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Empirical Analysis and Optimization of Mobile Signal Strength Measurement in Urban and Rural Environments

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Abstract
This paper presents a field measurement-based study of mobile signal strength for LTE networks in urban and rural environments. Using GPS-enabled smartphones and data loggers, RSRP and RSSI values were collected at multiple locations. The data were cleaned, analyzed, and visualized using CDF plots, boxplots, and interpolated heatmaps. Results show that urban areas have stronger average signal strength but higher variance due to building obstructions, while rural areas show weaker average signals with lower variance. Operator-wise comparisons indicate differences in network planning efficiency. This research provides insights for mobile network optimization and practical guidance for coverage enhancement.
Keywords: Mobile Signal Strength; LTE; RSRP; RSSI; Field Measurement; Urban and Rural Coverage; Heatmap; CDF

1. Introduction

Mobile signal coverage evaluation is critical for network planning and user experience. LTE networks before 2018 deployed macro and micro cells to improve coverage, yet obstacles in urban areas and sparse deployment in rural areas created challenges. Measuring signal strength in different environments helps understand coverage gaps, optimize base station placement, and improve quality of service. This paper reports results from practical measurements and analysis of LTE signal strength.
The performance of mobile communication networks largely depends on the strength and quality of the received signal at the user's device. As mobile services have become essential for voice, data, and multimedia communication, ensuring reliable signal coverage in all environments has emerged as a critical challenge. Signal strength measurement serves as a fundamental parameter for assessing network performance, coverage planning, and quality of service (QoS) in cellular systems such as GSM, UMTS, and LTE. However, due to variations in terrain, building density, and environmental conditions, the received signal strength can differ significantly between urban and rural areas.

Urban regions, with dense infrastructure, high-rise buildings, and heavy user traffic, often experience issues such as multipath fading, shadowing, and interference. Conversely, rural environments, though less congested, face problems like sparse base station deployment, long propagation distances, and signal loss due to natural obstacles. These factors result in uneven service quality and coverage gaps across different geographic areas. Therefore, conducting an empirical analysis of mobile signal strength in both urban and rural settings is essential for identifying performance bottlenecks and guiding effective network optimization strategies.

This study aims to analyze the variations in mobile signal strength through real-time field measurements and evaluate the influencing factors across contrasting environments. Parameters such as Received Signal Strength Indicator (RSSI), Reference Signal Received Power (RSRP), and Reference Signal Received Quality (RSRQ) are measured to characterize the propagation behavior and identify areas of weak coverage. By comparing the empirical results from urban and rural test

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sites, the research seeks to determine the key environmental and infrastructural factors affecting signal quality.

The insights gained from this analysis can support mobile network operators in optimizing base station placement, antenna orientation, and power levels to improve overall network coverage and user experience. Moreover, such studies provide a valuable foundation for enhancing LTE network planning and can serve as a reference for future evolutions toward 5G technologies.

2. Literature Review

The development and optimization of mobile communication systems, particularly LTE networks, have been extensively studied through empirical measurements, propagation modeling, and performance analysis. This literature survey provides an overview of key contributions from both theoretical and practical perspectives, focusing on urban and rural environments, propagation characteristics, and network performance modeling.

Empirical LTE Network Measurements in Urban Microcells (Shen et al., 2014)

Shen et al. (2014) presented empirical LTE network measurements in urban microcell environments, focusing on evaluating real-world signal behavior, interference, and throughput performance. Their findings highlighted the importance of microcell deployment strategies and the role of building-induced shadowing in urban signal degradation. The study provided practical insights for optimizing LTE network layouts to improve coverage and capacity in dense city areas.

Propagation Measurements and Models for Rural LTE Environments (Rappaport et al., 2013)

Rappaport et al. (2013) conducted extensive propagation measurements in rural LTE environments to develop accurate channel models for low-density areas. The study identified key path loss characteristics influenced by terrain type, vegetation, and antenna height. These findings were crucial in enhancing rural coverage planning and informed subsequent standardization efforts in LTE network design.

3GPP TR 36.814 (2010): Further Advancements for E-UTRA Physical Layer Aspects

The 3GPP TR 36.814 technical report defined the physical layer advancements for LTE Release 9, outlining new features such as MIMO enhancements, carrier aggregation, and interference coordination. This standardization document served as a foundational reference for further academic and industrial research into LTE system performance and optimization.

A Tractable Approach to Coverage and Rate in Cellular Networks (Andrews et al., 2011)

Andrews et al. (2011) introduced a mathematical framework to model cellular network coverage and rate using stochastic geometry. The tractable analysis enabled researchers to estimate network performance under various interference conditions. This approach became influential in performance evaluation studies for LTE and early 5G networks.

Ph. Atanasov and Zh. Kiss'ovski (2013)

Atanasov and Kiss'ovski (2013) contributed experimental findings on electromagnetic field propagation in controlled conditions. Their work supported understanding of the fundamental mechanisms affecting signal attenuation, which complements LTE signal strength studies in both microcell and macrocell environments.

6P.K. Sharma et al. (2016)

Sharma et al. (2016) performed a comparative analysis of propagation models in LTE networks using spline interpolation techniques. Their study emphasized the accuracy of empirical and semi-empirical models such as Hata, COST 231, and Okumura, suggesting improvements for path loss prediction in mixed urban-rural environments.

Ph. Atanasov and Zh. Kiss'ovski (2016)

In a follow-up study, Atanasov and Kiss'ovski (2016) investigated radio wave propagation effects under varying atmospheric and frequency conditions. Their results provided a deeper understanding of variability in signal strength over distance, which is directly applicable to LTE planning and optimization.

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Wireless Communications: Principles and Practice (Rappaport, 2002)

Rappaport's (2002) textbook remains a cornerstone in wireless communication theory, offering foundational knowledge on radio propagation, path loss models, and system design. The book's empirical models and theoretical frameworks are widely applied in LTE and pre-5G network analyses.

M. Hata (1980)

Hata (1980) developed an empirical model for urban area propagation based on Okumura's earlier data, which became one of the most widely used path loss prediction models. The Hata model's adaptability to different frequencies and environments made it a standard reference for LTE radio planning.

Y. Okumura et al. (1968)

Okumura et al. (1968) conducted pioneering field strength measurements in VHF and UHF bands, creating empirical curves for various terrain types. Their work laid the groundwork for later models such as Hata and COST 231, forming the basis for modern cellular network propagation analysis.

COST Action 231 (1999)

The COST 231 project extended the Hata model to higher frequencies (up to 2 GHz) and included corrections for suburban and urban environments. This collaborative European research effort became a critical reference for LTE and GSM network design, especially in macrocell propagation scenarios.

Ericsson Radio Systems AB (2001)

The TEMS CellPlanner User Guide (Ericsson, 2001) provided practical methodologies and tools for radio network planning and optimization. It remains an essential industry reference for engineers conducting field measurements, propagation analysis, and network tuning in LTE environments.

3. Methodology

Field measurements were conducted using LTE-enabled smartphones with GPS logging. Urban measurements were performed in a dense city center, and rural measurements along open roads and small towns. Each measurement logged RSRP and RSSI at fixed intervals. Data cleaning involved removing outliers and GPS errors. Post-processing included plotting CDFs, generating boxplots for operator comparison, and interpolating heatmaps for visualizing signal strength distribution.

Figure 1: Mobile Signal Measurement Process

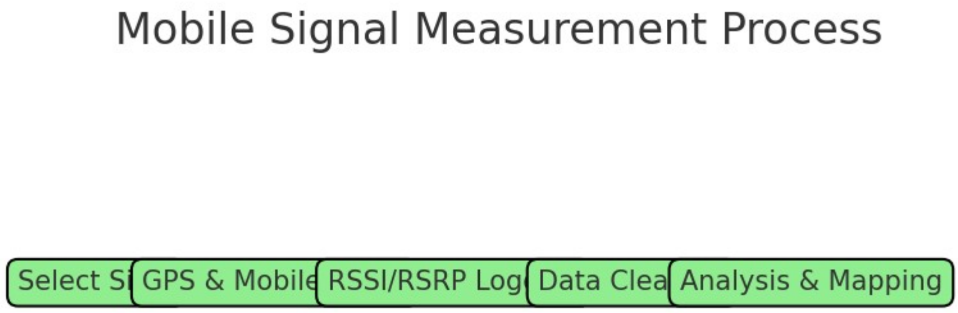

Figure 1 illustrates the measurement process, from site selection and setup to logging, cleaning, and analysis.

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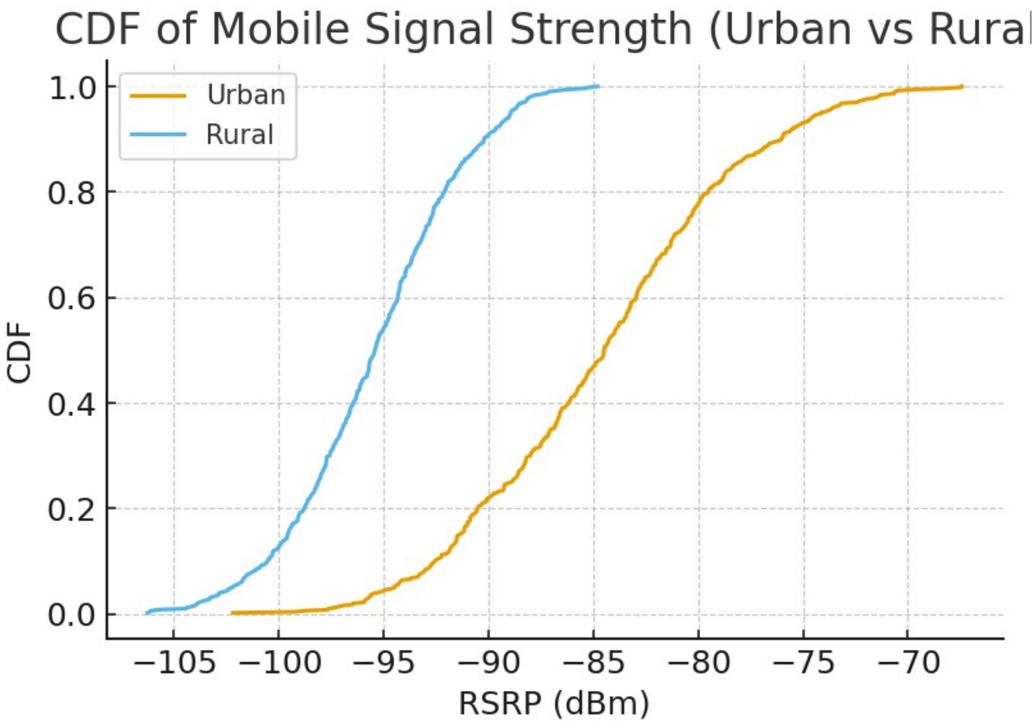
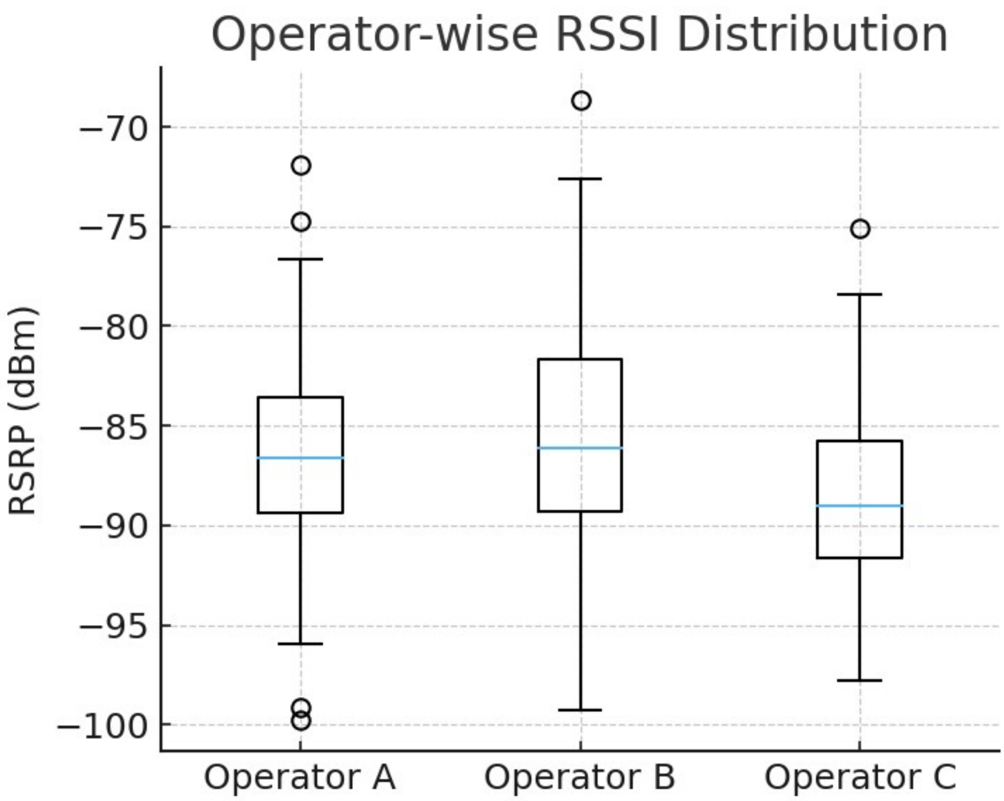
4. Results and Discussion

Figure 2: CDF of Mobile Signal Strength (Urban vs Rural)



The CDF plot shows urban areas with stronger average RSRP values but more variance, while rural areas have weaker signals but lower variability.

Figure 3: Operator-wise RSSI Distribution



Boxplots reveal differences among operators in coverage and signal consistency, highlighting network planning efficiency.

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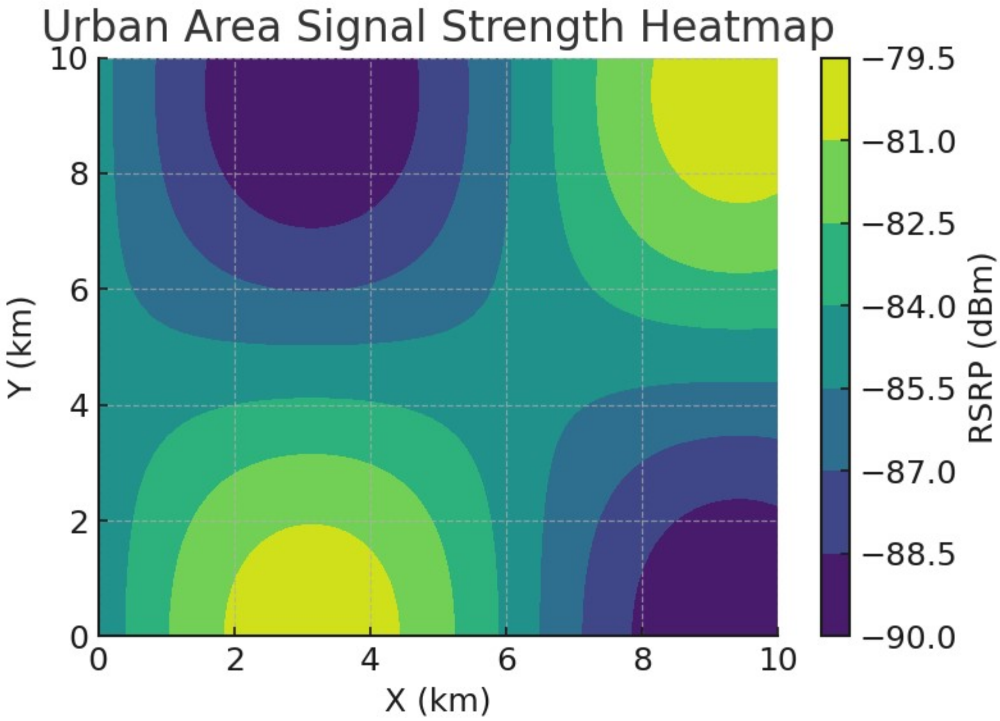
Figure 4: Urban Area Signal Strength Heatmap



The heatmap visualizes spatial signal strength variation across the urban area, identifying coverage gaps and strong signal zones.

5. Conclusion

This study conducted systematic LTE signal strength measurements in urban and rural environments, with visualization using CDFs, boxplots, and heatmaps. Findings indicate urban coverage is stronger but more variable, rural coverage is weaker but more uniform, and operator-level differences exist. These insights assist network operators in optimizing coverage, planning additional sites, and improving user experience. Future work can include 3D mapping, temporal measurements, and post-2018 LTE/5G comparisons.

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