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Radio Wave Propagation: Simulation of Free Space Propagation Path Loss

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ABSTRACT

In free space propagation, the propagation path between a transmitter and a receiver is direct to one another. Having no obstructions present in free space, there are minimal to no attenuation in signals. Still, there exists a free-space path loss. This is defined as the loss of the radio wave signal or its signal while it travels in free space. Determining the path loss is crucial for designing communication systems so that it can work at its best despite the issues that can be encountered. Additionally, path loss has been used in radio communications and wireless survey tools in order to identify the signal strength of antennas. With the increase in importance for wireless devices such as survey tools and software, it has become helpful to understand the concept of radio path loss as a whole. This paper focuses on simulating the free space propagation path loss to have a clear understanding of its function and the factors that affect it. The software used for this is MATLAB so that graphs can be obtained to have a direct and simple visual of the path loss.

Key words: Radio Wave propagation, Free Space propagation, Free Space Propagation path loss.

1. INTRODUCTION

In designing wireless applications, there are two most common and basic questions asked by the designers for them to take into consideration. First is the question of whether there is going to be a communication link between two stations if the said stations are built and located in certain places. Second, the question of what the maximum allowed distance would be in order for the wireless channel to work. To obtain answers to these questions with the simplest approach, designers must compare two important factors. These factors are the dynamic range of the system and the electromagnetic waves propagation loss [1].

The dynamic range of the system is a characteristic that looks for the maximum power loss permitted by the communication channel, which is between the transmitter and receiver, while the communication link is still present. The dynamic range is determined with the use of transmission power and receiver sensitivity [2]. On the other hand, the electromagnetic wave propagation loss is the characteristic that shows the part of the energy that is lost in the propagation path [3]. The propagation path is the path where the electromagnetic waves travel, starting from the location of the transmitter to the location of the receiver [4].
The free space propagation model is one of the two basic propagation models in radio wave propagation that have all mechanisms encountered in macrocell prediction [5]. The other model is known as the Plane Earth Loss model. The other models require more detailed information in terms of locations, dimensions, and parameters. In free space propagation, the propagation path is represented as a direct ray that connects the transmitter and receiver [6]. Like in any communication system, the prediction of path loss is an important element in free space propagation [7,8]. Path loss is affected mainly by the distance between the transmitter and the receiver of the communication system [9]. It is used to represent the mean signal attenuation at a given distance from the transmitter [10].

In this paper, the focus is to understand and grasp the concept of radio path loss in free space. The process of obtaining the path loss is also known as the prediction [11]. As this has a necessary part for planning communication systems, it is important to be able to comprehend how it functions. Simulations will be done to have a clear idea of it.

2. BACKGROUND OF THE STUDY

As stated previously, the free space propagation system occurs when the electromagnetic wave travels in free space in which its path is a direct line that connects the transmitter and the receiver. The free-space propagation loss model is used in order to predict what the strength of the signal received will be. However, this model is only applicable when the propagation path between the transmitter device and the receiver device is clear and there are no obstructions in its way. In most large-scale radio wave propagation models, the free space model predicts that the power received decays due to the distance of the transmitter and receiver devices [12]. The free-space propagation loss makes use of the Ferris Transmission equation. It is defined as the following:

$$\frac{Pr}{Pt} = Gt \cdot Gr \cdot \left(\frac{\lambda}{400\pi r}\right)^2 \text{ [Equation 2.1]}$$

In this equation, Pr is the received power, Pt is the transmitted power, and the Gr and Gt are the gain values of the transmitting and receiving antennas. Alternatively, the free space propagation loss could be obtained in its logarithmic form, wherein it is in terms of dB units, by using the equation given below [13].

$$PL(d) = -10\log\left(\frac{GtGr\lambda^2}{(4\pi)^2 d^2}\right) \text{ [Equation 2.2]}$$

In this equation, Gr and Gt remain to be the gain values of the transmitting and receiving antennas, L is taken as the wavelength presented in meters, and d is the distance of the transmitter and receiver that is also presented in meters. The free-space propagation loss equations generate better results when the receiving antenna is located at the Fraunhofer region of the transmitting antenna. This region is simply known as the far-field. The power in free space propagation loss model decreases as the inverse square of the distance between the transmitter and receiver increases by a factor of 2.

3. STATEMENT OF THE PROBLEM

One of the most common radio wave propagation loss is mainly from obstruction of big terrain or buildings. However, it may also be from free-space path loss where it is the loss in signal strength due to the loss in signal strength of electromagnetic wave that is a result of a line of sign path through free space. Additionally, it could also due to diffraction that happens when an object appears on the path where the signal would try to move around the object. It could also be because the signal will be reflected and therefore, would reach the receiver in different paths and this would make the convolving signals to add or subtract which are dependent on their relative phases. Likewise, atmospheric moisture may happen at high microwave frequencies as a result of precipitation that the signal loss varies according to weather conditions. Correspondingly, the transmitter and receiver's height is important. This is because t affects the transmission and a determining factor in line of sight loss [14]. Hence, conducting this study is done to be able to understand the path loss that occurs on radio waves in free space propagation.

4. SIGNIFICANCE OF THE STUDY

One of the simplest settings for radio signal propagation is free space propagation. Radio wave launched from any point in any direction given to it will spread outwards from its origin point at the speed of light, when in free space. Similar to other radio wave propagation, there is also a path loss between a transmitter and a receiver in free space [15,16]. The loss is dependent on frequency, or wavelength [17]. Knowing the radio signal path loss can consequently determine the power for a transmitter, the gain, height, and location for antennas. Being aware of this has an important role in designing any wireless communication system or radio communications system [18,19]. There may be difficulties encountered when designing which may be due to several factors, such as propagation medium or the propagation environment, which in turn, can affect its performance. Although any radio signal will undergo attenuation whenever it travels from the transmitter to the receiver, there are still numerous forces that bring about the radio path loss. It is vital to understand what causes this and the levels of the signal loss of the radio path, in order to be able to design a proper system that can perform its task despite the issues that may affect it. It has also been essential for determining the signal strength at various locations through the use of radio and wireless survey tools [20,21]. Thus, this research is done for the researchers to be knowledgeable about how this is used in real-life applications.

5. DESCRIPTION OF THE SYSTEM

Free Space Path loss is described as the loss of strength or signal as it moves along free space. Since in free space there is no apparent obstruction between the transmitter and receiver, then that would make the communication between the transmitter and receiver directly a type of Line of Sight communication which does not experience any form of reflection or diffraction which causes attenuation on the signal or power loss. In the code provided the free space path loss is calculated and displayed in terms of kilometers and in terms of dB along with the input frequency set at 500 MHz.

6. METHODOLOGY

The algorithm of the program is straightforward with no other processes involved aside from the calculation of the free space propagation path loss in km and the conversion into dB units as well as the generation of its display plots which shows the loss trend of the signal as it travels along with free space. The parameters required in order to simulate the free space path loss such as the input frequency in Mhz and the distance, as well as the required constant which is the speed of light 3x108, is already given and provided in the code and the only process left to do aside from the generation of plot diagrams is the use of the free space propagation formula along with the given input variables.

7. REVIEW OF RELATED LITERATURE

In a paper that was conducted, the researchers studied the behavior of radio propagated waves in wireless communications such as cellular mobile radio and how to predict the said behaviors. This is due to the fact that the said capability to predict the behaviors of radio propagated waves is becoming an essential part in the system design with regards to propagation models being a low-cost alternative as well as a convenient alternative compared to the use of site measurements which are very costly. The authors and researchers of the study are proposing a brand new generic system design for signal propagation model which is to be integrated into Wi-Fi and Wimax environments. The authors and researchers of the study used free-space propagation models and land propagation models as the basis for the said signal propagation model that they are proposing. The propagation models used as the basis for the researcher's study consists of different types of loss such as the path loss which is common with the free space propagation model, the slow fading and fast fading. The proposed signal propagation model of the authors and researchers of the paper is aimed to be a flexible model that can be utilized and be applicable to both indoor and outdoor environments. The results obtained by the researchers' and authors of the paper are promising and can be concluded that the proposed system design is excellent [22].

In a study conducted, the authors and researchers of the paper focused on the characterization of Path Loss of a 3G wireless signal in both urban and suburban environments. For the authors and researchers of the paper, this topic of study is important and significant since the propagation environment has a corresponding characteristic effect or influence on the transmitted and received the quality of the signal. The authors and researchers of the did an investigative analysis of the characteristic effects of the propagation environment on the wireless communication signals, specifically the 3G wireless communication signal, which is within a specified area. The researchers of the study conducted field measurements of the specified area which are then categorized either as an urban environment or suburban environment using a test phone and a GPS receiver. The results which were obtained from the study were used by the researchers and authors of the paper to compare the performances of the various existing signal propagation path loss prediction models on both suburban environments and urban environments in which case the propagation model such as the Okumura-Hata propagation model showed a better performance in an urban environment, on the other hand, propagation models such as the Cost 231 showed better results when performing in suburban environments [23].

In another study conducted, the researchers and authors of the study studied the existing propagation path loss models. The various existing signal propagation path loss models are compared to each other using field measured data. The researchers and authors of the paper did this for the main reason that signal propagation path loss models has many various types and each type produce different results based on the specific kind of propagation environment in which it is designed for and also different results when it is used in a propagation environment it isn't designed for. The authors and researchers of the paper used MATLAB's various functions specifically the plot function in order to display the obtained field measured data in a form of a plot and be able to compare it visually with other obtained field measured data. The types of environments used in order to obtain the field data are the urban environment which is a high-density region, the suburban environment which is a medium density region, and the rural environment which is a low-density region. The results of the study was obtained by the authors and researchers of the study with the help of a spectrum analyzer and with the said gadget the authors and researchers of the paper was able to conclude that some propagation models can function or produce remarkable results in more than one propagation environment and other signal propagation path loss models such as the COST-231 and the SUI path loss model can produce remarkable results and display good performances in all the three propagation environments mentioned [24].

8. THEORETICAL CONSIDERATIONS

The algorithm of the program allows the user to simulate the Free Space Path Loss of a given frequency. The program allows flexibility on the side of the user to choose what frequency the user wants to calculate and allows the user to be able to differentiate the results of the simulation through making use of different frequencies as input.

9. DATA AND RESULTS

A. Program Code

```
% Free Space Propagation Loss
clc;
close all;
clear all;

f = input('Enter carrier frequency(MHz)');
c = 300; %Speed of light in Km
d = 1:1:10000;
Lp =((4*pi*d*f)/c).^2;

subplot(2,1,1);
plot(d,Lp,'b');
xlabel('x--> D (distance in Km)');
ylabel('y--> Lp (path loss)');
title('Free space model');
grid on

subplot(2,1,2);
plot(d,10*log(Lp),'r');
xlabel('x--> D (distance in Meter)');

ylabel('y--> Lp (Path loss in dB)');
title('Free space model');
grid on;
```

B. Program Output

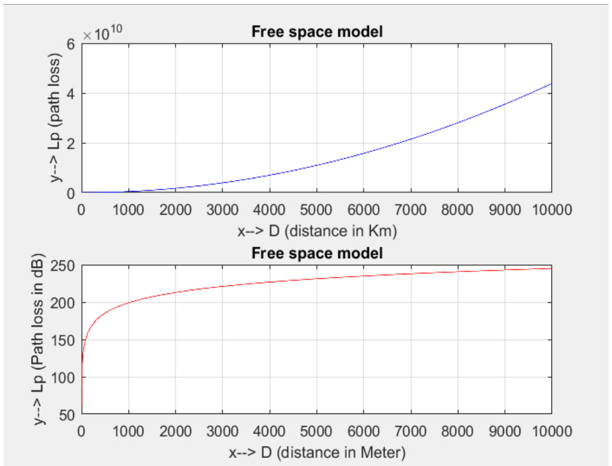

Figure 1: Plot Diagram of the free space path loss in km and in DB. (500 Mhz)

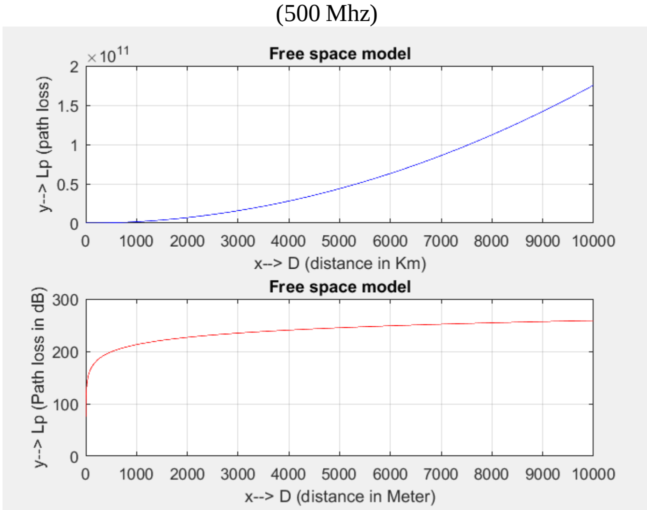

Figure 2: Plot Diagram of the free space path loss in km and in DB. (1000 Mhz)

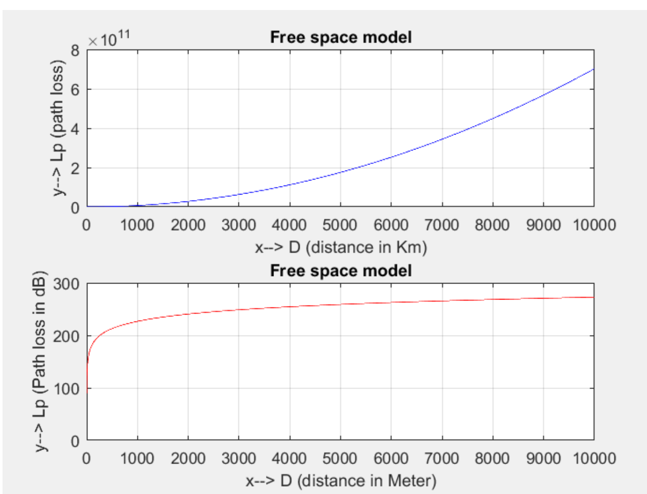

Figure 3: Plot Diagram of the free space path loss in km and in DB. (1500 Mhz)

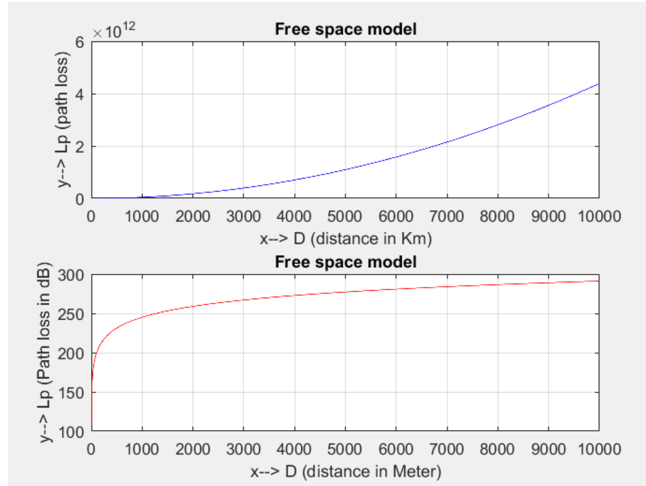

Figure 4: Plot Diagram of the free space path loss in km and in DB. (2000 Mhz)

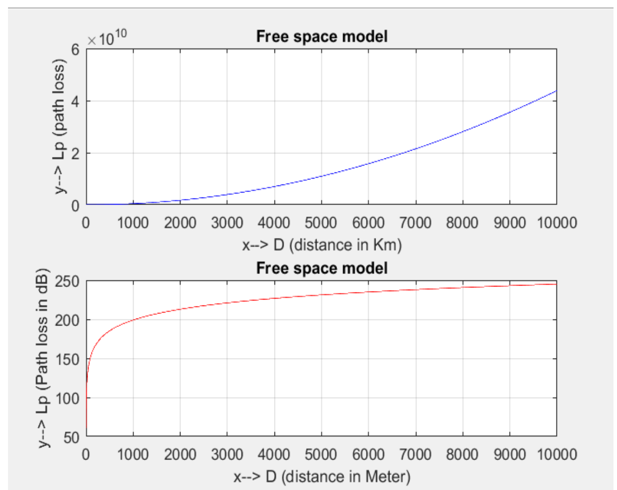

Figure 5: Plot Diagram of the free space path loss in km and in DB. (5000 Mhz)

10. ANALYSIS OF DATA

In the study conducted by the researchers, they simulated the Free Space Propagation Path Loss with the use of MATLAB. Free Space Propagation is the simplest model of propagation system which uses the ideal medium for wave propagation which is space. In Free Space Propagation the system assumes that there is only a straight line between the receiver and the transmitter with no other obstructions whatsoever between the two. One variable that is calculated in Free Space Propagation is the Path loss. Path loss in radio wave propagation is the total average loss of power over the distance the signal travels or propagates and is usually expressed in dB units. In the simulation done with the use of MATLAB, five frequencies in Megahertz units were chosen as input frequency for the program. The chosen frequencies are 500Mhz, 1000Mhz, 1500Mhz, 2000Mhz, and 5000Mhz. The reason for choosing various frequencies for the simulation is for the researchers to be able to observe the differences in the Path Loss experienced by each frequency through free space. Through the simulated results the researchers were able to observe the differences in the path loss among the five different chosen frequencies. In the first plot, the five frequencies showed results that follow a trend. For frequencies 500Mhz to 1500Mhz, the path loss showed a decreasing trend. On the other hand, on frequencies 2000Mhz and 5000Mhz showed an increase in path loss. This shows that at higher frequencies the signal tends to experience a great degree of path loss as it propagates along the distance between the transmitter and receiver. On the other hand, lower frequencies experience less path loss as it travels or propagates along the distance between the transmitter and receiver means that the signal of lower frequencies retains most of their original strength over long distances compared to higher frequencies. This is also true with the second plot of the results of the simulation which displays the Free Space Propagation Path Loss of the different frequencies in dB units.

11. CONCLUSION

For this project, the researchers have been successful in simulating a model for a radio wave propagation in free space. We have identified how different frequencies vary in free-space propagation path loss. Additionally, the researchers eventually learned on how to reduce problems regarding antenna transmission like increasing the gain of the antenna; type of antennas like Yagi-Uda which are directional which consists of multiple parallel elements which help in propagating electromagnetic field energy towards its direction. In addition, we could also change antenna shape and size, have additional parabolic reflectors, element arrays, and reflector arrays, and have spatial diversity. To further expound on the topic, the directionality is an important factor in improving the signal transmitted by the radio which is improved with alignment and in turn reduces interference from unwanted stations or signals close to the desired signal to be detected. Moreover, increase gain in the antenna would also help in improving to reduce free space loss because it could boost the signal and improve the reception of the receiver. Similarly, having additional bandwidth improves the quality of the antenna by having a broader range of radio waves that could be picked up.

This project helped the researchers to understand the use and importance of the free space propagation path loss model. MATLAB was utilized in order to simulate the propagation system. The output graph aided in having a better grasp of the concept of the free space path loss. Taken from the program code, the carrier frequency is to be input by the user. With the use of five different user input frequencies, the students were able to determine the similarities and differences of the generated outputs among the said frequencies. In conclusion, the free space propagation path loss as it travels along the line connecting the transmitter and receiver is greater when the frequency is higher.

12. RECOMMENDATIONS

There have been greater interests for wireless communication devices and different applications for radio waves in general. In order to create more systems, it is important to take note of the path loss. Even though free space propagation has less real-life applications compared to other radio wave propagations, concepts and ideas from this can still be applied to it, especially about path loss. Path loss can also be used as a core for developing a system for radio wave propagation. Studies were done wherein a new method was presented about a near-ground short-range path loss modeling in forest areas [25,26,27]. Another similar study was done as well but focuses on orchard environments [28]. The researchers of the said study were able to achieve good results for this research. With this, it is also recommended to present new systems of path loss models but on urban areas. Although this is challenging due to the presence of numerous obstructions, using different concepts about radio waves can be used in order to improve the way how radio communications work in cities. This, in turn, can then be applied for areas that face difficulties with communication like signal strength, like in communities in the provinces, or farther areas. In line with this, wireless communications with several applications in different aspects have been in demand nowadays [29,30,31]. It is recommended to design new methods or devices that can help lessen the effect of radio path loss on communication systems. Devices that can enhance signal strength using the radio path loss as the guide are recommended for more extensive research as well. For database configurations it can follow the studies of [32,33,34]. These can be used by telecommunication companies for when planning out the coverage of their network systems. The researchers also recommend using this paper as additional information or basis for those who have an intention to have studies regarding free space propagation.

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