Towards Novel Free Space Propagation Model for Humidity Based Mediums in Wireless Communication Systems

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***Abstract*:** This Free space propagation model in wireless communication systems is widely used for calculating the power received at the receiver side using different parameters in wireless communication systems which are power transmitted by the transmitter side, transmitter antenna gain, receiver antenna gain, the transmitter-receiver separation by a distance which is far located, system losses which are also known as path losses. The prominent characteristic of free space propagation model is that this model is only used and applied for the airy medium and it does not cope with the signal attenuation problems when the medium of transmission of signals change from air to humidity or rainy medium. In this paper I propose a novel free space propagation model which will address and solve the signal attenuation problem when the weather is humidity based or moisture based. The novel proposed model will be used to solve the issue of weak signal propagation in the humidity based medium when there is a rainy season in the locations where signal propagation takes place.

Keywords: system losses, path losses, signal attenuation, styling, antenna gains

1. INTRODUCTION

The free space propagation model is also known as Friis free space propagation model by the name of the scientist Friis who worked on the power received at the receiver side which is far located from the transmitter side as referred in [1]. The power received at the receiver side and the power transmitted from the transmitter side are calculated in decibels (dB). The T-R separation is defined as the distance between the transmitter and the receiver and it is assumed for the free space propagation model that this model will work for far located transmitter side. The indoor locations are usually not considered suitable for using free space propagation model because of the small locality of reference in power calculations as referred in [2]. The novel model proposed in the research paper will be useful for prediction of rains, computation of water levels during rain and humidity levels in the rainy cities.

2. LITERATURE REVIEW

2.1. Medium of Transmission of Signals

The essential characteristic of free space propagation model is the calculation of power received by the receiver side on received signals using the various parameters of wireless communication systems like receiver antenna gain, transmitter antenna gain, carrier wavelength and the transmitter-receiver separation as referred in [1]. The free space model does not include the channel characteristics in computing power because the model assumes that channel for communication is air or free space and the transmitter and receiver sides are far located. The free space propagation model does not work well if the channel for communication of signals is changed from air to humidity based channel when there is rain or dribbling during signal communication.

2.2. Path Losses

The free space propagation model also includes system loss factor which is not related with signal propagation and it is assumed that the system loss factor is always greater than or equal to 1. The system loss factor is represented with the variable L.

2.3. Free Space Propagation Model

The free space propagation model can be expressed mathematically using the equation number 1. In the free space propagation model, the receiver side is usually considered as mobile station whereas the transmitter side is usually considered as the base station controller. The free space propagation model includes the following parameters for calculating power received at the receiver side.

Pr (d) = Power received at the receiver side

Pt = Power transmitted by the transmitter side

Gt = Transmitter antenna gain

Gr = Receiver antenna gain

d = T-R separation or the distance between transmitter and receiver.

L = System losses or miscellaneous losses

⋋ = carrier wave length

Mathematically the free space propagation model can be represented by using the following equation 1.

$$\mathbf{Pr}(\boldsymbol{d}) = \frac{\boldsymbol{P_t G_t G_r} \lambda^{\mathbf{2}}}{(\mathbf{4}\boldsymbol{\pi})^{\mathbf{2}} \boldsymbol{d}^{\mathbf{2}} \boldsymbol{L}} \tag{1}$$

We can state that the free space propagation model is only used when the medium of transmission of signals is air or free space because of the standardization used by the scientist who proposed free space propagation model as referred in [1].

2.4. Antenna Gain

The antenna gain is a dimensionless quantity and there is no unit for measurement of antenna gain. The equation derived for antenna gain works equally for the transmitter side antenna gain and the receiver side antenna gain. When we calculate transmitter side antenna gain or receiver side antenna gain we do not use any unit for these gains and the same equation number 2 is used for calculating the transmitter side antenna gain and the receiver side antenna gain.

$$G = \frac{4\pi A_e}{\lambda^2} \tag{2}$$

The antenna gain is represented with the variable G and is related to the effective aperture Ae by using the equation number 2. The antenna gain is defined as the ratio of 4πAe with square of carrier wavelength. As the square of carrier wave length increases, the antenna gain decreases. The more gain of antenna gets the lesser carrier wave length. From the definition of antenna gain which can be deduced from equation number 2, we can derive the equation for carrier wavelength as referred in [2].

In the equation number 2, it is obvious that the carrier wavelength λ is dependent upon the effective aperture of the antenna. The effective aperture of antenna is the parameter dependent upon the physical size of antenna.

2.5. Dimensions of Free Space Propagation Model

The antenna gain is a dimensionless quantity and there is no unit for measurement of antenna gain. The equation derived for antenna gain works equally for the transmitter side antenna gain and the receiver side antenna gain. When we calculate transmitter side antenna gain or receiver side antenna gain we do not use any unit for these gains and the same equation number 2 is used for calculating the transmitter side antenna gain and the receiver side antenna gain.

2.6. Research Gap

The free space propagation model has been proposed for air based medium but does not include humidity factor for adaptation to the rainy weather. The novel free space propagation model includes the humidity factor in the new model to consider the rainy weather in the new model and adapt for the cities where rain fall occurs frequently.

3. PARAMETERS ASSOCIATED WITH FREE SPACE PROPAGATION MODEL

In order to propose a novel model which includes humidity based medium for transmission of signals from transmitter side to the receiver side, the parameters associated with free space propagation model should be discussed and elaborated as referred in [5]. The significance of these parameters associated with free space propagation model cannot be denied.

3.1. Carrier Wavelength

The carrier wavelength of the propagated signal can be represented mathematically by using the following equation number 3.The equation number 3 is used for calculating the carrier wavelength which is defined as the square root of the ratio of 4pA_eand G. As the antenna gain Ae increases the square of wavelength decreases whereas when the antenna gain Ae decreases the square of wavelength increases.

$$\lambda = \sqrt{\frac{4\pi Ae}{G}} \tag{3}$$

Also the carrier wavelength for signal propagation can be represented mathematically using the following equation 4. The equation number 4 is also used for calculating the carrier wavelength but this equation is the fundamental equation derived from the principles of optics as referred by the scientists who worked on optics.

$$\lambda = \frac{c}{f} \quad (4)$$

This fundamental equation is used for calculation of wavelength when certain signals are transmitted from the transmitter side and received on the receiver side. The wavelength is referred as the carrier wavelength in telecommunication systems or in wireless communication systems where as in optics the wavelength is referred to wavelength of light packets which are known as quanta in optics. From the equation number 4, we can define the wavelength as the ratio of speed of light to the carrier frequency. The carrier frequency is measured in Hertz. The carrier wavelength can also be mathematically represented using the following equation number 5.

$$\lambda = \frac{2\pi c}{w_c} \quad (5)$$

The equation number 5 is also used for the definition of wavelength. From the equation number 5, it is obvious that the definition of carrier wavelength uses the polar coordinate system for the measurement of angular frequency, since this definition of carrier wavelength uses the parameters of angular frequency measured in radians per second and the speed of light which is in the numerator. According to this definition, the carrier wavelength is the ratio of 2πc and wc where wc is the angular frequency measured in radians per second as referred in [7].

3.2. Effective Isotropic Radiated Power

The Effective Isotropic Radiated Power is abbreviated as EIRP, and this concept is essentially discussed with reference to free space propagation model updating for humidity factor. The reason for discussing the Effective Isotropic Radiated Power is that the power transmitted by transmitter and power received by receiver for free space medium is calculated using equation 1 but factoring into products form produces the effective components in the form of power radiation as referred in [5].

$$EIRP = P_t G_t \quad (6)$$

The equation number 6 is the mathematical representation of EIRP. The Effective Isotropic Radiated Power EIRP is the product of power transmitted from the transmitter side Pt and transmitter antenna gain Gt. The effective isotropic radiated power is the maximum power radiated from the transmitter antenna with the maximum gain in all directions.

3.3. Isotropic Radiated Power

In order to discuss the free space propagation model and its updating including humidity factor, the isotropic radiated power must be elaborated. An isotropic radiated power is the power transmitted or received at the isotropic antenna. An isotropic antenna is usually referred as the standard antenna in wireless communication systems which is used to define and measure the performance parameters of antennas used in wireless communication systems as referred in [7]. An isotropic antenna is defined as an antenna which radiates power with the unit gain and radiates power in all directions.

The isotropic antenna is usually referred as standard win wireless communication systems for evaluating the performance of different antennas.

3.4. Dimensions of Gain and System Losses

The free space propagation model uses the gains of antennas located and installed at the transmitter side and the receiver side. It should be mentioned that transmitter antenna gain and the receiver antenna gain are dimensionless quantities as referred in [3] whereas the power received at the receiver side and power transmitted from the transmitter side must be in the same units. Usually the power received and power transmitted are measured in decibels which is calculated in the logarithm with base 10. The system losses are represented by L. The wireless communication systems and its models like free space propagation model use system losses which occur because of the signal attenuation when received on the receiver side. The system losses should be equal to one or greater than one in order to be received perfectly on the receiver side. If L = 1 it means that there are no system losses in the wireless communication system. The system losses are also known as the miscellaneous losses. The factors due to which system losses or miscellaneous losses occur in wireless communication system are transmission line attenuation, filter losses, antenna losses or any other hardware losses as referred in [3].

3.5. Fraunhofer Distance

The Fraunhofer Distance is defined as the ratio of square of dimension of antenna with the wavelength of carrier as referred in [4]. This distance specifies that the transmitter-receiver separation also depends upon the antenna dimensions and the carrier wavelength. In calculation of Fraunhofer distance the square of the distance at which receiver is located apart from transmitter is used as a multiple of two. The effects of Fraunhofer distance on free space propagation model will be discussed in the future coming papers.

$$d_f = \frac{2D^2}{\lambda} \tag{7}$$

Equation number 7 is the mathematical representation of Fraunhofer Distance. This parameter depends upon the square of the dimension of antenna and the carrier wavelength as referred in [4].

4. HYPOTHESIS FOR PROPOSED MODEL

The hypothesis for the proposed research work is the consideration of humidity factor in the environment to the free space propagation model in a way that the power losses at the transmitter side of the antenna and the receiver side of antenna can be minimized and the relative permittivity of the water has been introduced in the novel proposed model to adapt for the rainy environment where the rain fall consistently appears and humidity factor is enhanced.

This model work in a better way where rain fall occurs more frequently. It is indispensable for the proposal of novel model which includes humidity factor that the physical parameters associated with transmitter side antenna and receiver side antenna cannot be neglected when signal propagation occurs and when power associated with received signals and the power associated with transmitted signals are calculated. Also the electrostatics and electromagnetics study is essential for modelling signal propagation when transmitted from the transmitter antenna and received at the receiver antenna, the reason is that the antennas allocated at the transmitter and receiver side are usually metallic in nature and because of the flow of current from the antennas, antennas are surrounded by the charge produced on the surface of antennas and electric field is produced around the antennas because of the flow of current. Also magnetic field is produced around the antennas because of the presence of charge on the surface of antennas.

Therefore, I propose a new model which will include the relative permittivity of humidity based medium by including the electric field affects and the magnetic field effects on the free space propagation model.

$$\mathbf{Pr}(\boldsymbol{d}) = \frac{\boldsymbol{P_t G_t G_r} \lambda^{\mathbf{2}}}{\in_{\boldsymbol{r}} (\mathbf{4}\boldsymbol{\pi})^{\mathbf{2}} \boldsymbol{d}^{\mathbf{2}}\, \boldsymbol{L}} \tag{8}$$

In this novel model the relative permittivity of humidity based weather has been included in the updated free space model which will depict the power received by the receiver side which is the mobile station and the power radiated or transmitted by the transmitter side , antenna gains and the distance at which transmitter and receiver are separated in far locations. It has been proposed that the new proposed model of free space propagation including humidity factor is also applicable only for T-R separations which are far located, and the indoor signal propagations are not included in the new proposed free space propagation model including humidity factor.

In the novel proposed model for measurement of power received at the receiver side from the power transmitted by the transmitter side including humidity as the medium of transmission , the relative permittivity of humidity or water is included in the novel proposed model with typical values of water medium. This novel model will work well for the rainy weather when the signal propagation suffers problem and the problem of signal attenuation takes place. The signal attenuation problem is reduced too much using the novel model including relative permittivity of water in equation number 7.

5. PRACTICAL APPLICATIONS OF NOVEL MODEL

The novel free space propagation model is practically applicable for calculation of power received at the receiver side and power transmitted at the transmitter side when the medium of communication is rain water. This model can be used by department of Meteorology to predict the allocation and installation of antennas at different sites of base station controllers in the cities where rain fall occurs frequently like Islamabad, Mumbai, South India, Dhaka, Chat gam and London.

6. CONCLUSION

Free space propagation model is an standard model usually used to compute power transmitted or received in wireless communication systems when the transmitter side and the receiver side are far located, but I tried to elaborate on the weakness in the free space propagation model which is that it is only limited for free space and it does not include the power losses of the received signal when there are heavy rains or moisted weather in the location where signals propagation take place. I included the relative permittivity parameter in the model so that the free space propagation model can be more updated including the medium change when the change of weather takes place.

FUTURE WORK

The tabular work and graphical representation of the proposed model will be included along with empirical results in the forth coming research papers. The applications of the proposed model has been highlighted by me in an articulate manner in the current research paper in above mentioned paragraphs. The antenna design field study is indispensable for completion of the mathematical modelling and simulation of the models used in wireless communication systems. Without the study of antenna design and the geometrical aspects of antenna structures, the complete understating of signal processing and signal propagation is incomplete. The design factors of antenna and geometrical parameter affect signal processing and signal envelope representation and detection at the receiver side more.

REFERENCES

[1] A. E. Forooshani, S. Bashir, D. G. Michelson and S. Noghanian, "A Survey of Wireless Communications and Propagation Modelling in Underground Mines," in IEEE Communications Surveys & Tutorials, vol. 15, no. 4, p 1524-1545, Fourth Quarter 2013, doi: 10.1109/SURV.2013.031413.00130.

[2] C. Han and Y. Chen, "Propagation Modeling for Wireless Communications in the Terahertz Band," in IEEE Communications Magazine, vol. 56, no. 6, pp. 96-101, June 2018, doi: 10.1109/MCOM.2018.1700898.

[3] S. P. Kyösti, W. Fan, G. F. Pedersen and M. Latva-Aho, "On Dimensions of OTA Setups for Massive MIMO Base Stations Radiated Testing," in IEEE Access, vol. 4, pp. 5971-5981, 2016, doi: 10.1109/ACCESS.2016.2610721.

[4] D. Cheng, "On the simulation of Fraunhofer radiation patterns in the Fresnel region," in IRE Transactions on Antennas and Propagation, vol. 5, no. 4, pp. 399-402, October 1957, doi: 10.1109/TAP.1957.1144533.

[5] T. Stoyanova, F. Kerasiotis, A. Prayati and G. Papadopoulos, "A Practical RF Propagation Model for Wireless Network Sensors," 2009 Third International Conference on Sensor Technologies and Applications, 2009, pp. 194-199, doi: 10.1109/SENSORCOMM.2009.39.

[6] S. K. S. Gupta, S. Lalwani, Y. Prakash, E. Elsharawy and L. Schwiebert, "Towards a propagation model for wireless biomedical applications," IEEE International Conference on Communications, 2003. ICC '03., 2003, pp. 1993-1997 vol.3, doi: 10.1109/ICC.2003.1203948.

[7] P. -Z. Tong, L. -Y. Ong and M. -C. Leow, "Wi-Fi Group Monitoring System Using Free Space Propagation Model with Active Scanning," 2021 IEEE International Conference on Artificial Intelligence in Engineering and Technology (IICAIET), 2021, pp. 1-6, doi: 10.1109/IICAIET51634.2021.9573699.