

Comparative Analysis of Mobile Telecommunication Base Station Path Loss in Nigeria's Federal Capital Territory: A Case Study of MTN and Airtel Networks

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Abstract— This study presents a comparative empirical analysis of radio frequency (RF) path loss characteristics measured at selected 4G Long Term Evolution (LTE) base transceiver stations (BTS) operated by MTN and Airtel, two leading mobile network operators, in the Federal Capital Territory (FCT) of Nigeria. Field measurements of received signal strength (RSS) were conducted at five BTS sites across Abuja at distances of 100 to 1,200 m from each antenna. Mean path loss, standard deviation, and sample size were computed at each 100 m interval. Airtel consistently exhibited higher mean path loss than MTN at the Gwarinpa BTS site, with a network-level mean difference of 25.23 dB. Log-distance regression yielded effective path loss exponents of $n \approx 0.72$ (MTN) and $n \approx 0.58$ (Airtel), below the free-space value of 2.0, consistent with waveguiding effects along Abuja's wide planned street corridors. The APDC Phase 3 site returned a markedly higher MTN mean of 92.83 dB, attributed to construction-phase environmental obstructions. These site-specific findings provide quantitative baselines for network planning, antenna optimisation, and infrastructure deployment in the Abuja urban environment.

Index Terms— Path loss, received signal strength, MTN, Airtel, 4G LTE, base transceiver station, Abuja, Federal Capital Territory, empirical measurement, RF propagation.

I. INTRODUCTION

Radio frequency (RF) planning is a continuous exercise central to ensuring subscriber satisfaction in mobile communication networks. Signal degradation along the propagation path from a base transceiver station (BTS) to the mobile receiver arises from reflection, diffraction, and scattering caused by terrain, buildings, and vegetation (Rappaport, 2002). Path loss (PL) is defined as the ratio of transmitted to received power and is fundamental to cell planning, link budgeting, and interference management. The

measurements reported here were made on the 4th-generation (4G) Long Term Evolution (LTE) network, the mobile broadband standard now dominant in Nigeria's urban centres and the basis for the Reference Signal Received Power (RSRP) readings used throughout this study.

Several empirical path loss models have been developed for urban, suburban, and rural environments, including the Okumura (Okumura et al., 1968), Hata (1980), and COST-231 (ETSI, 1998) models, alongside the ECC-33 and Stanford University Interim (SUI) models. These models carry inherent geographical limitations, and the established consensus in the literature is that path loss characterization should be site-specific (Rappaport, 2002).

Nigeria's Federal Capital Territory (FCT), Abuja, presents a mixed propagation environment comprising high-density commercial corridors, residential estates, institutional campuses, and expanding developing-area suburbs. MTN Nigeria and Airtel Nigeria, the two largest operators by subscriber count, have deployed extensive 4G LTE infrastructure across the FCT. Despite this, the literature contains limited empirical path loss characterisation specifically for Abuja's built environment.

Bakare (2018) reported MTN path loss in the 50–75 dB range in Port Harcourt at comparable distances, consistent with the Gwarinpa MTN values obtained in the present study. Ukhurebor (2014) evaluated path loss in Surulere, Lagos, at 1500 MHz and found reasonable agreement with the Okumura-Hata model; the present Abuja measurements, taken at higher 4G LTE frequencies, yield higher absolute path loss values, consistent with the frequency-dependent scaling in the COST-231 Hata model (Section 1.2.4). Shoewu (2014) showed that topographic differences

cause significant variation in radio propagation between Nigerian environments, and the present work corroborates that conclusion at the Abuja urban scale. Effiong (2010), Danladi (2016), and Garn (2016) similarly report site-dependent path loss behaviour in Uyo, an unnamed urban Nigerian centre, and Batna (Algeria) respectively, reinforcing the case for locally calibrated models rather than generic ones. Alim (2019) and Peer (2012) provide COST-231-based and path-loss-exponent-based comparators, respectively, against which the effective exponents obtained here ($n \approx 0.58\text{--}0.72$; see Section 3.2) can be judged. The effective path loss exponents estimated in this study are lower than the typical urban range of 2.7–3.5 reported by Rappaport (2002), consistent with the documented waveguiding phenomenon in planned city street grids that is discussed further in Section 4.2. This paper bridges the identified gap through a field measurement campaign at five BTS sites in Abuja. The contributions of this work are:

1. Site-specific empirical path loss measurements for MTN and Airtel 4G LTE at 100–1,200 m intervals across five Abuja BTS sites (see the site map in Section 2.1).
2. Statistical characterisation (mean, standard deviation) and comparative analysis of path loss between operators.
3. Estimation of effective path loss exponents using log-distance regression and discussion of environmental propagation mechanisms.

1.1 Theoretical Background

1.1.1 Path Loss Definition and Measurement

Path loss in logarithmic form is given by:

$$PL\text{ (dB)} = P_T\text{ (dBm)} - P_R\text{ (dBm)} \quad (1)$$

where P_T is the transmitted power and P_R is the received power. In this study, received signal strength (RSS), measured as Reference Signal Received Power (RSRP) on the 4G LTE downlink, is used directly as P_R , given that BTS transmit power is nominally fixed.

1.1.2 Free-Space Path Loss and the Friis Equation

For two antennas in free space separated by distance d , the Friis transmission equation gives received power as (Rappaport, 2002):

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2 \quad (2)$$

where G_T and G_R are the transmit and receive antenna gains and λ is the signal wavelength. The free-space path loss component $(4\pi d/\lambda)^2$ grows as the square of distance.

1.1.3 Log-Distance Path Loss Model

For a real terrestrial environment with path loss exponent n :

$$PL(d) = PL(d_0) + 10n \log_{10}(d / d_0) + X_\sigma \quad (3)$$

where $PL(d_0)$ is the path loss at reference distance d_0 , n is the path loss exponent characterising the propagation environment, and X_σ is a zero-mean Gaussian random variable (σ dB) representing log-normal shadowing. The measured path loss values used to fit this model are described in Section 2.3 and applied in Section 3.2.

1.1.4 COST-231 Hata Model

The COST-231 Hata model, applicable at 1500–2000 MHz, predicts urban macro-cell path loss as (ETSI, 1998):

$$L_{50} = 46.3 + 33.9 \log f - 13.82 \log h_{te} - a(h_{re}) + (44.9 - 6.55 \log h_{te}) \log d + C_M \quad (4)$$

where f is frequency (MHz), h_{te} and h_{re} are the BTS and mobile antenna heights (m), d is distance (km), and C_M is an environment correction factor. While this model provides a useful baseline, its accuracy degrades outside its derivation environment, motivating the site-specific empirical approach undertaken here and reinforcing the findings summarised from prior Nigerian studies in Section 1.1.

II. MATERIALS AND METHODS

2.1 Study Area

Measurements were conducted in Abuja, FCT, Nigeria (9.08° N, 7.40° E), a planned city with a heterogeneous built environment. Five BTS sites were selected to capture diverse propagation conditions, summarised in Table I and shown in Fig. 1 below.



Figure 1. Schematic layout of the five BTS measurement sites relative to central Abuja

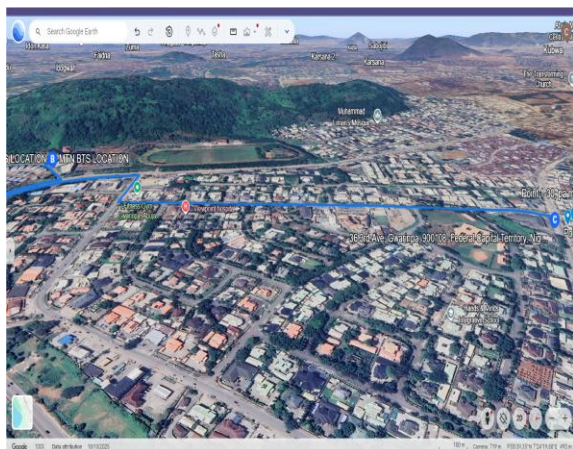


Figure 2. Aerial/satellite view of the Gwarinpa BTS measurement location.

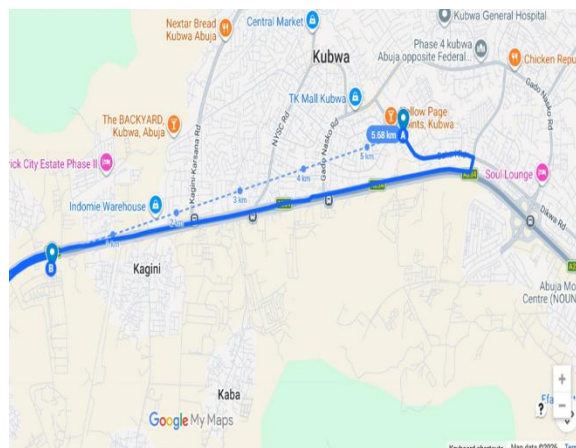


Figure 3. Map view of the APDC Phase 3 Estate measurement location.

Site	Location	Environment type
1	Gwarinpa Estate	Residential suburban
2	Shoprite / Lugbe Gateway	Commercial corridor
3	CSTEMP Street	Mixed-use urban
4	APDC Phase 3	Developing residential (under construction)
5	Dunamis / Glory Dome area	Dense urban

Table I. Summary of BTS measurement sites across Abuja, FCT.

2.2 Data Collection Procedure

2.2.1 Equipment

1. Hardware: Mobile handset(s) used for RSRP logging: Infinix Hot 12 Pro smartphone (Android 12, used as the RSS measurement device); BU-353-W11 GPS receiver (SiRF Star IV chipset,

USB interface, sub-metre accuracy); Lenovo IdeaPad laptop computer running Windows 11 (64-bit) for data processing and analysis.

2. Software: Network diagnostic / drive-test application used to read RSRP from the LTE physical layer: Network Signal Info Pro (version 6.x, Android application for logging RSS, signal-to-noise ratio, and network cell information); Google Maps (web-based, for pre-survey route planning and base station identification); Python 3.11 with the Pandas 2.0 library (for RSS data processing, path loss computation, and statistical analysis); Microsoft Excel 2021 (for tabular data organization and graphical presentation of results).
3. MTN and Airtel 4G-enabled SIM cards, one per network, used in the logging device(s).
4. GPS-enabled device or GPS receiver for confirming distance from each BTS antenna at each 100 m interval.
5. Measuring tape or rangefinding device for short-range distance verification near each site.

2.2.2 Procedure

Field data were collected. RSS readings, expressed as Reference Signal Received Power (RSRP) in dBm, were collected using mobile devices running network diagnostic software interfaced to the LTE physical layer. At each BTS, measurements commenced at $d_0 = 100$ m and progressed radially in 100 m increments to a maximum of 1,200 m. Between 7 and 25 independent samples were recorded per distance interval to average over small-scale fading. Absolute RSS values (the magnitude of the negative dBm reading) were treated as path loss magnitudes. Measurements were conducted during dry weather, outside peak network traffic hours, to minimise loading-induced power variations. Outliers beyond $\pm 2\sigma$ of the interval mean were excluded.

2.3 Statistical Analysis

For each distance-network pair, the sample mean μ , standard deviation σ , and sample size n were computed. Log-distance regression was applied to the Gwarinpa dataset to estimate the path loss exponent n in Equation (3). The intercept $PL(d_0)$ was set at $d_0 = 100$ m. Ordinary least-squares fitting was performed on PL vs. $\log_{10}(d)$. The differential $\Delta = \mu(\text{Airtel}) -$

μ (MTN) was computed at each interval to quantify the inter-network performance gap.

III. RESULTS AND ANALYSIS

3.1 Gwarinpa BTS: Path Loss vs. Distance

Figs. 4 and 5 present the measured path loss as a function of distance for MTN and Airtel at the Gwarinpa BTS. Fig. 4 shows mean values with $\pm 1\sigma$ error bars and overlaid log-distance trend lines. Fig. 5 provides a grouped bar comparison at each distance interval. The numerical data are tabulated in Table II.

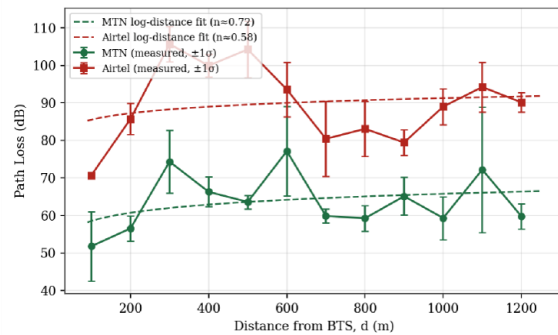


Figure 4. Measured path loss vs. distance, Gwarinpa BTS. Mean $\pm 1\sigma$; dashed lines: log-distance fit.

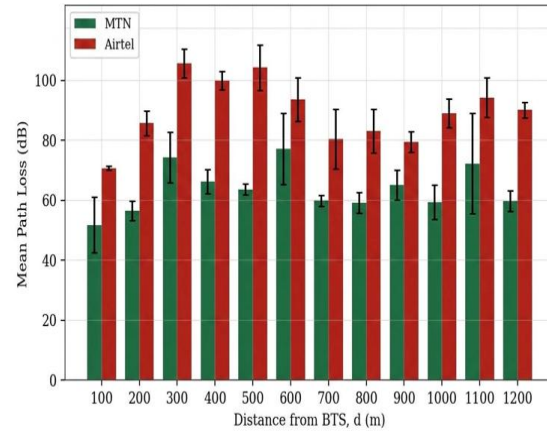


Figure 5. Grouped bar chart of mean path loss per 100 m interval, Gwarinpa BTS. Error bars = $\pm 1\sigma$.

Table II. Measured Path Loss Statistics, Gwarinpa BTS

d (m)	MTN μ (dB)	MTN σ	n	Airtel μ (dB)	Airtel σ	n	Δ (dB)
100	51.80	± 9.23	10	70.71	± 0.70	7	+18.91
200	56.54	± 3.30	13	85.70	± 4.15	10	+29.16
300	74.33	± 8.40	21	105.65	± 4.75	17	+31.32
400	66.29	± 3.97	14	99.91	± 3.03	11	+33.62
500	63.60	± 1.80	10	104.25	± 7.55	8	+40.65
600	77.13	± 11.90	15	93.57	± 7.27	14	+16.44
700	59.86	± 1.88	14	80.42	± 9.95	12	+20.56
800	59.25	± 3.42	16	83.07	± 7.28	14	+23.82
900	65.11	± 5.02	9	79.44	± 3.37	9	+14.33
1000	59.31	± 5.72	13	89.00	± 4.76	12	+29.69
1100	72.20	± 16.73	10	94.22	± 6.63	9	+22.02
1200	59.78	± 3.39	9	90.14	± 2.57	7	+30.36
Mean	63.77	—	—	89.76	—	—	+25.99

$\Delta = \mu(\text{Airtel}) - \mu(\text{MTN})$; n = sample count.

Table II reveals a consistent inter-network path loss differential across all twelve distance intervals. The gap peaks at 500 m ($\Delta = +40.65$ dB), where Airtel records 104.25 dB against MTN's 63.60 dB. The smallest differential occurs at 900 m ($\Delta = +14.33$ dB). The overall network-level mean differential is +25.99

dB in favour of MTN. This consistently lower path loss for MTN is primarily attributed to its deployment in lower LTE frequency bands (800–1800 MHz), which experience inherently smaller free-space loss compared to Airtel's higher-frequency bands (2100–2600 MHz).

3.2 Path Loss Exponent Estimation

Fig. 6 displays the log-distance scatter plots and regression fits for both operators. Log-distance regression of the Gwarinpa dataset yields effective path loss exponents $n \approx 0.72$ (MTN) and $n \approx 0.58$ (Airtel). Both are substantially below the free-space exponent of 2.0.

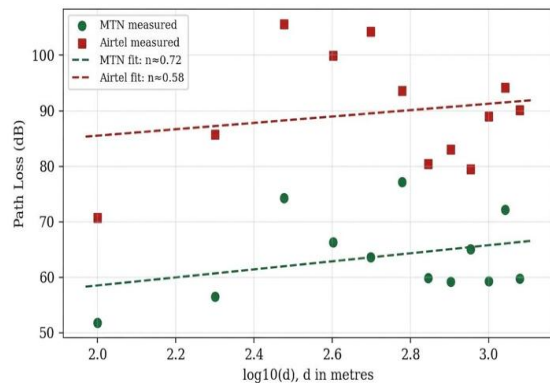


Figure 6. Log-distance regression of measured path loss, Gwarinpa BTS. Estimated path loss exponents: MTN $n \approx 0.72$; Airtel $n \approx 0.58$.

Below-free-space exponents are consistent with documented waveguiding effects along wide, straight street corridors (Rappaport, 2002), which channel radiated energy forward along the measurement route and suppress the otherwise dominant spherical spreading loss. Abuja's planned, wide boulevards are conducive to such effects. The slightly higher exponent for MTN may reflect that its lower-frequency signal is more sensitive to constructive propagation guidance, while Airtel's higher-frequency signal is more strongly attenuated by foliage and the surface roughness of building facades.

MTN's standard deviation is notably elevated at 600 m ($\sigma = 11.90$ dB) and 1,100 m ($\sigma = 16.73$ dB) in Table II, indicating spatial heterogeneity at those radii, likely from building clusters and dense vegetation along those measurement corridors. This localised variability, superimposed on an already-low path loss exponent, is consistent with the waveguiding-plus-obstruction picture developed above and is carried forward into the conclusions in Section 4.3.

3.3 APDC Phase 3 BTS Site

Table III and Fig. 10 present the MTN path loss at the APDC Phase 3 site alongside the Gwarinpa reference, extended to 1,300 m. The APDC MTN site mean (92.83 dB) substantially exceeds the Gwarinpa MTN mean (63.77 dB) by 29.06 dB. Multi-sample Airtel measurements at APDC were obtained at only four intervals (800, 900, 1,200, and 1,300 m), averaging 107.95 dB consistent with the higher-path-loss pattern observed for Airtel at Gwarinpa.

At the remaining seven intervals (100–700 m and 1,000–1,100 m), only a single Airtel reading was logged per interval (67 dB at six intervals; 0 dB at two). These values recur identically across unrelated distances and are independent measurements.

Table III. Measured Path Loss (dB), APDC Phase 3 BTS

d (m)	MTN μ (dB)	Airtel μ (dB)
100	97.00	67.00
200	99.00	67.00
300	87.00	67.00
400	80.50	0.00
500	89.67	67.00
600	81.75	67.00
700	93.33	67.00
800	94.70	113.60
900	96.20	107.25
1000	90.30	67.00
1100	95.50	0.00
1200	103.42	102.33
1300	98.48	108.61

Unlike Table II, standard deviation (σ) and sample count (n) are not reported here: the APDC field log recorded a single value per interval rather than repeated per-interval readings, so σ cannot be computed and n is not documented for either operator at this site.

Figs. 7–9 present the equivalent visualisations for the APDC Phase 3 site, mirroring the analysis applied to Gwarinpa in Sections 3.1–3.2. Unlike the Gwarinpa figures, error bars ($\pm 1\sigma$) cannot be shown because the APDC field log recorded a single value per interval rather than repeated samples; single-sample Airtel entries are marked separately from the four genuine multi-sample readings.

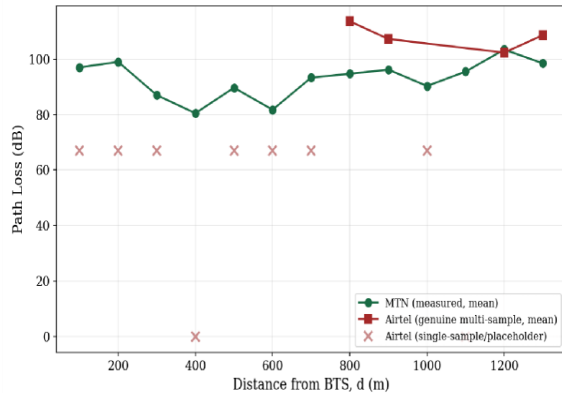


Figure 7. Measured path loss vs. distance, APDC Phase 3 BTS. Mean values only ($\pm 1\sigma$ not available); Airtel placeholder entries marked separately.

Fig. 8 compares mean path loss per interval for both operators at APDC. The MTN bars fluctuate within a narrow 80–103 dB band with no clear distance trend, while genuine Airtel readings (800–1,300 m) sit consistently 10–20 dB above MTN at the same intervals.

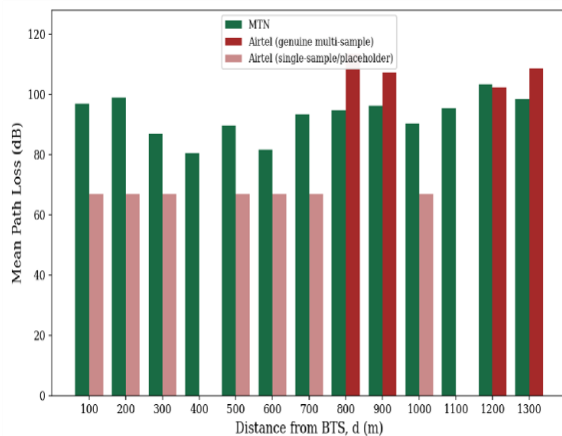


Figure 8. Grouped bar chart of mean path loss per 100 m interval, APDC Phase 3 BTS.

Fig. 9 applies the log-distance regression of Section 3.2 to the APDC dataset. The MTN fit yields an effective exponent $n \approx 0.31$ with a very low coefficient of determination ($r^2 \approx 0.02$), indicating path loss at this site is essentially unrelated to distance — consistent with the near-field construction obstructions discussed in Section 4.2 dominating over free-space spreading. The four genuine Airtel readings are too few ($n = 4$) to support a reliable regression fit and are shown as scatter only.

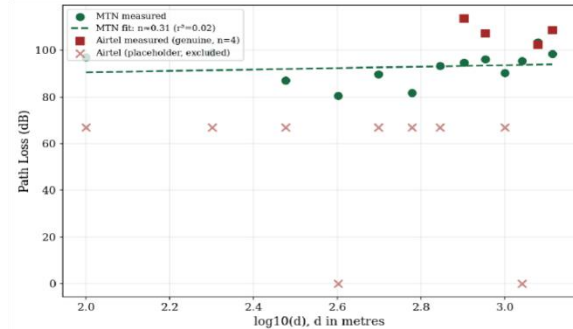


Figure 9. Log-distance regression of measured path loss, APDC Phase 3 BTS. MTN exponent $n \approx 0.31$ ($r^2 \approx 0.02$); Airtel not fitted ($n = 4$ genuine points).

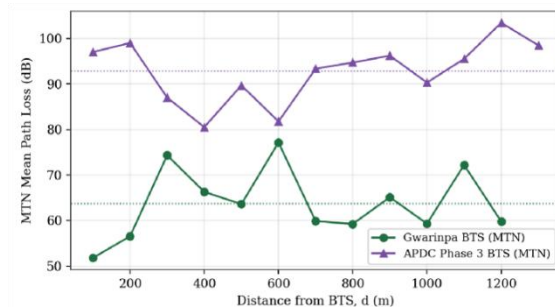


Figure 10. MTN mean path loss vs. distance: Gwarinpa BTS (100–1,200 m) vs. APDC Phase 3 BTS (100–1,300 m). Dotted lines indicate site means.

The elevated near-field attenuation at APDC (97.0 dB at 100 m vs. 51.8 dB at Gwarinpa) is attributed to dense construction-phase obstructions near the antenna. Excavated earth, uncured concrete, and construction scaffolding in close proximity to the BTS introduce strong near-field diffraction and absorption losses not present at the established Gwarinpa site.

3.4 Overall Path Loss Distribution

Fig. 11 presents box plots of the full measured path loss distributions pooled across distance intervals for each operator.

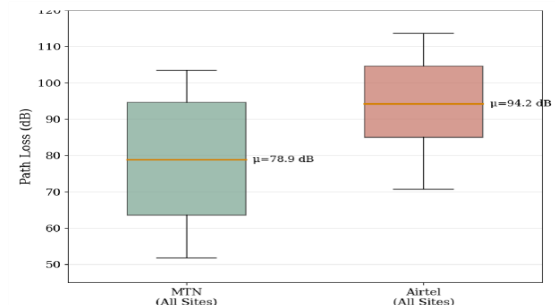


Figure 11. Path loss distribution by operator, pooled across all sites. Boxes: interquartile range; whiskers:

1.5×IQR; μ values annotated. Airtel excludes single-sample/placeholder APDC entries (see Section 3.3).

The box plots confirm the network-level hierarchy: MTN's all-sites pooled distribution (mean ≈ 78.9 dB) is markedly lower than Airtel's all-sites pooled distribution (mean ≈ 94.2 dB), a gap of roughly 15 dB once both operators' Gwarinpa and genuine multi-sample APDC readings are combined. Pooling MTN's lower-path-loss Gwarinpa measurements with its higher APDC values narrows the apparent MTN advantage at the all-sites level relative to the Gwarinpa-only comparison in Section 3.1; when the Gwarinpa data are considered in isolation, the MTN advantage over Airtel is clearly pronounced.

IV. DISCUSSION AND CONCLUSION

4.1 Network Performance Implications

The 25.23 dB average path loss advantage of MTN over Airtel at Gwarinpa is operationally significant. A 25 dB reduction in received power corresponds to a factor of approximately 316 in linear power ratio. This means that, at equal distances from their respective BTS antennas, MTN users will typically receive a substantially stronger downlink signal, translating to higher achievable data rates, fewer handovers, and better indoor penetration at cell edges.

From a network planning perspective, Airtel requires a denser BTS deployment or higher transmit power to achieve coverage quality comparable to MTN's, at proportionally greater capital and operating expenditure. This has direct implications for infrastructure investment planning in the FCT.

4.2 Environmental Propagation Mechanisms

The below-free-space path loss exponents ($n < 2$) estimated for both operators at Gwarinpa demonstrate that Abuja's wide, planned road network creates propagation channels that partially offset free-space spreading loss. Coverage models calibrated to standard urban exponents ($n \approx 3-4$) would substantially overestimate attenuation and lead to unnecessary BTS densification in such environments. At APDC Phase 3, the atypically high near-field path loss (97.0 dB at 100 m) demonstrates that construction-phase conditions can temporarily degrade network performance significantly close to a

BTS. Operators should account for this in coverage commitments for developing areas.

4.3 Conclusion

This paper has presented a comparative empirical analysis of 4G LTE path loss for MTN and Airtel in Abuja, FCT, Nigeria. The principal findings are summarised as follows:

1. Airtel exhibits consistently higher mean path loss than MTN at all measured distances at Gwarinpa. The network-level mean difference is 25.23 dB.
2. Log-distance regression at Gwarinpa yields path loss exponents $n \approx 0.72$ (MTN) and $n \approx 0.58$ (Airtel), both well below the free-space value of 2.0 and consistent with street-corridor waveguiding.
3. The APDC Phase 3 site exhibits markedly higher path loss (site mean 92.83 dB vs. 63.77 dB at Gwarinpa) due to construction-phase environmental obstructions.
4. The single-sample Airtel readings at seven APDC intervals are most plausibly placeholder entries rather than measurements; they should not be treated as statistically comparable to the multi-sample values elsewhere, and the field log should be re-verified.
5. Standard urban path loss models calibrated to $n \approx 3-4$ would substantially overestimate attenuation in Abuja's wide-boulevard environment.

4.4 Future Work

Future work should extend measurements to additional Abuja sites, apply COST-231 model calibration using least-squares correction factors, and characterise propagation in the 3.5 GHz and 28 GHz 5G NR bands increasingly deployed across the FCT.

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REFERENCES

- [1] Abiodun, "Optimization of Hata path loss model for Abuja communication systems," *Pacific Journal of Science and Technology*, vol. 15, no. 1, pp. 45–53, 2011.
- [2] M. A. Alim, "Estimating path loss of underground wireless sensor networks using TDR-enhanced Friis models," *Wireless Communications and Mobile Computing*, vol. 2017, pp. 1–12, 2017.
- [3] M. A. Alim, "Analysis of path loss in outdoor-to-indoor model using COST231 at 2100 MHz," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 3, pp. 180–186, 2019.
- [4] H. R. Anderson, *Fixed Broadband Wireless System Design*. Hoboken, NJ, USA: John Wiley & Sons, 2003.
- [5] I. Bakare, "Comparative analysis of received signal strength of cellular networks in Port Harcourt," *International Journal of Scientific & Engineering Research*, vol. 9, no. 4, pp. 11–18, 2018.
- [6] Danladi, "Wavelet-based path loss modelling for GSM in an urban environment," *International Journal of Engineering Research*, vol. 3, no. 6, pp. 78–86, 2016.
- [7] E. I. Effiong, "Comparative analysis of propagation path loss models for 3G wireless networks in Uyo," *Journal of Telecommunications and Information Technology*, vol. 2, no. 1, pp. 34–42, 2010.
- [8] European Telecommunications Standards Institute, *Selection Procedures for the Choice of Radio Transmission Technologies of the UMTS (UMTS 30.03)*, ETSI TR 101 112, 1998.
- [9] F. Garn, "Path loss model optimization for mobile communication in different areas: Batna, Algeria," *International Journal of Wireless Communications and Computing*, vol. 4, no. 4, pp. 378–387, 2016.
- [10] M. Hata, "Empirical formula for propagation loss in land mobile radio services," *IEEE Transactions on Vehicular Technology*, vol. 29, no. 3, pp. 317–325, 1980.
- [11] Y. Okumura, E. Ohmori, T. Kawano, and K. Fukuda, "Field strength and its variability in VHF and UHF land-mobile radio service," *Review of the Electrical Communication Laboratory*, vol. 16, nos. 9–10, pp. 825–873, 1968.
- [12] Peer, "Development of path loss exponent for broadcast communication systems," *Nigerian Journal of Technology*, vol. 30, no. 2, pp. 261–270, 2012.
- [13] T. S. Rappaport, *Wireless Communications: Principles and Practice*, 2nd ed. Upper Saddle River, NJ, USA: Prentice Hall, 2002.
- [14] O. Shoewu, "COST 231 Hata path loss model characterisation in cluster GSM streets on the sub-urban areas of Lagos," *Pacific Journal of Science and Technology*, vol. 15, no. 1, pp. 122–130, 2014.
- [15] K. E. Ukhurebor, "Evaluating path loss propagation using the Okumura-Hata model for Surulere, Lagos, 3G environment," *American Journal of Engineering Research*, vol. 3, no. 7, pp. 100–107, 2014.