Novel effect of Vegetation (Foliage) on Radio Wave Propagation

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Abstract— This work investigates the effects of Vegetation (foliage) on radio wave propagation in the Calabar metropolis, Nigeria. Measurement of the radio signal strength from Cross River State Broadcasting Co-operation Television (CRBC-TV), ($4^0$57'54.7"N, $8^0$19'43.7"E) at 35mdB and 519.25 MHz (UHF) to investigate foliage loss was carried out in two forested channels ($4^0$56'56.2"N, $8^0$20'42.0"E and $4^0$56'35.4"N, $8^0$20'48.2"E respectively) in the University of Calabar. The results obtained showed that foliaceous canopies are mainly responsible for vegetation (foliage) loss, due to their obstruction of point-to-point contacts or line-of-sight communication of the antennas (transmitter and receiver) and shielding of the raining sky waves from the receiver antenna, but not other non-foliaceous parts that interfere with the ground and surface wave at UHF. The correlations between the signal strength (mdB) and depth (m) in the first and second forested channels were r = -0.17 and r = -0.06 respectively. The standard deviations of the vegetation (foliage) losses in the two channels were σ = 3.24 mdB and σ = 2.23 mdB respectively. The first forested channel contains predominantly pride of Barbados and the second forested channel contains mainly palm trees. The loss was higher in the former than the latter channel because of the difference in the thickness of their foliaceous canopies.

Keywords— Signal strength, Vegetation (Foliage) loss, Ultra High Frequency (UHF), Radio wave, Foliaceous canopy, Radio propagation, Forested channel.

INTRODUCTION

Signal path losses are an essential factor in the plan of any radio communications system. They decide a large number of factors of a communications system, particularly the receiver and transmitter powers including their gains, heights with locations in general. The method of transmission employed and required receiver sensitivity amongst other factors will also influence signal path losses [5].

Basically, signal path loss is the degradation or dissipation in strength of a signal as it travels through a particular region or medium [10], [11].

The following are some of the factors that may give rise to signal path losses during propagation. They are: free space path losses, absorption losses, diffraction losses, multipath, terrain, buildings and vegetations and the atmosphere [5].

This research work zero in on the effects of two forested channels or territories (predominantly pride of Barbados and palm trees respectively) in the University of Calabar, Cross River State, Nigeria on signal of about 519.25 MHz, which is the frequency of transmission for the Cross River Broadcasting Corporation Television (CRBC-TV), Calabar, Cross River State, Nigeria and defined by the Institute of Electrical and Electronics Engineers as Ultra High Frequency (UHF).

To score the goal of this work, experiments were carried out to obtain sufficient data that gave birth to the effects of vegetation (foliage) on signal from the twin forested channels. Signal strength evaluations were made just in front of the forested channel and under the cascade of canopies of tree(s) at both forested channels at varying depths from the transmitter into the thick of the forest to probe the vegetation or foliage loss and comparing it with Weissberger's and Early ITU's models.

A BRIEF REVIEW OF RELATED RESEARCHES

Mir, Jun-ichi and Tetsuro (2013) in southern Kanagawa - Japan researched on; "Radio wave propagation through vegetation" and reported that: "contrary to the widely assumed homogeneous random scattering media, it is observed that the radio waves in the vegetated channel are received from distinct directions in clusters of multipath [9].

Meng, Lee and Ng (2009) in Singapore worked on; "The effects of tropical weather on radio wave propagation over foliage channel". Also, still in Singapore, Meng *et al.* (2013) worked on; "Study of propagation loss prediction in forest environment" [7]. They affirmed that: "wind and rain can impose an additional attenuation on the propagation signal within the forest environment; the additional attenuation increases as the strength of the wind and rain increases" [8]. Also, "the direct wave travelling through the canopy layer is the only wave that can be affected by falling rain drops during a rain event, but not the lateral wave along air-canopy interface and the ground reflected waves over large foliage depth at VHF band" [8].

Adegoke and Siddle (2011) in Victoria Park, Leicester - United Kingdom carried out; "Investigation into vegetation effects on propagating waves" and worded that: "preliminary investigation reveals that interaction of radio waves with vegetation leads to attenuation" (p. 4). Full foliage recorded a loss of 8 dB to 16 dB even at shorter foliaceous depth while partial foliage recorded a loss of 2.4 dB to 7 dB at higher depth [1].

Alade (2013) in Ogbomosho, Oyo state - Nigeria worked on; "Further investigation into VHF radio wave propagation loss in a forested channel" and encapsulated that: "radio wave propagation loss in a forested channel is due to tree-canopy and ground reflection rather than the reflections from the groove and trunk of trees" [2]. He further said: "if there is any additional propagation loss, it is due to foliage induced effect therefore, the appropriate propagation model is tree-canopy and ground reflection (CGR) mode" [2].

A REVIEW OF FOLIAGE OR VEGETATION LOSS MODELS USED

In this work, we are going to condense our attention on two foliage or vegetation loss models. They are the Weissberger's and Early ITU's models.

Weissberger's model

This is a modified exponential decay model. In simple words, it is a radio wave propagation model which determines the loss in a path caused by the obstruction of one or more trees in the "point-to-point" distant communications connection. It is categorized under vegetation or foliage models.

This model is applicable to the case of "line-of-sight" propagation (LOS). Example is microwave transmission when there is an obstruction made by some trees or foliage in the connection, between the transmitter and the receiver. Ideally, this model is applicable in the situation where the LOS path is blocked by dense, dry and leafy trees.

The coverage frequencies and depths of foliage range from 230 MHz to 95 GHz and few metres up to 400 m respectively. This model was formulated in 1982; it is a development of the International Telecommunications Union's (ITU's) *Model for Exponential Decay* (MED).

Mathematically, this model is expressed formally as shown in equation (11).

$$L=\begin{cases} 1.33 f^{o.284}\ d^{0.558}\ if\ 14 < d \leq 400 \\ 0.45\ f^{o.284} d \text{, if } 0 < d < 14 \end{cases} \quad (11)$$

Where,
L = Loss due to foliage (dB)
f = Frequency of transmission (GHz)
d = Depth of foliage along the channel (m)

The points to take into account are that the above equation is sealed for frequency specifically in *gigahertz* (GHz) range and the foliage depth must be specifically in *meters* (m).

The shortcomings of this model are that it is significantly for frequencies ranging from 230 MHz to 95 GHz only, as clearly sketched out by Blaustein. When the depth of the vegetation is more than 400 m, it does not define the operation. And, it only predicts foliage or vegetation loss; the path loss must be calculated in summation to the loss due to free space [6].

Early ITU's model

The Early ITU's vegetation or foliage model is a radio propagation model that gives an estimative calculation of the path loss encountered because of the presence of one or more trees in-between a "point-to-point" distant communications connection. The predictions discovered from this model parallel those from Weissberger's modified exponential decay model at low frequencies. The ITU was predeceased by the International Radio Consultative Committee (CCIR), She adopted this model in the late 1986.

This model finds application to the situations where the telecommunications connection has some obstructions made by trees or foliage along its way. It is suitable for "point-to-point" microwave connection that has vegetation in their path; to predict the path losses.

The coverage range of frequencies and depths of foliage are not specified for this model.

Mathematically, this model is formulated as shown in equation (12).

$$L = 0.2\, f^{0.3}\, d^{0.6} \quad (12)$$

Where,
L = Loss due to foliage (dB)
f = Frequency of transmission (MHz)
d = Depth of foliage along the channel or connection (m)

Points worthy of note are that this equation is scaled for frequency specifically in *megahertz* (MHz). And, the foliage depth must be specifically in the units of *meters* (m).

The major limitation of this model is that the results get unrealistic or impractical at high frequencies [6].

METHODOLOGY

The campaign was carried out in two forested channels in the University of Calabar within the Calabar metropolis; in Cross River State, Nigeria. The main object of the experiments was to obtain statistical data of signal strengths just outside and inside the forested channels at different depths to determine the vegetation (foliage) loss. The measurement of the signal strength was made using the digital Community – Access (Cable) Television (CATV) analyzer with 24 channels, spectrum 46 MHz – 870 MHz, connected to a domestic receiver antenna of height 4.23 m.

To be able to reach a justifiable conclusion on the vegetation (foliage) loss, the dependence of the signal strength on the relevant parameter was analyzed. This parameter was the depth of the forest channel to ascertain vegetation (foliage) loss. The received signal strengths were measured only on the downlink and at every measurement, the receiver antenna was adjusted until the best obtainable reading of signal strength was captured on the cable analyzer before recording.

Sites descriptions

To probe vegetation (foliage) loss, measurements were carried out in two forested channels in the University of Calabar – Nigeria.

The first site of investigation ($4^0$56'56.2"N, $8^0$20'42.0"E) is a narrow channel of trees, predominantly the pride of Barbados with average trunk width of 3 m, average height of 20 m and spacing of about 20 m. The full depth of the channel is about 80 m with a level topography and scanty undergrowth.

The second site of investigation 0.6 km away along the University drive ($4^0$56'35.4"N, $8^0$20'48.2"E) is a heavily forested channel completely palm trees. The spacing of the trees is about 20 m to 30 m. The average height of the trees is about 15 m and the channel's depth is about 250 m. The topography is undulating with short grass as undergrowth. Find in the appendices the picture of the two forested channels or sites.

Measurement method

The measurement to determine the effect of foliage or trees or vegetation on signal was achieved by taking readings of signal strength on a straight path at different depths into the forested channels away from the CRBC-TV transmitter antenna ($4^0$57'54.7"N, $8^0$19'43.7") with the aid of a Global Positioning System (GPS) for direction. The digital CATV analyzer was connected to a domestic receiver antenna of about 4.23 m for a better reception and moved from one point to another into the depth of the forested channels to acquire measurements at each position under the foliaceous canopy of trees(s).

Sampling with the CATV analyzer

Measurements with the digital CATV analyzer being time dependent were made approximately every sixty seconds (60 s). The average signal strength value (mean of minimum and maximum reading) was recorded when the sharpest images were registered on the Analyzer.

EXPERIMENTAL RESULTS AND DISCUSSION

The results of each of the experiments are analyzed separately. To determine the vegetation (foliage) loss curves; the whole data or measurements made was used for both forested channels (that is, site one and site two). Also the losses were compared with that of Wessbieger's and Early ITU's models.

Analysis of measurement from first forested channel (site one)

The analysis of the measurements is preceded by Table 1and the Figures 1 and 2.

TABLE 1
Measured loss from site one and the Wessbieger's and Early ITU's models losses

Depth (m)	Signal Strength (mdB)	Weissberger's Model Loss (dB)	Early ITU's Model Loss (dB)	Measured Foliage Loss (mdB)
0	-3.1	-	-	-
5	-4.7	1.9	3.4	1.6
10	-10.5	3.7	5.2	7.8
15	-11.4	1.8	6.6	8.3
20	-11.9	2.2	7.9	8.8
25	-12.0	2.5	9.0	8.9
30	-12.2	2.8	10.0	9.1
35	-12.6	3.0	11.0	9.5
40	-10.8	3.3	11.9	7.7
45	-3.1	3.5	12.8	0.0
50	-7.1	3.7	13.6	4.0

Figure 5 shows the graphical representation of the signal strength at different depths of the forested channel. Also, Figure 6 shows measured foliage or vegetation loss curve in comparison with curves of the Weissberger's and Early ITU's model losses.

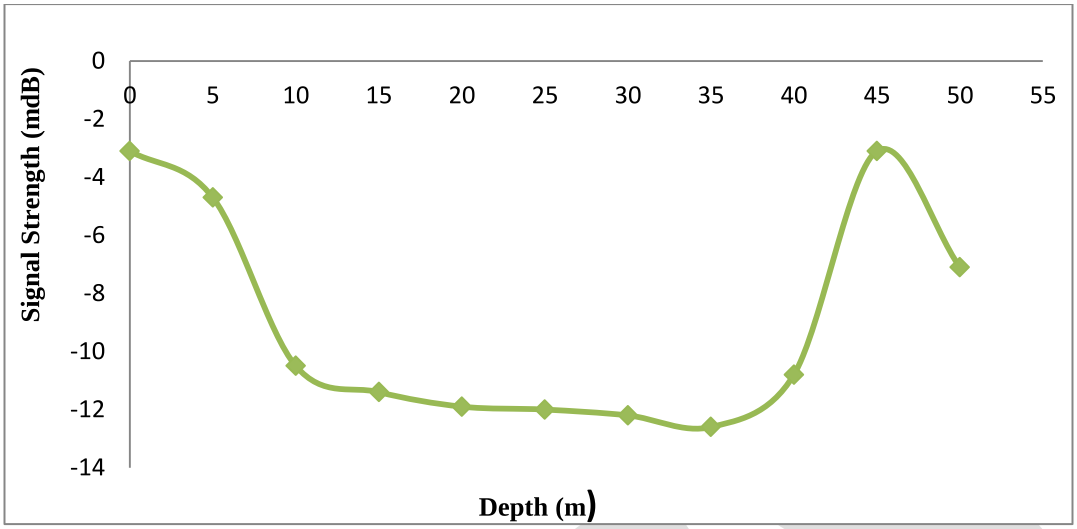

Figure 1. Signal strength curve at different depths (site one).

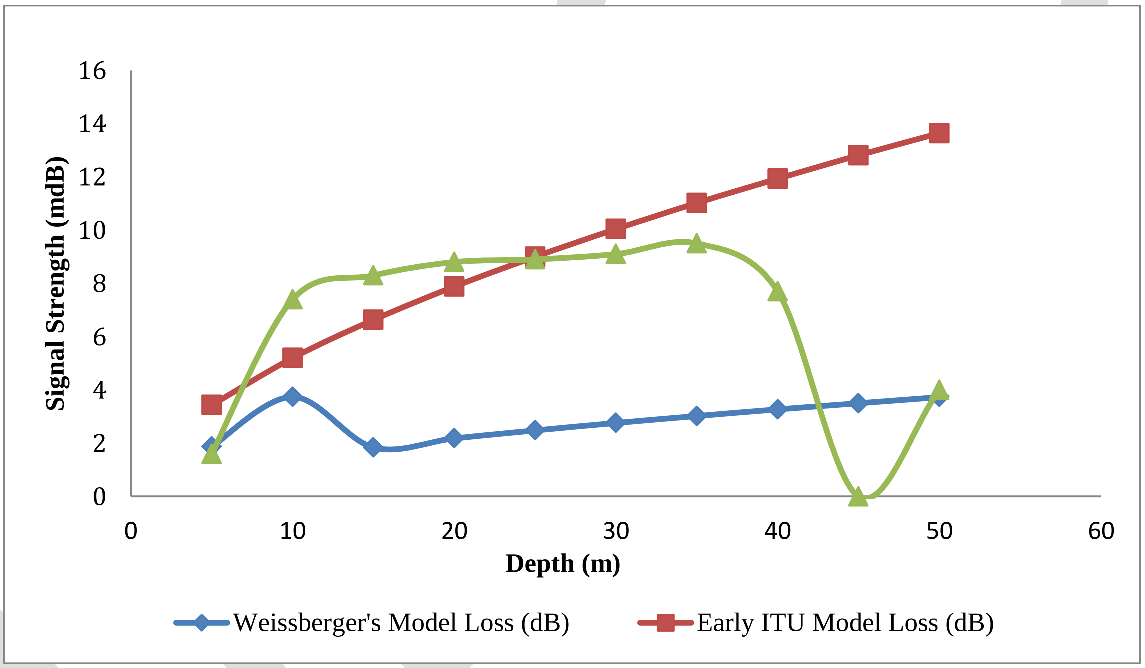

Figure 2. Comparison between curves of the measured foliage or vegetation loss and the Weissbeger's and Early ITU's models losses (site one).

In Figure 5, there is a gradual degradation or dissipation or decay of the signal with increasing depth. This is due to the thickening canopy of foliage obstructing the signal direct or line-of-sight path or point-to-point connection between the transmitter and receiver antennas and shading of sky waves from the receiver antenna. Further down the channel, as the canopy of foliage thins, the signal is strengthened, because of gradual restoration of point-to-point contact or connection and increasing sky waves raining on the receiver antenna. At the end of every canopy of tree(s), a good direct or line-of-sight or point-to-point connection or link is re-established between the transmitter and receiver antennas and the receiver antenna gets link with abundant sky waves. The signal is strengthened as if there were no vegetation (foliage) on its path.

Farther down the channel, as the direct or line-of-sight or point-to-point contact or connection is lost and the sky waves diminish with the presence of another canopy, the foliage fading or loss increases again, depending on the canopy's width and thickness. This phenomenon fluctuates deeper into the forest channel. It implies that the signal loss due to trees or vegetation is caused mainly by the foliage canopy and not the obstruction of the ground or surface waves by the trunk and other non-foliaceous parts of the tree(s). Hence, for UHF signals, the depth of the forest counts less. It is the presence of the falling sky waves and the point-to-point contact or connection that speaks volume.

In Figure 2, the measured loss curve appears to rise gradually like that of the Early ITU's model, but at about 25 m, the former deviates far from the latter because of the restoration of the point-to-point or direct line-of-sight connection and the presence of abundant sky waves due to few or no presence of foliage, that is just at the end of the width or terminal of the first foliaceous canopy on the channel.

Analysis of measurement from the second forested channel (site two)

Analysis or discussion of the measurements is preceded by TABLE 2 and the Figure 3 and 4.

TABLE 2

Measured loss from site two and the Wessbieger's and Early ITU's models losses

Depth (m)	Signal Strength (mdB)	Weissberger's Model Loss (dB)	Early ITU's Model Loss (dB)	Measured Foliage Loss (mdB)
0	-15.0	-	-	-
5	-15.2	1.9	3.4	1.2
10	-15.8	3.7	5.2	0.8
15	-19.0	1.8	6.6	4.0
20	-20.0	2.2	7.9	5.0
25	-21.6	2.5	9.0	6.6
30	-17.8	2.8	10.0	2.8
35	-17.6	3.0	11.0	2.6
40	-17.3	3.3	11.9	2.3
45	-15.1	3.5	12.8	0.1

Figure 7 shows the graphical representation of the signal strength at different depths of the channel. Also Figure 8 shows the measured foliage or vegetation loss curve in comparison with the curves of the Weissberger's and early ITU's model losses.

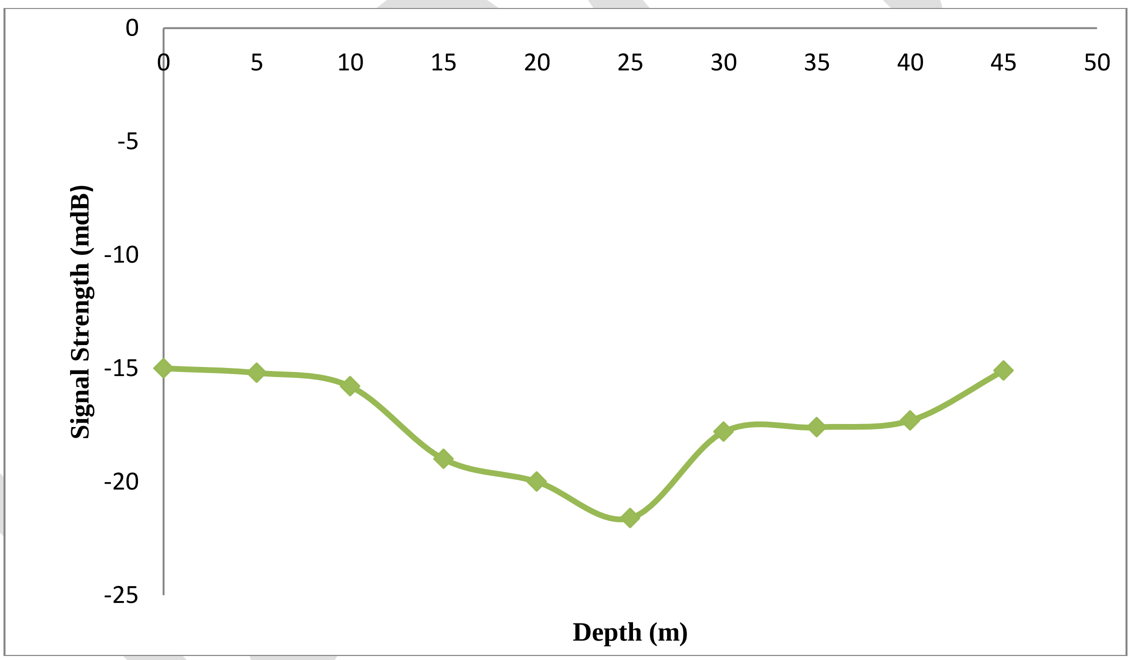

Figure 3. Signal strength curve at different depths (site two)

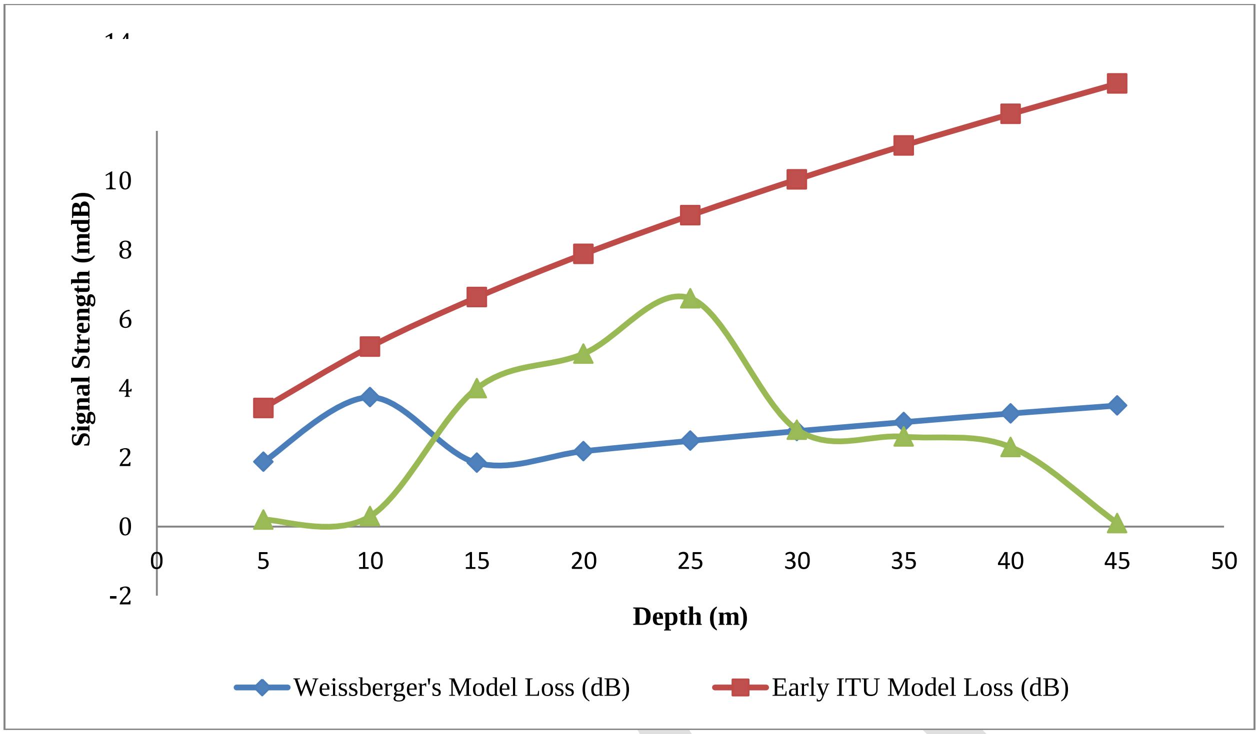

Figure 4. Comparison between curves of the measured vegetation or foliage loss and the Weissbeger's and Early ITU's models losses (site two)

Similarly in Figures 4 and 5, the explanation in section 4.1 is echoed or paralleled. There is a gradual degradation or dissipation of the signal with increasing depth to about 35 m due to the thickening foliage disrupting point-to-point connection or direct or line-of-sight communication and shading the rain of sky waves from the receiver antenna. However, beyond the 35 m mark, the phenomenon reverses as the raining sky waves began to fall increasingly on the receiver antenna and point-to-point connection or direct or line-of-sight communication is gradually restored due to the thinning of the foliaceous canopy. At the end of the foliaceous canopy, that is about 45 m, there is a little or no loss because of the full re-establishment of the point-to-point or direct or line-of-sight link or communication and the raining sky waves are once more heavy. Afterwards, the signal diminishes or depreciates as seen from the curve in Figure 3 due to the encounter or collision again of the radio signal or waves with another canopy.

Also in Figure 4, the measured loss curve almost parallels that of the ITU's model, but begins to drift tangentially over 35 m due to the reconnection or re-link of point-to-point or direct or line-of-sight communication and a huge fall from the raining sky waves on the receiver antenna. At 40 m, the shielding or shading from the foliaceous canopy is heavier and the signal disintegrates or diminishes, reading an increase in vegetation (foliage) loss.

From the two forested channels and the curves generated from the measurements acquired, it is obvious or self-evident that vegetation (foliage) loss is mainly caused by the foliaceous canopy, due to its obstruction of the point-to-point or direct or line-of-sight communication between the receiver and transmitter antennas and shielding of the raining sky waves. The obstruction of the ground and surface waves by the trunks and other non-foliaceous parts of tree(s) is not really significant. Hence, for UHF signals, the depth of the forested channel does not really matter much (excluding the free space path loss). Any position in the channel, where point-to-point or direct or line-of-sight communication is achieved between the transmitter and receiver antennas and the falling sky waves is generous; the signal strength loss or vegetation (foliage) loss is near negligible.

CONCLUSION

In conclusion, it was observed that the foliaceous canopy was mainly responsible for the loss of the signal strength, but not other non-foliaceous part that may only obstruct the surface and ground waves - that is, at UHF and transmitter antenna height higher than the trees in the forested channels. This is because the canopy obstructs the direct or line-of-sight or point-to-point communication and shields the receiver antenna from the raining sky waves. The aforementioned phenomenon is similar to directing a light source across a foliaceous canopy. It will be observed that the canopy will shield or shade the falling light particles from reaching a target object behind the canopy. This is true because, all members of the electromagnetic spectrum shear the same characteristics [12], [3], just that some can travel farther than the other because of the difference in propagation energy. The correlations between the signal strength (mdB) and depth (m) in the first and second sites of investigation were r = -0.17 and r = -0.06 respectively. The standard deviations of the foliage losses in the two sites were σ = 3.24 mdB and σ = 2.23 mdB respectively. Hence, the thicker the foliaceous canopy, the higher the vegetation or foliage loss, since there was higher fading in the signal strength with depth in the pride of Barbados' channel than that of the palm trees' channel with thinner foliaceous canopy than the aforementioned channel.

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Appendices

Appendix 1: Picture of forested channel in the university of Calabar (site one) with the receiver antenna

Appendix 2: Picture of forested channel in the University of Calabar (site two)

Appendix 3: Picture of campaign in one of the forested site with the CATV (cable) Analyzer, its charger and the receiver antenna pole