Unmanned Aerial Systems Techology (RMUAST) Spring 2017
University of Southern Denmark

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Module 8: Wireless communications, C2 & telemetry links

1 Exercises

1.1 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.

1.1.1 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?

$$P_{dBm} = 10 \cdot log_{10} \frac{P_{mW}}{1mW}$$

Converted values:

- 100 $mW \rightarrow 20dBm$
- 500 $mW \rightarrow 26.9897dBm$
- 1000 $mW \rightarrow 30dBm$

dBm are used when expressing an absolute value of power. For expressing the ratio between two power values dB units are used instead.

1.1.2 Free-space basic transmission loss

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

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

$$\approx -147.55 + 20\, log_{10}(f) + 20\, log_{10}(d) \tag{3}$$

Equation 3 shows the expression for calculating the free space loss, when assuming that the transmitter and receiver uses isotropic antennas and there are no hardware imperfections. As explained in the lecture, we can use a sphere to illustrate the signal propagation from an isotropic antenna, which means that the bigger the radius the bigger the area of the sphere will become. This means that the same amount of energy has to cover a larger area, which naturally results in a decay in energy seen from the receiving end. From equation 3 we also see that the frequency affects the free-space loss. This is due to that a higher frequency will be affected more by refractions in the atoms in the atmosphere.

1.1.3 Radio link budget

A radio link budget contains the following factors listed below expressed in decibels. Optionally the calculation may include Bit Error Rate (BER) for digital links.

1. The transmitted power level
2. Signal loss as it travels to the receiver (free-space)
3. Frequency band background noise level (what is the minimum SNR that will allow the receiver to extract a usable signal).
4. How the transmitting and receiving antenna systems shape the signal
5. Receiver sensitivity

Please create (and document) 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. This is not a trivial task, and you may want to search the web for examples of radio link budgets. The course materials for this module contains a few references as well.

Budget for 5.8 GHz

System parameters:

- Distance: 5 km
- Frequency: 5.8 GHz
- Radio System: 2x TR-5plus-24
  - TX power: +23 dBm
  - antenna gain: 24 dBi
  - receiver sensitivity at 54 MBps: -72dBm

Free-space signal loss was computed according to equation 3. $L_{bf} = 121.70\ dB$. By summing up TX power, antenna gains and L_{bf} we obtained received power of $-50.70\ dBm$.

Purpose of this link is to transfer video signal, so it is practical to use high data rate of $54\,MBps$. This rate can be provided by modulation and encoding scheme 64-QAM 3/4. Furthermore minimum SNR for this data rate is $25\,dB$. Next it is possible to calculate the maximum amount of noise, which can be present in transmission:

$$\begin{aligned}\text{Maximum Channel Noise (dBm)} &= \text{Received Power (dBm)} - \text{SNR (dB)} && (4)\\ &= -50.70 - 25 && (5)\\ &= -75.70\,dBm && (6)\end{aligned}$$

Equation 6 means, that noise power is about $25\,dB$ lower than received signal. If we used calculation in Watts instead of dBm, we would use division by SNR instead of subtraction. Now we have all parameter needed for link budget description. We can calculate link margin:

$$\begin{aligned}\text{Link Margin (dB)} &= \text{Received Power (dBm)} - \text{Receive Sensitivity (dBm)} && (7)\\ &= -50.70 - (-75.70) && (8)\\ &= 21.30\,dB && (9)\end{aligned}$$

Having $21.30\,dB$ link margin means, that we have 99% time availability of the signal.

Budget for 2.4GHz C2-Link

For this part we again consider a desired distance of 5km. This time we choose a Bullet2 transceiver with a transmitting power of 20dBm and a receiver sensitivity of -84dBm at a data rate of 24Mbps. We use this unit for both the receiver and transmitter and attach a 10dBi antenna on each end. We assume minimal losses in the cables. For 5km at 2.4GHz we obtain a FSPL of 114 dBm. Therefore, our budget becomes:

$$Received\ Power = 20dBm + 10dBi - 114dBm + 10dBi = -74dBm,$$

which leaves us with a link margin of 10dB. This margin gives us a time availability of >90%. The minimum SNR for 24Mbps is 16dB which gives us a maximum channel noise of -90dB.

Budget for 433MHz telemetry

Again, consider a desired distance of 5km. This time we choose a Seed HC-12 transceiver with a transmitting power of 20dBm and a receiver sensitivity of -117dBm at a data rate of 5kbps. We use this unit for both the receiver and transmitter and attach a 10dBi antenna on each end. We assume minimal losses in the cables. For 5km at 433MHz we obtain a FSPL of 99dBm. Therefore, our budget becomes:

$$Received\ Power = 20dBm + 10dBi - 99dBm + 10dBi = -59dBm,$$

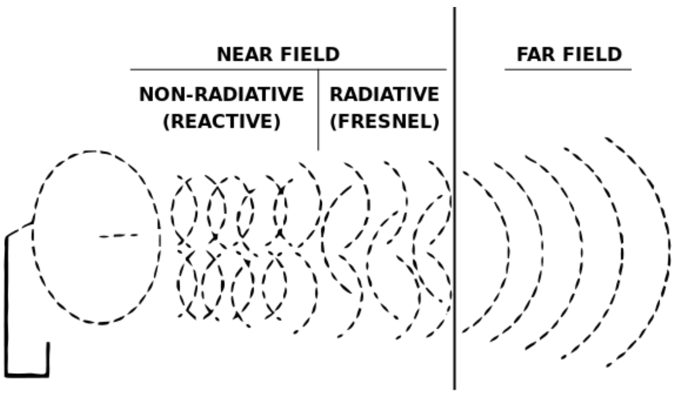
which leaves us with a link margin of 72dB. This margin gives us a time availability of >99.999%.

1.2 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.

1.2.1 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.



Figur 1: A figure (from https://en.wikipedia.org/wiki/Near_and_far_field showing the different fields in radio communication

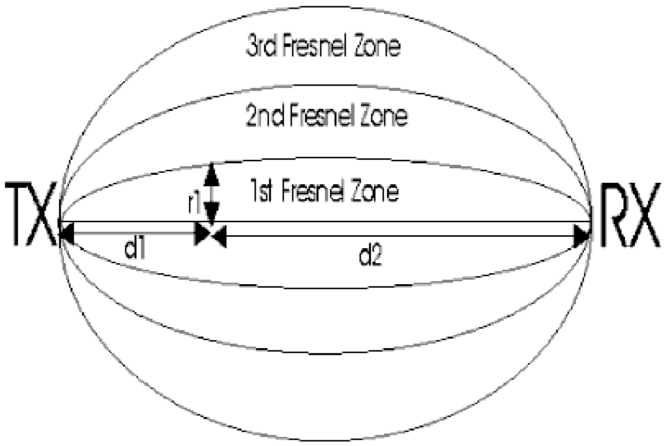
Our field is divided into two main categories: Near and far field. The far field follows basic theory for its propagation, while the near field is described with two subfields: the reactive and radiative field. In the reactive field it is hard to predict the relationship between the E- and B-field and you might encounter all four polarization types. If an object is within this field and it absorbs some of the signal then the antenna is able to detect this and will try to counteract(react to) this effect.

1.2.2 Fresnel zones

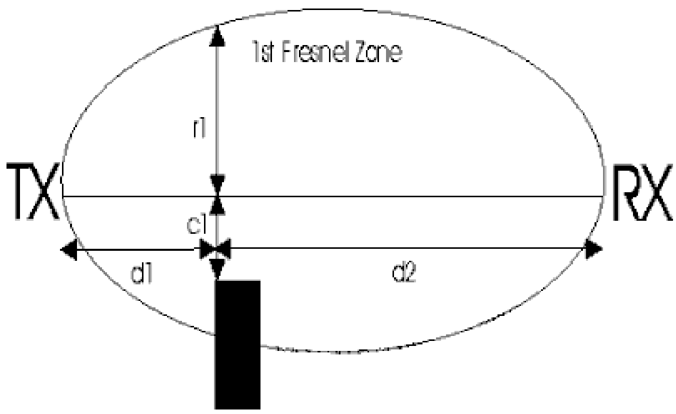
Please explain in details using a sketch or an image from the web what is a Fresnel zone (equation 10) and how does it relate to drone C2 and telemetry links?

$$F_n = \sqrt{\frac{n\,\lambda\,(d_1\,d_2)}{d_1 + d_2}} \tag{10}$$

A Fresnel zone is a way to describe your signals propagation and check whether the environment you wish to send in is feasible taking the frequency of the signal, the obstacles and the distance of the transmission, when considering reflections of your signal. Figure 2 shows the variables mentioned in equation 10 and shows the form of the Fresnel zones. It is important to note that a reflection in the 3rd Fresnel zone will make a phase shift corresponding to a signal in the 1st Fresnel zone and so forth. As a rule of thumb there must be a maximum of 40 % obstruction in the 1st Fresnel zone.



Figur 2: A figure (from http://www.zytrax.com/tech/wireless/fresnel.htm showing Fresnel zones in general

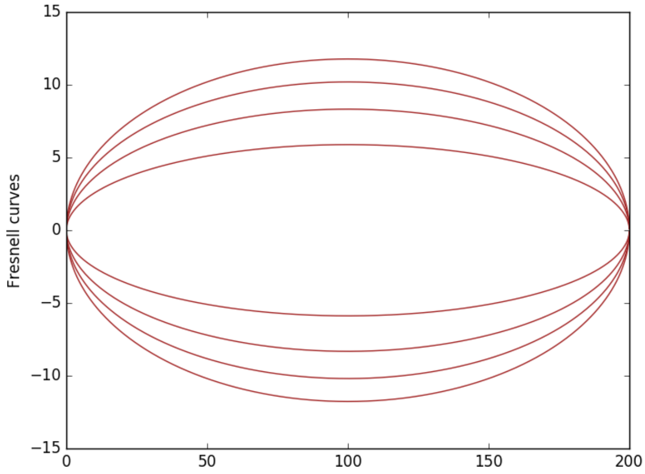


Figur 3: A figure (from http://www.zytrax.com/tech/wireless/fresnel.htm showing a Fresnell zone, which has an obstacle disturbing the LOF

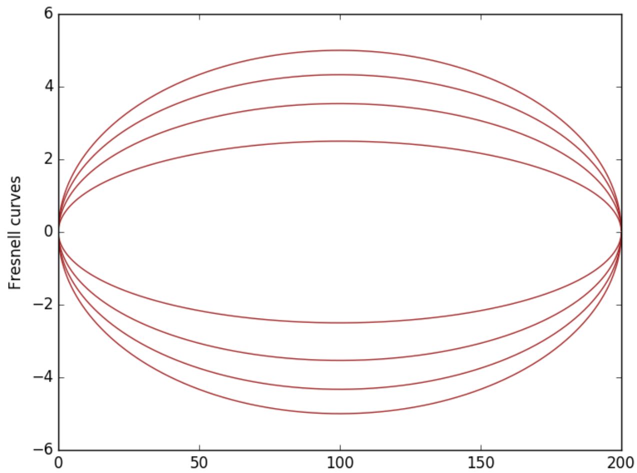
1.2.3 Plotting Fresnel zones

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.

Figure 4, 5 and 6 shows these plots



Figur 4: A figure showing the Fresnel zones for 433 Mhz



Figur 5: A figure showing the Fresnel zones for 2.4 GHz

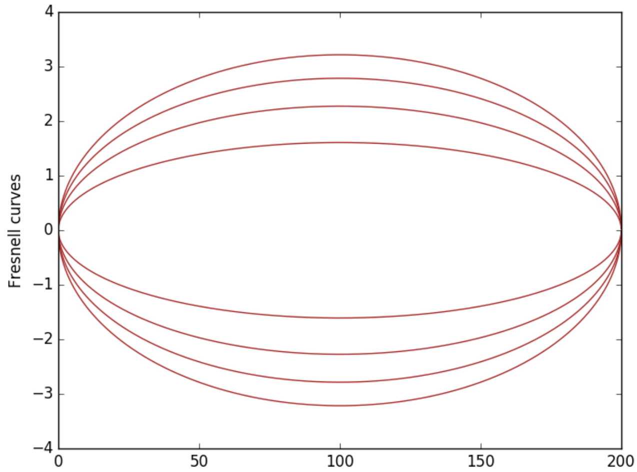
1.2.4 Fresnel zone loss

Assuming that the greatest Fresnel zone losses occur when a diffracting object blocks about 40% 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. This is shown in figure 7.

Please consider another situation where a standing drone operator controls a drone at 200m distance. The drone is visible just above the ride line of the metal roof of a building at a distance of 30 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?

From the calculations of the script we have the following results:

$433\ MHz => 5.37m$ $\quad$ $2.4\ GHz => 6.84m$ $\quad$ $5.8\ GHz => 7.23m$

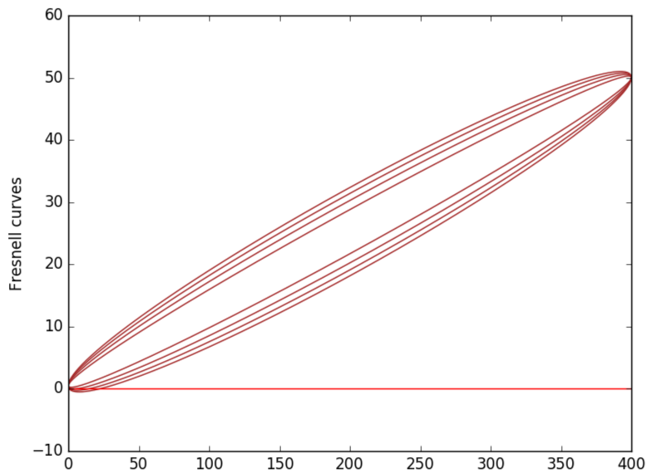


Figur 6: A figure showing the Fresnel zones for 5.8 GHz

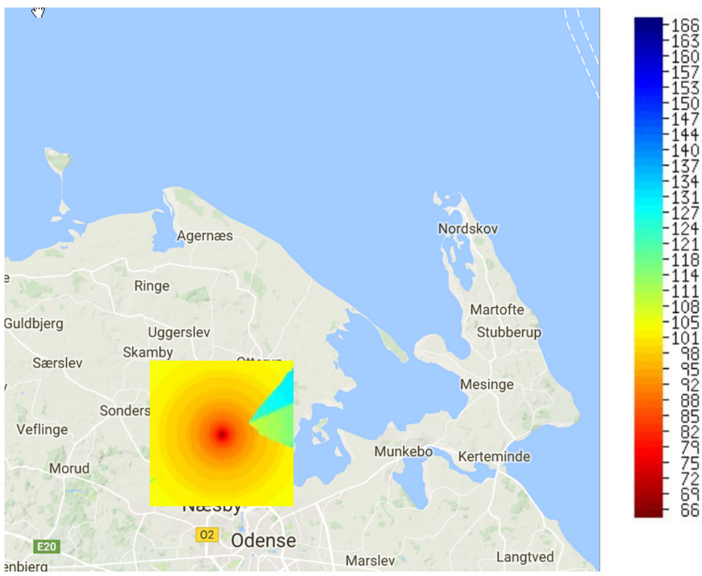
1.3 Path loss model based on terrain contours

Use the VHF/UHF Area Prediction Tool to model path loss influenced by the terrain contours. Is the result comparable to the free space loss estimated in exercuse 1.1.2 if you select HCA Airport as location (N55.47036, E010.32967)? What if you select Svanninge Bakker (N55.12518, E010.25419)?

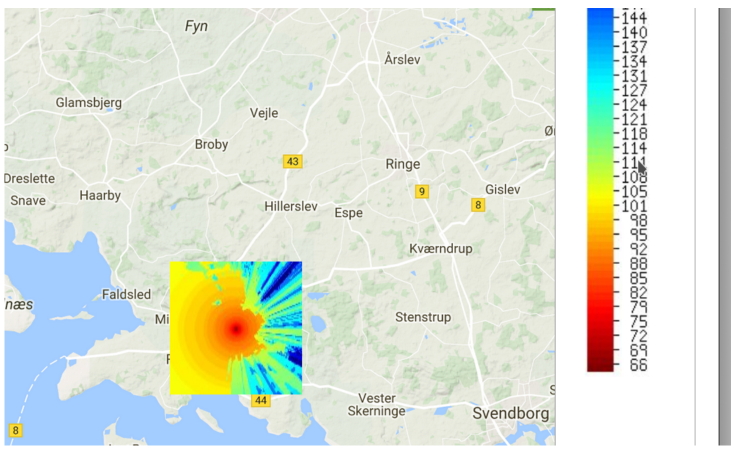
Model of path loss influenced by the terrain contours is depicted on figures 8 and 9. Calculated signal loss according to eq. 3 is 114.03 dB. After color checking of graphs 8 and 9 we can conclude that calculated values are in average about 10 dB larger. However as can be seen on the pictures, model influenced by the terrain contours isn't isotropic.



Figur 7: A figure showing the Fresnel zones for a 2.4 GHz link with a drone 400 meters away at a height of 50 meters, while the operator is holding the transmitter of a height of 0.5 meters. It can be seen that the first Fresnel are not violated.



Figur 8: HCA Airport path loss



Figur 9: Svanninge Bakker path loss