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

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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.

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 observed.

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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 shown 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],

\[ P_l = P_r + P_s + P_a \]  

(1)

\[ P_L = P_s + P_a \]  

(2)

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

\[ P_l = P_r + P_L \]  

(3)

The power loss as a result of both absorption and scattering for a single leaf or branch is...
measured data and results for isolated trees

Presented in this section are analysis of antenna, $20 \log$ value, which is the distance from the transmitting from the path of the equations that change in

The $20$ decibels $f = \text{the frequency}$
$r = \text{the distance from the transmitter (KM)}$

PLFS = free space path

Where

Equation (9) can be simplifies as

Where

PLFS = free space path loss
$r = \text{the distance from the transmitter (KM)}$
f = \text{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, $20 \log_a(r)$.

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 $2450$ MHz and for a maximum distance of $100$ meters 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 ($L_{\text{tree}}$). 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];

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

Where:

$PL_{\text{tree}} = \text{Path loss in the presence of a tree.}$
$L_{\text{FS}} = \text{Free space loss.}$
$L_t = \text{Tree loss factor.}$

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 $(b_1 b_N)$ and $bN$ is used to denote branches of the $n^b$ 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](image1)

![Fig. 2. The Basic Block of Experimental setup](image2)
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) | 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.

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