz zone crosses below 0, meaning the ground interferes with the Fresnel zone and may cause issues.

Considering the drone 200m away and still 50m above the ground, and a transmitter in standing-level at 1.5m. The max height of a building at 100m can be calculated by first deciding how much it may interfere with the Fresnel zone (40% by rule of thumb) and adding the height of the low Fresnel zone boundary.

$$\begin{aligned} max_h &= fres_{low} + 0.6(fres_{high} - fres_{low}) \\ &= 24.19\ [m] + 0.6(27.41\ [m] - 24.19\ [m]) \\ &= 26.122\ [m] \end{aligned} \tag{5}$$

The building must thus be maximum 26.122m tall.

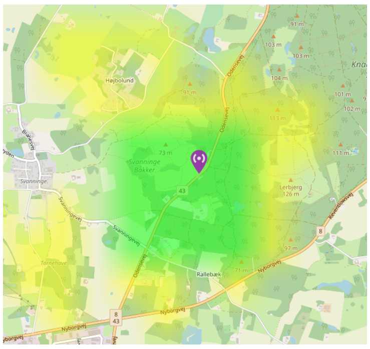

Figure 2: Svanninge Bakker Path Loss

3.3 Simulation of path loss based on terrain contours

On Radio Mobile Online, one can simulate the link and coverage influenced by the terrain contours and properties. In figure 2 one can see the extent of communication at a hilly location (Svanninge Bakker) compared to figure 3 which is much more level (HCA Airport). The green area in HCA Airport is roughly twice as wide.

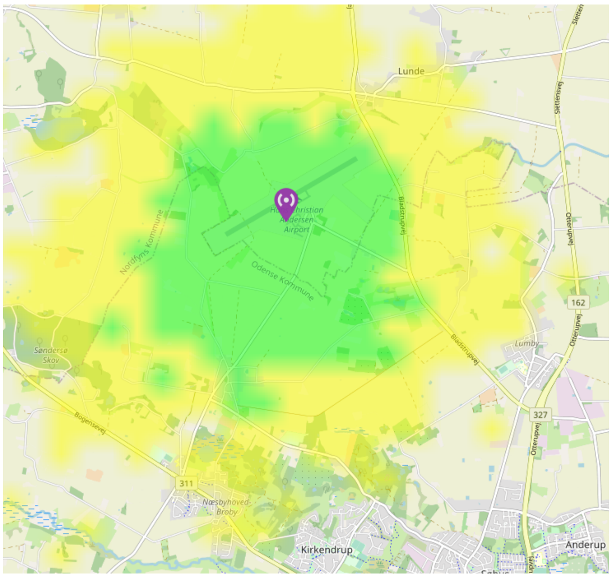

Figure 3: HCA Airport Path Loss