Course notes, module 4

Radio communication theory

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1 Agenda

1. Presentation of module 2 lab exercises.
2. Introduction to the module theory and exercises.
3. Exercises.

2 Theory presented in class

This module contains most of the basic theoretical elements of radio communication that you need to know. Subsequent modules will include work on Telemetry links and Command and Control (C2) links.

1. Radio wave propagation
2. Radio frequency spectrum
3. Antennas, gain, reciprocity
   - isotropic
   - half wave dipole
   - quater wave ground-plane
   - yagi-uda
4. Feed lines and connector attenuation
5. Path loss, inverse square law, near field obstacles, Fresnel zones, polarization
6. Radio link budget

3 Exercises

3.1 Radio link budget

The objective of this exercise is to learn about radio link budgets and how they may be applied when designing radio communication systems for drones.

3.1.1 Unit conversion mW and dbm

What is the unit conversion between power expressed in mW and dBm? What is the value in dBm for 100mW, 500mW and 1W?

3.1.2 Free-space basic transmission loss

The *free-space basic transmission loss* (attenuation) L_{bf} expressed in dB in equation 3 where P_r is the power received by an isotropic antenna, P_t is the power transmitted by an isotropic antenna, f is the frequency in MHz, d is the distance in meter between transmitter and receiver [1].

$$\frac{P_t}{P_r} = \left(\frac{4\pi f d}{300}\right)^2 \tag{1}$$

$$L_{bf} = 10\,log_{10}\left(\frac{4\pi f d}{300}\right)^2 = 20\,log_{10}\left(\frac{4\pi f d}{300}\right) \tag{2}$$

$$\approx -27.55 + 20\,log_{10}(f) + 20\,log_{10}\,(d) \tag{3}$$

Please explain what is free-space basic transmission loss and what physical properties contributes to this?

[1] RECOMMENDATION ITU-R P.525-2

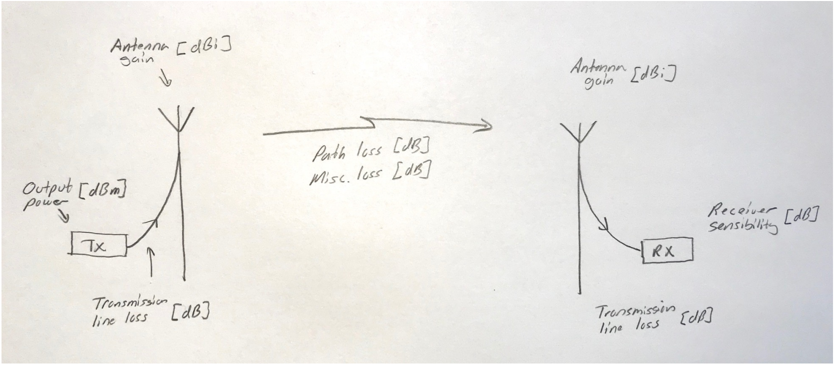

Figure 1: *Radio link budget overview*

3.1.3 Radio link budget

A radio link budget contains essentially the below factors expressed logarithmically. The radio link budget is illustrated in the radio link overview fig. 1):

$$Margin = TX_{Power} + Link_{Loss} - RX_{Sensitivity} \quad (4)$$

where:

TX_{Power} is the transmitted output power expressed in dBm minus the transmission line loss and plus the transmitting antenna gain.

$Link_{Loss}$ is the sum of the path loss and other factors contributing to loss. For the path loss we will use the free-space basic transmission loss discussed above. We will treat other factors such as polarization, aperture, Fresnell zone, Doppler effect and fading as a single contributing factor.

$RX_{Sensitivity}$ is the receiving antenna gain minus transmission line loss minus the required minimum signal power expressed in for proper decoding of the transmitted signal, all expressed in dB.

A good rule of thumb is that the $Margin$ should be at least 30 dB.

Please create in a spreadsheet a radio link budget for a a 2.4 GHz C2 link, a 433 MHz telemetry link and a 5.8 GHz video downlink respectively. It is worth spending some time to format the spreadsheet properly (good structure, easy input of value etc.) as you will likely be using this in your future work. Please notice that the course materials for this module contains some references on this.

For the 433 MHz radio link budget you should use data from the SiK Telemetry Radio (MRO)[2] which we will be using in this course.

For the 2.4 GHz and 5.8 GHz you should use specs similar to the 433 MHz. It will be close anyway and one of the key learnings is how the path loss differ at different frequencies, thus it makes sense to keep other values equal.

3.2 Near field absorption and Fresnel zones

The objective of this exercise is to learn about near field absorption and Fresnel zones and how they relate to drone technology.

3.2.1 Near field absorptions

Please explain what is *near field absorption* and to the extent possible based on information available on the web please quantify the signal attenuation.

[2] https://ardupilot.org/copter/docs/common-sik-telemetry-radio.html

3.2.2 Fresnel zones

Please explain in details using a sketch or an image from the web what is a Fresnel zone (equation 5) and how does it relate to drone C2 and telemetry links?

$$F_n = \sqrt{\frac{n\,\lambda\,(d_1\,d_2)}{d_1 + d_2}} \tag{5}$$

3.2.3 Plotting Fresnel zones

Using Python please plot the Fresnel zones for a 2.4 GHz C2 link, a 433 MHz telemetry link and a 5.8 GHz video downlink respectively.

3.2.4 Fresnel zone loss

Assuming that the greatest Fresnel zone losses occur when a diffracting object blocks 40% or more of the 1st Fresnel zone. Please calculate and discuss what this means to a drone at a height of 50m with respect to the ground at 400m distance from an operator sitting on the ground holding the TX at an approx height of 0.5m.

Please consider another situation where a standing drone operator controls a drone at 200m distance. The drone is visible just above the ridge line of the metal roof of a building at a distance of 100 meter. How much visual clearance must there be between the direct line of sight and the ridge line to ensure that the first Fresnel zone is clear for a 2.4 GHz C2 link, a 433 MHz telemetry link and a 5.8 GHz video downlink respectively?

3.3 Simulation of path loss based on terrain contours

The purpose of this exercise is for you to get an idea about the terrain influence on radio signal propagation.

Use the Radio Mobile Online [3] to model the Link and Coverage influenced by the terrain contours and properties. Do the results align quantitatively with the free space loss estimated in exercise 3.1.2 and your radio link budget developed in 3.1.3 when using the same input data?

I suggest that you select HCA Airport as location (N55.47182, E010.32581). Try also to use Svanninge Bakker (N55.12518, E010.25419) as an example of a more hilly location where lack of coverage in valleys will be more pronounced.

Please spend some time working with Radio Mobile, looking into the functionality and possible information output etc. as this may become a valuable tool to you.

[3] http://www.ve2dbe.com/rmonline.html