International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 9 Issue 3, May-Jun 2025 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Optimization of the CI Model for Wireless Channel Characterization of 5G Cellular Networks at 3.5 GHz in an Urban Environment

Aremu O. A.[1]; Mufutau, J. A.[2]; Azeez, A. O.[3]; Liadi, A. O.[4]

[1]Physics Department, The Polytechnic, Ibadan, Oyo State, Nigeria
[2,3,4]Physics Unit, Directorate of General Studies, Federal School of Surveying, Oyo State, Nigeria

ABSTRACT

Accurate pathloss modeling is vital for efficient 5G network planning, especially in urban environments. This study presents the propagation characteristics of fifth generation (5G) signals and compares three candidate propagation pathloss models—Free Space (FS), Close-In (CI), and Alpha-Beta-Gamma (ABG)—in urban macro-cellular scenarios at 3.5 GHz. Data acquisition was carried out through a drive test approach and the signal strength data was collected using TEMS Investigation software, a spectrum analyzer, a GPS device, and a laptop, all installed in a vehicle moving at 30 km/h. Measurements were taken from 10 m up to 1.5 km and the average reference signal strength values obtained were converted into pathloss values for further analysis. Data from ten measurement routes were used for model evaluation. The results revealed that, the pathloss exponent (n) for the line-of-sight (LOS) scenario was 2.29, which falls within the expected range for urban environments. Among the models evaluated, the CI model demonstrated a reasonably good fit with a root mean square error (RMSE) of 7.37 dBm. In contrast, both the FS and ABG models overestimated the pathloss in the measured environment. A linear iterative tuning technique was applied to optimize the CI model parameters, resulting in a refined model with a reduced RMSE of 5.85 dBm which is within the acceptable ITU-R range ≤6 dB.The refined CI model offers better accuracy in predicting pathloss in urban areas and can help network providers enhance 5G service quality and user experience.

KEYWORDS: *5G network, ABG, close-in, pathloss exponent, wireless channel*

How to cite this paper: Aremu O. A. | Mufutau, J. A. | Azeez, A. O. | Liadi, A. O. "Optimization of the CI Model for Wireless Channel Characterization of 5G Cellular Networks at 3.5 GHz in an Urban Environment" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-9 | Issue-3, June 2025, pp.868-874, URL: www.ijtsrd.com/papers/ijtsrd81141.pdf

IJTSRD81141

1. INTRODUCTION

The desire for more traffic voice and data transmission capacity requires the planning of wireless communication networks and this makes the number of base stations to grow rapidly and complicate the process of determining and enhancing the location of these stations. The authors developed the ANN based model for 4G network in tropical region, the developed model performed better and was found to be optimal, out-peering existing empirical pathloss models, [1]. Unlike fourth generation (4G), the fifth generation (5G) cellular network provides high speed, low latency, massive capacity, volume density, ultra-high link as well as ultra-high mobility [2]. Pathloss and wireless channel characterization is the basis of the design and planning of the wireless communication system. The detailed propagation models are requirement for the design and deployment of wireless system [3]. Emerging 5G network systems are anticipated to introduce groundbreaking technologies, while utilizing potential new spectra and novel architectural concepts [4], [5], hence it is critical to develop new standards and channel models as well as pathloss exponent to assist engineers in system design. A number of path loss propagation models have been developed in the past and are presently deployed for coverage prediction [6], [7]. These models cannot be seen as generalized models owing to the fact that the environment from which they were developed differs from where they are. This study being novel for such in environment intends to determine the best model suitable for 5G mm wave signal operating at 3.5 GHz with the objectives of improving the downlink and uplink peak data rates, scalable bandwidth and improved spectral efficiency in urban environment [8]. The paper also presents the alpha-beta-gamma (ABG) and close-in (CI) free space reference distance path loss models at 3.5 GHz, comparison between the parameters is also presented. The data so generated would be useful in assessing the pathloss in the region. The pathloss exponent which is an important parameter indicating the rate at which the received signal strength decreases with separation distance between the transmitter and receiver is also presented.

2. 5G PATHLOSS MODELS

Free space (FL), CI and ABG path loss models are broad all frequency models that designate large-scale propagation path loss at all applicable frequencies in a certain scenario.

2.1. Free Space Model

The free space model as a function of distance and frequency (1) is given by [9], [10]

$$FL\ (dB) = 32.45 + 20log_{10}d + 20log_{10}f \quad (1)$$

where FL denotes the free space path loss in dB at a separation distance (d) between TX and RX at the carrier frequency f:

2.2. CI Model

The expression for the CI model pathloss (dB) [10], [11] with minimum SF standard deviation χ_σ, is given as *(2)*

$$PL = FL + 10nlog_{10}d + {\chi_\sigma}^{CI} \quad (2)$$

Eq. (3) becomes (4) with ${\chi_\sigma}^{CI}$ the subject,

$${\chi_\sigma}^{CI} = PL - FL - 10nlog_{10}d \quad (3)$$

For simplicity, $Y = PL - FL$ and $Z = 10log_{10}d$, The expression (3) which is the standard deviation becomes,

$$\sigma^{CI} = \sqrt{\frac{\sum {\chi_\sigma}^{CI}}{N}} = \sqrt{\frac{\sum(Y - Zn)^2}{N}} \quad (4)$$

where N is the number of measured data points., n is the pathloss exponent. When $\sum(Y - Zn)^2$ is minimized, its derivative with respect to the pathloss exponent becomes zero, that is,

$$\frac{d\sum(Y - Zn)^2}{dn} = \sum 2Z(Zn - Y) = 0 \quad (5)$$

Then,

$$n = \frac{\sum YZ}{\sum Z^2} \quad (6)$$

2.3. Alpha, Beta, Gamma (ABG) model

The expression for ABG model is given by [12]

$$PL_{ABG}(dB) = 10\alpha log_{10}(d) + \beta + 10\gamma log_{10}f + {\chi_\sigma}^{ABG} \quad (7)$$

where $PL_{ABG}(dB)$ represents the pathloss over distance and frequency, α and γ are coefficients depicts the dependence of pathloss on distance and frequency respectively, β is an enhanced offset value for path loss, f is the carrier frequency in GHz, d is the separation distance (m), and ${\chi_\sigma}^{ABG}$ is the SF standard deviation describing large-scale signal fluctuations about the mean path loss over distance

2.4. Second order Polynomial

$$y = a + bx + cx^2 \quad (8)$$

$$f(x) = a_j x^j + a_{j-1}x^{j-1} + a_{j-2}x^{j-2} + \dots + a_0 \quad (9)$$

$$a_0 N + a_1 \sum x_i + \cdots + a_j \sum {x_i}^j = \sum x_i f(x)_i \quad (10)$$

$$\begin{aligned} a_0 \sum x_i + a_1 \sum {x_i}^2 + \cdots + a_j \sum {x_i}^{j+1} &= \sum {x_i}^2 f(x)_i \\ \vdots \quad\quad \vdots \quad\quad \vdots \quad\quad & \quad \vdots \\ a_0 \sum {x_i}^j + a_j \sum {x_i}^{j+1} + \cdots + a_j \sum {x_i}^{2j} &= \sum {x_i}^j f(x)_i \end{aligned} \quad (11)$$

$$\begin{bmatrix} N & \sum x_i & \dots & \sum {x_i}^j \\ \sum x_i & \sum {x_i}^2 & \dots & \sum {x_i}^{j+1} \\ . & . & . & . \\ . & . & . & . \\ \sum {x_i}^j & \sum {x_i}^{j+1} & \dots & \sum {x_i}^{2j} \end{bmatrix} \begin{bmatrix} a \\ b \\ . \\ . \\ c \end{bmatrix} = \begin{bmatrix} \sum x_i f(x)_i \\ \sum {x_i}^2 f(x)_i \\ . \\ . \\ \sum {x_i}^j f(x)_i \end{bmatrix} \quad (12)$$

where N is the number of data points, $f(x)_i$ is the pahtloss as a function of distance. (12) can be expressed in terms of the measured pathloss (PL_m) and the separation distance (d) between the transmitter and receiver as (13)

$$\begin{bmatrix} N & \sum d_i & \dots & \sum {d_i}^j \\ \sum d_i & \sum {d_i}^2 & \dots & \sum {d_i}^{j+1} \\ . & . & . & . \\ . & . & . & . \\ \sum {d_i}^j & \sum {d_i}^{j+1} & \dots & \sum {d_i}^{2j} \end{bmatrix} \begin{bmatrix} a \\ b \\ . \\ . \\ c \end{bmatrix} = \begin{bmatrix} \sum d_i PL_m \\ \sum {d_i}^2 PL_m \\ . \\ . \\ \sum {d_i}^j PL_m \end{bmatrix} \quad (13)$$

where *i* is the position of each of the data points, and *j* is the order of the polynomial.

For the measured pathloss, a second order polynomial equation in terms of the fitted data is of the form of (14)

$$PL(dB) = a + b(d) + c(d^2) \quad (14)$$

3. METHODOLOGY

3.1. Measurement Campaign

All-encompassing measurement campaigns to acquire pathloss data at varying distances from two different 3.5 GHz base station transmitters were conducted in Ibadan, Oyo State, Nigeria (Latitude 7°22'39'″N, Longitude 3° 54′21'″E). A total of ten survey itineraries were mapped out to accommodate sufficient diversity in the propagation environment and to cover radio wave propagation in the antenna direction of the base station transmitters. Signal measurements were carried out by drive test in a clear weather. Distance covered by the drive routes were considered long enough to allow the noise floor of the receiver to be reached as shown in *Figure 1*. Transmission Evaluation and Monitoring System (TEMS) network performance investigation software and spectrum analyzer shown in *Figure 2* capable of measuring signal strength at microwave frequency band were used to collect the data. TEMS Investigation software an on an Intel Core PC, it has data collection, real-time network data analysis, and post-data processing capabilities. A TEMS mobile station software USB dongle, and a Garmin Global Positioning System (GPS) were connected to the laptop and the whole setup was placed in a vehicle, and the vehicle was driven at an average speed of 30 km/h. The signal strength was measured starting from 13 m up to 1.443 km. The average reference signal strength measured was converted to the equivalent pathloss values for further analysis. The pathloss is calculated using (15) as reported by Rapparport [13],

$$PL(dBm) = P_{BS} + G_{BS} + G_{MS} - L_{FC}RSS \quad (15)$$

where P_{BS} is the transmitter power (43 dBm), G_{BS} is the transmitter antenna gain (12 dBi), G_{MS} is the receiver antenna gain (0 dBi), L_{FC} is feeder cable and connector loss (2 dB), L_{AB} is the Antenna Body Loss (4 dB), and L_{CF} = Combiner and filter loss (4.5 dB). Therefore, *(15)* becomes (16),

$$PL(dBm) = 44.5 - RSS \quad (16)$$

The measured data were compared with empirical propagation models (CI, ABG and free space) in order to determine the best model for pathloss prediction in this study area. To evaluate the performance of different models considered, four statistical tools (MAPE, MSE, MAE and RMSE) were chosen as metrics. These were determined by comparing the measured pathloss and predicted data using Equations (17), (18), (19) and (20) respectively.

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{P_m - P_p}{P_m}\right) \times 100 \quad (17)$$

$$MSE = \frac{1}{N}\sum_{i=1}^{N}\left|P_m - P_p\right|^2 \quad (18)$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|\overline{P_m} - P_p\right| \quad (19)$$

$$RMSE = \sqrt{\frac{\sum\left(P_m - P_p\right)^2}{N}} \quad (20)$$

where P_m is the measured pathloss, P_p is the predicted pathloss, $\overline{P_m}$ represents mean pathloss.

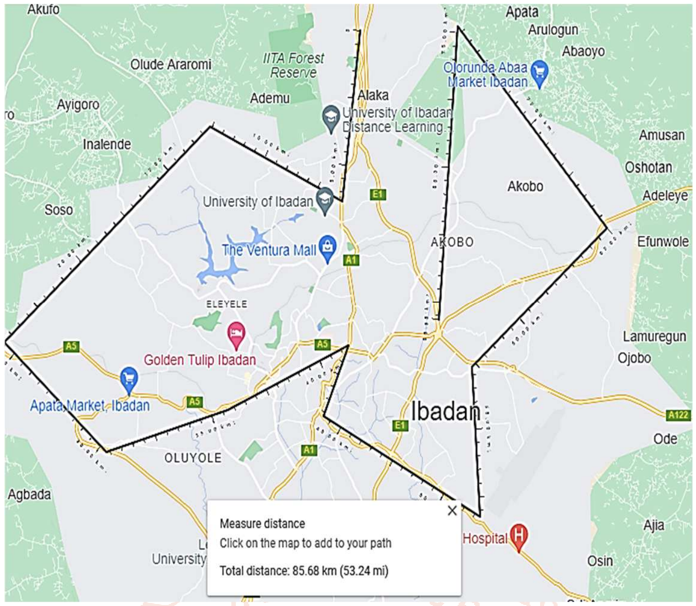

Figure 1. Google Map showing the study area [14]

Figure 2 Spectrum analyzer

4. Result and discussions

4.1. Variation of pathloss with distance

As presented in Figure 3 and Table 1 the overall pattern displays the pathloss values which increase as the separation from Tx to Rx increases. The results revealed that the closed-in and ABG models offered very comparable modeling performance using actual data, with the CI model offering simplicity and a physical basis with one parameter, and providing a more conservative NLOS path loss estimate at large distances. The deviation of experimental path loss from the empirical and optimized models have been expressed in terms of performance measurement metrics using MSE, MAPE, MAE and RMSE for each environment understudy. The comparison between the measured data and the pathloss predictions obtained using free space and ABG models show that, the two models are inadequate in this study area having RMSE 60.47 and 19.85 dBm respectively. However, CI has the least MSE, MAPE, MAE and RMSE values 129 dB, 8.20%, -7.84 and 7.37dB respectively but not absolutely in good agreement with experimental data. The results show that, it is necessary to modify CI model for correct and accurate prediction of pathloss in this area.

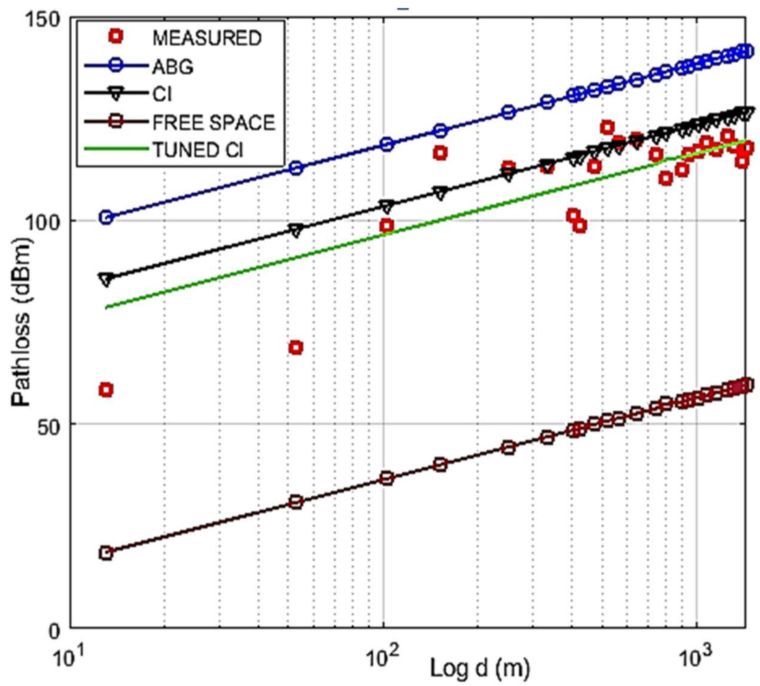

Figure 3. Comparison of measured pathloss, empirical and tuned models

4.2. Optimization of CI model

The main factors in the process of optimization is the estimation of pathloss exponent which is a crucial parameter in wireless communication system, it indicates the rate at which the received signal strength decreases with distance.

4.3. Estimation of pathloss exponent (n)

The pathloss exponent is obtained using (6) and the data in Table 1 as,

$$n = \frac{\sum YZ}{\sum Z^2} = 2.19$$

Substituting the value of Y and Z in (4), the value of σ^{CI} is obtained as *(21)*,

$$\sigma^{CI} = \sqrt{\frac{\sum(PL - FL - 2.19 \times 10\, log\, d)^2}{N}} \quad \textbf{(21)}$$

From the observation in Table 1, $\sum PL - FL = 1376$ and $\sum 10 \log d = 614.83$. The number (N) of data point = 23.

$\therefore \sigma^{CI} = 6.25$

By modification of CI model shown in (2), the proposed model for 5G network operating in urban environment is presented as *(22)*

$$PL = 32.45 + 20log_{10}d + 20log_{10}f + 2.19log_{10}d + 6.25 \qquad (22)$$

4.4. Second order polynomial

The values of a, b, and c in (12) are obtained using the observed values in Table 1. The values obtained are: a = 72.88, b = 0.09173 and c = -0.0000433. Therefore, a second order polynomial model in terms of the fitted data using (14) is presented as,

$$PL(dB) = 72.88 + 0.09173(d) - 0.0000433(d^2) \qquad (23)$$

Table 1 Pathloss and parameters estimation from the selected database

d (m)	Z=10log d	PL (dB)	FL(dB)	Y = PL-FL	YZ	Z^2
13	11.13943	58.44	18.66	45.11	443.1267	124.087
53	17.24276	68.57	30.87	37.18	650.052	297.3127
103	20.12837	98.59	36.64	59.68	1246.953	405.1514
153	21.84691	116.65	40.07	75.71	1673.037	477.2877
253	24.03121	112.7	44.44	68.74	1640.37	577.4988
333	25.22444	113.37	46.83	67.58	1678.434	636.2725
403	26.05305	101.05	48.49	53.91	1369.348	678.7614
423	26.26340	98.75	48.91	51.27	1308.968	689.7664
473	26.74861	113.37	49.88	65.08	1698.269	715.4882
523	27.18502	122.86	50.75	73.82	1960.312	739.0251
563	27.50508	118.96	51.39	69.37	1858.519	756.5296
643	28.08211	119.98	52.54	69.38	1893.857	788.6049
743	28.70989	116.21	53.80	64.50	1791.784	824.2577
803	29.04716	110.42	54.97	58.10	1610.665	843.7372
903	29.55688	112.27	55.49	59.03	1678.240	873.6090
943	29.74512	115.96	55.87	62.37	1787.384	884.7720
1013	30.05609	117.10	56.49	62.94	1821.700	903.3688
1083	30.34628	119.17	57.07	64.48	1884.504	920.8970
1163	30.65580	117.32	57.69	62.05	1828.005	939.7779
1263	31.01403	120.66	58.41	64.72	1930.624	961.8703
1313	31.18265	118.29	58.75	62.04	1856.615	972.3575
1403	31.47058	114.37	59.32	57.58	1732.455	990.3972
1443	31.59266	117.83	59.56	60.81	1840.904	998.0964

4.5. Validation of Optimized CI model

The tuned CI path loss model obtained (22) was applied for path loss estimation so as to validate its performance. The results gave the lowest MAPE and RMSE value 1.62 % and 5.85 dB respectively as depicts in Table 2. A significant reduction in the MAPE and RMSE obtained indicates that the tuned/optimized model is valid. Hence, the optimized model gave better results as compared to the existing CI model. From the available literature [15], the performance of any pathloss model is considered acceptable if it provides an overall RMSE of 6 -7 dB for urban areas

Table 2 Performance analysis of the model

Statistical parameters	Free space	CI	ABG	Tuned CI
MSE (dB)	3657	129	568	78
MAPE (%)	54.80	8.20	22.30	1.62
MAE	59.13	-7.84	-22.8	-0.86
RMSE (dBm)	60.47	7.37	19.85	5.85

Conclusion

The tuning of the CI model for wireless channel characterization of a 5G cellular network at 3.5 GHz in an urban environment has been studied. Pathloss measurement results were used to optimize empirical models. The analysis of the models shows that, the free space and ABG models underestimated the pathloss with RMSE values of 60.47 and 19.85 dBm respectively. However, the CI model has the lowest MSE, MAPE, MAE and RMSE values 129 dB, 8.20%, -7.84 and 7.37dB respectively but not absolutely in good agreement with experimental data. The tuned model generated was validated using twenty new measurements and subjection to statistical criteria revealed good model performance having root mean square error 5.85 dBm.

References

[1] Aremu, O. A., Oyinkanola, L. O. A., Makinde, O. S., Fajemiroye, J.A., Ajani, S.A., Alade, M.O (2022). Development of Artificial Neural Network Based Model for Prediction of Radio Pathloss of a 4G-LTE-A Network in Ogbomoso, Nigeria. European Modern Studies Journal. Vol. 6 (5). Pp 399 – 410.

[2] Yang Y, Xu J, Shi G and Wang C-X 2018 5G Wireless Systems; simulation and evaluation techniques ed Xuemin Sh Sh (Switzerland, S: Springer) 45-147

[3] Zhang K, Zhang R, Wu J, Jiang Y and Tang X 2019 Measurement and Modeling of Path Loss and Channel Capacity Analysis for 5G UMa Scenario 11th Int. Conf. on Wireless Communications and Signal Processing (WCSP) 1–5

[4] Seybold, J.S. (2005) "Introduction to RF Propagation". John Wiley& Sons Inc, Hoboken, New York 2005, Pp 135 – 162.

[5] Yadav Umesh, (2013) "Outdoor Propagation models Comparison: Literature Review," International Journal of Electronics Communication and Computer engineering", Vol. 4, (3), 755- 760.

[6] Abhayawardhana, V. S., Wassell, I. J., Crosby, D., Sellars, M. P., and Brown, M. G. (2005), "Comparison of empirical propagation path loss models for fixed wireless access systems", Proceedings of the IEEE 61st Vehicular Technology Conference, VTC 2005Spring, Stockholm, Sweden, Vol. 1, May, pp. 73-77.

[7] Dimou, K., Wang, M., Yang, Y., Kazmi, M., Larmo, A., Pettersson, J. and Timner, Y. (2009), "Handover within 3GPP LTE: design principles and performance", Proceedings of the IEEE 70th Vehicular Technology Conference (VTC 2009-Fall), Anchorage, Alaska, USA, September, pp. 1-5.

[8] Milanovic, J., Rimac-Drlje, S., and Bejuk, K. (2007), "Comparison of propagation models accuracy for WiMAX on 3.5 GHz", Proceedings of the 14th IEEE International Conference on Electronics, Circuits and Systems, ICECS 2007, Marrakech, Morocco, pp. 111-114.

[9] Rakesh, N., and Srivasta, S.K., (2012) "An Investigation on Propagation Path loss in Urban Environments for Various Models at Transmitter Antenna Height of 50 m and Receiver Antenna heights of 10 m, 15 m and 20 m respectively" International Journal of Research and Reviews in Computer Science. Vol. 3 No.4, pp. 1761-1767

[10] Piersanti, S. (2012) "Millimeter waves channel measurements and path loss models," in 2012 IEEE International Conference on Communications (ICC), Jun. 2012, pp. 4552–4556.

[11] Andersen, J. B., Rappaport, T. S., Yoshida, S. (1995) "Propagation measurements and models for wireless communications channels," IEEE Communications Magazine, vol. 33, no. 1, pp. 42–49, Jan. 1995.

[12] Deng, S., Samimi, M. K., Rappaport, T. S (2015). "28 GHz and 73 GHz millimeter-wave indoor propagation measurements and path loss models," in 2015 IEEE International Conference on Communications (ICC), ICC Workshops, Jun. 2015

[13] Rappaport, T. S., MacCartney, G. R., Samimi, M. K., Sun, S. (2015). "Wideband millimeter-wave propagation measurements and channel models for future wireless communication system design," IEEE Transactionson Communications, vol. 63, no. 9, pp. 3029–3056, 2015.

[14] Google Maps, 2020. Map of UFRN campus. [Online]. Google. Available from: https://goo.gl/maps/1RbPQwn5o6y [Accessed 24 November 2020].

[15] Wu, J., and Yuan, D. (1998). Propagation measurements and modeling in Jinan city. In Personal, Indoor and Mobile Radio Communications, In 9th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, 8-11 September 1998, Boston, Massachusetts USA, 3: 1157-1160. DOI: 10.1109/PIMRC.1998.731360