1 | Fresnel Zones

Fresnel zone [ZyTrax, 2016] [Solutions, 2016] calculations gives a mean to calculate on how to avoid the interference from the strongest radio signals that are not direct line signals. This can be caused by reflections of obstacles, these reflected signals will have a different phase and when added with the direct line signal, may cause power loss. There are an infinite amount of Fresnel zones, and all will impact the direct line signal.

In terms of a radio signal travelling from a transmitter to a receiver it can travel along different paths. It can travel directly without any reflection, or it could reflect of the ground and thereby carry on to the receiver, or it could be reflected by a hill, and carry on to the receiver. These reflections can cause a signal loss from the transmitter to the receiver. The receiver does not differentiate between the reflected and the direct line signals, and therefore it will consider both the reflected and the direct line signal as the intended signal [Solutions, 2016]. It is important to notice that there will be a phase shift of 180°, if the wave is linearly polarized and hits a surface that is parallel to the waves polarization.

If these signals reflect of an obstacle and are out of phase with the direct line signals, they may end up having phase cancellation effect which could end up minimizing the power of the signals. For example two identical radio signals out of phase will cancel each other out and therefore no signal will be received, by the receiver. So therefore when calculating Fresnel zones it must be taken into consideration which out of phase signals from reflections have the most effect on the direct line signal, and make sure that it does not lose a lot of power.

There are an infinite amount of Fresnel zones, but the most important Fresnel zone is the first one. This is due to that the strongest signals are the ones that are closets to the direct line signal and they always lie in the first Fresnel Zone. Which also means that the second, third and so on Fresnel zones are further and further from the Direct signal and obstacles in these will have a lesser impact [Seybold, 2005]. This can be seen on the following Figure, which is illustrated with 2 Fresnel zones, Fresnel zone 1 and 2:

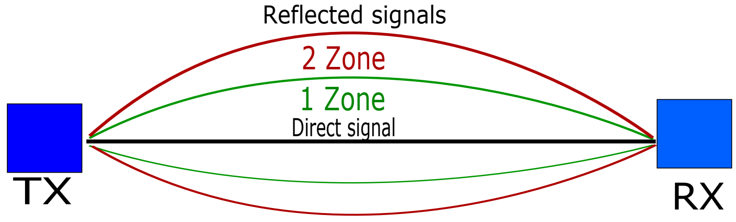

Figure 1.1: Illustration of the First and Second Fresnel zone, along with the Direct signal travelling from the Transmitter TX to the Receiver RX

As it can be seen the first Fresnel zone is closets to the direct signal and will have the strongest cancelling effect, if not taken into consideration. It has the least amount of delay in the reflected signal of the first Fresnel zone as it travels least from the transmitter to the receiver. Inside the first Fresnel zone phase delay due to increase in path distance of the reflected wave are 0°-90°, when remembering the phase change done by the reflection itself that means the signal is 180°-270° out of phase in total. When the reflected signal then interfere with the direct signal destructive interference occur. In terms of the second Fresnel zone, it creates longer phase delay, in total between 270° to 450° out of phase. This become constructive interference. The phase cancelling effect in even numbered Fresnel zones are good while odd numbered zones are bad. A rule of thumb in terms of the first Fresnel zone is that 60% *of the first Fresnel zone must be cleared of any obstacles*, as this reduces the destructive interference significantly [Seybold, 2005][Solutions, 2016].

Fresnel zone 1

As mentioned 60% of the first Fresnel zone must be cleared of objects, an illustration of this can be seen on the following Figure:

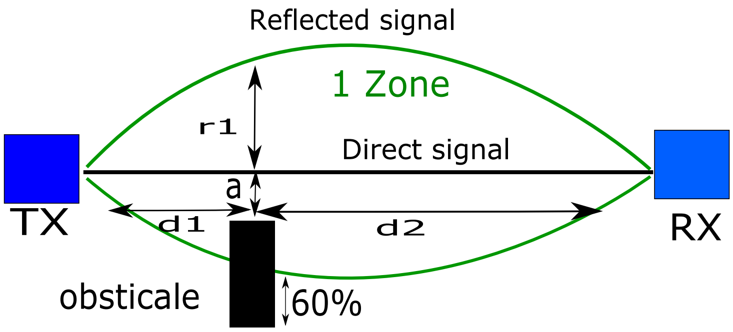

Figure 1.2: Illustration of the First Fresnel zone cleared 60%, with an building representing the obstacle

The obstacle on the Figure above could illustrate a building where d_1 is the distance from the transmitter TX to the building while d_2 is the distance from the receiver RX to the building. The radius of the first Fresnel zone is r_1. The distance from the direct signal to the obstacle is a. With this in mind the rule of thumb states that $a > 0.6 \cdot r_1$.

Fresnel Zone calculations

The general equation for calculating the Fresnel zone radius at any point a in between the endpoints is given as [Seybold, 2005]:

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}} \tag{1.1}$$

Where:

F_n	The n^{th} Fresnel Zone radius	[m]
d_1	The distance of a from TX	[m]
d_2	The distance of a from RX	[m]
λ	The wavelength of the signal	[m]

A conservative calculation of the 60% rule of thumb is to use the maximum radius of the first Fresnel zone to calculate maximum obstacle heights.

The wavelength λ can be expressed as:

$$\lambda = \frac{c}{f} \tag{1.2}$$

Where:

c	The speed of light in a vacuum	$[3 \cdot 10^8 ms^{-1}]$
f	Signal frequency	$[Hz]$

The maximum radius is found at the point where $d_1 = d_2$. Then by using this as well as setting $n = 1$ as it is the first Fresnel zone. An expression for the maximum radius can be found and if Equation 1.2 is inserted into Equation 1.1 that yields:

$$r = 8.67 \cdot \sqrt{\frac{D}{f}} \tag{1.3}$$

Where:

D	Total distance $= d_1 + d_2$	[km]
f	Signal frequency	[GHz]

As an example to calculate the clearance radius of the first Fresnel zone of two antennas operating 5.5 GHz, with a distance D of 500m. The 60% clearance radius a is given as:

$$a = 0.60 \cdot 8.67 \cdot \sqrt{\frac{0.50}{5.5}} = 1.57m \tag{1.4}$$

Then by subtracting the antenna height form a, the maximum obstacle height with respect to the 60% clearance can be calculated. So if the the antenna height is 10m, then by subtracting 10m-1.57m we get 8.43 m, which is the maximum obstacle height.

2 | Large Scale Fading

Large scale fading [Schmitz and Becker, 2003] [Keysight, 2016] is a result of signal attenuation due to signal propagation over large objects caused by shadowing through surroundings like buildings,hills,trees, streets etc. and losing power. Shadowing is caused by blockage of large objects, where new waves get created as a result of the obstacle. And over the whole path it represents the average signal attenuation. An illustration of Shadowing can be seen on the following Figure:

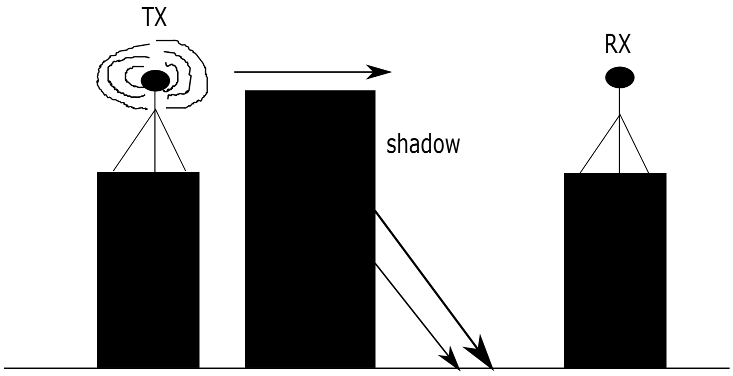

Figure 2.1: Illustration of the First and Second Fresnel zone, along with the Direct signal travelling from the Transmitter TX to the Receiver RX

The path when working with large scale fading is of distances several hundred wavelengths or more. The wavelengths of course depends on the frequency. So when working with Bluetooth or Wi-Fi where the frequency is 2.4 [GHz]. Then given the equation for the wavelength:

$$\lambda = \frac{c}{f} = 12[cm] \tag{2.1}$$

This gives us one wavelength, this means that for 100 wavelengths this shall be 12[m], which is then considered large scale fading. In the free space case the attenuation of the signal due to distance follows the inverse square law given as:

$$\text{Average Signal Attenuation} = \frac{1}{d^2} \tag{2.2}$$

So the larger the distance from the transmitter to the receiver, the larger the signal attenuation will be.

In the case of effects caused by trees, buildings etc. The average signal attenuation cannot be characterized as the inverse square law given in 2.2, which only holds for free space. The effects of buildings, trees etc. are called shadows, which are waves that are caused by a building or something that is in the way, which creates new waves.

When taking shadowing into the equation a Lognormal Distribution is used to model the power variation, caused by the effects of shadowing [ELEC 6040 Mobile Radio Communications, 2016]. The power level in dB is distributed as a Gaussian random variable. The power level in dB at a distance d is given by the following equation:

$$P_{dB}(d) = \overline{P}_{dB}(d) + \sigma_{dB}X = \overline{P}_{dB}(d_0) + 10n\log_{10}(\frac{d}{d_0}) + \sigma_{dB}X \tag{2.3}$$

Where σ_{dB} is the standard deviation, and X is a standard random variable.

3 | Link Budget

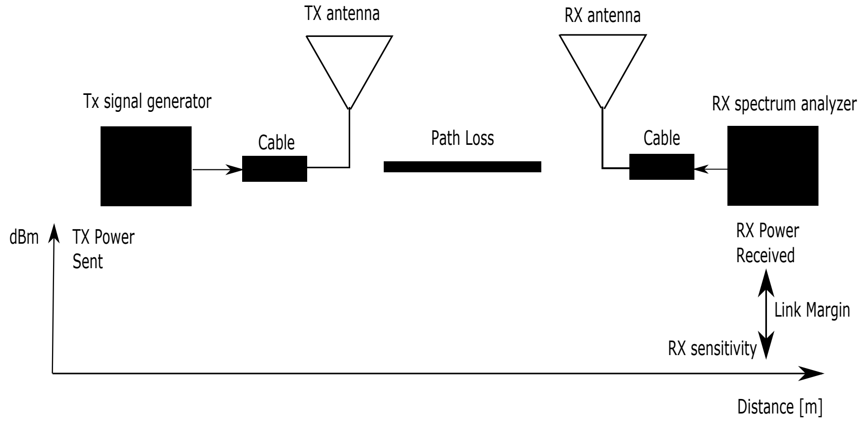

Figure 3.1: Link budget illustration

A Link budget, takes into account all the losses and gains from the transmitter antenna to the receiver antenna. A Link budget is calculated to take into account the attenuation of the transmitted signal due to propagation, which depends on the circumstances like reflections, free-space loss ,buildings etc. other factors included are cable loss, antenna gains, polarization loss. Such a calculation is given as:

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{PL} - L_{MISC} + G_{RX} - L_{RX} \tag{3.1}$$

Where:

P_{RX}	Power Received	[dBm]
P_{TX}	Power transmitted	[dBm]
G_{TX}	Transmitter antenna gain	[dBi]
L_{TX}	Transmitter losses (cable,coax)	[dB]
L_{PL}	Path Loss	[dB]
L_{MISC}	misc losses(polarization losses, other losses)	[dB]
G_{RX}	Receiver antenna gain	[dBi]
L_{RX}	Receiver losses (cable,coax)	[dB]

Different LOS and Fresnel zone

Other factors to consider when calculating a link budget is if there is **Line-Of-Sight(LOS)**, which means that if there is an obstacle in between the transmitter antenna and the receiver antenna it does not block the signal, as the two antennas can see each other, this is illustrated on the following Figure:

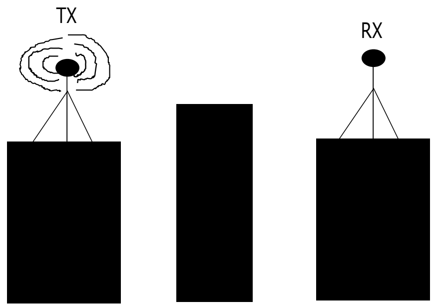

Figure 3.2: LOS illustration

Where the counter-part is **Non-Line-Of-Sight(NLOS)**, which means that the path is interfered, which could be by a building standing in-between the transmitter antenna and the receiver antenna, where the two antennas cannot see each other, this is illustrated on the following Figure:

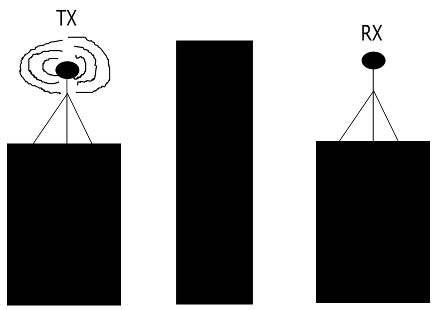

Figure 3.3: NLOS illustration

Another one is **Near Line Of Sight(nLOS)**, which means that the path is partially interfered, which could be by a building. Which is illustrated on the following Figure:

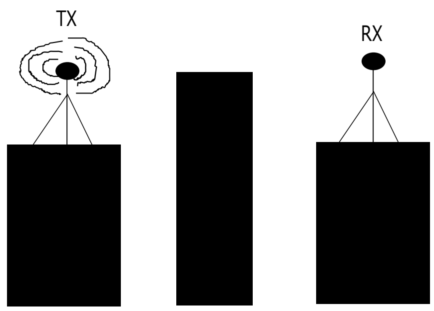

Figure 3.4: nLOS illustration

The different Line-Of-Sights, play a big factor when considering the Fresnel Zones which is further explained in Chapter 1, which also plays a big part in the received Power. As explained in the Fresnel Zone chapter there must be 60% clearance in the first Fresnel zone, as the strongest signals are in the first Fresnel zone ,this could be a problem if there is too much **NLOS**, as the antennas would need to be risen higher.

Another thing that could be considered is Shadowing which is further explained in Chapter 2, this comes from when a building is in-between, where new waves gets created and are added to the other waves coming from the direct line signal and the reflected signals and will have an impact on the Power received which is all the waves added together. The shadowing loss will in the Link Budget equation given in 3.1, be under L_{MISC}.

Polarization loss factor (PLF)

Polarization loss as plays a factor in the Link Budget calculation. There is **Linear Polarization**, **Circular Polarization**. For Linear polarization the antenna can be turned horizontal and vertical direction this is illustrated in the following Figure:

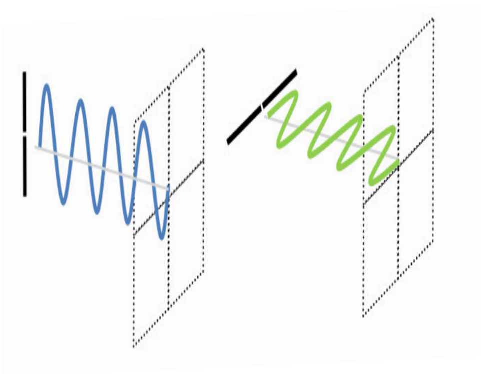

Figure 3.5: Linear horizontal and vertical polarization

The PLF for Linear Polarized antennas can be calculated by the equations given on the following Figure depending on the angle of the the antennas, an illustration of the PLF for max, non and signal loss with dependence on an angle:

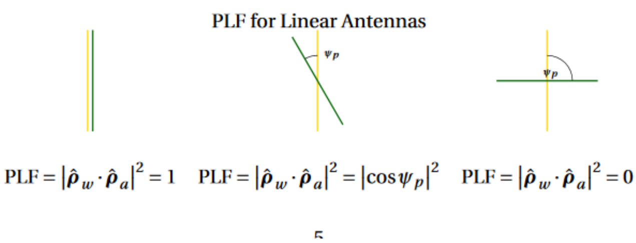

Figure 3.6: Minimum, maximum and PLF loss depending on the angle

As it can be seen if the two antennas are pointing directly at each other with the same polarization there will be no PLF. While if one antenna is vertically polarized and the other is horizontally polarized, then no power will be transferred. While there will be some power loss if the two antennas are not 100% polarized, meaning there is an polarization miss match ,there will be some power loss depending on the angle.

Cable Loss

As a part of the Link Budget cable loss is also included. The cable loss is depended on the length of the cable, where the longer the cable the more cable loss there will be as the signal will lose travelling strength through the cable. Where for each cable it is indicated in the data sheet how much power is lost per meter at different frequencies, this is different for each type of cable.

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