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Empirical Path Loss Modelling for Selected LTE Networks in FUTA Campus, Ondo State, Nigeria

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ABSTRACT

Deployed Long Term Evolution (LTE) networks in Nigeria can barely meet the desired 100 Mbps downlink throughput leading to unsatisfactory quality of experience by mobile users. Typically, mobile network operators (MNOs) rely on network planning tools designed for generalized environments. These tools employ legacy propagation models that may not be suited to the operational environments under consideration. As such, the efficiency of such legacy path loss models suffers when they are used in environments different from those for which they have been designed, and this poses a major challenge to the MNOs. This is because the Nigerian geographical areas and topographical features vary widely from the areas where the legacy models were developed. Several studies in Nigeria and other African countries have shown that the legacy path loss models perform unsatisfactorily when compared with field measurement data. To address this challenge and enable accurate path loss prediction for an urban campus environment, extensive measurements at 2600 MHz were carried out in the main campus of the Federal University of Technology Akure (FUTA), Ondo State, Nigeria. The measurement results were compared with the path loss predictions from the commonly-used legacy propagation models (Free space and 3GPP TR 36.873). The results show that the legacy path loss models under-predict the path loss averagely by 20-40 dB, and up to 88 dB in some cases, for the considered environment. Root mean square error (RMSE) values in the range of 1.895 and 9.159 were also observed along the routes. The measurement results will enable the MNOs to adjust the path losses in order to deliver improved quality of service.

Keywords: LTE, Propagation Models, Path Loss, Root Mean Square Error, Reference Signal Received Power.

1 Introduction

According to Cisco's visual networking index for 2018–2023, there will be 5.3 billion internet users worldwide by 2023, up from 3.9 billion in 2018 [1]. This results in a huge rise in mobile traffic over the course of five years. For Nigeria, the number of mobile data subscribers was 148 million as at April 2022 for a country with approximately 220 million people [2], [3] showing the high and growing demand for data and broadband services in the country. In order to deliver higher throughput and better quality of service (QoS) and quality of experience (QoE) for the users, the major mobile network operators (MNOs) in Nigeria (including Globacom, MTN, AIRTEL, 9MOBILE, SMILE, and NTEL) have deployed fourth-generation (4G) long-term evolution (LTE) networks. However, the intended 100 Mbps downlink speed [4] is frequently not achieved, resulting in user complaints and discontent, which can lead to regulatory action by the Nigerian Communications Commission (NCC) [5].

To address the challenge and deliver improved QoS by the MNOs, accurate characterization of the wireless channel is highly important. The base station (BS) transmits signals, and as these signals travel across the wireless channel to the receiver (RX), attenuations occur that cause the signal intensity and quality to degrade [5]. The signals are degraded due to distance-dependent attenuation as well as reflection, diffraction, and scattering as they collide with objects in their path. Propagation or path loss (PL) modeling is frequently used to describe this phenomenon. But historically, the propagation models have concentrated on forecasting the received signal strength as well as the signal strength variability at a specific distance from the transmitter (TX). These models are helpful in determining the radio coverage area of a transmitter because they provide signal strength predictions for various TX- RX separation distances [6], [7].

In wireless network planning, propagation models are used to, among other things, estimate cell coverage and evaluate the consequences of interference [6]. There are three major classes of propagation models: stochastic, deterministic and empirical. Stochastic models predict path loss using statistical parameterization. They do not consider environmental peculiarities and therefore have limited accuracies in diverse terrains. The deterministic models, on the other hand, employ ray tracing theories that incorporate environmental parameters to their finest granularity. As a result, deterministic models are computationally complex but they give highly accurate predictions. As for empirical models, they are developed based on field measurements. They are, therefore, site-specific and accurate for the specific propagation environment of interest [7]-[11].

To accurately characterize and predict path loss for a University Campus – which is a hotspot for the MNOs, this study employs the empirical, measurement-based path loss modelling approach. Reference Signal Received Power (RSRP) measurements of LTE BSs of selected operators at 2600 MHz are undertaken. Through fine-tuning their operations, the MNOs will be able to deliver improved QoS and QoE because the resulting path loss models better precisely represent the environment under consideration.

The remainder of the paper is structured as follows: The pertinent material is reviewed in Section 2 of the literature text. Section 3 presents the methodology of the study with respect to

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the measurement procedures and the legacy models used for comparative analyses. Result discussion was presented in Section 4 and Section 5 offers conclusion and recommendation for further studies.

2 Related Works

Various path loss models have been put forth over time for various terrains and frequency ranges. However, there is still much research to be done on how these path loss models perform when utilized in wireless terrains other than those for which they were initially designed [6]. Therefore, as shown by numerous studies around the globe, these models have to be adjusted to the measured data of the specific areas under consideration for accurate performance [12].

The predictions of three empirical propagation models were compared to the measured path loss data at 3.5 GHz in Cambridge in [13]. The findings demonstrated that the COST-231 and Stanford University Interim (SUI) models overestimated path loss in the environment under consideration.The ECC-33 model was suggested for usage in urban settings since it provided the best fit to the measurement data. In [14], the Hata path loss model was optimized for precise prediction suitable for a suburban area in Malaysia using the least-square method. Additionally, tests in the open air in a frequency range of 400 MHz to 1800 MHz were made in Cyberjaya, Malaysia. The Hata model demonstrated the best fit when the measurement results were compared to the current models. The Putrajaya region verified the optimized Hata model, which was used to quantify relative error and assess performance effectiveness. The reduction of mean relative errors was successful, as evidenced by the data.

The authors also provided path loss models for LTE-Advanced networks [14], [15]. Several propagation models, were used to calculate the path loss for different contexts (i.e., remote, partly dense, and cities), all for the 2.3 - 3.5 GHz frequency bands. When comparing other models in the terrain under consideration, the results shows that, COST-231 Hata model provides the least PL for all situations. However, this investigation only uses models with the least path loss and did not contrast the forecast of classical models with that of conventional models.

Similarly, extensive measurement campaigns at 3.4 GHz frequency were undertaken in Lagos, Nigeria and presented in [10]. Six classical path loss models were compared with the measurement results. The COST 231-Hata and Ericson models were shown to perform the best in urban and suburban regions. Additionally, the authors of [16] used data gathered in urban Nigerian cities to create the path loss models to assess the effectiveness of empirical, heuristic, and geographical methodologies used for signal path loss predictions. The resulting models were compared to field data that was measured. All models, with the exception of the ECC-33 and Egli models, provided acceptable root mean square error (RMSE) values. The three methods submitted were straightforward to use and were most frequently used.

Additionally, research has been done to compare the path loss of city and suburb areas to determine whether certain propagation model can be applied in the two environments. The authors of [17] demonstrated that compared to suburban areas, metropolitan areas experience larger losses in propagation models. In all settings, it was impossible to recommend just one generic model. Authors [18], examined 4G LTE BS's throughput performance to see whether LTE can support data requirements of broadband applications.

The 4G LTE BS running on 2600 MHz that was deployed in Ghana gave the highest recorded output of 29.9 Mbps in each sector in the field. Users around 2.5 km of the cell range from the BS experienced the highest downlink throughput of 62.318 Mbps. These established that 4G LTE can satisfy Ghanaians' rising demand for broadband. After contrasting these throughputs with desired outputs necessary to support data-centric broadband usage, this result was reached.

Further, the author of [19], examined the path loss of mobile radio series in L-band frequency (i.e., 800 MHz) in Akure, South Western Nigeria. The city of Akure is a dense urban environment. Measurements were carried out to determine the received signal strength (RSS) of MTN network within the Akure metropolis. The analysis did not take into account the 2600 MHz spectrum being considered in this article and instead concentrated on the 800 MHz band. Also, the study was limited to only one MNO (i.e., MTN) and did not consider multiple MNOs as studied in this work.

It is crucial to choose the optimum model for each environment under consideration because different path loss models perform differently in various settings. As far as the authors are aware, no research has examined the path loss for the FUTA campus setting for LTE networks from various MNOs. This study, therefore, addresses this gap and aims to not only enable operators deliver improved QoS but also facilitate seamless connectivity and enhanced QoE and customer satisfaction.

3 Field Measurements

In this section, we present the procedures for the field measurements carried out and describe the considered environment as well as the legacy path models used for comparison.

3.1 Measurement Procedures

For the empirical path loss modelling approach considered in this work, reference signal received power (RSRP) measurement values were taken along three different routes within the main campus of the Federal University of Technology Akure (FUTA), Ondo State, Nigeria. The size of the FUTA campus is 640 hectares ($\mathrm{i.e.}, 6.4\ km^2$) [20]. The drive tests were conducted using smartphones pre-installed with an LTE software app named Cell Tower Locator connector [21]. The smartphone was connected to a computer via the universal serial bus (USB) port. The Cell Tower Locator probe is a software instrument for data collection. Location and distance were determined using the global positioning system (GPS). For six different LTE BSs operating on 2600 MHz carrier frequency on the campus, RSRP values were measured at intervals of 10 m away, and up to 1000 m away from the respective BSs. The starting reference distance (d_r) of 10 m was used.

The height of the mobile antenna receiver of 1.5m was kept constant during the measurements. The personal device, maintaining information gathered, also received the measured data via the phones. After then, post-processing and analysis were performed on these record log files. From February through May 2022, field measurements were made. Both line of sight (LOS) and non-LOS were used to measure the RSRP (dBm) values. The BSs of the different MNOs have varied transmitter heights between 16 m and 40 m. Fig. 1 shows the measurement system setup.

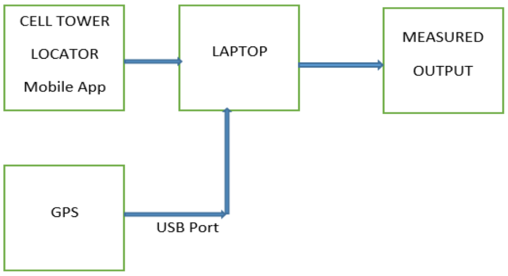

Fig. 1 Measurement setup block diagram.

Table 1 Assignment Table for Ondo State, Nigeria Frequency

2.6 GHz BAND FOR ONDO STATE NIGERIA				
PARAMETERS	**FDD**		**TDD**	
CHANNEL BLOCK	A1	B1	C1	D
MOBILE NETWORK OPERATOR	AIRTEL	MTN	OPEN SKY	MEGATECH
BANDWIDTH	20 MHz	30 MHz	10 MHz	40 MHz
TX Frequency (MHz)	2500-2520	2520-2550	2560-2570	2575-2615
RX Frequency (MHz)	2620-2640	2640-2670	2680-2690	

3.2 Environmental Details

Several test measurements were collected along the stated three routes (A, B and C) of the FUTA main campus as shown in the map of Fig. 2 and as described thus:

Route A: This route is from the Center for Renewable Technology (CRET) to the Middle Belt area (close to the School of Engineering and Engineering Technology (SEET), Obanla, Ondo State, South West Region of Nigeria). The coordinates for CRET are: 7° 18' 11.322" N (latitude), 5° 7' 38.1288" E (longitude) while the coordinates for Middle Belt are: 7° 18' 13.032" N (latitude), 5° 8' 13.668" E (longitude). The route is a flat terrain with a few high rise buildings separated apart with vegetation.

Route B: This route is from the School of Environmental Technology (SET) to the Middle Belt, FUTA. The coordinates for SET are: 7° 17' 56.3244" N (latitude), 5° 8' 14.0748" E (longitude) while the coordinates for Middle Belt are: 7° 18' 13.032" N (latitude), 5° 8' 13.668" E (longitude). The route is characterized with high rise buildings, automobiles and machines.

Route C: This route is from the Students' Union Building (SUB) to the Middle Belt area of the University campus. The coordinates for SUB are: 7° 18' 15.264" N (latitude), 5° 8' 46.0644" E (longitude) while the coordinates for Middle Belt are: 7° 18' 13.032" N (latitude), 5° 8' 13.668" E (longitude). The route is characterized as an urban area due high rising buildings, few vegetation, automobiles and business areas.

Base Stations Locations: CRET (MTN / AIRTEL), SET (MTN / AIRTEL) and SUB (MTN / AIRTEL).

3.3 Network Parameters

The parameters used to create the path loss models for various routes are listed in Table 2. For all locations and networks, the carrier frequency is 2600 MHz, distance covered in each route is 10 -1000 m, reference distance (d_r) is 10 m while the receiver antenna height is 1.5 m throughout the measurement campaign.

Table 2 Network Parameters

S/N	Location	MNO BS	TX. antenna height (m)	TX. Power (dB)
1.	CRET	MTN	40	13.5
		AIRTEL	32	18.0
2.	SET	MTN	30	12.5
		AIRTEL	32	18.0
3.	SUB	MTN	32	3.1
		AIRTEL	32	18.0

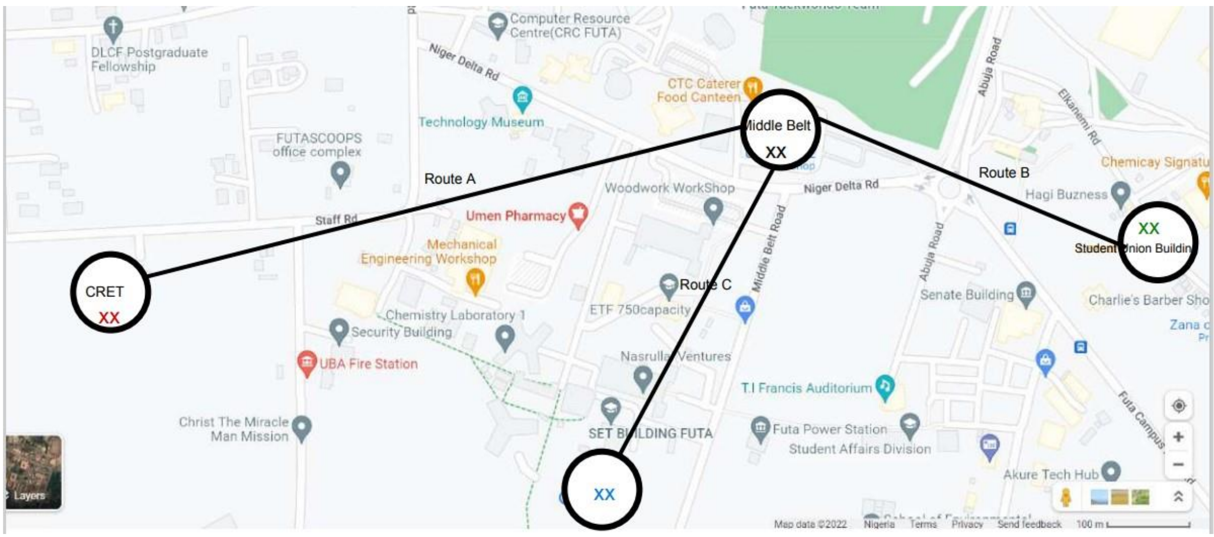

Fig. 2: Map of all considered routes of the FUTA Campus (Akure, Ondo State, Nigeria).

3.4 Propagation Models

The measurement-based path loss model developed in this study is compared to the following legacy path loss models.

3.4.1 Free Space Path Loss

The free space path loss (FSPL) model [22] is given in Eq. (1)

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

The frequency is denoted as f (MHz) and distance is d (km).

3.4.2 3GPP TR 36.873 (3D Urban-Macro) Channel Model

The Third Generation Partnership Project (3GPP) TR 36.873's three dimensional (3D) channel model is used for comparison because it is applicable for the frequency range 0.5-6 GHz [23]. Using the model, the path losses for LOS and NLOS are given by Eq. (2) and Eq. (3), respectively:

$$PL_{los} = \begin{cases} 28 + 22\,log_{10}(d_{3D}) + 20\,log_{10}(f). & 10 < d_{2D} < d_{BP} \\ 28 + 40\,log_{10}(d_{3D}) + 20\,log_{10}(f) - 9\,log_{10}\left((d_{BP})^2 + ((25 - h_{UE})^2)\right). & d_{BP} < d_{2D} < 500 \end{cases} \quad (2)$$

$$PL_{Nlos} = 69.51 + 39.09\,log_{10}(d_{3D}) + 20\,log_{10}(f) + 7.5\,log_{10}(h_{UE}) - 0.6h_{UE} - 0.0825(h_{UE})^2 \quad (3)$$

where the shadow fading (SF) for LOS is 4 dB and SF for NLOS is 6 dB; f (GHz) is frequency, $d_{2D}(m)$ is the two dimensional (2D) separation distance, $d_{3D}(m)$ is the 3D distance and $h_{UE}(m)$ *denote the* height of the user equipment (UE) or the mobile receiver.

The breakpoint distance d_{BP} is given $d_{BP} = 320\left((h_{UE} - 1)fc\right)$ [24] for the urban-macro (UMa) setting considered in this work. The LOS probability Pr_{LOS} is evaluated using Eq. (4)-(6).

$$Pr_{LOS} = \left(min\left(\frac{18}{d_{2D}}, 1\right)\left(1 - exp\left(\frac{-d_{2D}}{63}\right)\right) + exp\left(\frac{-d_{2D}}{63}\right)\right)(1 + C(d_{2D}, h_{UE})) \quad (4)$$

$$C(d_{2D}, h_{UE}) = \begin{cases} 1, & d_{2D} \le 18 \\ 1 + 1.25C'(h_{UE})\left(\frac{d_{2D}}{100}\right)^3 exp\left(\frac{-d_{2D}}{150}\right), & 18 < d_{2D}, h_{UE} \le 13 \end{cases} \quad (5)$$

$$C'(h_{UE}) = \begin{cases} 0, \\ \left(\frac{h_{UE} - 13}{10}\right)^{1.5}, & 13 < h_{UE} \le 23 \end{cases} \quad (6)$$

3.5 Performance Metrics

The following metrics were used to assess and compare the models' performance:

3.5.1 Path Loss Exponent

From the measured data, for each of the routes taken into consideration, the path loss exponent (n) was calculated. It illustrates the lossy nature of the specific propagation terrain. The path loss exponent is computed using Eq. (7) [25]:

$$n = \frac{\sum_{i=1}^{k}\left(Pl_{d_r} - P_i\right) \times 10\,log\left(\frac{d}{d_r}\right)}{\sum_{i=1}^{k}\left(10log\left(\frac{d}{d_r}\right)\right)^2} \quad (7)$$

where, n denotes the path loss exponent, separation distance is denoted as d, measured data point is k, and p_i denotes the power received at the reference distance (d_r), the path loss at reference distance is denoted as Pl_{d_r}.

3.5.2 Root Mean Square Error

The difference between the signal power predicted by a model and the actual measured signal is quantified by the root mean square error (RMSE). Comparing the prediction errors of the various propagation models with the provided measurement data provides a measure of accuracy. Computed RMSE values were obtained using Eq. (8):

$$RMSE = \sqrt{\frac{\sum_{k=1}^{k}[p_i - \widehat{p_i}]^2}{k}} \quad (8)$$

where k is the number of measured samples, p_i is the measured power value at a given distance, $\widehat{p_i}$ is the predicted power value at a given distance.

4 Results and Analysis

In this section, measurement results are presented for the selected MNOs (MTN-Nigeria and Airtel-Nigeria) for the 2600 MHz frequency along the three routes of the FUTA campus considered in this study.

4.1 RSRP Results

The RSRP results for MTN and Airtel BSs along the three routes (Routes A, B and C) are shown in Fig. 3. Established average received power for each measurements were achieved by averaging the data taken at each point from the BS antennas. Each result indicates the power received computed against distances of two different LTE networks (MTN-Nigeria and Airtel-Nigeria) deployed within the FUTA campus. The RSRPs are plotted against distances as shown in Fig. 3. The results show decrease in the RSRP measurement values as the receiver moves away from the base stations of each network. The decay is due to the distance-dependent attenuation with increasing distance, and the variations in measured values of the same network along different routes are attributable to the differences in shadow fading (due to obstacles) and terrain of the different routes.

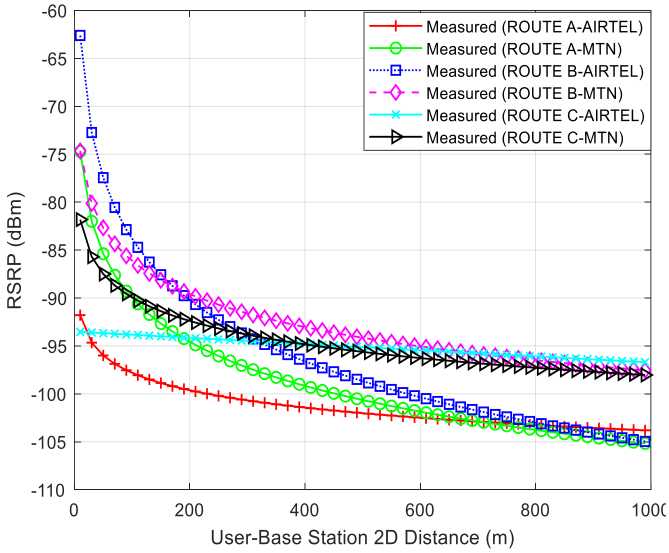

Fig. 3: RSRP of all Routes.

4.2 Path Loss Results

The following formula (Eq. (9)) was employed to determine the path loss at each measured site with distance d (m):

$$PL\ (dB) = E\ (dBm) - P_{mr}\ (dBm) \tag{9}$$

where $P_{mr}\ (dBm)$ is the mean received power, the E (dBm) is the effective isotropic radiated power and $PL\ (dB)$ is the path loss. The E is further given by Eq. (10).

$$E = P_{tx} + G_s - L_s \tag{10}$$

where G_s and L_s stands for gains and losses respectively. Antennas gains at both the transmitter and receiver ends are typically taken into account, and connector, body and combiner losses are typically considered as well Eq. (11).

$$E = P_{tx} + G_{tx} + G_{mrx} - L_c - L_{co} - L_b \tag{11}$$

P_{tx} Stands for transmit power (dBm), G_{tx} for the antenna transmit gain (dBi), G_{mrx} for antenna gain of the mobile receiver antenna (dBi), L_{co} for connector loss (dB), L_b denotes the body loss (dB) and L_c is given as combiner loss (dB). These parameter's actual values for LTE are given in [26] and substituted into (10) for the E. In order to determine the path loss, the estimated values of E (dBm) and $P_{mr}\ (dBm)$ are then substituted into (9). Fig. 4 displays the resulting path loss for all the routes. Plots of path loss against distance were used to examine the impact of increasing distance on PL as illustrated.

It can be seen from Fig. 4 that as distance increases from the BS, the path loss also increases. Comparing the computed path losses along the routes for the same network, the differences in the path loss values obtained along the different routes is due to differences in the BS parameters as given in Table 2, thus justifying Fig. 4.

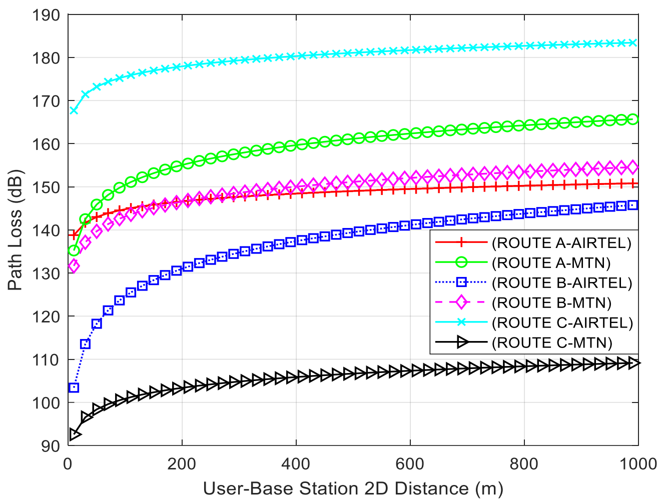

Fig. 4: Measured Path Loss of all Routes.

4.2.1 Path Loss Measurement Results Compared to Legacy Models

Each observed environment's path loss is compared to the two legacy path loss models' estimated path losses (i.e., the FSPL [22] and the 3GPP TR 36.873 (Urban-Macro-3D) [24]) at 2600 MHz for urban area of the FUTA campus, for the two networks (i.e., MTN and Airtel). Fig. 5, Fig. 6 and Fig. 7 Shows the respective results for the three routes plots. The results show that the two classical models under-predict the path losses along the three routes.

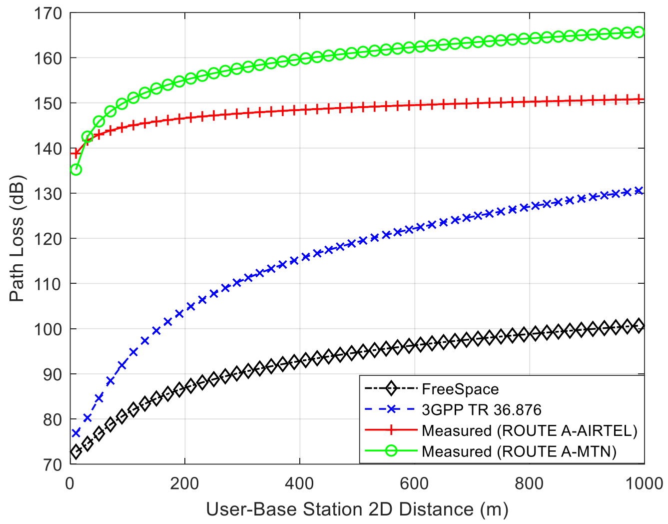

Fig. 5: Route A Path Loss.

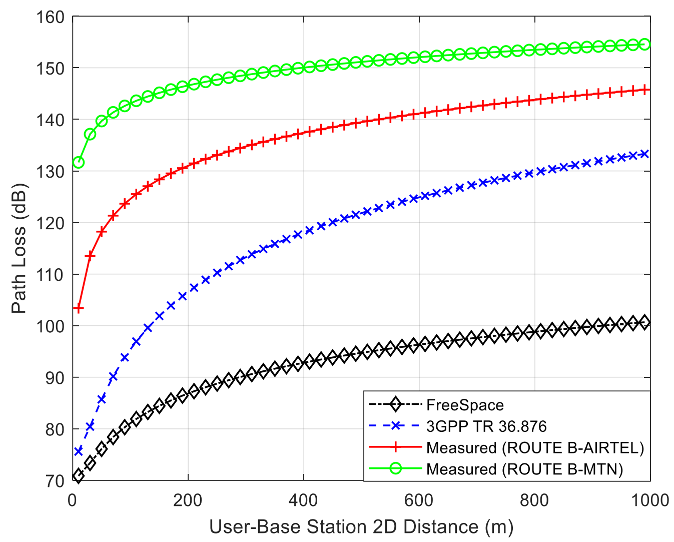

Fig. 6: Route B Path Loss.

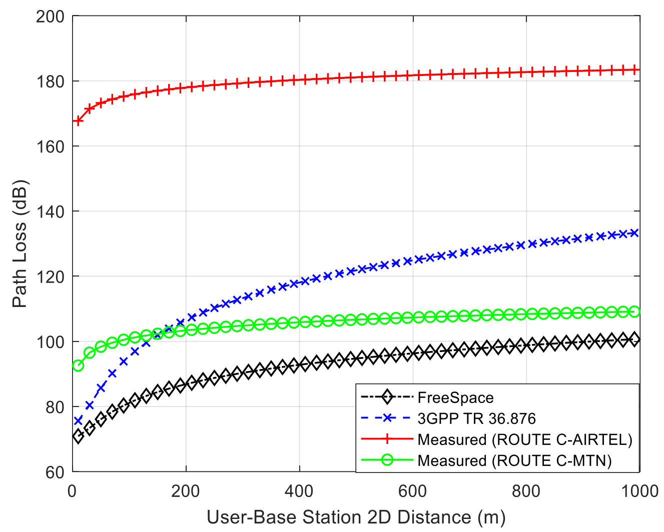

Fig. 7: Route C Path Loss.

4.2.2 Result Analysis

Table 3a and Table 3b show the summary of path losses against distances. Few samples (i.e., at 400 and 800 m) were considered and compared generated path loss measured data against legacy path loss models at stated distance in other to observe and come out with reasonable results of the models along each route.

Table 3a Path Loss Summary Result

	Measured Path Loss against Distance		Legacy Path Loss against Distance	
	MTN	**Airtel**	**3GPP TR 36.873**	**Free Space**
Route A	159.67 dB @ 400 m	148.43 dB @ 400 m	115.49 dB @ 400 m	92.83 dB @ 400 m
	164.26 dB @ 800 m	150.25 dB @ 800 m	127.01 dB @ 800 m	98.82 dB @ 800 m
Route B	150.04 dB @ 400 m	137.40 dB @ 400 m	118.09 dB @ 400 m	92.81 dB @400 m
	153.49 dB @ 800 m	143.79 dB @ 800 m	129.72 dB @ 80 0 m	98.82 dB @ 800 m
Route C	105.88 dB @ 400 m	180.32 dB @ 400 m	118.09 dB @ 400 m	92.81 dB @ 400 m
	108.38 dB @ 800 m	182.69 dB @ 800 m	129.72 dB @ 800 m	98.82 dB @ 800 m

Table 3b shows the summary of the differences between the measured path loss and the legacy path loss model results of the two considered MNOs (MTN and Airtel) on the three routes in the FUTA campus while maintaining the same distance as stated in Table 3a.

Table 3b Differences between Measured and Legacy Path Loss Results

	Measured - Legacy Path Loss		Measured - Legacy Path Loss	
	MTN-3GPP TR 36.873	**MTN- Free Space**	**Airtel - 3GPP TR 36.873**	**Airtel - Free Space**
Route A	44.177 dB @ 400 m	66.833 dB @ 400 m	32.944 dB @ 400 m	55.605 dB @ 400 m
	37.426 dB @ 800 m	65.442 dB@ 800 m	23.239 dB @ 800 m	51.428 dB @ 800 m
Route B	31.941 dB @ 400 m	57.222 dB @ 400 m	19.309 dB @ 400 m	44.59 dB @ 400 m
	23.765 dB @ 800 m	54.673 dB @ 800 m	14.07 dB @ 800 m	44.978 dB @ 800 m
Route C	-12.219 dB @ 400 m	13.061 dB @ 400 m	62.223 dB @ 400 m	87.503 dB @ 400 m
	-21.35 dB @ 800 m	9.56 dB @ 800 m	52 dB @ 800 m	83.872 dB @ 800 m

4.2.2.1 Route A

Considering the path loss for Route A results shown in Fig. 5, Table 3a and Table 3b , we analyze the results of the measured data path loss against distance in comparison with legacy path loss models such as the free space and 3GPP TR 36.873 models.

At 400 m of MTN the differences between the measured path loss and legacy path loss models are 44.177 dB (3GPP TR 36.873) and 66.833 dB (Free Space) while for Airtel network at same distance the differences are 32.944 dB (3GPP TR 36.873) and 55.605 dB (Free Space). At 800 m for MTN network, the difference between the measured path loss and legacy path loss models are 37.426 dB (3GPP TR 36.873) and 65.442 dB (Free Space) while for the Airtel network at same distance, the differences are 23.239 dB (3GPP TR 36.873) and 51.428 dB (Free Space).

4.2.2.2 Route B

Next we consider the path loss analysis for Route B results shown in Fig. 6, Table 3a, and Table 3b. For MTN at 400 m, the differences between the measured path loss and legacy path loss models are 31.941 dB (3GPP TR 36.873), 57.222 dB (Free Space) while for Airtel network at same distance the differences are 19.309 dB (3GPP TR 36.873) and 44.59 dB (Free Space). At 800 m of MTN network the difference between the measured path loss and legacy path loss models are 23.765 dB (3GPP TR 36.873) and 54.673 dB (Free Space) while for Airtel network at same distance, the differences are 14.07 dB (3GPP TR 36.873) and 44.978 dB (Free Space).

4.2.2.3 Route C

For Route C, we consider the path loss analysis for the results shown in Fig. 7, Table 3a, and Table 3b. At 400 m for MTN, the differences between the measured path loss and legacy path loss models are: -12.219 dB (3GPP TR 36.873) and 13.061 dB (Free Space) while for Airtel network at same distance the differences are 62.223 dB (3GPP TR 36.873) and 87.503 dB (Free Space). At 800 m for MTN network, the differences between the measured path loss and legacy path loss models are -21.35 dB (3GPP TR 36.873) and 9.56 dB (Free Space) while for Airtel network at same distance, the differences are 52 dB (3GPP TR 36.873), and 83.872 dB (Free Space).

Overall, the path loss values along the three routes show that the 3GPP TR 36.873 and the FSPL under-predicted the path loss, in some cases by up to approximately 88 dB for the considered environment.

4.3 RMSE Results

The RMSE results for the measurement data as compared to the predictions form legacy path loss models are given in Table 4. The lower the RMSE value, the better suited is the model for the environment under consideration [7].

Table 4 RMSE Values

Route	RMSE
Route A (Airtel)	5.766
Route A (MTN)	7.287
Route B (Airtel)	9.159
Route B (MTN)	5.561
Route C (Airtel)	6.375
Route C (MTN)	1.895

5 Conclusion

This study investigated a measurement-based path loss modelling for a University campus environment, using two LTE networks' measurement data, each network measurement taken around three routes on the campus. The measurement results are compared to the FSPL and the 3GPP TR 36.873 path loss models. Analyses of the results (using path loss and RMSE) show that the legacy models under-predict the path loss for the considered environment. The measurement-based results will enable the MNOs to accurately characterize their network by adjusting their predicted path losses and enable them to deliver improved QoS. This will translate to the improved QoE and customer satisfaction for the users. Future works will consider other carrier frequencies and MNOs.

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