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Reference-Normalized Signal Attenuation and Effective Absorptivity in Urban Mobile Networks: An Empirical Study in Jalingo, Nigeria.

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Abstract

Accurate characterization of signal attenuation is essential for mobile-network planning, particularly in urban environments where propagation conditions vary considerably. This study investigated reference-normalized signal attenuation and field-derived effective absorptivity across four mobile networks (MTN, Airtel, GLO, and 9mobile) at five locations in Jalingo, Nigeria. The investigation utilized 12 reference observations obtained at a nominal distance of 10m and 300 received signal-strength measurements collected across the study locations, with recorded base transceiver station separations ranging from 241.88 to 1518.40m. Reference-normalized attenuation, effective attenuation coefficients, and model-relative excess losses were calculated and evaluated using free-space propagation comparisons, distance-dependent analysis, and reference-measurement sensitivity assessment. The calculated attenuation ranged from 8.50 to 19.10dB for MTN, 2.90 to 21.83dB for Airtel, 6.27 to 24.73dB for GLO, and −0.55 to 8.05dB for 9mobile. Free-space differential losses ranged from 27.67 to 43.63dB, whereas all 20 model-relative excess attenuation estimates were negative (−42.71 to −8.22dB). Correlations between propagation distance and nominal attenuation were statistically nonsignificant across the four networks. Sensitivity analysis further established that variations in reference signal strength substantially influenced the magnitude and, in some cases, the sign of the calculated effective attenuation coefficients. These findings identify important observations in deriving physically meaningful attenuation parameters from reference and field measurements without verified transmitter and operating-frequency consistency. The study contributes an uncertainty-aware comparative assessment of urban mobile-network attenuation and establishes that field-derived effective absorptivity should be interpreted as an empirical propagation parameter rather than an intrinsic material absorption coefficient.

Keywords: Reference-normalized attenuation; Effective absorptivity; Received signal strength; Radio-wave propagation; Free-space path loss; Measurement uncertainty.

1. Introduction

1.1 Background of the Study

Reliable mobile communication depends on the propagation of electromagnetic signals between base transceiver stations and receiving terminals. During transmission, radio waves experience attenuation arising from geometric spreading, reflection, diffraction, scattering, and interactions with surrounding structures. These mechanisms influence received signal strength (RSS), network coverage, and communication reliability, particularly in urban environments characterized by buildings, vegetation, irregular terrain, and other physical obstructions [[1], [2], [3]]. Consequently, accurate characterization of signal attenuation is essential for wireless-network planning, coverage optimization, and the assessment of propagation conditions.

Several theoretical and empirical methods have been developed to estimate radio-wave propagation losses. The Okumura–Hata model provides an established empirical approach to predicting terrestrial mobile-radio path loss, while ITU-R P.1411 and P.1546 specify propagation prediction methods for different frequency ranges and communication environments [[4], [5], [6]]. More detailed procedures, including ITU-R P.1812 and P.2108, incorporate terrain-dependent propagation and clutter-related losses [[7], [8]]. Nevertheless, the applicability of these models depends on local propagation characteristics, measurement conditions, and the availability of reliable experimental data.

Experimental investigations in Nigeria have established considerable variations in received signal strength across different propagation environments. Popoola et al., provided received signal-strength and terrain-profile measurements for radio-network planning and empirical propagation modelling [[9], [10], [11]]. Anamonye et al., investigated GSM propagation losses in Warri, while Suleiman et al., evaluated empirical path-loss models and atmospheric influences in Zaria [[12], [13], [14]]. Danladi et al., examined GSM signal fluctuations using wavelet decomposition, whereas Yabwa et al., investigated distance-dependent attenuation and atmospheric conditions for a broadcasting system in Jalingo [[15], [16]]. These studies establish the importance of location-specific propagation measurements but employ different experimental arrangements and communication systems.

Reference-normalized attenuation provides a means of assessing changes in received signal strength relative to measurements obtained at a specified reference distance. However, reliable attenuation estimates require comparable reference and distant measurements, preferably associated with the same serving base station, radio technology, operating frequency band, and receiver configuration. Furthermore, measured signal reduction includes geometric spreading and other propagation losses. Consequently, a field-derived effective absorptivity coefficient must be distinguished from intrinsic material absorption, and any excess attenuation should be evaluated relative to an explicitly defined propagation baseline [[1], [2], [3]].

1.2 Statement of the Problem

Urban mobile networks operate under heterogeneous propagation conditions, making direct comparisons of received signal strength among operators and measurement locations difficult. Variations in propagation distance, physical obstructions, transmitting characteristics, and network operating conditions can produce substantial differences in measured signal levels. Although previous investigations have examined empirical path-loss prediction and environmental influences on mobile communication, limited attention has been given to the uncertainty associated with reference-normalized attenuation parameters across multiple operational networks in Jalingo [[9], [12], [13], [14]].

A particular methodological concern arises when reference and distant signal measurements are obtained under different serving-cell or radio-technology conditions. Such differences may introduce variations unrelated to propagation attenuation. Moreover, conventional distance-dependent spreading losses may be incorporated into calculated effective absorptivity coefficients, potentially leading to misleading physical interpretations. Uncertainty in reference RSS measurements introduces an additional source of variability. Therefore, a comparative investigation is required that examines measurement comparability, separates reference-normalized attenuation from model-based excess loss, and evaluates the sensitivity of the derived parameters to reference-measurement uncertainty.

1.3 Aim and Specific Objectives

The aim of this study is to investigate reference-normalized signal attenuation and effective absorptivity characteristics of selected mobile communication networks in urban Jalingo, Nigeria, using experimentally measured received signal strength.

The specific objectives are to:

1. Assess the comparability of the available 10 m reference and distant received signal-strength measurements and determine reference-normalized attenuation for MTN, Airtel, GLO, and 9mobile using measurement pairs that satisfy the required conditions.
2. Calculate field-derived effective attenuation coefficients and evaluate excess attenuation relative to a specified geometric-spreading or conventional propagation baseline.
3. Investigate the dependence of reference-normalized attenuation, effective attenuation coefficients, and model-based excess losses on propagation distance.
4. Compare the attenuation characteristics of MTN, Airtel, GLO, and 9mobile across five urban measurement locations in Jalingo, accounting for differences in network operating conditions where the necessary information is available.
5. Evaluate the sensitivity of the calculated attenuation and effective attenuation coefficients to uncertainties in the reference received signal-strength measurements.

2. Theoretical Framework

The framework relates field-measured received signal strength (RSS), reference-normalized propagation loss, distance-dependent models, and an empirical effective absorptivity coefficient. Each comparison assumes a common serving cell, radio technology, frequency band, and receiver configuration; otherwise, the derived quantities are descriptive rather than channel-specific propagation parameters [[1], [2], [3]].

2.1 Received signal strength and reference-normalized attenuation

Let $P_r(d)$ be received power at transmitter–receiver separation d and let R(d) denote its level in dBm. The logarithmic conversion is

$$R(d) = 10\log_{10}\left(\frac{P_r(d)}{1(\mathrm{mW})}\right) \tag{1}$$

For reference distance $d_0 = 10$m and $d > d_0$, define the measured relative attenuation (positive when the distant signal is weaker) by

$$A(d; d_0) = R(d_0) - R(d) = 10\log_{10}\left(\frac{P_r(d_0)}{P_r(d)}\right) \tag{2}$$

For repeated measurements at comparable conditions, the attenuation based on average RSS is

$$\overline{A}(d; d_0) = \overline{R}(d_0) - \overline{R}(d) \tag{3}$$

Averages of dBm readings correspond to geometric, not arithmetic, averages of power. If reference observations are not matched to the distant link in time or serving cell, equation (3) is only a nominal contrast, not a verified propagation loss.

2.2 Conventional propagation models and geometric spreading

Under free-space, far-field, fixed-gain conditions, Friis transmission gives [[1], [2]]

$$P_r(d) = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \tag{4}$$

where P_t is transmitted power, G_t and G_r are antenna gains, $\lambda = c/f$, f is carrier frequency, and c is the speed of light. Thus the free-space path loss and its reference-normalized increment are

$$L_{\mathrm{FS}}(d) = 20\log_{10}\left(\frac{4\pi d f}{c}\right) \tag{5}$$

$$A_{\mathrm{FS}}(d;d_0) = 20\log_{10}\left(\frac{d}{d_0}\right) \tag{6}$$

Large-scale urban propagation is often summarized by a log-distance model, with path-loss exponent n and shadowing term ε_σ in dB [[1], [3]]:

$$A(d;d_0) = 10n\log_{10}\left(\frac{d}{d_0}\right) + \varepsilon_\sigma \tag{7}$$

If shadowing is neglected, a single reference–field pair gives the descriptive pathloss exponent

$$n_{\mathrm{eff}} = \frac{\overline{A}(d;d_0)}{10\log_{10}(d/d_0)} \tag{8}$$

Two additional empirical baselines are Hata's urban model [4] and its COST-231 extension [17]:

$$L_{\mathrm{H}}(d) = B_{\mathrm{H}} + M\log_{10}d_{\mathrm{km}} \tag{9}$$

$$B_{\mathrm{H}} = 69.55 + 26.16\log_{10}f_{\mathrm{MHz}} - 13.82\log_{10}h_b - a(h_m) \tag{10}$$

$$L_{\mathrm{C}}(d) = B_{\mathrm{C}} + M\log_{10}d_{\mathrm{km}} \tag{11}$$

$$B_{\mathrm{C}} = 46.3 + 33.9\log_{10}f_{\mathrm{MHz}} - 13.82\log_{10}h_b - a(h_m) + C_m \tag{12}$$

$$M = 44.9 - 6.55\log_{10}h_b \tag{13}$$

Here f(MHz) is frequency in MHz, d(km) is distance in km, h_β and h_m are antenna heights in metres, $a(h_m)$ is the mobile-height correction, and C_m the COST-231 area correction. Hata is intended for approximately 100–1500 MHz and 1–20 km; COST-231 Hata extends the frequency range to about 1500–2000 MHz but also assumes macrocell geometry and roughly 1–20km. Neither model should be extrapolated to d_0 = 10 m. ITU-R P.1411, P.1546, P.1812 and P.2108, together with 3GPP channel models, provide more scenario-specific treatments where their required inputs are known [[3], [5], [6], [7], [8]].

2.3 Excess loss relative to a propagation baseline

To avoid attributing ordinary spreading to environmental absorption, define excess attenuation as the measured relative loss minus a specified, applicable baseline:

$$A_{\mathrm{ex}}(d; d_0) = A(d; d_0) - A_{\mathrm{base}}(d; d_0) \tag{14}$$

For the free-space baseline, $A_{base} = A_{FS}$ from Equation (6). A negative excess loss is permissible because local interference, antenna patterns, fading, or reference mismatch can produce received-power ratios above the selected baseline. Excess loss is not a direct measurement of energy absorbed by materials.

2.4 Relationship between attenuation, effective absorptivity and RSS

The term “effective absorptivity” is used here for a phenomenological distance-normalized power reduction, not a material absorption constant. A pair of field powers can be represented by the identity

$$P_r(d) = P_r(d_0)\exp[-\alpha_{\mathrm{eff}}(d - d_0)] \tag{15}$$

Taking natural logarithms, substituting Equation (2), and rearranging gives

$$\alpha_{\mathrm{eff}} = \frac{\ln[P_r(d_0)/P_r(d)]}{d - d_0} = \frac{\ln 10}{10(d - d_0)} A(d; d_0) \tag{16}$$

Hence the attenuation rate in dB m^{-1}, γ_{eff}, and effective coefficient in m^{-1} are related by

$$\gamma_{\text{eff}} = \frac{A(d; d_0)}{d - d_0}, \qquad \alpha_{\text{eff}} = \frac{\ln 10}{10}\gamma_{\text{eff}} \tag{17}$$

An excess-loss coefficient can be introduced without incorporating the free-space baseline:

$$\alpha_{\text{ex}} = \frac{\ln 10}{10(d - d_0)} A_{\text{ex}}(d; d_0) \tag{18}$$

For completeness, the apparent reference-relative received-power deficit is

$$\mathcal{D}_{\text{app}} = 1 - \frac{P_r(d)}{P_r(d_0)} = 1 - 10^{-A(d;d_0)/10} \tag{19}$$

The apparent deficit is not a physical absorptance: transmitter and receiver power levels are not measurements of incident and transmitted power through an isolated material. Equations (2), (16) and (19) also show that RSS and effective absorptivity are algebraically linked; correlating them does not provide independent causal evidence.

2.5 Reference sensitivity and uncertainty propagation

Let $\Delta d = d - d_0 > 0$ and $k = \ln(10)/10$. Differentiation of equation (16) shows the sensitivity to the reference and distant RSS values:

$$\frac{\partial \alpha_{\text{eff}}}{\partial R(d_0)} = \frac{k}{\Delta d}, \qquad \frac{\partial \alpha_{\text{eff}}}{\partial R(d)} = -\frac{k}{\Delta d} \tag{20}$$

With standard uncertainties u and covariance Cov, the uncertainty of relative attenuation is [18]

$$u^2(A) = u^2[R(d_0)] + u^2[R(d)] - 2\text{Cov}[R(d_0), R(d)] \tag{21}$$

If attenuation and distance differences have independent uncertainties, first-order propagation yields

$$u^2(\alpha_{\text{eff}}) \simeq \left(\frac{k}{\Delta d}\right)^2 u^2(A) + \left(\frac{kA}{(\Delta d)^2}\right)^2 u^2(\Delta d) \tag{22}$$

For a free-space reference baseline, additionally assuming independent distance and RSS errors,

$$u^2\left(A_{\text{ex,FS}}\right) \simeq u^2(A) + \left(\frac{20}{\ln 10}\right)^2 \left[\frac{u^2(d)}{d^2} + \frac{u^2(d_0)}{d_0^2}\right] \tag{23}$$

The uncertainty in the reference measurement enters every derived loss and coefficient for that network; shared reference errors also induce correlations across locations. Equations (21)–(23) are first-order approximations and should be supplemented by sensitivity intervals when measurement uncertainty distributions are unknown.

2.6 Applicability to the Jalingo measurements

The source field records contain a nominal 10 m reference series and measurements at five sites with reported BTS separations. However, serving-cell identity and operating frequency are not documented for every reference–field pairing. The analysis must therefore verify cell and band comparability before assigning a physical propagation interpretation. When such matching or required model inputs are unavailable, A, n_{eff} and α_{eff} should be reported as nominal field-derived contrasts; excess losses based on unsupported models should not be presented as validated observations. In particular, a nominal 10 m ground separation should not automatically be treated as the three-dimensional radio-path length to an elevated BTS antenna.

3. Materials and Methods

3.1 Study area and measurement locations

The field investigation was conducted in Jalingo, Taraba State, Nigeria, from 19 to 23 July 2026. Five urban locations were investigated on consecutive days: Tashan Lau, Mile Six Market and Rice Mill, Jalingo Main Market, Motor Park/Danbatta–Mechanic Village, and Sayboss/Machilin.

The recorded geographic coordinates, measurement dates and base-transceiver-station (BTS)-to-field-point separations are given in Table 1. These separations were recorded for each site but are not independently verified network-specific or three-dimensional radio-path distances.

Table 1. Study locations, measurement dates, coordinates and recorded BTS separations.

Measurement location	Date (2026)	Latitude (°N)	Longitude (°E)	BTS separation (m)
Tashan Lau	19 July	8.911567	11.385499	241.880
Mile Six Market and Rice Mill	20 July	8.957562	11.367596	380.950
Jalingo Main Market	21 July	8.894454	11.359125	1518.400
Motor Park/Danbatta–Mechanic Village	22 July	8.937844	11.338350	741.188
Sayboss/Machilin	23 July	8.901802	11.359619	851.500

3.2 Instrumentation and field-measurement design

Received signal strength (RSS) was recorded in dBm using four Tecno Spark 7 smartphones, with one handset assigned to each of MTN, Airtel, GLO and 9mobile. The handsets operated in mixed 4G/GSM mode; therefore, the readings are described as mobile-network RSS, not exclusively 2G GSM measurements. Ambient temperature was measured using a MASTECH MS8217 instrument, and locations and BTS separations were recorded using an NP-198 GPS land meter. Environmental acoustic sound was recorded on a Samsung A06 with the Sound Meter application (Table 2). Acoustic levels are not radio-frequency receiver noise and are not used to determine RF signal-to-noise ratio. Documentation of acoustic calibration, frequency band, serving-cell identity and network-specific receiver calibration was unavailable in the supplied records.

Table 2. Equipment and recorded measurement functions.

Equipment	Function or recorded variable
Four Tecno Spark 7 smartphones	RSS in dBm for MTN, Airtel, GLO and 9mobile (mixed 4G/GSM mode)

MASTECH MS8217	Ambient temperature (°C)
NP-198 GPS land meter	Field-point coordinates and reported BTS separations
Samsung A06 with Sound Meter app	Indicative environmental acoustic sound level (dB)
TVS motorcycle	Field transportation

At each location, 15 sets of approximately contemporaneous network and environmental observations were obtained at roughly 30-minute intervals during the daytime measurement period. Thus, the field dataset contains 75 RSS observations per operator (300 in total), together with 75 temperature and 75 acoustic observations. A separate series of 12 observations was obtained at a nominal reference separation of $d_0 = 10$ m, with an RSS reading for each network in every reference record. All recorded values were retained as measured; ambiguous time labels were flagged rather than silently corrected. Because one site was investigated per day, differences among sites also contain possible day-specific effects.

3.3 Reference measurements and pair comparability

The 12 reference readings were used to calculate a network-specific mean reference RSS, $\bar{R}_{0,k}$; the 15 observations at site's provided the corresponding mean field RSS, $\bar{R}_{s,k}$. Here $s = 1,\ldots,5$ denotes the location and k identifies the mobile operator. Differences between the two mean dBm levels provide the nominal reference-normalized attenuation in equation (3) of Section 2. Using a mean in dBm corresponds to comparing geometric mean received powers; the reference series and site observations were not treated as time-matched pairs.

Before interpreting an attenuation estimate as a channel-specific propagation loss, the reference and field records must be checked for the same serving cell, compatible operating band and technology, receiver configuration, and correctly assigned transmitter-to-receiver path. These identifiers are not supplied for all records. Accordingly, unmatched comparisons in this study are designated nominal field-derived attenuation contrasts. The nominal 10 m ground separation is not assumed to equal the antenna-to-receiver slant range of an elevated BTS. The recorded site separation is applied consistently in descriptive calculations but not treated as verified for every operator.

3.4 Calculation of attenuation and effective absorptivity

For every site–operator combination, the sample mean and standard deviation of field RSS were calculated. The site-mean RSS was subtracted from the corresponding network-specific reference mean to obtain reference-normalized attenuation in decibels, as defined by equation (3). Negative attenuation estimates were preserved rather than truncated, since a stronger distant signal can occur with changing serving-cell association, interference conditions or reference mismatch. The contrast was divided by the reference-to-site distance difference (the site separation minus 10 m) to obtain the effective attenuation rate in dB m^{-1} and was converted to dB km^{-1} where useful. The related effective absorptivity coefficient, expressed in m^{-1}, was determined from equations (16)–(17). The descriptive path-loss exponent was calculated using equation (8).

These quantities are mathematical transformations of the same RSS contrasts, not independent measurements of absorption. In particular, a negative αeff is a signed comparative result and must not be interpreted as negative intrinsic material absorption. Site-level results are reported separately for the four networks, with units retained in every table.

3.5 Propagation-model comparison and distance dependence

The nominal measured attenuation was compared descriptively with the free-space differential baseline defined by equation (6); the model-relative difference was obtained using equation (14). Because the 10 m reference may not be an applicable free-space far-field point and the relevant antenna geometry is undocumented, A_{ex} is labelled a model-relative contrast, not a directly measured environmental absorption loss. An associated excess-loss coefficient is obtained from equation (18), subject to the same qualification.

Distance dependence was examined from the five site-level mean RSS or attenuation values for each network, rather than treating the 15 repeated readings at a fixed site as 15 different propagation distances. Scatter plots and exploratory log-distance trends were used to assess consistency with equation (7); any fitted exponents are descriptive because serving-BTS identity may vary across sites. Hata and COST-231 Hata were retained as comparative theoretical models but were not implemented numerically without documented carrier frequency, antenna heights and verified applicability ranges. Most recorded distances are also below the approximately 1km lower limit of these macrocell models [[4], [17]].

3.6 Reference sensitivity and uncertainty assessment

For each operator, the reference mean, sample standard deviation, and observed minimum and maximum were obtained from the 12 reference readings. Reference sensitivity was assessed by recalculating A, αeff and neff using the lower and upper observed reference RSS values in place of the mean. These bounds describe the effect of the observed reference variation; they are not formal confidence intervals or instrument-accuracy specifications. A change in the reference RSS produces an equal change in the attenuation contrast, while the change in effective absorptivity is inversely proportional to the reference-to-site distance difference, as established by equation (20).

Where uncertainties in both reference and field means can be justified, first-order propagation follows equations (21)–(22), retaining any covariance due to shared observations. Because the GPS distance uncertainty, instrument accuracy and serial dependence were not adequately documented, a fully calibrated combined uncertainty was not claimed. The common reference series for each network introduces shared variation across the five site coefficients and is accounted for in interpretation.

3.7 Data presentation and analytical safeguards

Results will be presented in the following order: the 12 original reference observations, the original field RSS records at the five locations, descriptive summaries, reference-normalized loss, effective attenuation and absorptivity coefficients, model-relative comparisons, and reference-sensitivity ranges. Comparisons across networks will use matched study locations and preserve the distinction between 75 repeated readings per network and only five site-level distance values per network. Any correlations of attenuation or absorptivity with RSS will be identified as algebraically coupled, not evidence of an independent physical effect. Since the serving cell, frequency band, antenna heights and network-specific path lengths cannot be verified from all supplied records, the study is framed as an empirical comparison rather than a validated determination of intrinsic material absorptivity.

4. Results and Discussion

4.1 Results

The original nominal 10 m reference measurements are presented first, followed by the original observations at the five measurement locations. The calculated results comprise reference and field summaries, nominal reference-normalized attenuation, model-relative loss, reference sensitivity, and distance-dependent statistics. Detailed physical interpretation and literature comparisons are reserved for Section 4.2.

4.1.1 Original reference field measurements

Table 3. Original measurements obtained at the nominal reference distance of 10 m.

S/N	Time	Temperature (°C)	Sound level (dB)	MTN (dBm)	Airtel (dBm)	GLO (dBm)	9mobile (dBm)
1	10:00	35.8	74	-61	-71	-68	-80
2	10:30	34.9	84	-65	-61	-60	-78
3	11:00	32.7	70.1	-88	-89	-90	-100
4	11:30	34.2	72.5	-94	-75	-88	-98
5	12:00	25.2	74	-61	-71	-111	-90
6	12:30	33.4	78.38	-65	-69	-102	-100
7	1:00	30.7	75.1	-88	-89	-113	-100
8	1:30	31.2	70.5	-96	-75	-110	-97

9	2:00	26.8	75.1	-88	-79	-92	-91
10	2:30	31.2	70.5	-75	-80	-89	-112
11	3:00	33.3	69.8	-80	-113	-77	-110
12	3:30	32.5	67.4	-77	-110	-60	-113

4.1.2 Original measurements at the five study locations

Table 4. Original field measurements at Tashan Lau, 19 July 2026 (reported BTS separation: 241.88 m).

S/N	Time	Temperature (°C)	Sound level (dB)	MTN (dBm)	Airtel (dBm)	GLO (dBm)	9mobile (dBm)
1	10:30 Am	31.6	71.5	-75	-80	-92	-91
2	11:00Am	30.7	79.3	-74	-81	-89	-112
3	11:30Am	36.0	84.3	-76	-82	-93	-101
4	12:00 Am	33.2	80.5	-75	-85	-90	-112
5	12:30Pm	32.1	76.5	-90	-89	-91	-104
6	1:00Pm	34.6	74.5	-97	-102	-101	-99
7	1:30Pm	34.7	88.7	-96	-100	-95	-111
8	2:00Pm	40.1	81.4	-99	-103	-95	-110
9	2:30Pm	41.2	74.6	-103	-105	-86	-103
10	3:00Pm	40.7	76.4	-95	-99	-91	-78
11	3:30Pm	37.8	75.1	-104	-94	-81	-112

12	4:00Pm	37.6	75.8	-94	-98	-89	-110
13	4:30Pm	36.5	81.9	-98	-99	-101	-89
14	5:00Pm	34.7	72.8	-104	-112	-111	-95
15	5:30Pm	30.7	70.8	-106	-103	-114	-90

Table 5. Original field measurements at Mile Six Market and Rice Mill, 20 July 2026 (reported BTS separation: 380.95 m).

S/N	Time	Temperature (°C)	Sound level (dB)	MTN (dBm)	Airtel (dBm)	GLO (dBm)	9mobile (dBm)
1	10:00Am	37.0	84.8	-77	-89	-113	-84
2	10:30Am	36.9	84.5	-73	-94	-112	-90
3	11:00Am	36.9	87	-83	-97	-110	-86
4	11:30Am	36.8	88.1	-99	-97	-116	-92
5	12:00Pm	36.6	85.2	-96	-85	-110	-101
6	12:30Pm	37.1	83.7	-97	-86	-111	-113
7	1:00Pm	37.2	83.6	-100	-87	-117	-98
8	1:30Pm	36.8	84.9	-76	-88	-114	-105
9	2:00Pm	36.5	86.2	-92	-85	-110	-106
10	2:30Pm	37.3	89.6	-89	-83	-108	-102
11	3:00Pm	34.2	85.9	-88	-78	-111	-114
12	3:30Pm	33.8	86.8	-92	-84	-107	-100
13	4:00Pm	33.0	84.6	-90	-83	-113	-86
14	4:30Pm	32.0	85	-89	-88	-116	-89
15	5:00Pm	30.5	77.3	-91	-90	-108	-87

Table 6. Original field measurements at Jalingo Main Market, 21 July 2026 (reported BTS separation: 1518.4 m).

S/N	Time	Temperature (°C)	Sound level (dB)	MTN (dBm)	Airtel (dBm)	GLO (dBm)	9mobile (dBm)
1	10:00 Am	37.9	88.1	-70	-89	-113	-70
2	10:30 Am	38.0	88.2	-90	-74	-112	-80
3	11:00 Am	38.1	85.2	-90	-94	-110	-88
4	11:30 Am	39.1	84.8	-91	-81	-116	-86
5	12:00Pm	47.1	85.2	-72	-85	-111	-98
6	12:30Pm	39.3	83.7	-95	-88	-112	-101
7	1:00Pm	40.1	85.9	-96	-87	-115	-114
8	1:30Pm	37.1	83.6	-70	-88	-113	-119
9	2:00Pm	36.9	84.9	-87	-89	-114	-113
10	2:30Pm	37.3	84.8	-89	-82	-108	-116
11	3:00Pm	37.0	85.9	-77	-87	-111	-112
12	3:30Pm	36.7	84.8	-92	-86	-113	-105
13	4:00Pm	35.5	85.2	-91	-82	-116	-100
14	4:30Pm	34.9	80.6	-89	-72	-119	-86
15	5:00Pm	34.0	70.2	-116	-87	-113	-87

Table 7. Original field measurements at Motor Park/Danbatta–Mechanic Village, 22 July 2026 (reported BTS separation: 741.188 m).

S/N	Time	Temperature (°C)	Sound level (dB)	MTN (dBm)	Airtel (dBm)	GLO (dBm)	9mobile (dBm)
1	10:00 Am	31.2	60.2	-102	-98	-100	-102
2	10:30 Am	30.3	69.8	-103	-112	-113	-110
3	11:00 Am	31.6	70.3	-101	-115	-114	-91
4	11:30 Am	36.0	76.5	-98	-96	-112	-111
5	12:00 Pm	30.7	81.5	-98	-93	-101	-120
6	12:30 Pm	30.4	86	-97	-76	-102	-118
7	1:00Pm	37.2	74.5	-97	-102	-110	-119
8	1:30Pm	37.1	80.3	-98	-103	-99	-120
9	2:00Pm	32.7	69.5	-101	-111	-98	-80
10	2:30Pm	35.1	72.3	-97	-99	-97	-93
11	3:00Pm	36.5	88	-100	-118	-96	-98
12	3:30Pm	37.0	79.4	-98	-119	-90	-82
13	4:00Pm	34.3	73.2	-86	-116	-89	-95
14	4:30Pm	30.5	72.5	-84	-96	-86	-112
15	5:00Pm	30.7	66.6	-99	-70	-120	-101

Table 8. Original field measurements at Sayboss/Machilin, 23 July 2026 (reported BTS separation: 851.5 m).

S/N	Time	Temperature (°C)	Sound level (dB)	MTN (dBm)	Airtel (dBm)	GLO (dBm)	9mobile (dBm)
1	10:00 Am	34.6	71.5	-85	-89	-96	-118
2	10:30 Am	34.7	72.2	-86	-126	-100	-119
3	11:00 Am	35.0	80.7	-83	-111	-113	-120
4	11:30 Am	35.7	79.3	-86	-93	-114	-111
5	12:00Pm	36.5	82.6	-84	-97	-114	-120
6	12:30Pm	36.6	84.3	-92	-99	-90	-112
7	1:00Pm	37.6	80.5	-88	-95	-98	-80
8	1:30Pm	40.2	76.5	-85	-96	-96	-85
9	2:00Pm	40.1	74.5	-87	-93	-110	-93
10	2:30Pm	41.7	81.9	-90	-110	-99	-118
11	3:00Pm	39.9	76.4	-95	-117	-102	-100
12	3:30Pm	38.7	75.1	-88	-91	-111	-101
13	4:00Pm	38.1	81.9	-89	-119	-98	-95
14	4:30Pm	39.2	72.8	-74	-116	-97	-100
15	5:00Pm	33.5	70.8	-88	-103	-112	-110

4.1.3 Descriptive RSS statistics

Table 9. Network-specific reference RSS statistics from the 12 original readings.

Network	Mean RSS (dBm)	Sample SD (dB)	SEM (dB)	Observed range (dBm)
MTN	−78.17	12.83	3.70	-96 to -61
Airtel	−81.83	15.97	4.61	-113 to -61
GLO	−88.33	18.93	5.47	-113 to -60
9mobile	−97.42	11.33	3.27	-113 to -78

Table 10. Location-specific field RSS means and sample standard deviations (15 observations per network and location).

Location	MTN (dBm)	Airtel (dBm)	GLO (dBm)	9mobile (dBm)
Tashan Lau	−92.40 ± 11.66	−95.47 ± 9.84	−94.60 ± 8.89	−101.13 ± 10.60
Mile Six Market	−88.80 ± 8.29	−87.60 ± 5.28	−111.73 ± 3.08	−96.87 ± 9.96
Jalingo Main Market	−87.67 ± 11.85	−84.73 ± 5.78	−113.07 ± 2.71	−98.33 ± 14.93
Motor Park	−97.27 ± 5.34	−101.60 ± 14.56	−101.80 ± 10.04	−103.47 ± 13.52
Sayboss/Machilin	−86.67 ± 4.69	−103.67 ± 11.84	−103.33 ± 8.08	−105.47 ± 13.16
Overall (n = 75)	−90.56 ± 9.49	−94.61 ± 12.37	−104.91 ± 9.82	−101.05 ± 12.64

4.1.4 Nominal reference-normalized attenuation and effective coefficients

Table 11. Calculated nominal attenuation, effective path-loss exponent, distance-normalized attenuation rate and effective coefficient.

Location	Network	BTS separation d (m)	Nominal A (dB)	n_eff	γ_eff (dB km⁻¹)	α_eff (×10⁻³ m⁻¹)
Tashan Lau	MTN	241.880	14.23	1.029	61.38	14.1338
Tashan Lau	Airtel	241.880	13.63	0.985	58.79	13.5380
Tashan Lau	GLO	241.880	6.27	0.453	27.03	6.2228
Tashan Lau	9mobile	241.880	3.72	0.269	16.03	3.6907
Mile Six Market	MTN	380.950	10.63	0.673	28.67	6.6004
Mile Six Market	Airtel	380.950	5.77	0.365	15.55	3.5795
Mile Six Market	GLO	380.950	23.40	1.480	63.08	14.5250
Mile Six Market	9mobile	380.950	−0.55	-0.035	−1.48	−0.3414
Jalingo Main Market	MTN	1518.400	9.50	0.436	6.30	1.4502
Jalingo Main Market	Airtel	1518.400	2.90	0.133	1.92	0.4427
Jalingo Main Market	GLO	1518.400	24.73	1.134	16.40	3.7756
Jalingo Main Market	9mobile	1518.400	0.92	0.042	0.61	0.1399
Motor Park	MTN	741.188	19.10	1.021	26.12	6.0148
Motor Park	Airtel	741.188	19.77	1.057	27.03	6.2247
Motor Park	GLO	741.188	13.47	0.720	18.42	4.2408
Motor Park	9mobile	741.188	6.05	0.324	8.27	1.9052
Sayboss/Machilin	MTN	851.500	8.50	0.440	10.10	2.3258
Sayboss/Machilin	Airtel	851.500	21.83	1.131	25.95	5.9742
Sayboss/Machilin	GLO	851.500	15.00	0.777	17.83	4.1044
Sayboss/Machilin	9mobile	851.500	8.05	0.417	9.57	2.2027

Computed from equations. (3), (8), (16) and (17) using $d_0 = 10\text{m}$ and $\Delta d = d - 10\text{m}$. Values are nominal field-derived contrasts; no unmatched reading is interpreted as independently verified channel loss. Negative values are retained.

4.1.5 Comparison with the free-space distance baseline

Table 12. Free-space differential loss, nominal measured attenuation and model-relative excess attenuation.

Location	Network	Nominal A (dB)	A_FS (dB)	A_ex = A − A_FS (dB)	α_ex (×10⁻³ m⁻¹)
Tashan Lau	MTN	14.23	27.67	−13.44	−13.3447
Tashan Lau	Airtel	13.63	27.67	−14.04	−13.9405
Tashan Lau	GLO	6.27	27.67	−21.41	−21.2556
Tashan Lau	9mobile	3.72	27.67	−23.96	−23.7878
Mile Six Market	MTN	10.63	31.62	−20.98	−13.0253
Mile Six Market	Airtel	5.77	31.62	−25.85	−16.0462
Mile Six Market	GLO	23.40	31.62	−8.22	−5.1007
Mile Six Market	9mobile	−0.55	31.62	−32.17	−19.9671
Jalingo Main Market	MTN	9.50	43.63	−34.13	−5.2096
Jalingo Main Market	Airtel	2.90	43.63	−40.73	−6.2171
Jalingo Main Market	GLO	24.73	43.63	−18.89	−2.8842
Jalingo Main Market	9mobile	0.92	43.63	−42.71	−6.5199
Motor Park	MTN	19.10	37.40	−18.30	−5.7624
Motor Park	Airtel	19.77	37.40	−17.63	−5.5525
Motor Park	GLO	13.47	37.40	−23.93	−7.5364
Motor Park	9mobile	6.05	37.40	−31.35	−9.8720
Sayboss/Machilin	MTN	8.50	38.60	−30.10	−8.2372
Sayboss/Machilin	Airtel	21.83	38.60	−16.77	−4.5889
Sayboss/Machilin	GLO	15.00	38.60	−23.60	−6.4586
Sayboss/Machilin	9mobile	8.05	38.60	−30.55	−8.3604

$A_{FS} = 20 \log_{10}(d/10m)$ is a mathematical free-space differential baseline. Because the 10m reference may not satisfy far-field assumptions, A_{ex} and α_{ex} are model-relative comparisons, not confirmed material absorption losses. Hata/COST-231 Hata predictions are not computed because serving frequency, antenna heights and valid 1–20km geometry are not established for the dataset.

4.1.6 Reference-measurement sensitivity

Table 13. Sensitivity of nominal attenuation and effective coefficient to the observed reference RSS range.

Location	Network	A at mean reference (dB)	A range (dB)	α at mean reference ($\times 10^{-3}$ m^{-1})	α range ($\times 10^{-3}$ m^{-1})
Tashan Lau	MTN	14.23	−3.60 to 31.40	14.1338	−3.5748 to 31.1804
Tashan Lau	Airtel	13.63	−17.53 to 34.47	13.5380	−17.4107 to 34.2256
Tashan Lau	GLO	6.27	−18.40 to 34.60	6.2228	−18.2713 to 34.3580
Tashan Lau	9mobile	3.72	−11.87 to 23.13	3.6907	−11.7837 to 22.9716
Mile Six Market	MTN	10.63	−7.20 to 27.80	6.6004	−4.4692 to 17.2562
Mile Six Market	Airtel	5.77	−25.40 to 26.60	3.5795	−15.7665 to 16.5113
Mile Six Market	GLO	23.40	−1.27 to 51.73	14.5250	−0.7863 to 32.1123
Mile Six Market	9mobile	−0.55	−16.13 to 18.87	−0.3414	−10.0144 to 11.7110
Jalingo Main Market	MTN	9.50	−8.33 to 26.67	1.4502	−1.2721 to 4.0707
Jalingo Main Market	Airtel	2.90	−28.27 to 23.73	0.4427	−4.3149 to 3.6229
Jalingo Main Market	GLO	24.73	0.07 to 53.07	3.7756	0.0102 to 8.1007
Jalingo Main Market	9mobile	0.92	−14.67 to 20.33	0.1399	−2.2389 to 3.1039
Motor Park	MTN	19.10	1.27 to 36.27	6.0148	0.3989 to 11.4207
Motor Park	Airtel	19.77	−11.40 to 40.60	6.2247	−3.5900 to 12.7854
Motor Park	GLO	13.47	−11.20 to 41.80	4.2408	−3.5270 to 13.1632
Motor Park	9mobile	6.05	−9.53 to 25.47	1.9052	−3.0021 to 8.0197
Sayboss/Machilin	MTN	8.50	−9.33 to 25.67	2.3258	−2.5539 to 7.0231
Sayboss/Machilin	Airtel	21.83	−9.33 to 42.67	5.9742	−2.5539 to 11.6748
Sayboss/Machilin	GLO	15.00	−9.67 to 43.33	4.1044	−2.6451 to 11.8572
Sayboss/Machilin	9mobile	8.05	−7.53 to 27.47	2.2027	−2.0613 to 7.5157

The lower and upper values are recalculated using the observed minimum and maximum 10m reference RSS for each operator while holding the site mean fixed. These are observed-range sensitivity bounds, not confidence limits.

4.1.7 Distance association and aggregate log-distance trend

Table 14. Five-location correlation and reference-anchored log-distance fit for each network.

Network	Pearson r: distance vs A	Two-sided p	Reference-anchored fitted n	Residual sample SD (dB)
MTN	-0.343	0.5720	0.667	5.30
Airtel	-0.275	0.6541	0.692	8.80
GLO	0.583	0.3018	0.938	6.38
9mobile	-0.022	0.9714	0.202	3.52

Each analysis uses five location-level values, not 75 independent distances. The anchored fit uses $A = 10n \log_{10}(d/10m)$ with the intercept constrained to zero; the fitted n is descriptive and is not a validated single-link propagation exponent.

4.1.8 Exploratory repeatability-based uncertainty estimates

Table 15. Exploratory uncertainty estimates from observed reference and field RSS repeatability.

Location	Network	Reference SEM (dB)	Field SEM (dB)	u(A), illustrative (dB)	u(α), illustrative ($\times 10^{-3}$ m^{-1})
Tashan Lau	MTN	3.70	3.01	4.77	4.7389
Tashan Lau	Airtel	4.61	2.54	5.26	5.2273
Tashan Lau	GLO	5.47	2.29	5.93	5.8859
Tashan Lau	9mobile	3.27	2.74	4.26	4.2332
Mile Six Market	MTN	3.70	2.14	4.28	2.6548
Mile Six Market	Airtel	4.61	1.36	4.81	2.9840
Mile Six Market	GLO	5.47	0.80	5.52	3.4282
Mile Six Market	9mobile	3.27	2.57	4.16	2.5823
Jalingo Main Market	MTN	3.70	3.06	4.80	0.7332
Jalingo Main Market	Airtel	4.61	1.49	4.85	0.7397
Jalingo Main Market	GLO	5.47	0.70	5.51	0.8411
Jalingo Main Market	9mobile	3.27	3.85	5.05	0.7715
Motor Park	MTN	3.70	1.38	3.95	1.2442
Motor Park	Airtel	4.61	3.76	5.95	1.8733
Motor Park	GLO	5.47	2.59	6.05	1.9050
Motor Park	9mobile	3.27	3.49	4.78	1.5059
Sayboss/Machilin	MTN	3.70	1.21	3.90	1.0659
Sayboss/Machilin	Airtel	4.61	3.06	5.53	1.5135
Sayboss/Machilin	GLO	5.47	2.09	5.85	1.6006
Sayboss/Machilin	9mobile	3.27	3.40	4.72	1.2904

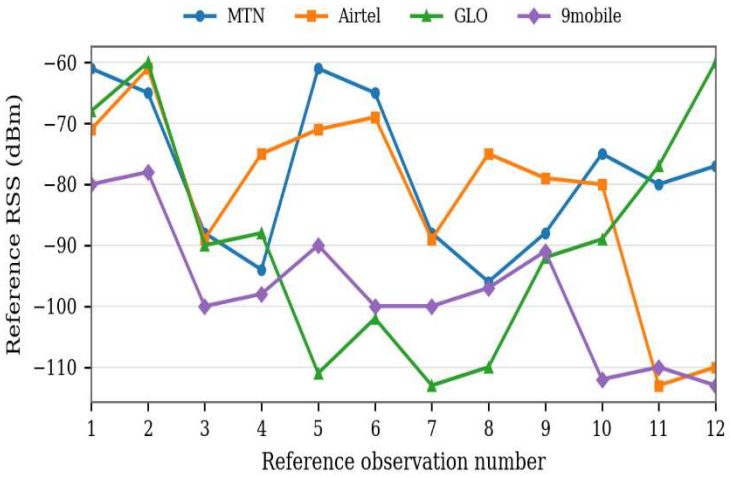

Figure 1. Reference RSS variation at the nominal 10 m measurement distance.

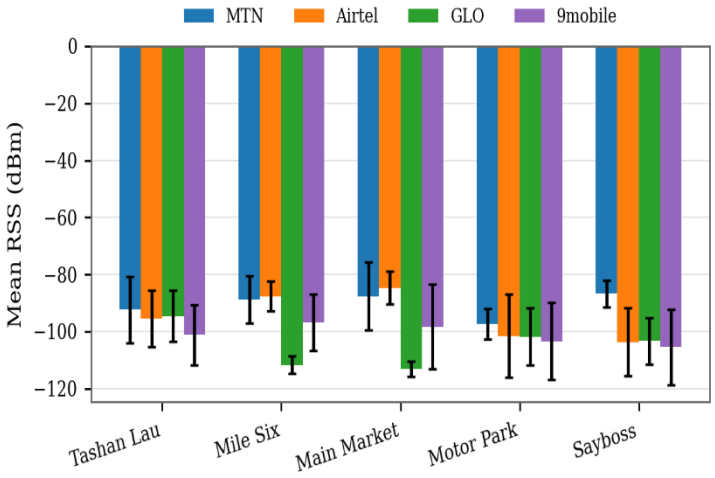

Figure 2. Mean RSS and sample standard deviation at the five field locations.

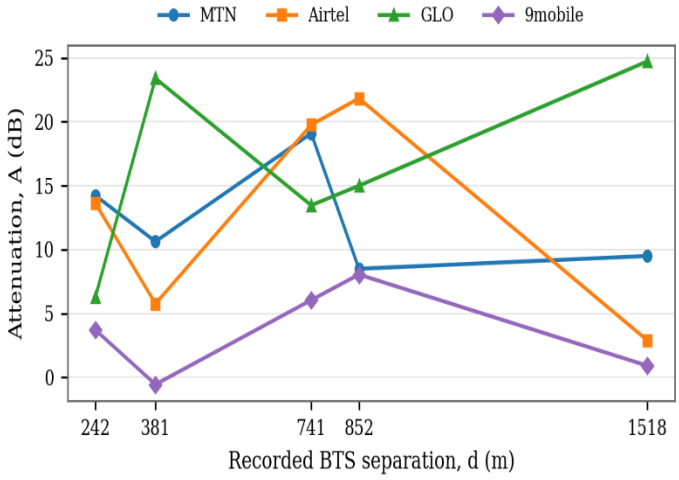

Figure 3. Reference-normalized attenuation versus recorded BTS separation.

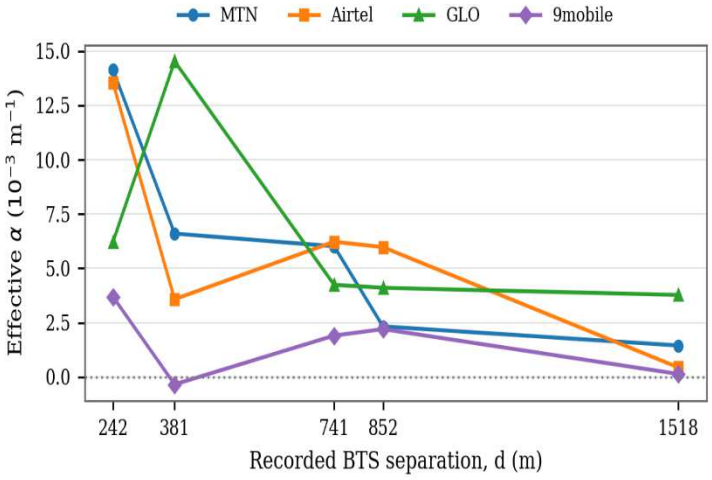

Figure 4. Effective attenuation coefficient versus recorded BTS separation.

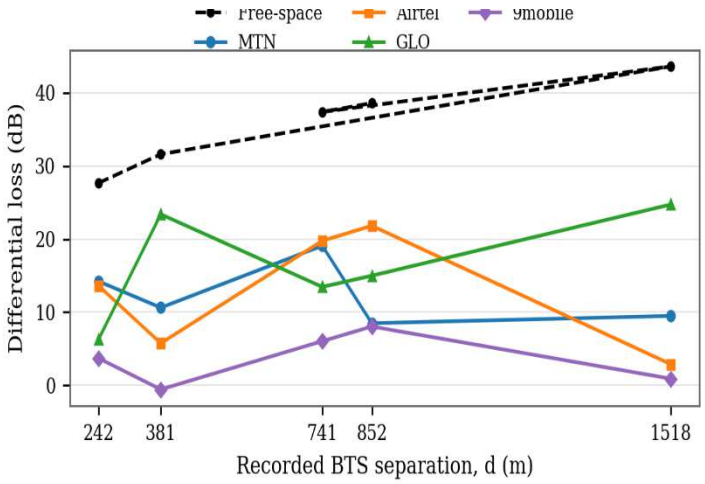

Figure 5. Measured attenuation compared with the free-space differential baseline.

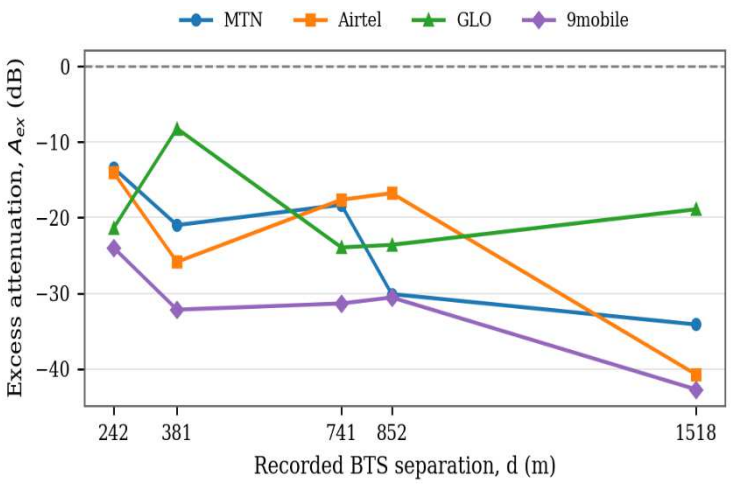

Figure 6. Model-relative excess attenuation versus recorded BTS separation.

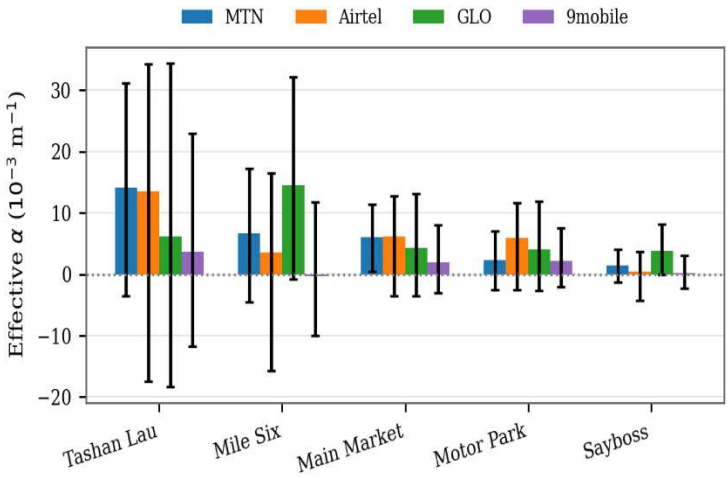

Figure 7. Sensitivity of effective attenuation coefficients to reference RSS variation.

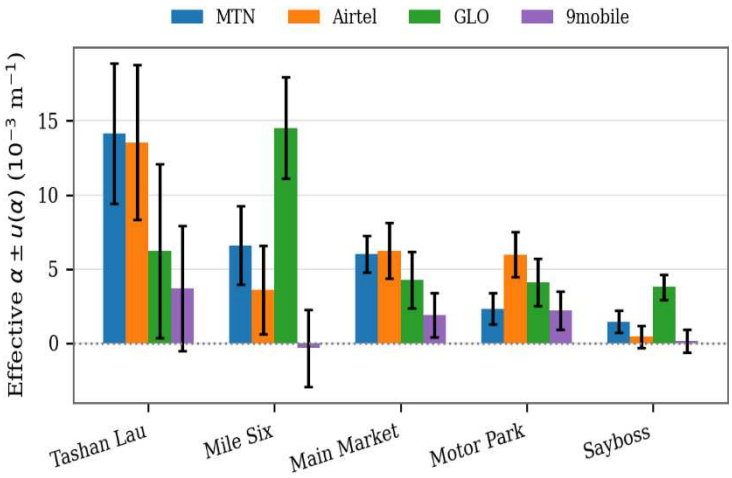

Figure 8. Effective attenuation coefficients with illustrative uncertainty bars.

4.2 Discussion of Results

4.2.1 Reference and field received signal strength

The 12 reference measurements Table 3 and Figure 1 show substantial fluctuations at the nominal 10 m distance. Mean reference RSS values were −78.17, −81.83, −88.33 and −97.42dBm for MTN, Airtel, GLO and 9mobile, respectively, with standard deviations of 11.33–18.93dB (Table 9). These fluctuations directly affect attenuation calculated relative to the reference means. The original measurements from Tashan Lau, Mile Six, Jalingo Main Market, Motor Park and Sayboss/Machilin Tables 4–8 likewise vary by network and site (Table 10; Figure 2). At Jalingo Main Market, for example, Airtel averaged −84.73dBm and GLO −113.07dBm. The location-dependent differences are consistent with Nigerian propagation measurements reported by Popoola and colleagues [9] and Anamonye and colleagues [12], although serving-cell and transmitter characteristics cannot be isolated from the present records.

4.2.2 Reference-normalized attenuation and effective absorptivity

Table 11 and Figure 3 give nominal attenuation of 8.50–19.10dB (MTN), 2.90–21.83dB (Airtel), 6.27–24.73dB (GLO) and −0.55–8.05dB (9mobile). The negative 9mobile value at Mile Six means that the distant mean RSS slightly exceeded its reference mean; it does not imply negative material absorption. The distance-normalized effective coefficients Table 11 and Figure 4 also differ substantially. For MTN, the coefficient was $14.13 \times 10^{-3} m^{-1}$ at Tashan Lau but $1.45 \times 10^{-3} m^{-1}$ at Jalingo Main Market. Because distance appears in the denominator, this decrease cannot independently establish a reduction in environmental absorption. These coefficients remain empirical descriptors of the observed RSS contrasts, not independently measured material properties.

4.2.3 Comparison with the propagation baseline

In Table 12 and Figure 5, the free-space differential baseline increases from 27.67 to 43.63dB across the recorded separations (241.88–1518.40m). All 20 nominal attenuation estimates fall below this baseline; consequently, the model-relative excess values in Table 12 and Figure 6 are negative (−42.71 to −8.22dB). This is not evidence of environmental propagation gain. It indicates that the field/reference comparisons do not satisfy all assumptions of a common, controlled free-space link. Differences in serving cell, carrier band, antenna configuration or measurement

geometry could contribute. The need for appropriate propagation conditions and model inputs is consistent with Hata [4] and ITU-R guidance [[5], [6], [8]].

4.2.4 Reference sensitivity and uncertainty

The sensitivity analysis (Table 13; Figure 7) shows how strongly the effective coefficients depend on reference RSS. At Tashan Lau, MTN's estimate of $14.13 \times 10^{-3} m^{-1}$ spans -3.57×10^{-3} to 31.18×10^{-3} m^{-1} when the observed reference extremes are used. These are sensitivity limits, not confidence intervals. The repeatability-based results (Table 15; Figure 8) provide a separate uncertainty measure: MTN at Tashan Lau has an illustrative uncertainty of approximately 4.74×10^{-3} m^{-1}. Instrument calibration, transmitter matching and distance uncertainties were not quantified; the reported values therefore do not constitute complete uncertainty budgets, as distinguished in the JCGM guidance [18].

4.2.5 Distance dependence

Table 14 gives nonsignificant correlations between BTS separation and nominal attenuation: MTN $r = -0.343$ ($p = 0.572$), Airtel $r = -0.275$ ($p = 0.654$), GLO $r = 0.583$ ($p = 0.302$) and 9mobile $r = -0.022$ ($p = 0.971$). Reference-anchored log-distance fits produced descriptive exponents of 0.667, 0.692, 0.938 and 0.202, respectively. With only five site-level distances per network and no confirmed common serving-cell identity, these values cannot validate a path-loss law. The contrast with distance-dependent findings reported by Yabwa et al., [16] also underscores the importance of transmitter type and measurement design.

5. Conclusion

5.1 Conclusion

This study investigated reference-normalized signal attenuation and effective absorptivity across four mobile networks at five urban locations in Jalingo, Nigeria. The calculated attenuation ranged from 8.50 to 19.10dB for MTN, 2.90 to 21.83dB for Airtel, 6.27 to 24.73dB for GLO, and −0.55 to 8.05dB for 9mobile. The effective attenuation coefficients exhibited considerable network- and location-dependent variability. Comparisons with the free-space propagation baseline produced negative model-relative excess attenuation values, indicating limitations in the comparability of the reference and field measurements. Furthermore, the distance-dependent correlations were

statistically nonsignificant for all four networks. Sensitivity analysis established that variations in reference received signal strength substantially influenced the estimated attenuation coefficients. Consequently, the calculated effective absorptivity coefficients should be regarded as empirical attenuation parameters rather than intrinsic electromagnetic absorption properties.

5.2 Recommendations

Future investigations should employ calibrated radio-frequency measurement equipment and verify serving-cell identity, operating frequency, and antenna characteristics for corresponding reference and distant measurements. Measurements should cover multiple propagation distances and observation periods to improve the reliability of attenuation estimates. Comprehensive uncertainty analysis incorporating instrumental, reference-signal, and distance-related errors is also recommended.

5.3 Contribution to Knowledge

The study provides comparative experimental evidence of reference-normalized attenuation characteristics for MTN, Airtel, GLO, and 9mobile in urban Jalingo. It establishes the sensitivity of effective attenuation coefficients to reference-signal variability and identifies the limitations of conventional free-space comparisons when transmitter–receiver conditions are not independently verified. These findings provide a basis for assessing the reliability of field-derived attenuation parameters in heterogeneous urban environments.

5.4 Novelty Statement

The novelty of this investigation lies in the integrated assessment of network-specific reference-normalized attenuation, distance-dependent effective coefficients, propagation-baseline comparisons, and reference-measurement uncertainty. Rather than reporting signal-strength differences alone, the study evaluates the reliability and physical interpretation of attenuation parameters derived from experimental observations across multiple urban locations.

5.5 Research Gap Filled

Previous Nigerian radio-propagation investigations have principally examined received signal strength, empirical path-loss prediction, and environmental influences on network performance. The combined evaluation of reference-normalized attenuation, effective absorptivity, and

reference-measurement sensitivity across multiple operational networks in Jalingo has received comparatively limited attention. This study contributes to filling that gap by providing a comparative, uncertainty-aware assessment of these parameters and identifying the measurement conditions necessary for their physically reliable interpretation.

Statements and Declarations

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Author Contributions: Y.D. Musa: Conceptualization, Formal analysis, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing-original draft, Writing-review, investigstion and editing. M. R. Cland: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Writing-original draft, Writing-review and editing. I. A. Shahruzzaman: Data curation, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing-original draft, Writing-review and editing. M. A. Tahir: Data curation, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing-original draft, Writing-review and editing. N. Richard: Data curation, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing-original draft, Writing-review and editing.

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List of Tables

Table 1. Study locations, measurement dates, coordinates and recorded BTS separations.

Table 2. Equipment and recorded measurement functions.

Table 3. Original measurements obtained at the nominal reference distance of 10m.

Table 4. Original field measurements at Tashan Lau, 19 July 2026 (reported BTS separation: 241.88m).

Table 5. Original field measurements at Mile Six Market and Rice Mill, 20 July 2026 (reported BTS separation: 380.95m).

Table 6. Original field measurements at Jalingo Main Market, 21 July 2026 (reported BTS separation: 1518.4m).

Table 7. Original field measurements at Motor Park/Danbatta–Mechanic Village, 22 July 2026 (reported BTS separation: 741.188m).

Table 8. Original field measurements at Sayboss/Machilin, 23 July 2026 (reported BTS separation: 851.5m).

Table 9. Network-specific reference RSS statistics from the 12 original readings.

Table 10. Location-specific field RSS means and sample standard deviations (15 observations per network and location).

Table 11. Calculated nominal attenuation, effective path-loss exponent, distance-normalized attenuation rate and effective coefficient.

Table 12. Free-space differential loss, nominal measured attenuation and model-relative excess attenuation.

Table 13. Sensitivity of nominal attenuation and effective coefficient to the observed reference RSS range.

Table 14. Five-location correlation and reference-anchored log-distance fit for each network.

Table 15. Exploratory uncertainty estimates from observed reference and field RSS repeatability.

List of Figures

Figure 1. Reference received signal strength at the nominal 10m distance.

Figure 2. Mean network signal strength and standard deviation at five locations.

Figure 3. Reference-normalized attenuation versus recorded BTS distance.

Figure 4. Effective attenuation coefficient versus recorded BTS distance.

Figure 5. Reference-normalized attenuation and free-space differential baseline.

Figure 6. Model-relative excess attenuation versus recorded BTS distance.

Figure 7. Sensitivity of attenuation coefficients to the observed reference RSS range.

Figure 8. Effective attenuation coefficients with illustrative repeatability uncertainty.