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Exercise 1

1. Computing PL_{FSP}

$$PL_{FSP} = 10.log_{10}\frac{P_t}{P_r}]$$

Putting P$_r = \frac{P_t.\lambda^2}{d^2.(4\pi)^2}$,
$PL_{FSP} = 10.log_{10}\frac{P_t}{\frac{P_t.\lambda^2}{d^2.(4\pi)^2}}$
Rearranging terms we get:

$$PL_{FSP} = 10.log_{10}\frac{d^2.(4\pi)^2}{\lambda^2}$$

Computing PL$_{TRG}$

$$PL_{TRG} = 10.log_{10}\frac{P_t}{P_r}$$

Putting P$_r = \frac{P_t.h_t^2.h_r^2}{d^4}$,
$PL_{TRG} = 10.log_{10}\frac{P_t}{\frac{P_t.h_t^2.h_r^2}{d^4}}$
Rearranging terms we get:

$$PL_{TRG} = 10.log_{10}\frac{d^4}{h_t^2.h_r^2}$$

2. Computing the ratio of PL_{FSP} and PL_{TRG} for $d = d_c$

$$10.log_{10}\frac{(\frac{4\pi.h_t.h_r}{\lambda})^2.(4\pi)^2}{\lambda^2} : 10.log_{10}\frac{(\frac{4\pi.h_t.h_r}{\lambda})^4}{h_t^2.h_r^2}$$
$$\Rightarrow \frac{(4\pi)^4.h_r^2.h_t^2}{\lambda^4} : \frac{(4\pi)^4.h_r^2.h_t^2}{\lambda^4}$$
$$\Rightarrow 1 : 1$$

This shows that the transition at $d = d_c$ is smooth.

Exercise 2:

The implementation was done using done Python. For the combined model, after taking the necessary user inputs, the value of d_c was calculated. Using this value, either the FSP path loss or TRG path loss values were calculated for each distance value between 0 and 10,000 meters. The resulting path loss values were plotted against the distance. Similarly, for the TLD model, path loss values were computed using given formulae and necessary user inputs. The results were plotted.

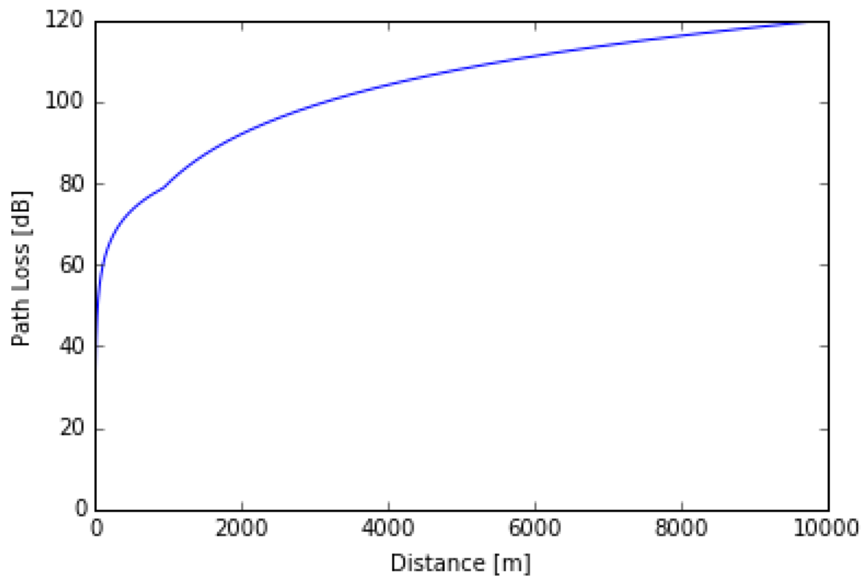

Figure 1: Plot for combined FSP and TRG models

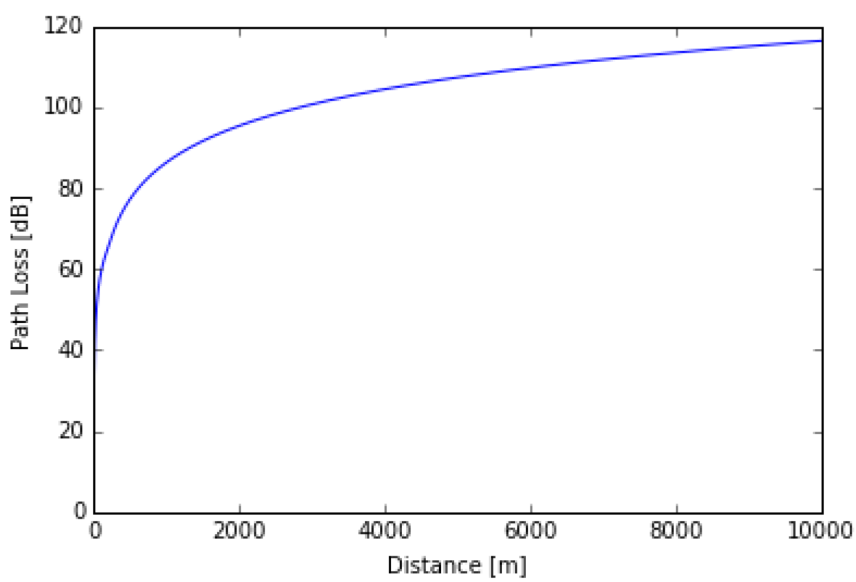

Figure 2: Plot for TLD model

Both of the above plots show that the path loss values increase with distance. The rate of increase is higher at lower distances and goes down as the distance increases.

Exercise 3:

To extend the program to calculate the path loss vales using given data, we first had to calculate the distance in meters between the transmitter and the car using the coordinate information. For this we used the Haversine formula, where the distance between two set of longitude and latitude values is given by:

$$2r \arcsin\left(\sqrt{\sin^2\left(\frac{\varphi_2 - \varphi_1}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right)$$

Here,

- φ_1, φ_2: latitude of point 1 and latitude of point 2, in radians
- λ_1, λ_2: longitude of point 1 and longitude of point 2, in radians
- Earth is assumed to be a sphere with radius r = 6371 km
- We take the transmitter as point 1 and the location of the car as point 2

Using these distances, we obtained the following plot for the expected path loss according to the two given models:

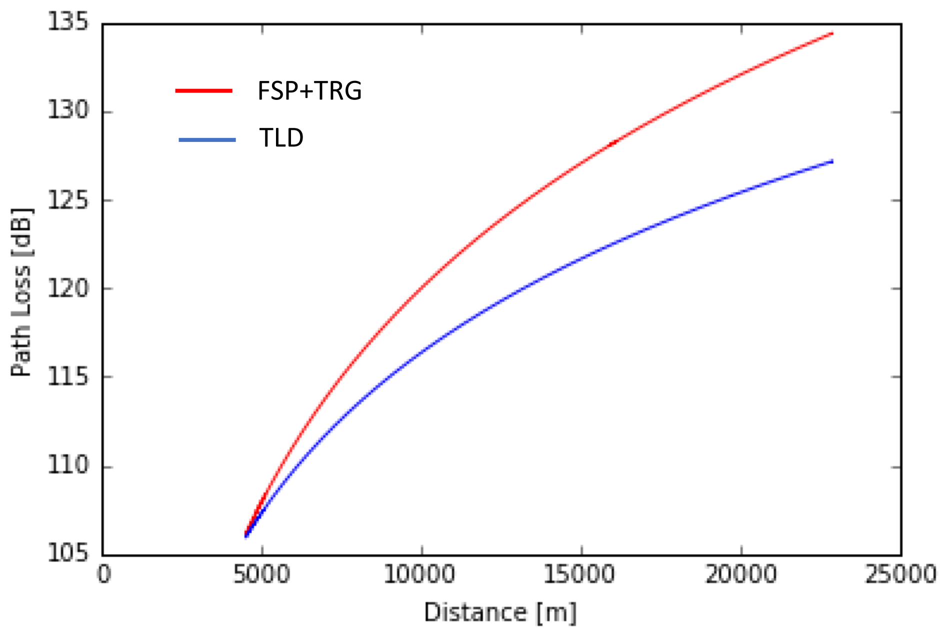

Figure 3: Expected Path Loss

We can see that as the distance increases, the path loss values also increase for both the models. The loss values for TLD model are lower than those of FSP-TRG model.

And the following is the plot for the measured relative signal strength values at the same distances as above:

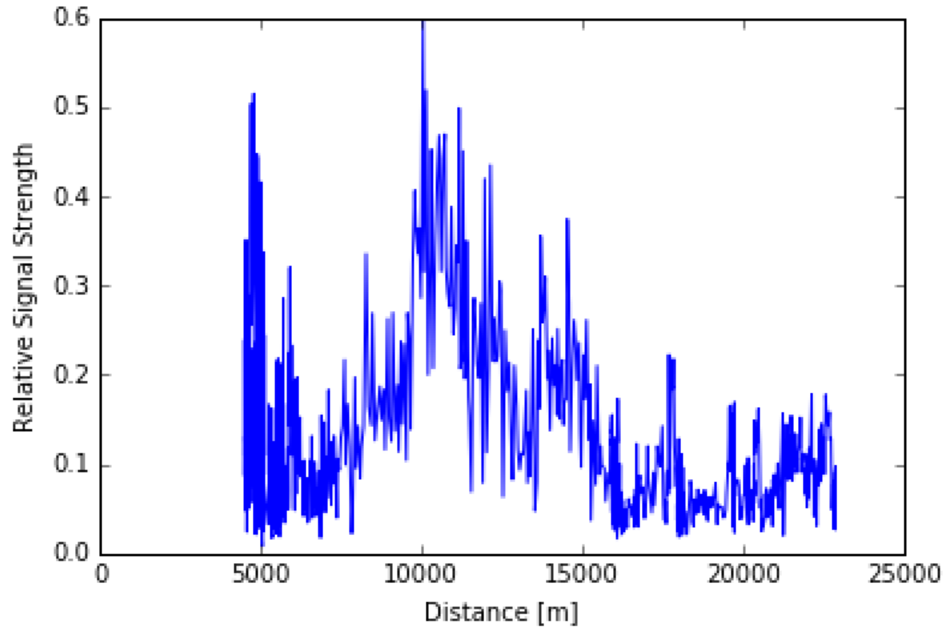

Figure 4: Measured Relative Signal Strength

Ideally, the relative signal strength should go down as the path loss increases. As shown in figure 3, the expected path loss using both the models increases very smoothly. But as seen in figure 4, the drop in the relative signal strength is not as smooth. There are many fluctuations and many highs and lows. This difference in the real-world measurements and the expected values, can be caused by many factors which the mathematical models have not taken into account. Some of these factors can be:

- Attenuation due to different air densities or signal crossing through materials other than air such as trees or buildings.
- Obstacles in the path can also lead to signal strength loss through scattering and diffraction.
- The path from transmitter to receiver is not always a straight line of sight path. Total received signal strength is also affected by reflection of signals from various objects in the environment.

All these factors are highly variable and hence hard to approximate in a mathematical model to measure path losses.