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DIURNAL VARIATION OF CELLULAR RADIOFREQUENCY POWER DENSITY FROM SHORT-RANGE FIELD MEASUREMENTS IN TROPICAL PROPAGATION ENVIRONMENTS

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ABSTRACT

Reliable cellular network performance depends on stable radio frequency (RF) signal propagation under varying environmental and temporal conditions. Although distance and meteorological influences on signal behaviour are well documented, few field-based studies have quantified short-range diurnal variation in broadband aggregate RF power density around base transceiver station (BTS) infrastructure, particularly in tropical urban environments. This study investigates diurnal variation in broadband RF power density around three operational BTS sites within a 2.5-3 km radius. Field measurements were obtained using a calibrated Trifield TF2 RF meter, which records broadband aggregate RF exposure, while meteorological data were sourced from the Nigeria Meteorological Agency (NiMet). Measurements were collected across morning, afternoon, and evening time blocks over twenty-eight consecutive days. Results show a clear diurnal pattern, with mean power density highest in the evening (6.00 W/m²), followed by afternoon (5.37 W/m²), and lowest in the morning (4.08 W/m²). One-way ANOVA indicated statistically significant differences ($p < 0.001$), with a moderate effect size ($\eta^2 \approx 0.06$), and Tukey HSD testing confirmed differences between time blocks. Correlation analysis showed weak associations between power density and distance ($r = -0.121$), temperature ($r = 0.14$), and relative humidity ($r = -0.142$), indicating small practical effect, despite statistical significance. Regression analysis identified distance as the dominant predictor ($R^2 = 0.015$), with only marginal improvement when meteorological variables were included ($R^2 = 0.038$). These results provide short-range tropical field evidence of diurnal variability in broadband RF power density, where atmospheric effects remain secondary to distance-dependent attenuation.

Keywords: Diurnal variation, RF power density, Radiofrequency propagation, Base Transceiver Station (BTS), Tropical atmospheric effects, Wireless network reliability

INTRODUCTION

Radio frequency (RF) propagation governs how electromagnetic signals travel from transmitters to receivers, thereby determining the reliability and quality of service of modern wireless communication systems. In cellular networks, signal behaviour around base transceiver stations (BTS) is influenced by geometric path loss and environmental factors such as surface reflections, diffraction, scattering, and urban structures (Rappaport, 2002; Goldsmith, 2005; Ohworho & Ossai, 2023). These effects introduce variability in signal coverage, necessitating accurate modelling and empirical validation for efficient network planning, interference management, spectrum utilisation, and performance optimization (Bakare *et al.*, 2019; Parsons, 2000; Saunders & Aragón-Zavala, 2007; Poddar *et al.*, 2025). Predictive models for microwave attenuation often incorporate atmospheric parameters, as moisture and temperature gradients influence refractive index and signal absorption, particularly in tropical climates (Ohworho *et al.*, 2026; ITU-R P.530-17, 2017; ITU-R P.676-12, 2019; Mehina & Cavalina, 2023).

Despite extensive research on RF propagation, most empirical studies focus on long-range microwave links, large-scale propagation modelling, or long-term climatic effects. Comparatively few field-based investigations have examined short-term diurnal variation in RF signal behaviour at short distances from BTS infrastructure, particularly using direct broadband power density measurements in humid tropical urban environments. This represents an important knowledge gap because tropical climates are characterised by high humidity, strong diurnal thermal cycles, and dynamic atmospheric moisture content (Molisch, 2012; Saunders & Aragón-Zavala, 2007).

Theoretically, distance-induced attenuation is expected to dominate signal behaviour at short ranges, as received power decreases rapidly with transmitter-receiver separation according to free-space and terrestrial path loss models (Rappaport, 2002; ITU-R P.530-17, 2017). Under such conditions, atmospheric absorption effects and diurnal atmospheric variability are often assumed to be secondary and comparatively small. (ITU-R P.676-12, 2019). Temperature modifies dielectric properties, atmospheric density and refractive index structure of the transmission medium potentially influencing multipath and signal stability within the lower atmosphere. Relative humidity impacts signal attenuation, as water vapour increases atmospheric absorption. (Omotoso & Olajide-Owoyomi, 2025; Molisch, 2012; Rappaport, 2002; Diton & Odu, 2025; ITU-R P.838-3, 2005). This raises an important empirical question: whether short-range BTS environments, which are dominated by geometric attenuation, still exhibit measurable diurnal variability associated with atmospheric conditions.

Existing studies suggest that even small atmospheric variations, especially when structured diurnally, can contribute to short-term signal fluctuations (Iwuji & Onuabuchi, 2018; Suleman *et al.*, 2025; Sharma & More, 2017; Adediji *et al.*, 2019). However, quantitative field measurements that explicitly compare diurnal variability with distance-driven attenuation and short-term meteorological conditions remain limited, particularly in tropical coastal urban environments where atmospheric moisture levels are persistently high. This study therefore investigates diurnal variation in broadband RF power density around operational BTS infrastructure within a short-range (≤150 m) terrestrial environment in a humid tropical urban setting. Specifically, the study aims to:

i. Quantify diurnal variation in broadband RF power density across morning, afternoon, and evening periods.
ii. Evaluate the relative influence of distance and short-term meteorological variables (temperature and relative humidity) on observed signal variability.
iii. Assess whether measurable atmospheric sensitivity exists in short-range BTS propagation environments where geometric attenuation is expected to dominate.

By providing short-term field measurements from a tropical urban context, the study contributes empirical evidence to ongoing efforts to better understand RF signal variability in real operational environments and supports improved network monitoring, coverage assessment, and propagation modelling in humid tropical regions.

MATERIALS AND METHODS

Study Area

The study was conducted in Abraka, a semi-urban town in Delta State, southern Nigeria (5.79°N, 6.10°E). The area is characterized by a humid tropical climate with high temperatures, elevated relative humidity, and pronounced diurnal atmospheric variability driven by daytime solar heating and nocturnal cooling. Its low elevation and proximity to the coast contribute to high atmospheric moisture content, which is relevant for short-range RF propagation. The mixed urban landscape - comprising residential buildings, institutional structures, vegetation, and road networks - introduces realistic propagation conditions, including obstruction and multipath effects.

Description of BTS Sites

Measurements were conducted at three operational base transceiver station (BTS) sites (Site A, Site B, and Site C) within the study area. The sites operate within typical cellular frequency bands (approximately 900 MHz, 1800 MHz, and 2100 MHz) used for GSM, 3G, and 4G communication. These systems employ sectorized directional antennas mounted on elevated masts to provide spatial coverage through controlled radiation patterns.

Although specific transmitter power levels and antenna gains were not accessible, BTS installations of this type typically operate under continuous transmission conditions, with emitted RF fields representing the aggregate contribution of multiple active communication channels. Therefore, the measured RF power density reflects a time-varying but continuous broadband electromagnetic field environment. The geographic coordinates of the BTS sites are: Site A (latitude 5.7914°N, longitude 6.1719°E), Site B (latitude 5.7908°N, longitude 6.1008°E), and Site C (latitude 5.7953°N, longitude 6.1153°E). The sites are spatially separated, thus reducing overlapping coverage and inter-site interference during measurements. Within the measurement distances considered, propagation conditions were predominantly near line-of-sight, with some influence from surrounding urban structures and vegetation. These BTS installations therefore provide a representative real-world electromagnetic environment for investigating short-range diurnal variations in broadband RF power density under normal network operating conditions.

Measurement Equipment

RF field measurements were conducted using a Trifield TF2 broadband RF meter, which operates over a frequency range of approximately 600 MHz to 6 GHz, covering common cellular communication bands. The instrument measures broadband aggregate RF power density and reports values in W/m². It is equipped with an isotropic sensor, enabling detection of RF signals from multiple directions without directional alignment. According to manufacturer specifications, the meter has an approximate measurement accuracy of ±20%. The device was factory-calibrated, and measurements were conducted under consistent positioning and handling conditions. Although the instrument does not provide frequency-selective measurements, its broadband response is appropriate for assessing temporal variations in aggregate RF exposure. Similar broadband field instruments have been widely employed in empirical RF measurement studies for base station environments (Sedara, 2023).

Electromagnetic Field Regime and Far-Field Considerations

To ensure physical validity of the measurements, observations were conducted within the far-field region of the transmitting antennas. For BTS antennas operating within 900–2100 MHz and having typical dimensions of 1-2 m and corresponding wavelengths ranging from approximately 0.14 m - 0.33 m, the far-field boundary occurs within a few meters from the transmitter. Since measurements were taken at distances ranging from 25 m to 150 m, all observation points lie well within the far-field region, where electromagnetic waves can be approximated as plane waves and power density measurements are physically meaningful and spatially stable. This ensures that the recorded RF power density values are representative of propagating electromagnetic fields rather than near-field reactive effects. It is important to note that "short-range" in this study refers to distances relative to BTS coverage (≤150 m), which remain well within the far-field region of the transmitting antennas.

Data Collection Procedure

Field measurements were conducted around each BTS site following a structured and repeatable procedure. At each site, RF power density readings were taken at a height of 1.5 m above ground level at radial distances of 25 m, 50 m, 100 m, and 150 m from the base of the transmitter. At each measurement point, three readings were recorded and averaged. Measurements were collected during three diurnal time blocks: morning (07:00-09:00), afternoon (12:00-14:00), and evening (18:00-20:00), over twenty-eight consecutive days under normal BTS operating conditions. Meteorological data, including temperature and relative humidity, were obtained from the Nigerian Meteorological Agency (NiMet). Hourly meteorological data were temporally aligned with RF measurements by averaging values corresponding to each time block. Given the proximity of the meteorological station to the study area, the data are considered representative of local atmospheric conditions. Geographic position data were obtained using a GPS mobile compass app, providing latitude and longitude information for each BTS site.

Statistical Sampling Structure and Data Aggregation

The measurement design follows a hierarchical structure, with observations grouped by site, distance, time of day, and measurement day. To reduce short-term variability and avoid pseudo-replication, repeated measurements at each site-distance-time combination were averaged across observation days prior to statistical analysis. This aggregation approach provides independent representative values for subsequent analyses, including ANOVA, correlation, and regression.

Measurement Uncertainty Considerations

Measurement uncertainty arises from both instrument limitations and environmental variability. The Trifield TF2 meter has an estimated accuracy of ±20%, representing the primary source of instrumental uncertainty, while additional variability may result from multipath propagation, reflections from surrounding structures, and transient environmental conditions. These effects were minimized by taking measurements at a standardized height and consistent spatial positions, with repeated readings averaged. The reported values are therefore interpreted within the context of these uncertainties.

Reference to RF Exposure Standards

To contextualize the measured RF power density values, they were compared with international exposure guidelines established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), which specify reference levels of approximately 4.5 W/m² at 900 MHz and up to about 10 W/m² at higher cellular frequencies. The measured values fall within these recommended limits, indicating that the observed variations occur within established safety thresholds.

RESULTS AND DISCUSSION

Table 1: Descriptive Statistics of Measured Parameters across All BTS Sites

Variable	Mean	SD	Min	Max
Power Density (W/m²)	5.15	3.15	0.41	14.72
Distance (m)	81.25	48.03	25	150
Temperature (°C)	25.03	1.79	21.8	29.5
Relative Humidity (%)	85.83	6.84	62	97

Table 1 presents summary statistics of the measured parameters across all BTS sites. Power density ranged from 0.41 to 14.72 W/m², with a mean of 5.15 ± 3.15 W/m² (SD). Measurement distances varied between 25 m and 150 m (mean 81.25 ± 48.03 m). Ambient temperature during the measurement period ranged from 21.8 to 29.5 °C (mean 25.03 ± 1.79 °C), while relative humidity varied from 62% to 97% (mean 85.83 ± 6.84%). To provide an estimate of statistical precision, the mean power density corresponds to an approximate 95% confidence interval of 4.96 - 5.34 W/m², assuming normality of the aggregated measurements. The relatively wide spread of power density values (SD = 3.15 W/m²) reflects substantial variability across sites, distances, and time periods under real operating conditions. These results indicate typical humid tropical atmospheric conditions and sufficient variability in both geometric (distance) and environmental parameters to support subsequent analysis of diurnal signal behaviour. However, the observed dispersion also suggests that multiple contributing factors influence RF power density beyond any single variable.

Descriptive Statistics of Power Density

Table 2: Diurnal Distribution of BTS Power Density and Associated Atmospheric Conditions

Time Block	Power Density						Mean Temp. (°C)	Mean Relative Humidity (%)
	N	Mean	Std.	Min	Median	Max		
Morning	339	4.08	2.81	0.48	3.48	12.94	23.54	90.35
Afternoon	333	5.37	3.10	0.47	5.20	14.11	26.28	83.04
Evening	336	6.00	3.24	0.41	6.83	14.72	25.29	84.02

Diurnal Variation in BTS Power Density

Table 2 presents the distribution of BTS power density across the three diurnal time blocks. The results show a clear increase in mean power density from morning (4.08 W/m²) to afternoon (5.37 W/m²) and peaking in the evening (6.00 W/m²). Median values followed a similar trend, increasing from 3.48 W/m² in the morning to 5.20 W/m² in the afternoon and 6.83 W/m² in the evening, indicating a consistent shift in central tendency across the day. To provide an estimate of statistical precision, the mean power density values correspond to approximate 95% confidence intervals of 3.79 - 4.37 W/m² (morning), 5.05 - 5.69 W/m² (afternoon), and 5.66 - 6.34 W/m² (evening). These intervals show partial separation between time blocks, supporting the presence of systematic diurnal variation.

Variability in power density, as indicated by the standard deviation, increased slightly toward the evening period (SD = 3.24 W/m²) compared to morning (SD = 2.81 W/m²), suggesting greater signal fluctuation later in the day. The observed diurnal pattern occurred alongside expected atmospheric trends, with temperatures lowest in the morning (23.54 °C) and highest in the afternoon (26.28 °C), while relative humidity was highest in the morning (90.35%) and lower during afternoon and evening periods.

To quantify the magnitude of diurnal differences, the increase from morning to evening corresponds to an approximate effect size (Cohen's d) of ~0.60, indicating a moderate practical difference in power density across time periods. However, given the relatively large within-group variability, these differences should be interpreted as moderate in magnitude despite being statistically robust. Overall, the results indicate a measurable diurnal structure in BTS power density under tropical conditions, although variability within each time block suggests that multiple contributing factors influence the observed signal behaviour.

Diurnal Differences in BTS Power Density

Table 3: ANOVA Test of Power Density across the Three Diurnal Time Blocks

F-test	F	p
	34.48	< 0.001

A one-way ANOVA test was conducted to evaluate differences in BTS power density across the three diurnal time blocks (Table 3). The analysis revealed a statistically significant effect of time block on power density, $F(2, 1005) = 34.48$, $p < 0.001$, indicating that mean power density differs across morning, afternoon, and evening periods. The estimated effect size **(**$\eta^2 \approx 0.064$**)** indicates that approximately 6.4% of the total variance in power density is associated with diurnal time differences. These findings are consistent with the descriptive statistics (Table 2), which shows a progressive increase in mean power density from morning through afternoon to evening. However, the modest effect size indicates that additional factors beyond time-of-day contribute substantially to the observed variability in RF power density.

Post-Hoc Tukey HSD Analysis

Following the significant ANOVA result, a Tukey HSD post-hoc test was conducted to identify pairwise differences between the diurnal time blocks.

Table 4a: Tukey HSD Post-Hoc Test - Multiple Comparison Of Means - Tukey HSD, FWER=0.05

Group1	Group2	Mean Diff.	p-adj	Lower	Upper	Reject
Afternoon	Evening	0.6332	0.0204	0.0788	1.1877	True
Afternoon	Morning	-1.2825	0.0	-1.8357	-0.7293	True
Evening	Morning	-1.9157	0.0	-2.4677	-1.3638	True

Table 4b: Tukey HSD Post-Hoc Test - Multiple Comparison Of Means - Tukey HSD, FWER=0.05

Comparison	Mean Diff.	p-value	Significant
Afternoon- Evening	+0.633	0.0204	Yes
Afternoon- Morning	-1.283	<0.001	Yes
Evening- Morning	-1.916	<0.001	Yes

Since ANOVA has confirmed the significance of the diurnal mean power density, a Tukey post-hoc test was carried out to tell which time blocks are responsible for the significant differences. The Tukey HSD results (Table 4) show statistically significant differences in power density between all pairs of time blocks. Evening values were higher than afternoon (mean difference = 0.633 W/m², $p = 0.020$), and both afternoon and evening values were higher than morning (mean differences = 1.283 W/m² and 1.916 W/m², respectively; $p < 0.001$ for both comparisons). The 95% confidence intervals for all pairwise comparisons do not include zero, confirming that the observed differences between time blocks are statistically significant.

Diurnal Plots Description

The diurnal variation in BTS power density is illustrated in Figure 1 (boxplot) and Figure 2 (mean ± standard deviation plot). The boxplot (Figure 1) shows the distribution of power density across the three time blocks, including median values, interquartile ranges, and outliers. The median and overall distribution shift upward from morning to afternoon and evening periods. The point plot (Figure 2) presents the mean power density for each time block with error bars representing ±1 standard deviation. The mean values increase from morning (≈4.08 W/m²) to afternoon (≈5.37 W/m²) and evening (≈6.00 W/m²), with slightly larger variability observed during the evening period.

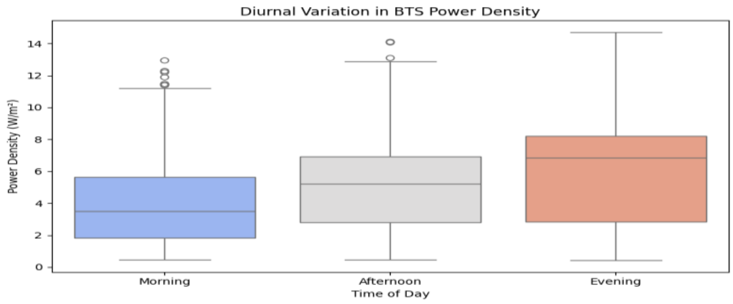

Figure 1: Boxplot showing the Distribution of BTS Power Density across Morning, Afternoon, and Evening time Blocks. Median, Interquartile Range, and Outliers are Displayed

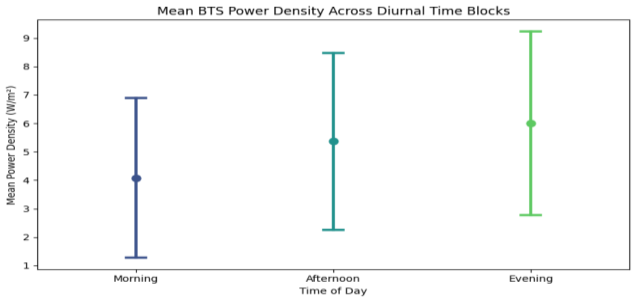

Figure 2: Mean BTS Power Density ± Standard Deviation across Diurnal Periods. Error Bars Represent ±1 Standard Deviation

Supporting Correlation and Regression Analysis

Correlation Analysis

Table 5: Pearson Correlation Coefficients among Key Variables Affecting Power Density

Variable	Power Density	Distance	Temperature	Relative Humidity
Power Density	1.000	−0.121	0.140	−0.142
Distance	−0.121	1.000	−0.000	0.008
Temperature	0.140	−0.000	1.000	−0.696
Relative Humidity	−0.142	0.008	−0.696	1.000

Pearson correlation analysis (Table 5) indicates weak linear relationships between power density and the evaluated variables. Power density shows a weak negative correlation with distance ($r = -0.121$) and relative humidity ($r = -0.142$), and a weak positive correlation with temperature ($r = 0.140$). Distance exhibits negligible correlation with both temperature ($r \approx 0.000$) and relative humidity ($r = 0.008$). A stronger negative correlation is observed between temperature and relative humidity ($r = -0.696$). Approximate 95% confidence intervals for the correlation coefficients indicate that the associations between power density and the evaluated variables are small in magnitude, despite statistical significance ($p < 0.05$).

Regression Analysis

Simple Linear Regression

Table 6a: Simple Linear Regression of Power Density on Distance

Predictor	B	p-value	R^2
Distance	-0.0079	<0.001	0.015

A simple linear regression analysis (Table 6a) shows that distance has a statistically significant negative association with power density ($\beta = -0.0079$ W/m² per meter, $p < 0.001$). The model explains approximately 1.5% of the total variance in power density **(**$R^2 = 0.015$**)**.

Multiple Regression Analysis

Table 6b: Multiple Regression of Power Density on Distance, Temperature, and Relative Humidity

Predictor	B	p-value	R^2
Distance	-0.0079	<0.001	0.038
Temperature	0.1415	0.062	-
Relative Humidity	-0.0397	0.046	-

A multiple linear regression model incorporating distance, temperature, and relative humidity shows a slight increase in explanatory power ($R^2 = 0.038$), indicating that approximately 3.8% of the variance in power density is accounted for by the combined predictors. Within this model, distance remains statistically significant ($\beta = -0.0079$, $p < 0.001$), while relative humidity shows a weak negative association ($\beta = -0.0397$, $p = 0.046$). Temperature exhibits a marginal positive association ($\beta = 0.1415$, $p = 0.062$), which is not statistically significant at the 0.05 level.

Model Summary

Overall, the regression analyses indicate that the evaluated variables account for a small proportion of the observed variability in RF power density, as reflected by the low R^2 values across both models.

Discussion

Diurnal Behaviour of BTS Power Density

The results of this study demonstrate a clear and statistically significant diurnal variation in BTS power density within the studied humid tropical urban environment. Power density values were lowest during the morning period, increased during the afternoon, and reached peak levels during the evening. The ANOVA and post-hoc Tukey HSD results confirmed that these differences were statistically significant between all time-blocks, indicating that the observed variation reflects systematic temporal patterns rather than random measurement variability. This pattern is consistent with known diurnal variability in the lower troposphere, where temperature and humidity cycles influence atmospheric refractivity and consequently radio-wave propagation characteristics. Variations in refractivity can modify signal bending, scattering, and multipath behaviour, leading to measurable fluctuations in received signal levels over the course of the day (Rappaport, 2002; Goldsmith, 2005; Onuorah *et al.*, 2020; Iloke *et al.*, 2022).

Tropospheric propagation theory indicates that radio signal paths are influenced by refractivity gradients that vary with daily heating and cooling cycles. Under certain atmospheric conditions, particularly during evening stabilization of the boundary layer, propagation conditions may become more stable due to reduced turbulence and more uniform refractive profiles (Iloke *et al.*, 2022; Amajama *et al.*, 2023; ITU, 1998). These mechanisms provide a plausible physical context for the statistically significant differences observed across time blocks (ANOVA $p < 0.001$), although the magnitude of variation remains moderate. The elevated evening power density observed in this study may be associated with atmospheric transition processes typical of humid tropical environments. During daytime heating, increased atmospheric turbulence and convection can introduce signal scattering and variability, while evening conditions may support relatively more stable propagation. In addition, near-surface moisture stratification and urban thermal effects may contribute to variations in the dielectric properties of the propagation medium (Saunders & Aragón-Zavala, 2007; Molisch, 2012).

Relationship between Diurnal Variation and Atmospheric Conditions

Although diurnal variation is clearly observed, secondary statistical analyses indicate that meteorological variables exert only weak direct linear effects on power density. Correlation analysis showed weak positive association with temperature and weak negative association with relative humidity, while regression analysis demonstrated low explanatory power ($R^2 \leq 0.038$). This behaviour is consistent with propagation theory. Atmospheric water vapour influences electromagnetic wave absorption and refractivity, but at short terrestrial BTS distances, these effects are typically secondary compared with geometric path loss and local multipath interactions (Rappaport, 2002; Onuorah *et al.*, 2020; Ale *et al.*, 2024).

Humidity-driven absorption and refractivity effects are generally more pronounced at higher frequencies and over longer propagation paths, whereas short-range urban cellular links tend to exhibit relatively smaller meteorology-driven fluctuations (Ale *et al.*, 2024; Odesanya *et al.*, 2025; ITU, 1998). The observed weak correlations and low regression R^2 values therefore align with theoretical expectations, indicating that atmospheric conditions contribute to variability but do not dominate signal behaviour under the measurement conditions considered.

Role of Distance as a Primary Physical Mechanism

Distance remained the strongest predictor in regression models, which is consistent with free-space and terrestrial path loss theory (Rappaport, 2002; ITU, 1998). The inverse relationship between power density and distance reflects the fundamental role of geometric attenuation in RF propagation. However, the low R^2 values indicate that distance alone explains only a small proportion of the total variability in measured power density. This suggests that additional factors - including temporal atmospheric variability, local scattering, and environmental heterogeneity - contribute to observed signal fluctuations in real-world conditions (Matthews *et al.*, 2018; Ohworho *et al.*, 2026). Importantly, the regression results do not contradict the observed diurnal variation; rather, they indicate that distance defines the baseline propagation behaviour within which smaller temporal variations occur. Under short-range conditions, atmospheric effects appear detectable but remain secondary relative to geometric attenuation.

Implications for Cellular Network Performance and Planning

The presence of statistically significant diurnal variation in BTS power density has practical implications for cellular network performance and management. Temporal signal fluctuations may influence:

i. Link margin stability
ii. Handover thresholds
iii. Interference patterns
iv. User-perceived quality of service

From a network engineering perspective, these findings suggest that RF propagation conditions may vary within a daily cycle, particularly in humid tropical environments. While the magnitude of variation observed is moderate, it indicates the presence of predictable temporal variability that could be relevant for network monitoring and adaptive optimization. Previous studies have shown that tropospheric variability can influence terrestrial link performance and multipath behaviour, particularly in humid and tropical climates (Suleman *et al.*, 2025; Iwuji & Onuabuchi, 2018). Incorporating time-of-day-dependent propagation characteristics into network planning models may therefore improve performance assessment and operational reliability in such environments.

CONCLUSION

This study investigated diurnal variation in BTS power density under short-range terrestrial conditions. The results show a clear and statistically significant time-of-day dependence, with mean power density increasing from morning (4.08 W/m²) to afternoon (5.37 W/m²) and peaking in the evening (6.00 W/m²), confirming systematic temporal variability. Although this pattern is consistent with atmospheric boundary layer dynamics influencing refractivity and multipath conditions, the overall explanatory power of the evaluated variables remains limited. Distance accounted for only a small proportion of variability (R^2 = 0.015), with marginal improvement when meteorological variables were included (R^2 = 0.038). Weak correlations with temperature and relative humidity further indicate that atmospheric effects contribute primarily as secondary modifiers rather than dominant drivers of signal behaviour. These findings align with established RF propagation theory, where geometric path loss governs short-range links, while atmospheric influences remain modest (Rappaport, 2002; ITU, 1998). The observed diurnal variation is therefore detectable but of limited practical magnitude relative to distance-dependent attenuation.

From an operational perspective, the presence of measurable temporal variability suggests that RF conditions may not be entirely uniform within a day, which may have implications for network monitoring and performance optimisation in humid tropical environments. Incorporating time-of-day-dependent propagation behaviour into network monitoring and optimisation frameworks may therefore support improved performance assessment and adaptive network management. It should be noted that measurements were obtained using a broadband RF instrument, capturing aggregate exposure rather than frequency-specific signals, and that the short-range measurement geometry (≤150 m) inherently limits atmospheric effects. Future studies should extend measurements across seasons, environments, and frequency bands to further characterise propagation dynamics.

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