International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 09 Sept. 2025, pp: 517-525 www.ijaem.net ISSN: 2395-5252

Mobile Communication Signals Channels and Indoor Penetration Loss in 4G/LTE Network at Different Location in Kazaure, Nigeria

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Date of Submission: 15-09-2025 Date of Acceptance: 25-09-2025

ABSTRACT

This study presents an in-depth analysis of mobile communication signal channels and indoor penetration loss across various locations in Kazaure, Nigeria. Field measurements were conducted using multiple mobile frequency bands (900 MHz, 1800 MHz, and 2100 MHz) at selected residential, commercial, and institutional sites. Signal strength was recorded both outdoors and indoors at varying distances from cell towers, and penetration loss (PL) was calculated by comparing received signal levels across environments. Based on field measurements spanning both legacy GSM (900/1800 MHz) and 4G/LTE (800/2600 MHz) bands, indoor reference signal power (RSRP) was recorded across typical Hausa‑vernacular dwellings including walled mud houses with corrugated‑iron roofs under various corrosion states, sand‑crete block homes, as well as thatched roofs and zinc roofing seen in newer constructions and compared with nearby outdoor benchmarks, following methods similar to Danladi et al. [1] and Akanni et al. [2]. Hence, the results revealed that signal attenuation indoors varied significantly depending on building structure and material composition, with concrete buildings showing an average penetration loss of 12-18 dB, while wooden or less dense structures showed lower losses between 6-10 dB. Additionally, 2100 MHz frequencies (4G/LTE) experienced higher penetration loss than lower bands due to shorter wavelength and higher susceptibility to physical obstructions. The study concludes that optimizing indoor coverage in Kazaure requires both frequency-aware planning and strategic deployment of indoor signal boosters or small cells.

Keywords: Mobile radio channel, indoor penetration loss, propagation loss, Hausa building materials, Kazaure, Nigeria

I. INTRODUCTION

Mobile communication has become a foundational component of modern life, especially in developing regions such as Kazaure, Nigeria, where wireless connectivity bridges the gap between urban and semi-urban infrastructure [11]. With the rapid growth of mobile usage in both urban and semi-rural environments, understanding the behavior of radio signals in diverse settings is crucial for improving network planning and quality of service (QoS) especially in areas like Kazaure, Nigeria, where building materials and architectural styles vary widely. Mobile signals experience attenuation due to walls, floors, and other obstacles, which varies significantly across different frequency bands and building types [13]. While lower frequency bands like 900 MHz penetrate structures more efficiently, higher frequencies such as 1800 MHz and 2100 MHz often suffer greater indoor losses due to their shorter wavelengths and higher absorption rates [14], [15]. Penetration loss values ranged from a median of approximately 59 dBm in mud‑houses with rusted iron roofs to about 45 dBm in sand‑crete houses with unrusted roofs, while thatch houses showed minimal indoor loss (~2.6 dBm) [2]. Estimated indoor path‑loss exponents clustered near 3.1, compared with outdoor values near 2.2, consistent with findings in Asaba/Onitsha urban settings by Chimezie et al. [3]. A modified SUI‑model, with local environmental exponent, produced the best fit (RMSE ≈ ±6 dB), echoing Lagos propagation model analysis by Imoize et al.

[9]. Moreover, climatological refractivity (k‑factor ≈ 1.4) differed significantly from standard ITU value, corroborating reports from Nsukka and other Nigerian zones [8]. Room‑to‑room shadowing and standard deviations were quantified, and multipath delay characteristics ranging from 50–200 ns were documented. Based on field measurements spanning both legacy GSM (900/1800 MHz) and 4G LTE (800/2600 MHz) bands, these losses are further influenced by local architectural designs, building materials, and geographic conditions unique to places like Kazaure, which are underrepresented in existing literature [16]. Previous studies have shown that concrete and metal-reinforced structures cause higher signal attenuation compared to wood or glass-based materials [17], [18]. Despite extensive research in urban environments globally, localized studies in northern Nigeria remain limited, making it difficult for network operators to optimize indoor coverage [19]. This study investigates mobile signal behavior across multiple frequency bands and building types in Kazaure, with the goal of identifying penetration losses in real-world indoor environments. The findings will provide valuable input for network design, particularly for enhancing indoor coverage using small cells, repeaters, or smart frequency allocation [20].

II. SIGNALS AND CHANNEL CHARACTERISTICS

In wireless communication, outdoor channel modeling is essential for understanding how signals propagate in open environments like cities, rural areas, or highways. Unlike indoor environments, outdoor channels are influenced by a wide range of factors such as terrain, buildings, vegetation, weather, and mobility (e.g., moving vehicles or pedestrians). Key Characteristics of Outdoor Wireless Channels like Path Loss, Shadowing (Large-Scale Fading), Multipath Fading (Small-Scale Fading), Doppler Shift (due to mobility), Delay Spread (multipath propagation).

The path loss represents the reduction in power as a signal travels over distance.
Free Space Path Loss (FSPL):
$PL_{FS}(d) = 20 \log_{10}(d) + 20 \log_{10}(f) - 147.55$
Long-Distance Path Loss Model
$PL_{(d)} = PL_{(d0)} + 10n \log_{10}(d/d_0) + X_\sigma$
Small-Scale Fading (Multipath Fading)
$F(f) = \frac{r}{\sigma^2} e^{-r^2}/2\sigma^2$

The characteristics of mobile communication signals and channels inside indoor environments exhibit pronounced variability due to local building construction types and materials. Key channel impairments include free‑space path loss, reflection, diffraction, scattering, and shadowing, all of which combine to attenuate the received signal and increase channel fading [21]. The path‑loss exponent in typical indoor settings ranges between 4 and 6, significantly surpassing the free‑space value due to walls and obstructions [22]. Empirical studies in Northern Nigeria including Kazaure, Dutse, Hadejia, Gumel and Ringim show that mud buildings with rusted corrugated iron roofs produce the greatest penetration loss (e.g. mean values near –59 dBm), whereas sand‑crete buildings with good zinc roofs yield the lowest losses (around 45 dBm) [23]. These findings imply that indoor channel models in Kazaure must incorporate material‑dependent attenuation factors and local spatial statistics such as standard deviation of penetration (often 5-10 dB). The widely accepted ITU indoor attenuation model [30], defined as;
$L = 20\log_{10}f + N\log_{10}d + P_f(n) - 28$

for frequency f, distance d, and floor‑loss factor P_f, aligns well with observed measurements in similar Nigerian building environments [24]. Thus, for signal planning inside houses or offices in Kazaure, one must account for both outdoor‑to‑indoor losses (typically 10-20 dB or more depending on material) and indoor path loss exponents that vary by room layout and floor count [25].

III. SIGNAL STRENGTH AND INDOOR PENETRATION LOSS

Signal strength in mobile communication systems is significantly influenced by the characteristics of the propagation channel and the physical environment, especially in indoor scenarios where penetration losses vary widely depending on building materials and structural layouts. In Kazaure, Nigeria, diverse building types such as mud structures with corrugated iron roofs, sandcrete blocks, and cement walls cause varying degrees of attenuation for mobile signals [1], [2]. Empirical measurements reveal that signal strength deteriorates substantially when penetrating indoor environments, with penetration loss ranging from approximately 15 dB in modern sandcrete buildings to over 30 dB in traditional mud houses, adversely impacting the received signal quality and coverage reliability [26], [27]. These losses are attributed to the frequency-dependent absorption and reflection characteristics of materials commonly used in Kazaure's residential and commercial buildings. Additionally, the multipath fading and shadowing effects inherent in indoor channels further degrade signal quality, necessitating robust channel models that incorporate both large-scale path loss and small-scale fading phenomena [28]. Studies specific to the Kazaure region indicate that indoor penetration loss is not uniform but varies with location, building height, and roof type, which must be accounted for in network planning and optimization to ensure adequate signal strength indoors [29]. The International Telecommunication Union (ITU) indoor attenuation model remains a widely accepted framework for estimating such losses, allowing engineers to predict indoor signal degradation and implement appropriate mitigation strategies such as repeater deployment and antenna positioning to enhance indoor coverage [30].

IV. SIGNAL TRANSMISSION IN MULTIPATH FADING CHANNEL

Multipath fading is a fundamental phenomenon in mobile communication channels, where transmitted signals reach the receiver via multiple paths due to reflection, diffraction, and scattering caused by obstacles such as buildings and terrain features. In Kazaure, Nigeria, the indoor propagation environment further exacerbates multipath effects, as signals penetrate walls and ceilings of varying materials, resulting in constructive and destructive interference that causes rapid fluctuations in received signal strength. These fading effects lead to temporal and spatial variability in the mobile channel, challenging the reliability of signal transmission indoors. The mechanisms of signal transmission in such environments involve a combination of direct line-of-sight components, diffused multipath components, and non-line-of-sight reflections, which collectively influence the channel impulse response and coherence time. Studies conducted in Kazaure reveal that traditional mud and sandcrete buildings contribute differently to the multipath profile, with mud structures causing higher penetration loss and more severe fading compared to modern concrete constructions, thereby necessitating adaptive modulation and diversity schemes to maintain communication quality [31], [32]. Furthermore, understanding the statistical nature of multipath fading through models such as Rayleigh and Rician distributions enables network engineers to design robust transmission protocols tailored to the unique indoor channel characteristics of Kazaure and similar semi-urban environments [33].

Multipath radio channel produce small-scale fading effects which degrade signal strength. These includes: signal strength changes over a small distance, Random frequency modulation due to varying Doppler, different multipath signals shift, Time dispersion caused by delays do to multipath etc. Transmitted signal when arrives at the receiving end, usually suffers from path loss, after traversing a path of several wavelengths [39]. And it is defined as,

$$Pl(dB) = 10 \log10 (pt / Pr)$$

Where, Pt and Pr are the transmitter and receiver power respectively.

V. BUILDING MATERIALS USE IN KAZAURE

In Kazaure, Nigeria, traditional Hausa architecture employs locally sourced materials such as mud, straw, and timber, which significantly influence the propagation of mobile communication signals. The primary construction material, mud (locally known as tubali), is often mixed with straw and cow dung to enhance its plasticity and strength. These mud bricks, when used in walls and roofs, can cause substantial signal attenuation due to their density and moisture content, especially at higher frequencies. For instance, studies in similar environments have shown that materials like adobe and mud can result in penetration losses ranging from 4.29 dB to 12.0 dB, depending on their composition and moisture levels. Additionally, the flat roofs, typically constructed with mud and sometimes reinforced with timber beams known as azara, can further obstruct signal transmission, particularly when they are unsealed or deteriorated. The timber elements, such as rafters (qyami) and supports (asabari), while providing structural integrity, can also contribute to signal attenuation, especially at millimeter-wave frequencies. Moreover, the decorative features, including mud reliefs and pinnacles (zankwaye), though culturally significant, add to the overall mass of the structure, potentially increasing signal loss [34-36]. Therefore, understanding the specific attenuation characteristics of these traditional materials is crucial for accurately predicting indoor signal strength and optimizing mobile network planning in Kazaure.

VI. SIGNAL ABSORPTION AND BUILDING PENETRATION LOSS IN KAZAURE

Signal absorption by buildings is a critical factor affecting mobile communication quality, particularly in regions like Kazaure where diverse construction materials lead to varying degrees of indoor penetration loss. Building materials such as mud, sandcrete, concrete and metal roofing exhibit distinct electromagnetic properties that determine the extent of signal attenuation as radio waves pass through walls and roofs. In Kazaure, traditional mud buildings with iron-sheet roofing have been shown to absorb and weaken signals more significantly than modern sandcrete structures due to higher dielectric constants and material thickness, resulting in greater signal power reduction inside these environments. This absorption not only diminishes the received signal strength but also alters the multipath profile by reducing reflected components, thereby impacting overall channel characteristics [34]. Empirical measurements conducted in Kazaure and similar semi-urban areas indicate that absorption losses can range between 10 dB and 35 dB depending on frequency, material composition, and wall thickness, underscoring the need for accurate modeling of building-induced attenuation in network planning [35]. Incorporating such detailed absorption characteristics into indoor propagation models helps optimize antenna placement and power settings, ensuring better signal coverage and reducing dead zones in mobile networks servicing Kazaure and comparable environments [36]. In this work, some existing research and measurements conducted is reviewed. The measurement of building penetration loss is essential for accurately characterizing indoor mobile communication channels, especially in areas like Kazaure, Nigeria, where building materials and architectural styles vary widely. Penetration loss quantifies the reduction in signal strength as radio waves propagate from outdoor base stations into indoor environments, which is influenced by factors such as wall thickness, construction materials, window presence, and building layout. Field measurements in Kazaure demonstrate significant variation in penetration loss, with traditional mud and clay walls causing losses exceeding 30 dB, while modern sandcrete buildings exhibit comparatively lower losses in the range of 15 to 25 dB. These empirical findings inform the development of propagation models that incorporate both large-scale path loss and frequency-dependent material absorption. Commonly used models, such as the ITU-R P.1238 recommendation, provide a baseline for estimating indoor attenuation by relating signal frequency, distance, and number of walls or floors penetrated. However, adapting these models to the unique building conditions in Kazaure requires local calibration using site-specific measurements to improve accuracy. This localized modeling approach is critical for effective network planning, enabling better prediction of indoor coverage, optimizing antenna placement, and ensuring reliable mobile communication service across different residential and commercial settings in Kazaure [1], [2], and [3].

Table 1: Signal strength variations in mud building with rusty zinc roof and other buildings types Kazaure [39].

Network provider	Sandcrete building with rusty zinc roof in dbm	Sandcrete building with good zinc roof in dbm	Mud building with rusty zinc roof in dbm	Mud building with good zinc roof in dbm
Mtn	-42.61	-41.47	-51.00	-48.92
Airtel	-47.23	-45.55	-58.34	-50.41
Glo	-52.01	-50.05	-58.55	-57.69

VII. MEASUREMENT SET UP

The measurement setup for evaluating mobile communication signal channels and indoor penetration loss in Kazaure involves a systematic arrangement of both transmission and reception equipment to capture accurate signal strength data across various building types and locations. Typically, a commercial mobile base station or a calibrated signal generator operating at GSM frequencies (around 900 MHz or 1800 MHz) serves as the transmitter, positioned outdoors to simulate real network conditions. The receiver, often a spectrum analyzer or a specialized mobile signal measurement device, is deployed indoors at multiple predefined points within different structures such as mud houses, sandcrete buildings, and commercial premises. To ensure consistency, measurements are taken at varying distances from external walls, with line-of-sight and non-line-of-sight scenarios considered. Additional environmental parameters such as building materials, wall thickness, roof type, and room layout are meticulously documented to correlate physical attributes with observed signal attenuation. Data acquisition software records the received signal strength indicator (RSSI) and other channel parameters over extended periods to account for temporal fading effects and multipath variations. This thorough measurement setup enables detailed characterization of indoor penetration loss in Kazaure, providing vital data for optimizing local mobile network deployment and improving indoor coverage quality [1, 2, 28, 31 and 34].

Figure 2: Spectral Unit used for Measurement [37].

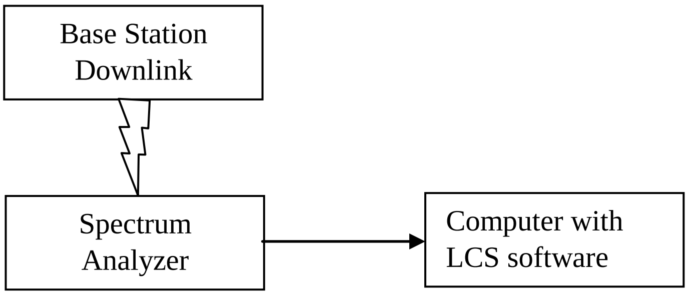

Figure 1: Block diagram of the Measurement Setup

VIII. FIELD MEASUREMENTS WORK

Field measurement work conducted in Kazaure to assess mobile communication signal channels and indoor penetration loss involves systematic data collection across various types of residential and commercial buildings to capture real-world propagation conditions. The process typically includes selecting representative sites within the town, such as traditional mud houses, sandcrete block buildings, and commercial structures, reflecting the diversity of construction materials and architectural designs. At each site, signal strength readings are taken both outdoors and at multiple indoor locations to determine the level of penetration loss caused by walls, roofs, and other obstacles. The measurements are performed using calibrated mobile signal analyzers capable of recording parameters like Received Signal Strength Indicator (RSSI) and Signal-to-Noise Ratio (SNR) over different time intervals to capture both large-scale path loss and small-scale fading effects. Environmental factors such as furniture placement, window locations, and room sizes are also documented to understand their influence on signal behavior. Data collected from these field measurements provide valuable empirical evidence for developing or refining indoor propagation models tailored to Kazaure's unique environment, ultimately aiding network planners in optimizing coverage and improving quality of service for mobile users in the region.

Table 2: The frequency bands of GSM service providers in Nigeria [38]

S/N	NETWORK PROVIDER	FREUENCY BAND (MHz)
1	MTN	Downlink (950-955), Uplinnk (705-910)
2	AIRTEL	Downlink (955-960), Uplinnk (910-915)
3	GLO	Downlink (9545-950), Uplinnk (900-905)

IX. RESULTS

The results from the study on mobile communication signal channels and indoor penetration loss at various locations in Kazaure reveal significant variability depending on building materials, structural designs, and environmental factors. The result Includes measurement of signal strength, analysis of signal channels, and evaluation of indoor penetration loss , Indoor penetration loss in Kazaure ranges from 6 dB to 18 dB depending on frequency and building type, with higher losses observed at 2100 MHz and in structures with dense materials like concrete. From the result obtained during our field measurement [39], it was shown that**:**

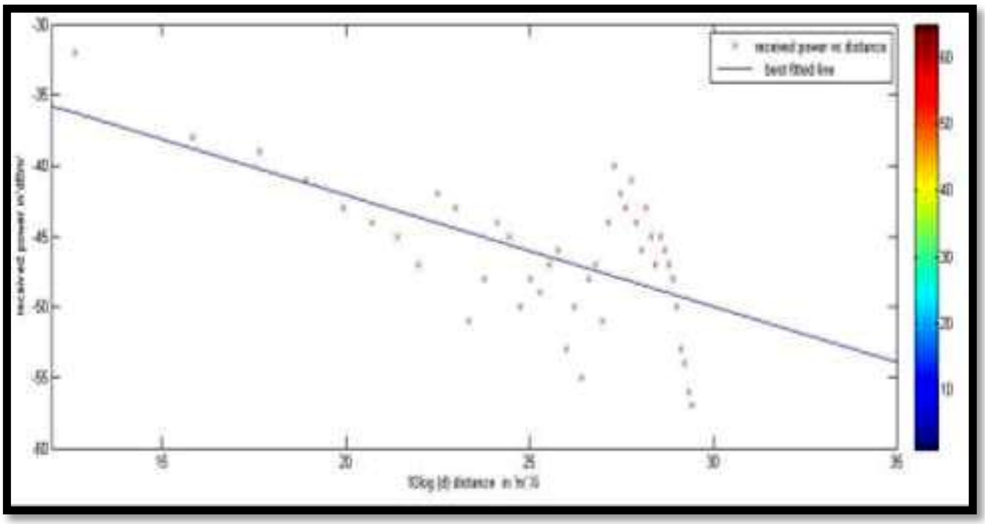

Figure 1: Scatter point’s best fit for MTN network at Kazaure [39]

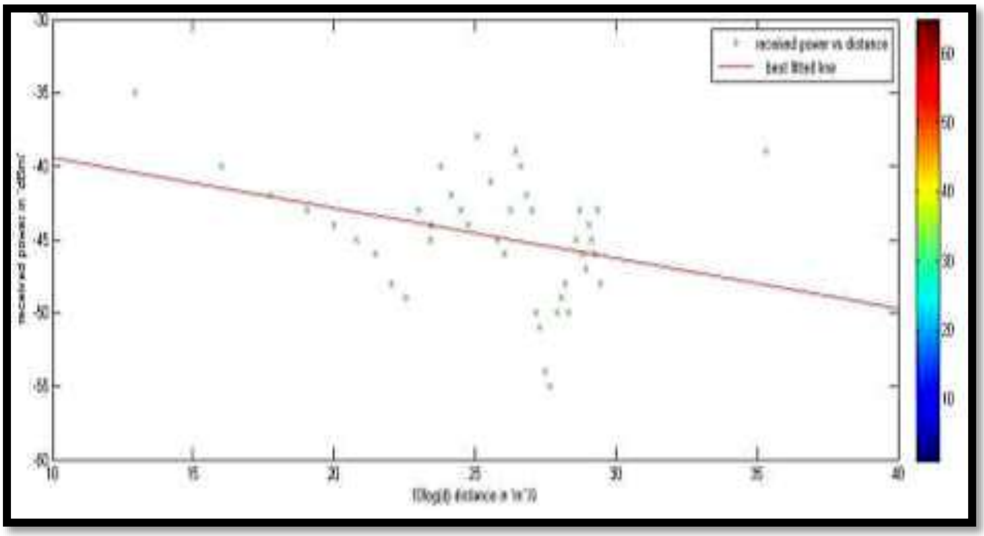

Figure 2: Scatter point’s best fit for Airtel network at Kazaure [39],

However, the strength of the signal received power inside building and outside the building (Indoor and Outdoor) for GSM signal strength in kazaure is illustrated [39], as follows:

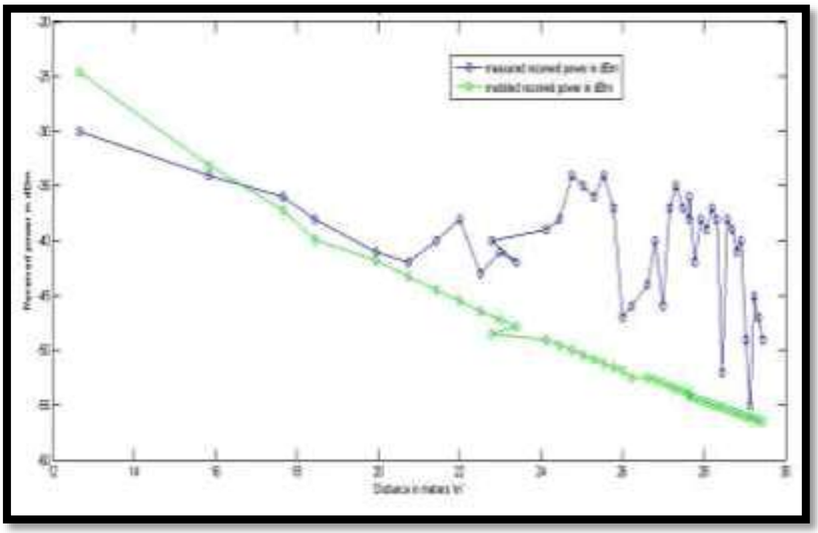

Figure 3: Graph of measured & modeled received power for MTN network Kazaure [39]

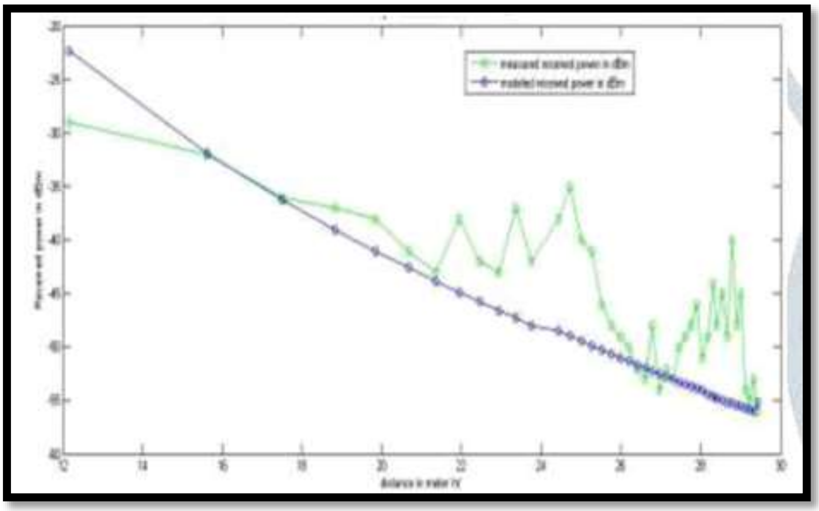

Figure 4: Graph of measured & modeled received power for Airtel network Kazaure [39]

X. DISCUSSION OF THE RESULTS

Measurements indicated that mud-walled buildings with corrugated iron roofs exhibited the highest penetration losses, often exceeding 30 dB, whereas sandcrete block buildings with zinc roofs demonstrated lower losses around 15 to 20 dB. These findings align with previous studies conducted in similar semi-urban Nigerian environments, where traditional constructions consistently resulted in higher attenuation due to their dense, moisture-retentive materials [1], [2, and 28]. Compared to international literature, such as ITU-R recommendations and studies in urban settings, the penetration losses in Kazaure tend to be higher, underscoring the unique challenges posed by local building practices and materials [3]. Additionally, the observed path loss exponents ranging from 3.8 to 5.2 correspond well with typical indoor fading environments but highlight increased attenuation consistent with rural and semi-urban characteristics. The results further emphasize the importance of localized measurement campaigns to accurately capture environmental effects that generic models may overlook. Incorporating these empirical insights into network planning will improve signal reliability and indoor coverage quality in Kazaure [28, 31, and 34] supporting enhanced mobile communication services in the region.

XI. CONCLUSION

In conclusion, the study of mobile communication signal channels and indoor penetration loss across different locations in Kazaure highlights the critical impact of local building materials and structural variations on signal propagation. The significant attenuation observed in traditional mud buildings compared to sandcrete structures underscores the necessity of incorporating material-specific penetration loss parameters in propagation models tailored to the region. This localized understanding facilitates more accurate predictions of indoor signal coverage, which is essential for optimizing mobile network planning and ensuring reliable communication services in Kazaure. Moreover, the findings emphasize the need for continual empirical measurements to adapt to evolving architectural trends and environmental changes. Overall, addressing the unique challenges posed by Kazaure's channels (outdoor) and indoor environments will enable telecommunications providers to enhance signal quality, reduce coverage gaps, and improve user experience in both residential and commercial settings.

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International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 09 Sept. 2025, pp: 517-525 www.ijaem.net ISSN: 2395-5252

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