American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-14, Issue-3, pp-14-22
www.ajer.org
Research Paper Open Access

Modeling the Effect of Building and Vegetation on Wireless Fidelity (WI-FI) Radio Wave Propagation: Case Study on LAUTECH Campus

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Abstract: *Wireless fidelity (Wi-Fi) has revolutionized communication, work, and entertainment, transforming various organizational environments like learning institutions, businesses, and homes, enabling efficient administration, lectures and business purposes. The environmental features impact Wi-Fi radio wave signal reception, leading to slow connections which usually disrupt workflow. Hence, this paper studied the effects of buildings and vegetation Wi-Fi radio wave propagation on LAUTECH campus as it is crucial for optimizing network performance in the growing reliance on Wi-Fi networks for communication and connectivity. Field measurements were conducted on LAUTECH campus to analyze Wi-Fi signal strength and quality across different buildings and vegetation densities. Network Signal Info Pro embedded with GPS and storage application was installed on a mobile phone and used alongside GSP 730 spectrum analyzer operating at frequency range of 150 kHz to 3 GHz to measure the signal strength at varying distance from Wi-Fi transmitting base stations at 2.4 GHz. Measurements were taken repeatedly across different locations namely Physics department, high rise building, college, ICT, CAD center, JUPEB and Senate building. Wi-Fi signal pathloss and attenuation due to buildings and vegetation were quantified and the developed models were compared with existing building and vegetation models vis a vis Okumura model, Hata model, COST 231 model, ECC-33 model, Weissberger's model, Early ITU, COST 235, FITU-R, Gradient Generic (MA) model. The results show that signal strength decreases while pathloss increases as distance from the Wi-Fi transmitting stations increases in both building and vegetation paths. The results of measurement taken along building paths show that physics department has the highest signal strength of an average value of -68.364 dBm which corresponds to the least building average pathloss of 88.4545 dB while College of Health Science has the least signal strength of an average value of -75.1 dBm with corresponding to highest building pathloss of 95.1 dB. Moreover, the results of measurement conducted along vegetation paths shows Physics department having the highest average vegetation pathloss of 114.5 dB followed by High building and CAD Centre with average vegetation pathloss of 112 dB and 107.5 dB respectively. The result of the deduced attenuation models gave an exponential increase in attenuation with increase in depth of buildings and vegetation with regression coefficients of (R^2) values of 0.93989 and 0.9233 respectively. Observation show that only Okumura-Hata model fitted closely to the developed building model while gradient generic model (MA) fitted closely to the developed vegetation model in all the building and vegetation attenuation scenarios. In conclusion, the developed models and other results obtained in this research has revealed the effect of building and vegetation on Wi-Fi radio propagation and will also aid in efficient Wi-Fi link planning and budgeting for seamless coverage and applications.*

Keywords: *wireless –fidelity, path loss, vegetation, building, attenuation*

Date of Submission: 08-03-2025 Date of acceptance: 22-03-2025

I. INTRODUCTION

Humankind has relied on communication channels since the evolution of communication, even before the development of modern technologies and techniques (Jiang*et al.*, 2021). Wireless communication, utilizing radio wave propagation techniques, is a crucial method for transmitting information over long distances, enabling mobility and widespread acceptance in modern times (Dai *et al.*, 2021).Wireless devices and software are utilized in various industries, including health, education, e-commerce, transportation, and smart agriculture. Wireless systems infrastructure, particularly Wi-Fi radio wave networks, offer advantages like high data rates, dual-band support, and quality of service (Subha *et al.*, 2020).Wi-Fi is a high-speed wireless networking technology that uses ultra-high frequency (UHF) radio waves, primarily operating in the 2.4GHz region (Polak *et al.*, 2019).Wireless communications networks require optimal signal transmission and reception, but radio wave impairments like trees, buildings, terrain, and mountains can block transmission channels. Investigating these impairment parameters is crucial for mitigating signal loss and improving efficiency, especially in educational settings where Wi-Fi services are used.(Alozie et al., 2022).The development of radio propagation models is crucial for quantifying WiFi attenuation due to vegetation and buildings, especially in higher learning institutions (El Khaled et al., 2020).Pathloss refers to signal weakening due to extensive fading, making precise models crucial for efficient WiFi communication deployment and link budget optimization (Javaid et al., 2021).Investigating the impact of buildings and vegetation on WiFi radio wave propagation is crucial for achieving high-speed data rates and interference-free WiFi connectivity in institutional environments (Imoize et al., 2023;Narayanan and Kurup 2023). LAUTECHWi-Fi radio wave network called (LAUNET) is utilized by scholars, researchers, students, and LAUTECH community staff for online information gathering, research opportunities, online lectures, student information, and CBT examinations.The LAUTECH WiFi radio wave network facilitates online access for scholars, researchers, students, and staff to resources, research opportunities, lectures, and CBT examinations.This paper investigated the factors affecting LAUTECH's WiFi radio wave network service accessibility with the intension of identifying the significant impact of buildings and vegetation on the WiFi signal on LAUTECH campus.

II. RADIO WAVE PROPAGATION MODELS

The environment consists of various scatterer classes, such as buildings and trees, in practical scenarios resembling a haphazard assembly of buildings (Adewumi et al.,2018; d'Aragona *et al.*, 2022). A forest can be quantitatively described using statistics, if the scatterer population per group and the statistical features of individual scatterers are known.Propagation modeling is a crucial tool in predicting the successful operation of communication systems relying on electromagnetic wave propagation(Samad *et al.*, 2023). Propagation channel modeling aims to predict signal strength at link end, but channel deficiencies like multipath-induced delay spread and rapid signal fading can negatively impact link performance. Predictive methods are crucial in radio frequency system planning for identifying characteristics that ensure effective and reliable coverage in a service area (Popoola et al., 2019). Trees and vegetation in rural areas can cause significant route losses due to shadowing, scattering, and absorption, particularly at higher frequencies.This study focuses on two existing prediction models: vegetation and building loss models.

2.1. VEGETATION MODELS

Most terrestrial communications systems require signals to cross or pass over foliage at some point (Adewumi et al., 2023). Different models estimate the increased attenuation from foliage within the line-of-sight path, with a wide range of foliage varieties. It's crucial to confirm the applicability of a model to a specific area based on its previous application or by comparing its predictions with actual outcomes. Reviewed below are some of the existing vegetation models

2.1.1 WEISSBERGER'S MODEL

Weissberger's modified exponential decay model is given by (Galvan-Tejada and Aguilar-Torrentera, 2019) as;

$$L(dB) = \begin{cases} 1.33F^{0.284}df^{0.588}, & 14 < df \leq 400m \\ 0.45F^{0.284}df, & 0 < df \leq 14m \end{cases} \qquad 1$$

Where df is the depth of foliage along the LOS path in meters and F is the frequency in GHz

2.1.2 EARLY ITU VEGETATION MODEL

Weissberger's modified exponential decay model is utilized when dense, dry, leafy trees block the propagation channel and the model is given as;

$$L(dB) = 0.2F^{0.3}df^{0.6} \text{ dB} \qquad d<400\text{m} \qquad 2$$

where F is the frequency in MHz and df is the depth of the foliage along the LOS path in meters.

2.1.3 COST 235 MODEL

This model was proposed based on measurements made in millimeter wave frequency through small grooves of trees and is given by (Barrios-Ulloa *et al.*, 2022) as;

$$L\,cost(dB) = \begin{cases} 26.6 \times f^{-0.2}d^{0.5}, & out\ of\ leaf \\ 15.6 \times F^{0.09}d^{0.26}, & in\ leaf \end{cases} \qquad 3$$

Where f is the frequency in MHz and d is the tree depth in meters (d < 400m)

2.1.4 FITU-R Model

This model was proposed through an optimization campaign carried out using data at 11.2GHz and 20GHz and the model is given by (Anzum et al., 2022) as;

$$L_{FITU-R}(dB) = \begin{cases} 0.37 \times f^{0.18}d^{0.59}, & out\ of\ leaf \\ 0.39 \times f^{0.38}d^{0.25}, & in\ leaf \end{cases} \qquad 4$$

Where f is the frequency in MHz and d is the tree depth in meter (d < 120m).

2.1.5 GRADIENT GENERIC (MA) MODEL

For maximum attenuation (ma) in the 30MHz–30GHz frequency band, the ITU suggests gradient generic models that use the starting point gradient of the attenuation curve and excess maximum attenuation (MA) as input parameters is given by (Kyari and Agajo, 2021) as;

$$L_{MA} = A_m\left(1 - e^{\left(\frac{-R_0 d}{A_m}\right)}\right) \qquad 5$$

Where Am is the maximum attenuation, Ro is the initial gradient of the attenuation rate curve and d is the tree depth in meter.

2.2BUILDING MODELS

The propagation of radio waves in built-up areas is significantly influenced by the environment, with terms like rural, suburban, urban, and dense urban often used in propagation studies (Cui et al., 2019).Dense urban areas are characterized by tall buildings, office blocks, and commercial buildings, while suburban areas consist of residential houses, gardens, and parks.

2.2.1OKUMURA MODEL

The model is empirical, based solely on the measured data. The actual predictions are made based on graphs of Okumura's results, with various correction factors applied for some parameters. For the Okumura model, the prediction area is divided into terrain categories: open area, suburban area, and urban area. The text defines a series of terrain types, with quasi-smooth terrain serving as the reference terrain and correction factors applied to other types.

According to Alfaresi et al., 2020, Okumura's expression for the median is;

$$L_{50} = L_{FSL} + A_{mu} + H_{tu} - H_{ru} \qquad 6$$

Where LFSL is the free-space loss, Amu is the median attenuation relative to free-space loss in an urban area, with quasi-smooth terrain. Htu is the base station height gain factor and Hru is the mobile antenna height gain factor.

2.2.2HATA MODEL

The Hata model (sometimes called the Okumura–Hata model) is an empirical formulation that incorporates the graphical information from the Okumura modeland is given by (Shoewu et al., 2019) as;

For Urban Areas;

$$L_{50}\,(dB) = 69.55 + 26.16\log(f_c) - 13.82log(h_t) - a(h_r) + [44.9 - 6.55\log(h_t)]\log(d) \qquad 7$$

and for a large city:

$$\text{a}(hr) = \begin{cases} 8.29(\log(1.54hr))^2 - 1.1, & fc \le 200MHz \\ 3.2(\log(11.75hr))^2 - 4.97, & fc \le 400MHz \end{cases} \qquad 8$$

for suburban Areas;

$$L_{50}(d\boldsymbol{B}) = L_{50}(urban) \ - 4.78(\log(fc))^2 + 18.33\log(fc) - 40.94 \qquad 9$$

2.2.3 THE COST 231MODEL

Model, sometimes called the Hata model is an enhanced version of the Hata model given by (Shoewu et al., 2019); as;

$$L_{50}(d\boldsymbol{B}) = 46.3 \ + 33.91\log(fc) - 13.82\log(ht) - a(hr) + [44.9 \ - 6.55\log(ht)]\log(d) + C \qquad 10$$

2.2.3ECC-33 MODEL

This model was developed by Electronic Communication Committee (ECC). ECC extrapolated the original measurements by Okumura and modified its assumptions so that it more closely represents a Fixed Wireless Access (FWA) system expressed as;

$$PL(dB) = \ Af_s + Ab_m - Gb - Gr \qquad 11$$

Where Afs is the free space alteration, Ab_m is basic median, Gt is the base station gain factor and Gr is the received antenna height gain factor.

2.2.4LEE MODEL

The Lee model was originally developed for use at 900MHz and has two modes: area-to-area and point-to-point. For area-to-area prediction, Lee uses a reference median at one mile, called L_0, the slope of the curve, ɣ in dB/decade, and an adjustment factor f_0. The median loss at distance, *d*, is given by;

$$L_{50}(d\boldsymbol{B}) = L_\circ \ + \gamma\log(d) - 10lof(f_\circ) \qquad 12$$

III. EXPERIMENTAL SET-UPAND MEASUREMENT CAMPAIGN

Figure 1 represent the experimental set-up for the measurement campaign in one of the location considered. The experiment was set-up and the campaign was carried out at Ladoke Akintola University of Technology (Lautech) Ogbomoso campus [Lat 8° 8' 0'' Long 4° 16' 0"] at different locations namely Physics department (Phy), High-rise building (HighR), College, ICT, CAD center, JUPEB, and Senate building (Senate). Measurement were conducted at various distance away from each Wi-Fitransmitting base station in each location. The WiFi transmitter in each location has a transmitting power of 100Mw (20dB) and transmitting at 2.4GHz. GPS 730 spectrum analyzer operating at frequency range of 150 kHz to 3GHz was used to measure the received signal strength at various distance away from the WiFi transmitting station in each location. Measurements were carried out in built up and vegetation areas and in some areas that are heterogeneous media (mixture of building and vegetation). Network signal info pro (Kabiit Software) application was used to validate the measured signal strength and determine the position coordinates using embedded GPS application. Data collected and collated were analyzed using origin software and Matlab 2015a. Pathloss in each location relative to the channel scenario (vegetation, building or both) were estimated using the equation given by (Tang et al., 2020) as;

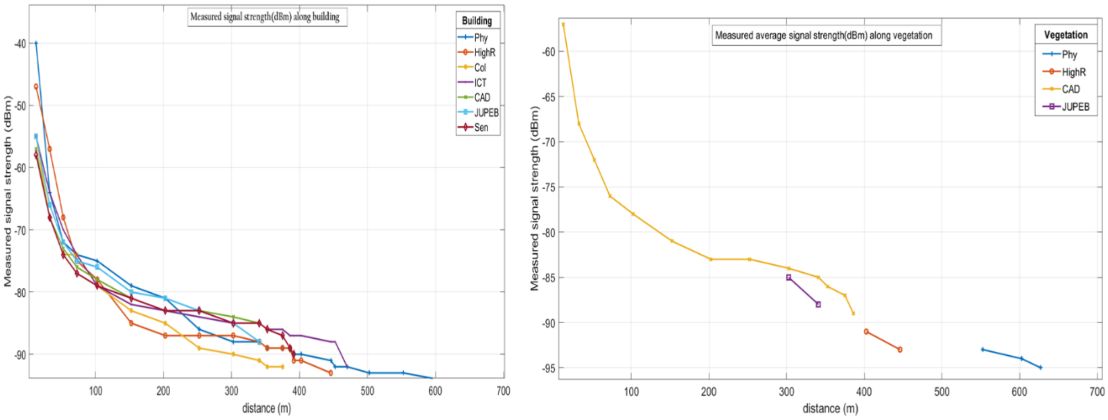
$$P = T_X - R_X \qquad 13$$

Where P is the pathloss in dBm, T_X is the transmitting power and R_X is the received signal strength. WiFi propagation attenuation due to the channel impairment parameters namely vegetation and buildingwere modeled for each scenario and compared with existing vegetation and building models.

Fig. 1.0 Experimental set-up for the measurement campaign

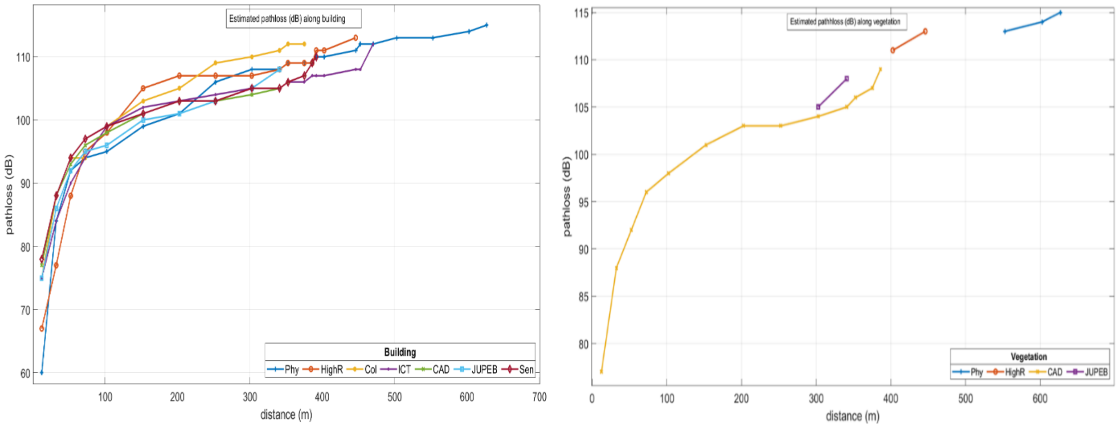
IV. RESULTS AND DISCUSSION

After the measurement, the data gathered were collated, filtered and analyzed using Matlab 2015a and origin pro software and the results obtained are shown in figure 2.0 to figure 2.8.



(a) (b)

Fig. 2.0:Measured Average Signal Strengthalong (a) Building Paths (b) Vegetation Paths



(a) (b)

Fig 2.1: Estimated Pathloss(dB) along (a) Building paths (b) Vegetation Paths

Fig 2.0 shows the measured WiFi signal strength along building and vegetation paths in the selected locations within the campus. Observation shows that the measured WiFi signal Strength gave an exponential decrease in signal strength with increase in distance along both building and vegetation paths, which implies that building and vegetation significantly impaired WiFi radio. signal propagation. Fig.2.1 shows the estimated path loss obtained from the measured signal strength from the building and vegetation paths. The results show an exponential increase in path loss with increase in distance in both scenarios. Observation also shows that physics department (Phy) has the highest signal strength of an average value of -68.364 dBm which corresponds to the least building average pathloss of 88.4545 dB while College of Health Science has the least signal strength of an average value of -75.1 dBm with corresponding to highest building pathloss of 95.1 dB. Moreover, the results of measurement conducted along vegetation paths shows Physics department (Phy) having the highest average vegetation pathloss of 114.5 dB followed by High rise building and CAD Centre with average vegetation pathloss of 112 dB and 107.5 dB respectively.

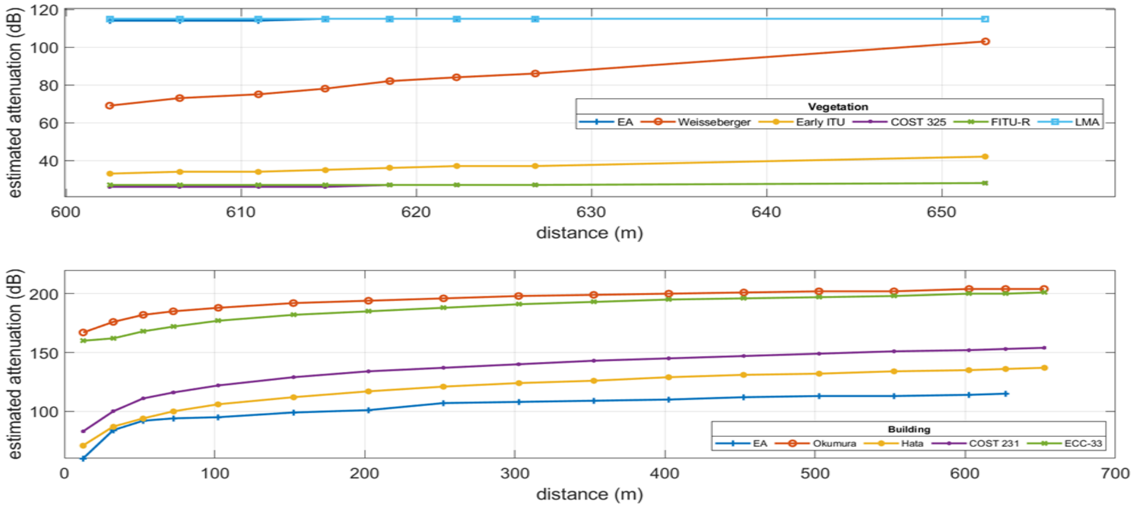


Fig 2.2: Developed (EA)Attenuation Model in Comparison with Existing Vegetation and Building Attenuation Models at Physics Department location

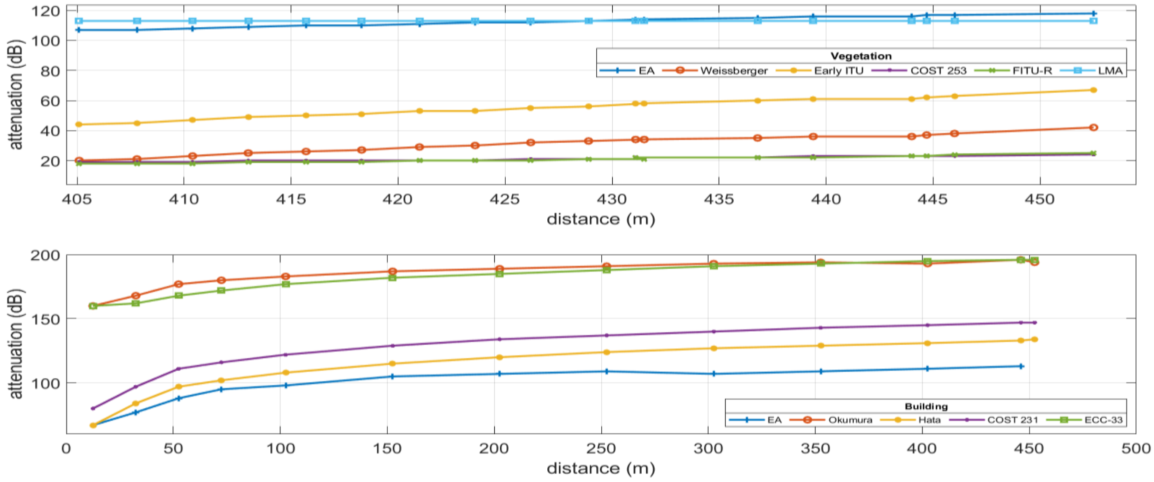


Fig. 2.3: Developed (EA) Attenuation Model in Comparison with Existing Vegetation and Building Attenuation Models at High-rise building location

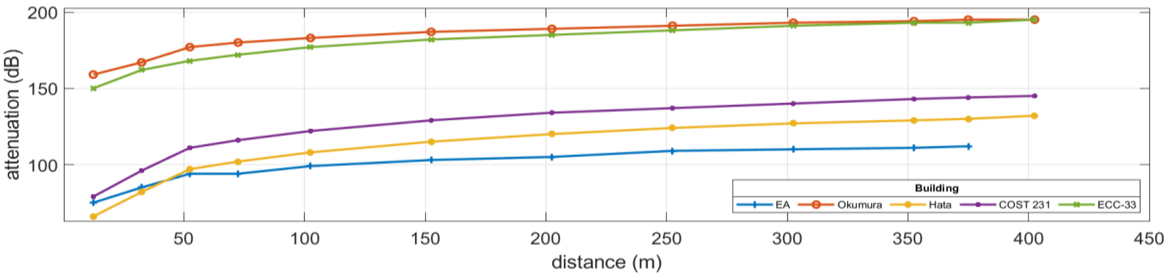


Fig. 2.4: Developed (EA) Attenuation Model in Comparison with Existing Building Attenuation Models ar College location

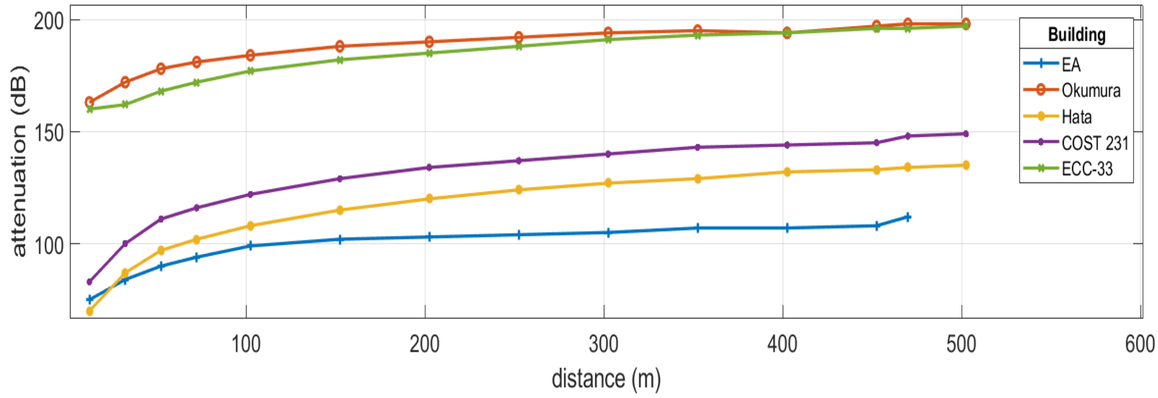


Fig 2.5: Developed (EA) Attenuation Model in Comparison with Existing Building Attenuation Models at ICT location

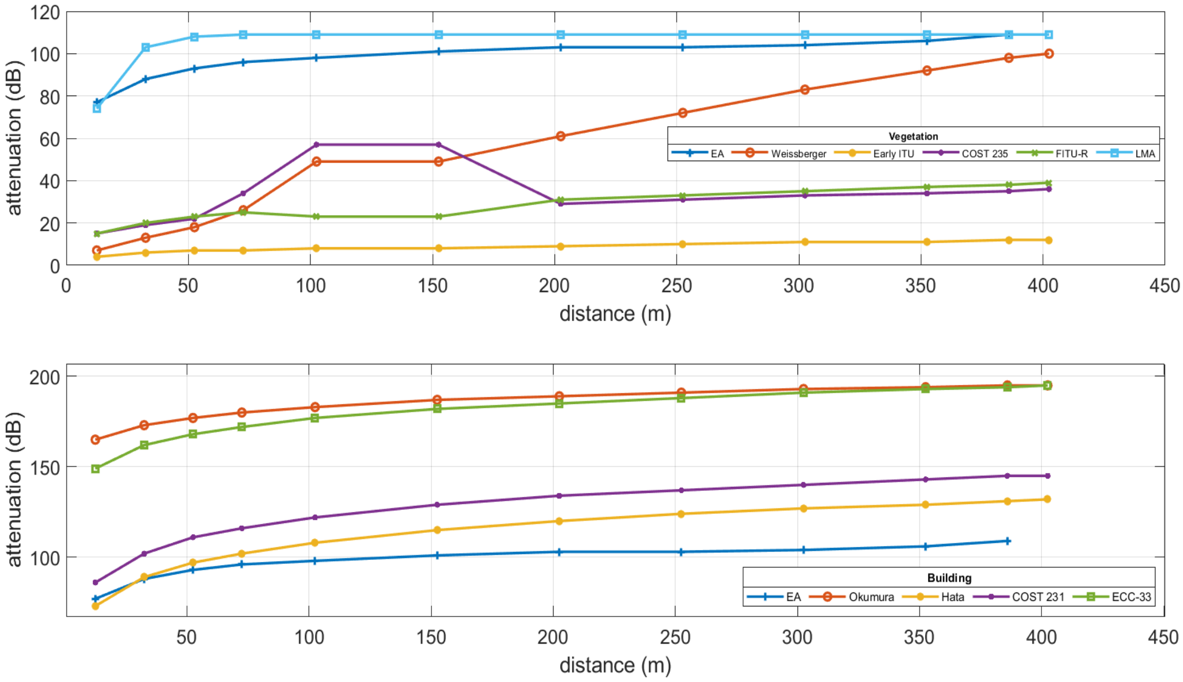
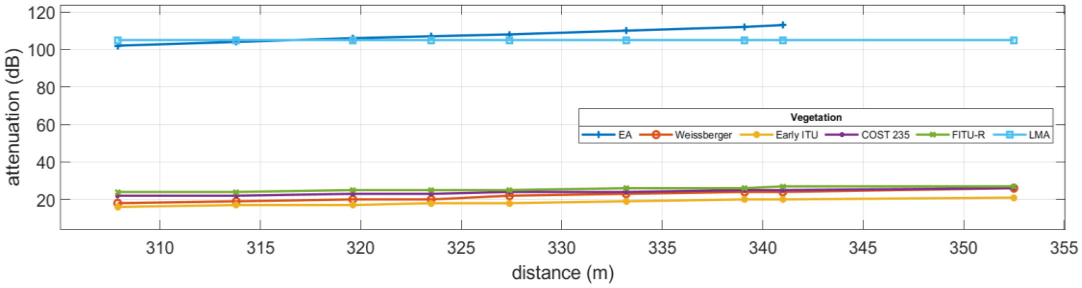


Fig 2.6: Developed (EA) Attenuation Model in Comparison with Existing Building Attenuation Models at CAD center location



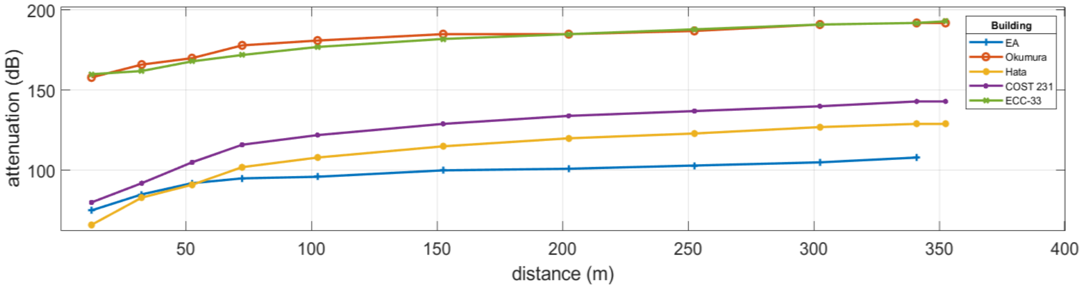


Fig. 2.7: Developed (EA) Attenuation Model in Comparison with Existing Building Attenuation Models at JUPEB location

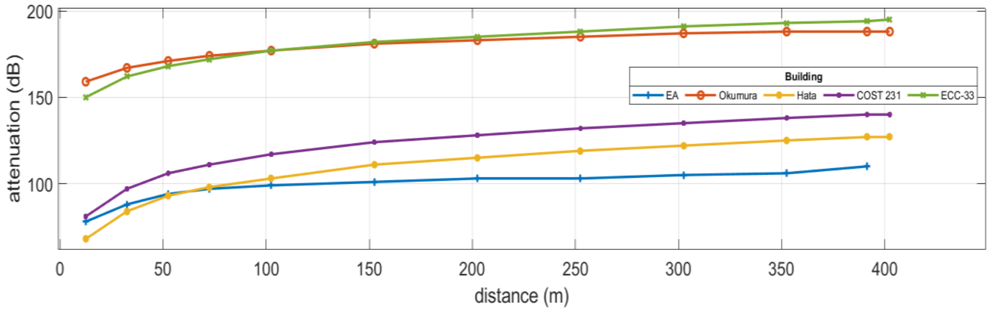


Fig. 2.8: Developed (EA) Attenuation Model in Comparison with Existing Building Attenuation Models at Senate Building location

Figures 2.2, 2.3, 2.4, 2.5, 2.6, 2.7 and 2.8 represent the comparison of the developed building and vegetation attenuation models in each location considered with the existing building and vegetation attenuation models. The developed building model (EA) in each location were compared with existing building models namely Hata, COST 231, Okumura, and ECC 33 models while the developed vegetation attenuation model in each location were compared with existing vegetation models vis a vis Weissberger, Early ITU, COST 235, FITU-R and MA models.Observations show that the developed (EA) building model fits more closely to MA buildingmodel thanother building models while the developed (EA) vegetation modelfit more closely to Hata model than other vegetation models.Further observation shows that the developed attenuation (EA) models gave an exponential increase in attenuation with increase in depth of buildings and vegetation with regression coefficients of (R^2) values of 0.93989 and 0.9233 respectivelyThis implies that the developed (EA) building and vegetation models for Wi-Fi radio propagation can be statisticallyused for predicting building and vegetation attenuation in another environment where building and vegetation are the major Wi-Fi radio propagation impairment parameters without using experimental approach.

V. CONCLUSION

This paper explored the impact of building structures and vegetation on LAUTECH Wi-Fi radio wave signal propagation. It is established that both building and vegetation can significantly influence Wi-Fi radio wave signal propagation. The findings in this study have important implications for the design and optimization of wireless networks, it was observed that locations with high rise structures significantly affected Wi-Fi radio wave signal propagation throughthe phenomena of diffraction, reflection and absorption whilelocations with vegetation also affected the Wi-Fi radio wave signal propagation through absorption, scattering and diffraction of the signal by tree trunks and leaves.The results also revealed that buildings and vegetation are the major impairment of Wi-Fi radio wave signal propagation leading to reduction in coverage and slow data transmission speeds. This necessitates the important of quality Wi-Fi network link planning and budgetingbased on the nature of the environment before deployment of the technology to any environment. This paper hasprovided information on the impact of building and vegetation on Wi-Fi radio wave propagation and also developed models can be suitably used to predict Wi-Fi radio wave propagation attenuation in other environment of similar features.

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