

Measurement and Prediction of Received Signal Level and Path Loss through Vegetation

J. T. Zhimwang^{1*}, E. P. Ogherohwo², D. D. Iliya³, Ibrahim Aminu⁴
and O. S. Shaka²

¹Department of Physics, Federal University, Lokoja, Nigeria.

²Department of Physics, Federal University of Petroleum Resources, Effurun, Nigeria.

³Department of Physics, University of Jos, Nigeria.

⁴Centre for Satellite Technology Development, Abuja, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Authors JTZ and DDI designed the study, wrote the first draft of the manuscript, set up the experiment, compelled the results and discussed them. Authors EPO and IA managed the literature searches and effect all the necessary corrections. Author OSS managed the measurement and analyses of the study. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJR2P/2021/v4i430148

Editor(s):

- (1) Dr. Jelena Purenovic, Kragujevac University, Serbia.
- (2) Prof. Shi-Hai Dong, National Polytechnic Institute, Mexico.
- (3) Dr. Jun Steed Huang, Jiangsu University, China.
- (4) Dr. Sebahattin Tüzemen, Atatürk University, Turkey.

Reviewers:

- (1) Beatriz Susana Marrón, Universidad Nacional del Sur, Argentina.
- (2) Elmissaoui Taoufik, Kairouan University, Tunisia.

Complete Peer review History: <https://www.sdiarticle4.com/review-history/69406>

Original Research Article

Received 25 May 2021
Accepted 29 July 2021
Published 06 August 2021

ABSTRACT

This paper presents the measurement and prediction of received signal level and path loss through vegetation. Results were estimated under free space, single tree, and vegetation conditions which revealed that the presence of isolated trees along a radio path can affect signal propagation leading to reduction in signal strength (attenuation). The attenuation was found to be dependent on many factors and parameters of the trees e.g. Geometry of measurement, (either trunk or canopy path), state of trees foliage, frequency, canopy thickness among others. In the measured data, high loss values were recorded at canopy geometry which is due to high presence of interacting and attenuating elements at the canopy. Also, high variation in Received signal strength (RSS) was

*Corresponding author: E-mail: jangfatimothy@gmail.com;

noted at canopy geometry. However, the trend shows variation from path to path. The main factor is the density of tree parameters along the chosen path. Depending on the density of tree parameters along the chosen path, the depth dependence may be extremely slow as seen in the measure data. With this evidence, for radio communication inside woodlands or forests, localizing the two nodes inside the vegetation will certainly give overall best performance in terms of signal impairment. The propagation mechanism in each case are the same at the antenna geometries used following the trend of signal decay. Different transmit antenna inclination angles were used and this has not shown any significant contribution to the excess loss. However, antenna height with respect to the trees canopy showed significant contribution to the excess loss. This information will be useful to network planning engineers in link budget estimation.

Keywords: Radio wave; signal strength; path loss; and vegetation propagation.

1. INTRODUCTION

In communication system where antennas are used to transmit information from one point to another medium between (and around) the transmitter and receiver has a major influence on the quality and performance of the transmitted signal. This is because radio wave propagation is very sensitive to the properties and effect of the medium located between the transmitting and the receiving antennas (Collin, 2013). There are often significant changes in the performance of a system if there are obstacles in the signal path. The interaction of radio wave with the obstruction reduces its received signal strength [1]. For the fact that radio waves are very sensitive to obstacles, the existence of vegetation elements such as trees along the path of communication link have been found to play a great influence on the quality of service in outdoor propagation is inevitable especially in suburban and rural areas, beside other factors from terrestrial objects that are diversified by buildings and mountains [2]. This factor should be taken into consideration in the deployment of radio communication systems in the vegetation environment. Their appearance either as a single tree or group of trees (is term as the foliage) have negative impact on propagated radio signal [3].

In wireless transmission, the channel is the physical environment surrounding the transmitter and receiver. Elements such as hills, buildings, or trees located on the path of the RF signal affect the way the signal propagates [4]. Most of the changes occurring on the signal propagation paths can be explained in terms of reflection, diffraction, and scattering. Reflection occurs when the electromagnetic wave impinges the smooth surface of an object having a size much larger than the wavelength of the RF signal [5]. Diffraction takes place when a very dense object with a sharp edge is located very near the line of

sight path. Waves bend over the sharp edge of the structure and reach the receiver. If the object is opaque and is in the line-of-sight path, then the only signal reaching the subscriber's antenna is the diffracted signal [11]. This phenomenon is called shadowing since the signal reaches the receiver despite the total obstruction of the LOS signal. Scattering occurs when the electromagnetic wave impinges upon objects of size comparable to or shorter than the wavelength. The resulting signal is composed of electromagnetic waves propagating in all directions [6].

Accurate modeling of the propagation of radio waves through tree foliage generally requires accurate electromagnetic description of the tree geometry, including its branches and leaves, valid over a wide range of frequencies.

1.1 Prediction of Power Density of Electromagnetic Wave in Tree Canopy

As the incident power travels down ward in the tree canopy, it undergoes both absorption and scattering by leaves and branches of the canopy. The loss contributed by randomly oriented leaves and branches that fill most of the canopy space, reduce the potential for the radio waves getting to the receiving antenna, In canopy space, the power in the volume is given by [3].

$$P_i = P_r + P_s + P_a \quad (1)$$

$$P_L = P_s + P_a \quad (2)$$

Where P_L is the total power loss by the elements of the tree canopy, therefore equation (1) becomes

$$P_i = P_r + P_L \quad (3)$$

The power loss as a result of both absorption and scattering for a single leaf or branch is

$$P_i = P_i ((\sigma_s^{l,b}) + ((\sigma_a^{l,b})) \quad (4)$$

The power loss contributed by the scattering and absorption of incident power by the leaves, represented by their number n_l and branches classified into N_b different size categories represented by their number n_b per unit volume is [7].

$$P_i = P_i (n_l ((\sigma_s^l) + ((\sigma_a^l)) + \sum_{b=1}^{N_b} n_b ((\sigma_s^b) + (\sigma_a^b))) dV \quad (5)$$

Superscripts b and l refer to leaves and branches of the canopy.

$$(n_l ((\sigma_s^l) + ((\sigma_a^l)) + \sum_{b=1}^{N_b} n_b ((\sigma_s^b) + (\sigma_a^b))) = \langle \sigma^T \rangle$$

Therefore equation (5) becomes;

$$P_i = P_i \langle \sigma^T \rangle dV \quad (6)$$

1.2 Free Space Path Loss Method

Free space path loss method (PLFS) is usually the reference technique for all the path loss propagation parametric equations (methods) commonly employed. Each propagation method predicts more accurately than free space propagation technique. This loss occurs as the signal travels from transmitter to receiver through space without any other effects attenuating the signal [8]. The value used to compute free space is dependent only on the distance that is from the transmitting antenna. In free space, the path loss increases by 20dB per decade. The equation used to determine free space follows (Idah, 2004)

$$PL_{FS} \text{ (dB)} = 32.4 = 20 \log (r) + 20 \log (f) \quad (7)$$

Equation (9) can be simplifies as

$$PL_{FS} \text{ (dB)} = 32.4 = 20 \log (r*f) \quad (8)$$

Where

PLFS = free space path loss

r = the distance from the transmitter (KM)

f = the frequency

The 20 decibels-per-decade comment comes from the path of the equations that change in value, which is the distance from the transmitting antenna, $20 \log_s(r)$.

1.3 Single Trees Path Loss Method

Presented in this section are analysis of measured data and results for isolated trees which culminated into prediction of propagation

loss parametric equation more suitable for isolated trees. Full details of measurement setups and tree states are discussed. The parametric equation incorporated both the free space loss and tree loss factors. The tree loss factor is incorporated in the technique to calculate for the increase in attenuation of the receive signal when radio waves propagates through a tree. Though this method is valid for wide range of frequencies, however analysis has been done on the radio wave operating at frequency band of 2450MHz and for a maximum distance of 100meters away from the access point [7].

Path loss (PL) is defined as the ratio of the effective transmitted power to the received power, calibrating out system losses, amplified gains, and antenna gains. Path loss prediction of radio signal propagation through a tree includes; free space loss plus tree loss factor (L_{tree}). The tree loss factor is incorporated in the method to calculate for the increase in attenuation of the received signal power when the receiver is placed behind a tree. The expression for the path loss from the transmitting antenna to a receiving antenna in the presence of a tree is written as [9];

$$PL_{tree} = L_{FS} + L_t \quad (9)$$

Where;

PL_{tree} = Path loss in the presence of a tree.

L_{FS} = Free space loss.

L_t = Tree loss factor.

A tree is represented as collections of branches, geometrically approximated by cylinders while leaves are represented as thin disks, whose dimensions are determined on the basis of measurements in a tree canopy. Tree canopies are represented as dielectric spheres of appropriate size. The branches in the tree canopy are classified into five size categories denoted as N_b . The number of leaves and branches are represented by n_l and n_b respectively, where the subscript b is an element of $(b | bN_b)$ and bN is used to denote branches of the n^{th} size category [10].

2. METHODOLOGY

The experiment was carried out at Federal College of Forestry Jos. The experimental setup for the prediction of the path loss and received power level through vegetation either a single isolated tree or group of trees (woodland) is showed in Fig. 1. Attenuation measurements are

conducted using two disjoint antennas, one operating as a transmitter and the other operating as a receiver. The system was setup such that the two antennas are operated in a line-of-sight mode with random medium (in this case the foliage) positioned between the two antennas. At the transmitting section, the network interface was used to enable data to be forwarded from one network transmission out at the path to the receive antenna. Along the transmission path lays either a tree or group of trees, which obstructs the radio signal. The receiving section consisted of a Router networking device that was

connected to a computer for data logging, a stabilizer for power regulation and an uninterruptible Power Supply (UPS) to provide emergency power whenever there was power disruption, which might eventually result in data loss. The Router was adjusted to a transmission frequency of 2450 MHz at sampling rate of 500ms. The receiver antenna was directional while the transmitting mast had no restriction. Investigation site captures ranges from 20m to 100m at intervals of 20 meters with a constant power of ± 19 dB from the transmitters.

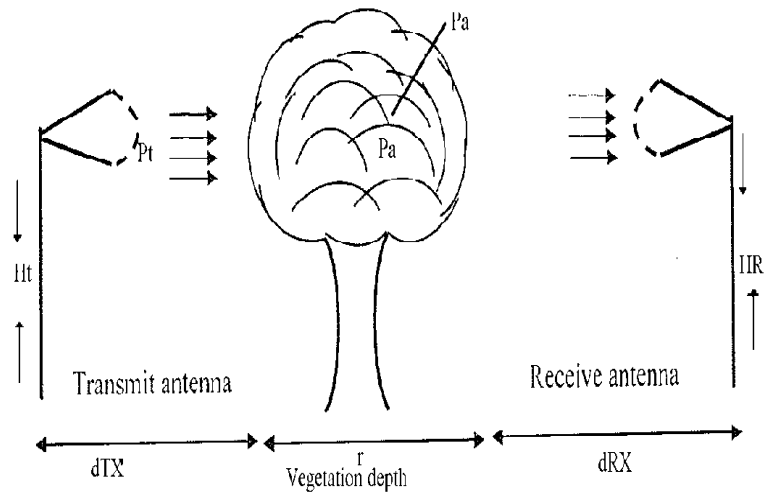


Fig. 1. Link configuration for isolated tree measurement

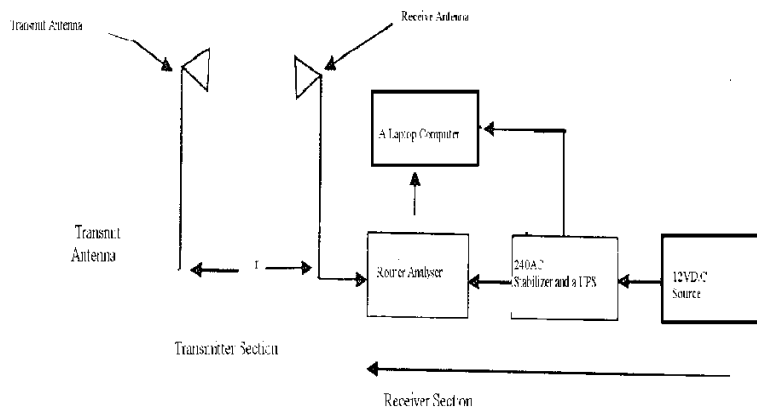


Fig. 2. The Basic Block of Experimental setup

3. RESULTS

Results of this research were calculated from the measured data following the ITU-Recommendations for propagation through vegetation.

4. DISCUSSION

Table 1 presents the measured received power level under free space condition, behind a Tree, and inside vegetation at frequency of 2450 MHz. The result shows that received power level under free space condition is higher though the received power level decreases with distance from -32.28dBm to -37.11dBm. The result also

shows that under the effect of a tree or group of trees, part of the transmitted signal is being absorbed or scattered by the tree canopy elements such as the leaves, branches, twigs and trunks. As it can be seen from the result, the signals are more absorbed under vegetation condition. Table 2 presents the Estimation of Path Loss under free space condition, behind a tree, and inside vegetation at frequency of 2450 MHz. Also, the result shows that path loss increases with distance regardless of the environmental condition. Fig. 3 presents the relationship of path loss with vegetation depth. As it can be clearly seen, the path loss increase as the vegetation depth also increases.

Table 1. Measured received power level under free space condition, behind a tree, and inside vegetation at frequency of 2450 MHz

Vegetation Depth (mm)	Transmission Power (dBm)	Received Power Level (dBm)		
		Free Space Condition	Effect of Single Tree	Effect of Vegetation
100	30	-32.28	-34.11	-37.05
150	30	-32.91	-35.22	-37.76
200	30	-34.45	-35.80	-39.04
250	30	-34.87	-37.91	-41.32
300	30	-37.11	-39.73	-45.65

Table 2. Estimated Path Loss under Free Space Condition, behind a Tree, and inside vegetation at Frequency of 2450 MHz

Vegetation Depth (mm)	Path Loss (dB)		
	Free Space Condition	Effect of Single Tree	Effect of Vegetation
100	62.3	64.1	67.0
150	63.0	65.2	68.0
200	64.5	66.0	69.0
250	65.0	68.0	73.8
300	67.1	70.0	76.0

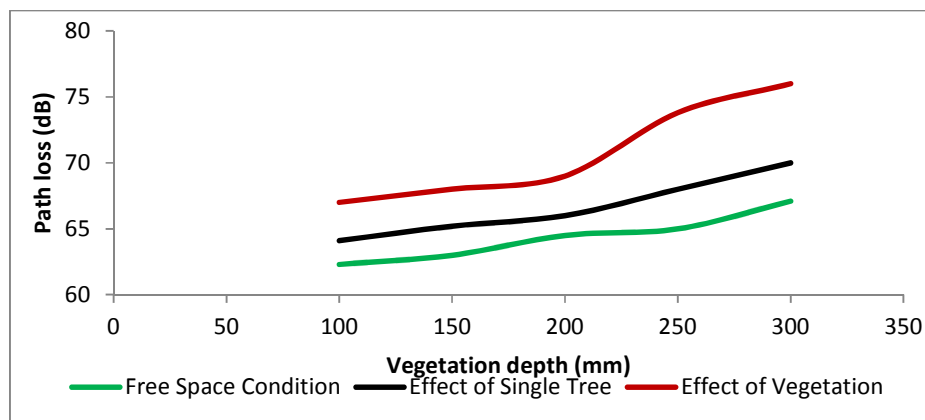


Fig. 3. Relationship between Path Loss and Vegetation Depth

5. CONCLUSION

The estimation and prediction of received signal level and path loss through vegetation was carried out. Results from this investigation revealed that the presence of isolated trees along a radio path can affect signal propagation leading to reduction in signal strength (attenuation). The attenuation was found to be dependent on many factors and parameters of the trees e.g. Geometry of measurement, (either trunk or canopy path), state of trees foliage, frequency, canopy thickness etc. In the measured data, high loss values were recorded at canopy geometry which is due to high presence of interacting and attenuating elements at the canopy. Also, high variation in Received signal strength (RSS) was noted at canopy geometry. However, the trend shows variation from path to path. The main factor is the density of tree parameters along the chosen path. Depending on the density of tree parameters along the chosen path, the depth dependence may be extremely slow as seen in the measure data. With this evidence, for radio communication inside woodlands or forests, localizing the two nodes inside the vegetation will certainly give overall best performance in terms of signal impairment. The propagation mechanism in each case are the same at the antenna geometries used following the trend of signal decay. Different transmit antenna inclination angles were used and this has not shown any significant contribution to the excess loss. However, antenna height with respect to the trees canopy showed significant contribution to the excess loss. This information will be useful to network planning engineers in link budget estimation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Herben AAJ, Yvo LC. "A Tree Scattering Model for Improved Propagation Prediction in Urban Microcells; Reviewed IEEE Transaction on Vehicular Technology. 2014;53(2).
2. Agugo FO, Adekunle AS. Characterizations of Near-Ground Radio Wave Propagation Profile Of, The Mangrove and Rain Forest Areas of Nigeria", IEEE International Conference on Adaptive Science And Technology. 2011;241-255.
3. Meng Y. S, Lee Y. H and Ng B. C. "Study of Propagation Loss Prediction in Forest Environment", Progress in Electromagnetics Research B. 2009;17: 117-133.
4. Bertom HL. Radio Propagation for Modern Wireless System; Prentice Hal Ptr' Upper Saddle River, Nj, Usa; 2000.
5. Ndzi DL, Karmarudin LM, Mohammed AA, Zakarial A; Ahmad RB, Fareqm MA, Shakaff AYM and Jafaar MN. Vegetation Attenuation Measurements and Modelling In Plantations for Wireless Sensor Network Planning." Progress In Electromagnetic Research B. 2012;36:283-301.
6. Crane RK. Tzler CM, Johannsson P. Dielectric Model of Leaves. Review IEEE Trans: Geosa. Remote Sens. 2011;32(5): 947-949.
7. Meng YS, Lee YH. "Investigation of Foliage Effect on Modern Wireless Communication System". A Review, Progress in Electromagnetics Research; 2010.
8. Tewari RK, Swarups S, Roy MN. Devaluation of Relative Permittivity and Conductivity of Forest Slab from Experimentally Measured Data on Lateral Wave Attenuation Constant". A Reviewed Prog; International Journal of Electronic. 2010;(611): 597-605.
9. Perras S, Bouchard L. Finding Characteristics of Rf Signal Due to Foliage in Review, Frequency Bands From 2 To 60ghz," IEEE Internal Symposium On Wireless Personal Multimedia Communications. 2010;1:367-271.
10. Crane RK. Propagation Hand Book for Wireless Communication System Design; Crs Press Lcc, Boca Raton London New York Washington, DC; 2013.
11. Ida N. Engineering Electromagnetics, 2nd Edition; Springer-Verlag New York, Llc; 2014.

© 2021 Zhimwang et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:
<https://www.sdiarticle4.com/review-history/69406>