An Educational Approach for the Study of Wave Propagation

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Abstract — *The main purpose of this paper is to present an computer tool developed to simulate a point to point digital radio link. This program allows the user to explore and study the phenomena involved in the wave propagation, as example, the Fresnell's ellipsoid and the free space attenuation. The attenuation caused by obstacles is also simulated which allows the user to realize a complete analysis about the propagation of an electromagnetic wave.*

Index Terms — *Wave propagation, simulation, Fresnell's ellipsoid.*

INTRODUCTION

Today, the digital radio links are widely used in many applications. The microwave links used to transmit telephony voice are the most common application [1]. Internet wireless access is also another important application that is growing fast. Usually, the capacity of a digital radio link varies between 64Kbps (one-voice channel) and 155Mbps (one STM-1 data stream).

The microwave digital radio links, which works with in a line of sight, has two main causes that reduce the performance of the system. The first one is the non-selective fading, which reduce the SNR (signal to noise ratio). The second one is the multipath, where a delayed version of a signal interferes in the received signal. This interference is called ISI (Intersymbol Interference) [2] [3]. The ISI provokes "notches" in the desired bandwidth, which characterizes a selective fading. Figure 1 shows the spectrum of a signal in a flat channel (non-selective), while Figure 2 shows the spectrum of a signal in a selective channel.

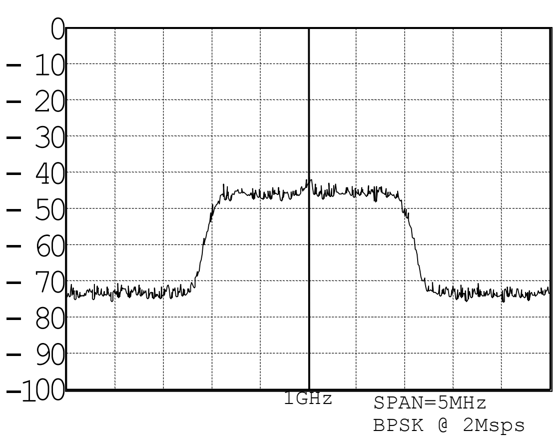

FIGURE 1
SPECTRUM OF A BPSK SIGNAL IN A FLAT CHANNEL

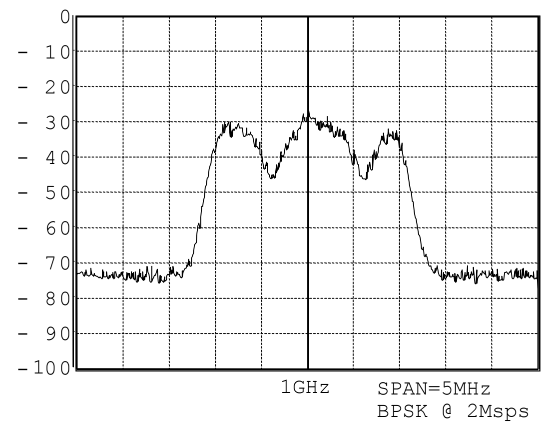

FIGURE 2
SPECTRUM OF A BPSK SIGNAL IN A SELECTIVE CHANNEL.

The weather conditions and the geometry of the links are some parameters that allow one to determine the phenomena in a link. In this paper, a computer tool to analyze microwave links is presented. This tool allows the user to verify how the parameters that define the system and the atmosphere affect the link. All results are presented in a window developed using a Graphic User Interface (GUI) over Matlab® platform [4] to provide a didactical interaction with the user.

TROPOSPHERE PROPAGATION IN LINE OF SIGHT

The trajectory described by an electromagnetic wave between the transmitter and the receiver depends, basically, on the density of the propagation medium. In the vacuum density, the electromagnetic wave propagates in a straight line, but it does not happen in the troposphere density, because it depends on the temperature, pressure and humidity. If the propagation medium does not have a uniform density, the trajectory of the electromagnetic wave is not a straight line because of the refraction phenomenon [1]. The refraction coefficient, or refraction index, n, is the ratio between the propagation speed of an electromagnetic wave in the vacuum, c_o, by the speed in the vacuum, c, as shown by (1).

$$n = \frac{c_o}{c} \tag{1}$$

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The propagation coefficient is always greater o equal to one, but for a wave propagating in the air, this coefficient is just a fraction greater than one. Thus, there is another parameter to study a wave propagating in the air, called refractivity (***N***), that is the number of parts per million that exceeds the unity, as shown by (2) [1].

$$N = (n-1)\cdot 10^6 \tag{2}$$

The refractivity ratio, for digital radio links up to 10GHz, can be obtained by (3).

$$N = 77.6\cdot\frac{P}{T}\cdot 3.732\cdot 10^5\cdot\frac{e}{T^2} \tag{3}$$

Where P is the dry atmosphere pressure in *mbar*, T is the absolute temperature in *Kelvin* and e is the water vapor pressure in *mbar*.

The value of N varies with the altitude because of the pressure and of the temperature. The pressure and the humidity usually decrease exponentially with the altitude, while the temperature decreases linearly. The typical values of refractivity ratio are between 200 and 500. In general, the refractivity decreases exponentially with the altitude, in a normalized atmosphere, as shown in (4).

$$N(h) = N_0\cdot\exp(-0.136\cdot h) \tag{4}$$

Where h is the altitude in *Km.*

The absolute value of the refractivity ratio is not important to study the degradations introduced by the troposphere in a digital radio link but the variations of this parameter can change the trajectory of an electromagnetic wave. Thus, it is important to define the refractivity gradient (G), as shown in (5).

$$G = \frac{dN}{dh} \tag{5}$$

For a homogenous atmosphere, the value of this parameter is a constant. When the atmosphere varies with time, the refractivity gradient also varies, which affects the propagation conditions. Because of this, the trajectory described by an electromagnetic wave propagating in the troposphere is not a straight line, but a curve. The radius of this curvature (ρ) depends on the refractivity gradient and can be described by (6).

$$\frac{1}{\rho} \cong -\frac{dN}{dh} \tag{6}$$

In addition, it is important to note that the Earth does not have a flat superficies, but it can be represented as a curvature with radius a that is equal to 6371Km. Thus, a precisely analysis of the line of sight between two antennas must consider the relative distance between the two curvatures. To facilitate this analysis, one may consider that the wave propagation trajectory is a straight line and the curvature of the Earth is modified by the refractivity of the medium. The new curvature of the Earth is defined as effective radium of the Earth (R_e). The effective radium is defined as the hypothetical radium of a spherical Earth without atmosphere, where the propagation of electromagnetic waves is described by a straight line. The effective radium of the Earth can be calculated by (7).

$$R_e = k\cdot a \tag{7}$$

Where k is the effective radium factor or k factor. The relationship between the Earth radium and the propagation trajectory can be obtained by (8).

$$\frac{1}{k\cdot a} = \frac{1}{a} - \frac{1}{\rho} = \frac{1}{R_e} \tag{8}$$

Thus, the k factor can be defined using the refractivity coefficient by (9).

$$k = \frac{1}{1 + a\cdot\frac{dN}{dh}\cdot 10^{-6}} \tag{9}$$

The value of k is usually between 1 and 2, depending on the weather of the region. The reference value of the refractivity coefficient is –40, which results in ρ=4a, which is defined as standard atmosphere. In this case, the value of k can be obtained by (10).

$$\frac{1}{k\cdot a} = \frac{1}{a} - \frac{1}{4\cdot a} = \frac{3}{4\cdot a} \therefore k = \frac{4}{3} \tag{10}$$

SIMULATIONS

The simulator presented in this paper has been developed to show to the user how the k factor can interfere in digital radio links. The user provides the frequency of the electromagnetic wave, the antennas heights and the k factor. The relief of the digital radio link must also be provided by a .DAT archive with the heights of the relief points. The distance between these points must also be provided. Figure 3 shows the program main window.

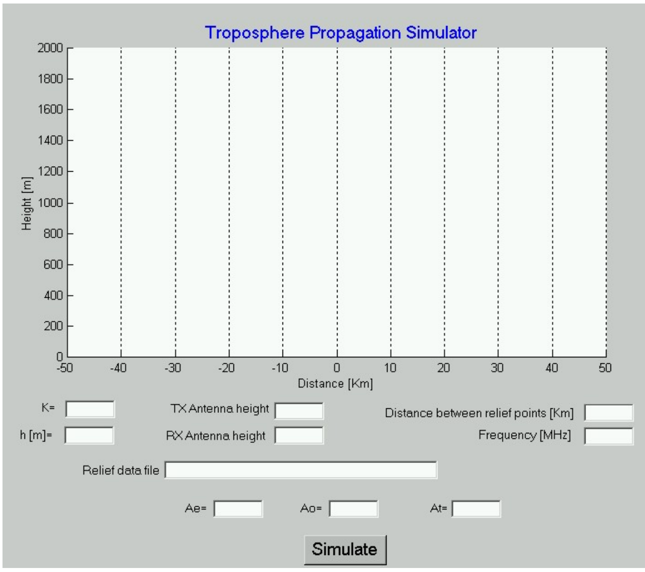

FIGURE 3
SIMULATOR MAIN WINDOW.

The parameters *Ae*, *Ao* and *At* are, respectively, the free space, the obstacle and the total attenuation. The free space attenuation is obtained by (11).

$$A_e = 32.44 + 20\log(f) + 20\log(d) \tag{11}$$

Where *f* is the signal frequency in MHz and *d* is the distance between the antennas in Km.

The knife cum model is used to define the obstacle attenuation. In this model, the obstacle attenuation can be calculated using the empiric formula given by (12).

$$A_o = \begin{cases} 0 & v \leq -1 \\ -20\log(0.5 - 0.62v) & -1 < v \leq 0 \\ -20\log\left(0.5e^{-0.95v}\right) & 0 < v \leq 1 \\ -20\log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1v)^2}\right) & 1 < v \leq 2.4 \\ -20\log\left(\dfrac{0.225}{v}\right) & v > 2.4 \end{cases} \tag{12}$$

Where *v* is the Fresnell-Kirchoff coefficient. This coefficient defines if the obstacle has affected the first Fresnell ellipsoid and it can be calculated based on the geometry of the link, as shown in Figure 4.

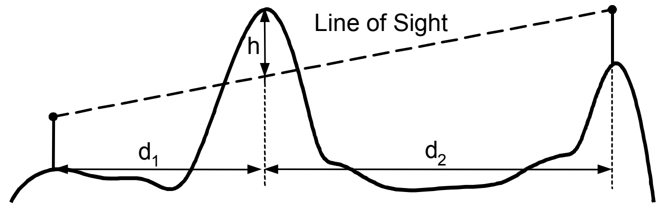

FIGURE 4
GEOMETRY OF A LINK

Finally, the Fresnell-Kirchoff coefficient can be obtained by (13).

$$v = h \cdot \sqrt{\frac{2 \cdot (d_1 + d_2)}{\lambda \cdot d_1 \cdot d_2}} \tag{13}$$

Where λ is the wavelength of the transmitted signal.

It is important to note that the height *h* may vary with the *k* factor. Figure 5 shows the simulation results obtained with a very high value of *k* (without atmosphere).

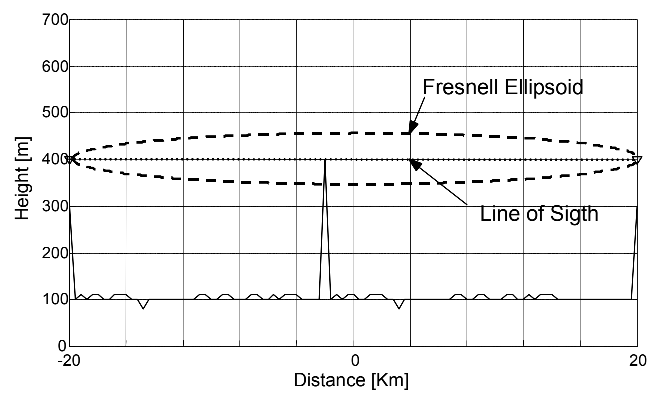

FIGURE 5
DIGITAL RADIO LINK WITHOUT ATMOSPHERE.

The results presented in Figure 5 have been obtained with a 1GHz electromagnetic wave. The free space attenuation is 244.37dB and the obstacle attenuation is 6dB. But, as showed in the previous section, the refraction in the atmosphere causes a curve trajectory in the waveform propagation. Readjusting the Earth curvature can compensate this trajectory. Figure 6 presents the results for the same simulation above, but with the standard atmosphere (k=4/3).

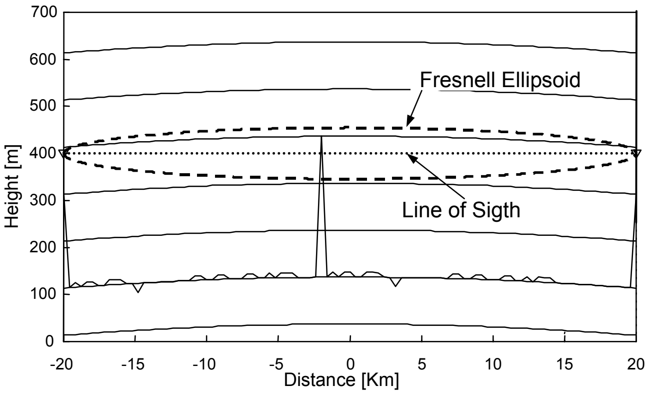

FIGURE 6
DIGITAL RADIO LINK IN A STANDARD ATMOSPHERE.

It is possible to note that the obstacle is, actually, above of the line of sight and the obstacle attenuation is, therefore, 13.14dB.

There are special conditions where the *k* factor is negative. In this case, the correction of the Earth curvature may reduce the obstacle attenuation, as can be seen in Figure 7. This result has been obtained with the same parameter used in the others simulations, but with k = -0.8. The obstacle attenuation is 0dB because the obstacle does not interfere in the first Fresnell Ellipsoid.

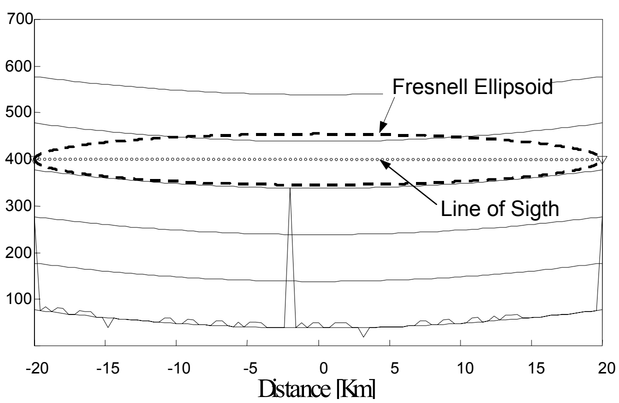

FIGURE 7
DIGITAL RADIO LINK IN ANOMALOUS CONDITIONS.

CONCLUSIONS

The propagation of electromagnetic waves is a very important issue in Telecommunication Engineering and must be presented clearly to the students. In this paper, a computer tool to simulate and analyze digital links has been presented with some commented results. With this tool, the student can visualize the effects of the different parameters in the link, as frequency, *k* factor and relief, which facilitates the apprenticeship of the issue.

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