International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 8, Issue 12, pp 60-65, December-2024

https://doi.org/10.47001/IRJIET/2024.812010

2.4 GHz Telecommunication Network Propagation Environment Characterization Using Ray Tracing Algorithm

[1]Ifeagwu E.N., [2]Ejimofor, Ihekeremma A.U.

[1]Department of Electrical and Electronic Engineering, Federal University Otuoke, Bayelsa State, Nigeria
[2]Department of Computer Engineering, Madonna University Nigeria, Akpugo Campus, Nigeria
Authors E-mail: [1]ifeagwuen@fuotuoke.edu.ng, [2]ejimofor@madonnauniversity.edu.ng

***Abstract* - This paper focused on 2.4 GHz telecommunication network propagation environment characterization using Ray Tracing Algorithm. In this paper, a geographical database of the 2.4 GHz telecommunication network environment was created and replicated with ray tracing algorithm. Computer modeling was used to determine crucial channel parameters for the Otuoke suburban environment in Bayelsa State, including the path loss exponent, power delay profile, and angle spread of radio propagation environment at the 2.4GHz band. The result showed that the root mean square delay spread is 0.5539 and the mean delay is 1.1733. The result also showed that the root mean square angle spread is 58.650 and the mean arrival angle is 1630. The pathloss exponent results obtained also matched with the measured field data.**

Keywords: Angle spread, mean delay, delay spread, pathloss exponent, Doppler shift.

I. Introduction

The goal of propagation modeling is to forecast how the sent signal will be impacted by the propagation channel. They are widely utilized in network planning, especially for preliminary deployment and feasibility studies. As the deployment moves further, they are also very helpful for conducting interference investigations.

These models fall into three general categories: deterministic, stochastic, and empirical models. Models that rely solely on measurements and observations are known as empirical models. Although models that predict multipath characteristics have also been suggested, these models are mostly employed to estimate the path loss (Azubogu, *et al*, 2011).

The environment is represented by a set of random variables in stochastic models, however. Although they use the least amount of environmental data and demand the least amount of computing power to provide predictions, these models are the least accurate (Moraitis, *et al,* 2022).

The received signal power at a specific point is determined by the deterministic models using the rules of electromagnetic wave propagation. The propagation environment must frequently be fully mapped in three dimensions for deterministic models to work. They are suitable, frequently as a standard, when precise radio network planning is needed. The path loss exponent, delay-spread, and angular-spread of the propagating waves are among the narrowband and wideband studies they can offer, depending on the modeling technique.

Capacity coverage prediction requires the path loss exponent. The correlation between the various pathways is seen by the power delay profile and angle spread. In fact, coverage is directly impacted by path correlation, which also affects capacity (Ifeagwu, *et al,* 2015a).

The performance of transmitters and receivers, smart antennas, signal processing algorithms, channel coding, and other components are all made possible by these findings. Topographical and material constants databases are needed to get deterministic propagation forecasts for particular situations.

II. Channel Characteristics for Wireless Propagation

Doppler shift, multipath and shadow fading, time dispersion or delay spread, and other variables make the wireless channel different and far more unpredictable than the wire line channel. All of these variables are associated with the variability brought about by the user's mobility and the diverse range of environmental conditions that are consequently encountered (Ifeagwu, *et al*, 2015b).

2.1 Multipath

When a sent signal is reflected by environmental objects between a transmitter and a receiver, multipath delays happen.

ISSN (online): 2581-3048
Volume 8, Issue 12, pp 60-65, December-2024
https://doi.org/10.47001/IRJIET/2024.812010

These things could be hills, trees, buildings, or even vehicles and trucks.

Since each reflected signal often takes a different route to get to the user's receiver, the reflected signals arrive at the receiver with a random phase offset. This causes a random signal that fades as the reflections either constructively or destructively superimpose on one another. For short times, this essentially adds or cancels off some of the signal energy. The delay spread of the reflected signals, as represented by their respective phases and power, will determine the extent of fading (Ifeagwu, *et al*, 2015b).

2.1.1 Spread of Delays

Both frequency and time dispersion are present in a mobile radio transmission.

The spreading of the modulation symbols across time is a manifestation of temporal dispersion, which is the distortion of the signal. Frequency-selective fading is the cause of this. Many frequency components that arrive at the receiver at varying times and experience varying degrees of attenuation make up a channel, which is referred to as frequency selective. A frequency zone where all frequency components operate in the same way is provided by the frequency band over which the attenuation stays constant. This frequency range is known as the channel's coherence bandwidth.

When the channel is band-limited or its coherence bandwidth is less than the modulation bandwidth, time dispersion happens. Inter-symbol interference (ISI), in which energy from one symbol spills over into another, is caused by time dispersion and raises the bit-error-rate (BER).

Multipath delay-induced fading frequently exhibits frequency selectivity, impacting only a subset of the total channel bandwidth at any one moment. The delay spread is greater than the symbol period when frequency selective fading is present.

Conversely, fading will be flat and influence all of the signal's frequencies equally if there is no dispersion and the delay spread is less than the symbol duration. Deep fades over 30 to 40 dB might result from flat fading.

The channel power delay profile (PDP), which is defined as the change in the mean power in the channel with delay, is frequently used to convey information about the temporal dispersive nature of a channel. PDP is therefore given as (Garg, 2019).

$$P(\tau)=\frac{E\left[\left|h(t,\tau)\right|^2\right]}{2} \qquad (1)$$

The PDP may be characterised by various parameters:

- Excess delay: the delay of any ray relative to the first arriving ray.
- Total excess delay: the difference between the delay of the first and last arriving ray; this is the amount by which the duration of a transmitted symbol is extended by the channel.
- Mean delay, τ_0: the delay corresponding to the 'centre of gravity' of the profile; defined by (Sousa et al, 2024):

$$\tau_0=\frac{1}{p_T}\sum_{i=1}^{n}p_i\tau_i \qquad (2)$$

Where $P_T=\sum_{i=1}^{n}P_i$

P_i is the relative powers of the taps P_T is the normalised power and τ_i is the relative delays.

- RMS delay spread τ_{RMS}: the second moment or spread, of the taps; this takes into account the relative powers of the taps as well as their delays, making it a better indicator of system performance than the other parameters; defined by (Rappaport, 2018)

$$\tau_{RMS}=\sqrt{\frac{1}{P_T}\sum_{i=1}^{n}P_i\tau_i^2-\tau_0^2} \qquad (3)$$

The RMS delay spread is a good indicator of the system error rate performance for moderate delay spreads (within one symbol duration). If the RMS delays spread is very much less than the symbol duration, no significant ISI is encountered and the channel may be assumed narrowband.

Typical values for the RMS delay spread are given in Table 1 for various environments.

Table 1: Typical RMS delay spreads (Sousa, *et al*, 2024)

Environment	Approximate RMS delay spread [μs]
Indoor cells	0.01–0.05
Mobile satellite	0.04–0.05
Open area	<0.2
Suburban	<1
Urban macrocell	1–3
Hilly area macrocell	3–10

International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 8, Issue 12, pp 60-65, December-2024

https://doi.org/10.47001/IRJIET/2024.812010

Other literatures also show that typical values of delay spread are on the order of microseconds in outdoor mobile radio channels and on the order of nanoseconds in indoor radio channels. In (Sousa et al, 2024) a delay spread measurement for digital cellular channel in Toronto was conducted. Their values for rms delay spread is shown in Table 2.

Table 2: Average of the rms delay spread in μs for various environments (Sousa et al, 2024)

	Mean	Median
Urban	0.73	0.71
Suburban	0.59	0.31
combined	0.66	0.48

The values of rms delay spread lie between 5 and 300 ns in indoor environments. In microcells, RMS delay spread is usually found between 0.35 and 2 μs. In macrocells, values around 5 μs and more were measured for rural and hilly terrains. Table 3 shows the typical measured values of RMS delay spread.

Table 3: Typical RMS delay spread values (Mani, et al, 2021)

Environment	RMS Delay Spread $\sigma_\tau(\mu s)$
Urban	3 - 5
Suburban	0.5 - 1
Rural	≤ 0.5
Microcell	0.3

2.1.2 Doppler Shift

Doppler shift is the random changes in a channel introduced as a result of a mobile user's mobility. Doppler spread has the effect of shifting or spreading the frequency components of a signal. This is described in terms of frequency dispersion.

Like the coherence bandwidth, *coherence time* is defined as the time over which the channel can be assumed to be constant. The coherence time of the channel is the inverse of the Doppler shift. It is the measure of the speed at which channel characteristics change. This determines the rate at which fading occurs. When the channel changes are higher than the modulated symbol rate, fast fading occurs.

Slow fading occurs when the channel changes are slower than the symbol rate.

2.1.3 Power Angle Profile

The PDP and the path delays are instructive in helping one to understand the dispersive characteristics of the channel and to calculate the channel bandwidth. The PDP is especially relevant for *single-input single-output* (SISO) channels since one can view the impulse response as being for a SISO system. However, when an array is used at the receiver, the angles of arrival are of interest as well. Since the array has varying gain vs. angle-of-arrival, it is instructive to also understand the statistics of the angles-of-arrival such as angular spread and mean angle-of-arrival (AOA). Every channel has angular statistics as well as delay statistics.

The concept of a PAP immediately conveys angular impulse response information which assists in channel characterization. Thus, the PAP is given as (Hashemi,et al, 2023).

$$P(\theta) = \sum_{n=1}^{N} P_n \delta(\theta - \theta_n) \qquad (4)$$

P_n and θ_n are the relative powers and angles respectively.

- ***Maximum Arrival Angle (θ_M):*** This is the maximum angle relative to the bore sight (θ_B) of the receive antenna array. The bore sight angle is often the broadside direction for a linear array. The maximum angle is restricted such that $|\theta_M| - \theta_B \leq 180°$.
- ***Mean Arrival Angle (θ_0):***The mean value or first moment of all arrival angles given as (Valenzeula, et al, 2024):

$$\theta_0 = \frac{\sum_{n=1}^{N} P_n \theta_n}{\sum_{n=1}^{N} P_n} = \frac{\sum_{n=1}^{N} P_n \theta_n}{P_T} \qquad (5)$$

Where $P_T = \sum_{n=1}^{N} P_n$ = multipath gain

- ***RMS Angular Spread (σ_θ):***This is the standard deviation for all arrival angles. $\boldsymbol{\sigma_\theta}$ is given as :

$$\sigma_\theta = \sqrt{\left(\frac{\sum_{n=1}^{N} P_n \theta_n^2}{P_T} - \theta_0^2\right)} \qquad (6)$$

Angular spread is an important propagation parameter which determines how spread out multipath power is about the horizon.

The spatial cross-correlation for receiver antennas at different positions within a local area is an important

International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 8, Issue 12, pp 60-65, December-2024

https://doi.org/10.47001/IRJIET/2024.812010

parameter for designing receivers that employ spatial diversity. The spatial cross-correlation function determines how far diversity antennas must be separated before the fading of their received voltage envelopes becomes uncorrelated.

2.1.4 Channel Impulse Response

The channel impulse responses are the fundamental results in time domain generated by the ray tracing algorithms (Liu and Guo, 2021). Most of all channel parameters can be derived from them. A channel impulse response contains impulses with a given delay, and a complex magnitude. Depending on the system bandwidth, some impulses can be separated and others cannot. RPS adds all those complex values coherently that cannot be distinguished on the time axis within one delay bin. Empty points in the diagram are set to the configured noise floor (-160 dBm).

2.1.5 Direction of Arrival

Every ray hits a receiver with a specific incidence angle, called direction of arrival (DoA) or angle of arrival (AoA). On the other hand, the outgoing angles at the transmitter can also be of interest. RPS stores directions of arrival at both transmitter and receiver objects in the impulse responses. The spatial resolution in the related charts is set to one degree. All magnitudes of rays that cannot be separated in space are added incoherently. In analogy to the channel impulse response chart, all empty points are replaced by the noise floor value.

III. Results and Discussion

The results derived from RPS simulation can be presented in surface plots, graphs and tables and be analysed for a given position (point analysis) and along a specific path (path analysis).

3.1 Channel Impulse Response

Channel impulse response at a receiver point derived from simulation is shown in Figure 1. Figure 2 shows the direction of arrival Phi-plane. Figure 3 shows the direction of arrival Theta-plane. Deploying the RPS, the received power and delay spread along a given path is showed in Figure 4 and Figure5 which indicate RSSI along the specified path and delay Spread along the Path respectively.

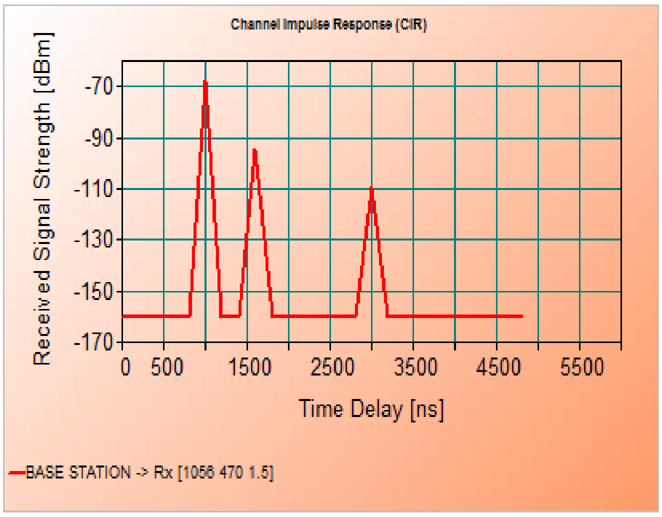

Figure 1: Channel Impulse Response at a Receiver Point

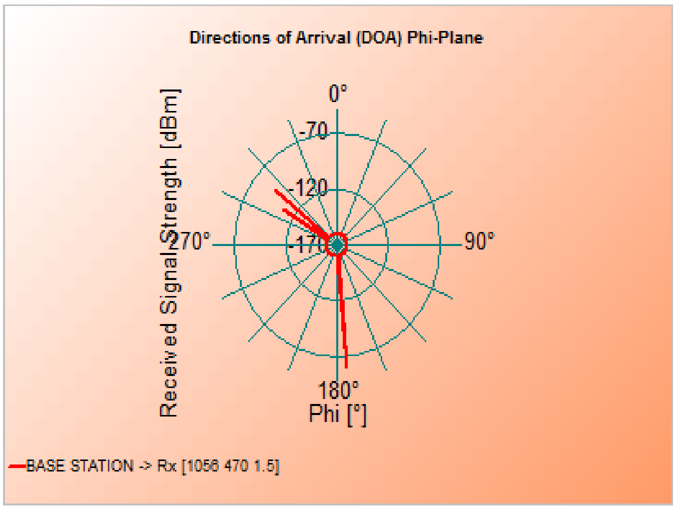

Figure 2: Direction of Arrival Phi-plane

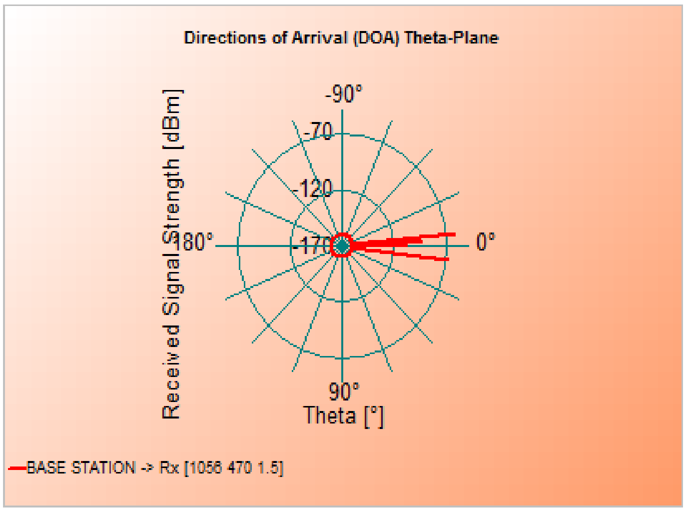

Figure 3: Direction of Arrival Theta-plane

International Research Journal of Innovations in Engineering and Technology (IRJIET)
ISSN (online): 2581-3048
Volume 8, Issue 12, pp 60-65, December-2024
https://doi.org/10.47001/IRJIET/2024.812010

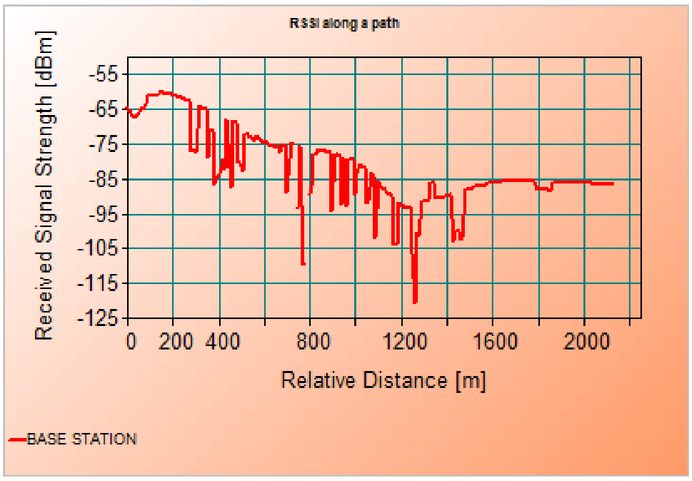

Figure 4: RSSI along the specified path

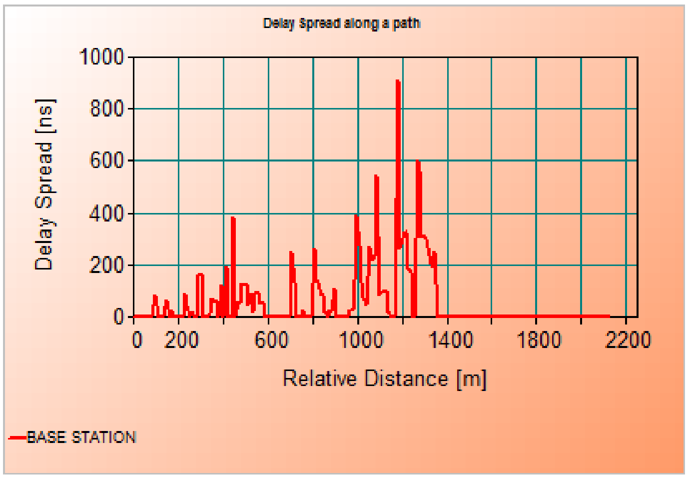

Figure 5: Delay Spread along the Path

IV. Conclusion

In order to investigate the wideband channel characteristics of wireless propagation at the 2.4GHz band for the suburban environment, we have provided an effective ray tracing computer simulation propagation model in this work. We have demonstrated that key wideband channel parameters required to describe this specific environment can be computed with reasonable computation time. Through simulation, a path loss exponent of 2.68 was found. This is a crucial pathloss model parameter. The RMS delay spread is 0.5539 and the mean delay is 1.1733. In particular, the number of fingers to consider in a Rake receiver, as well as the maximum symbol rate that can be broadcast via the multipath radio channel with moderate distortion, can be determined using this representation, which can provide valuable information for calibrating digital transmission systems.

REFERENCES

[1] Azubogu A.C.O., Onoh G.N., Idigo V.E., Ohaneme C.O.,(2011),"Empirical-Statistical Propagation Path loss Model for Suburban Environment of Nigeria at 800MHz Band", *International Union of Papers and Journal of Science and Technology*, Hyderabad, India, Vol. 7, No. 2.

[2] Garg V.K., (2019), "Wireless Communications and Networking", ed. 1, *Morgan Kaufmann Publishers, 500 Sansome Street, Suite 400, San Francisco*, CA 94111.

[3] Hashemi H. (2023), 'The indoor radio propagation channel', *Proceedings of IEEE*, Vol. 81, no. 7, pp. 943–968.

[4] Ifeagwu E.N. Abba M.O., Obi P.I., (2015a), "Analysis of Least Mean Square Adaptive Beamforming Algorithm of the Adaptive Antenna for improving the performance of the CDMA20001x base mobile radio network" *International Journal on Recent and Innovation Trends in Computing and Communication (IJRITCC)*, Vol 3, Issue 5, Pg 3296-3299.

[5] Ifeagwu E.N., Ejiofor H.C., Obi P.I., Okafor C.S., Okoro K.C. (2015b). "Bit Error Rate Reduction in Code Division Multiple Access (CDMA) 20001x Mobile Communication Network Using Antenna Diversity Technique" *International Journal Of Engineering and Innovative Technology (IJEIT)*, Vol 4, Issue 11, Pg 5-9.

[6] Liu and Guo, (2021) "A Quasi Three-Dimensional Ray Tracing Method Based on the Virtual Source Tree in Urban Microcellular Environments", *Progress In Electromagnetics Research*, Vol. 118, 397-414.

[7] Mbachu C.B., Onoh G.N., Idigo V.E., Ifeagwu E.N., (2011) "Processing ECG signal with Kaiser Window based FIR Digital Filters", *International Journal of Engineering Science and Technology, IJEST*, Vol 3, No8, Page no 6775-6783.

[8] Moraitis N., A. Kanatas, G. Pantos, P. Constantinou,(2022) 'Delay spread measurements and characterization in a special propagation environment for PCS microcells', *13th IEEE International Symposium on Personal, Indoor and Mobile Communications, Lisbon, Portugal*, Vol. 3,pp. 1190–1194.

[9] Rappaport T. S., (2018) "Wireless Communications Principle and practice", *Prentice Hall, U.S.A.*, pp 111-122.

[10] Sousa E.S., Jovanovik V.M., Daigneault C., (2024), "Delay Spread Measurements for the Digital Cellular Channel in Toronto", *IEEE Transactions on Vehicular Technology*, VOL. 43, NO. 4, pp 837-842.

[11] Rappaport T. S., (2018) "Wireless Communications Principle and practice", *Prentice Hall, U.S.A., pp* 111-122.

[12] Liu Z.-Y., Guo L.-X., (2021) "A Quasi Three-Dimensional Ray Tracing Method Based on the Virtual

ISSN (online): 2581-3048
Volume 8, Issue 12, pp 60-65, December-2024
https://doi.org/10.47001/IRJIET/2024.812010

Source Tree in Urban Microcellular Environments", *Progress In Electromagnetics Research*, Vol. 118, 397-414.

[13] Valenzuela R.A., (2024), "Ray tracing Prediction of Indoor Radio Propagation", *PIMRC, AT&T Bell Laboratories, Crawford Hill Laboratory, Holmdel*, NJ 0733, pp 140-142.

Citation of this Article:

Ifeagwu E.N., & Ejimofor, Ihekeremma A.U. (2024). 2.4 GHz Telecommunication Network Propagation Environment Characterization Using Ray Tracing Algorithm. *International Research Journal of Innovations in Engineering and Technology - IRJIET*, 8(12), 60-65. Article DOI https://doi.org/10.47001/IRJIET/2024.812010

****