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Evaluation of Key Performance Indicators (KPI) For Wireless Networks Application Using Drive Test Measurements

Jangfa Timothy Zhimwang

Department of Physics, Federal University Lokoja, Kogi State, Nigeria.

*Corresponding Author's Email: Jangfa.zhimwang@fulokoja.edu.ng

ABSTRACT

The demand for dependable wireless networks that can provide adequate Quality of Service (QoS) in a variety of environmental conditions has risen due to the ongoing expansion of mobile broadband services. Key Performance Indicators (KPIs) offer numerical measurements for evaluating network performance and directing improvement strategies. However, atmospheric phenomena like rainfall have a significant impact on wireless network performance, particularly in areas with complicated terrain and seasonal climate variations. This study uses driving test measurements taken in both clear-sky and rainy conditions to assess a few key performance indicators (KPIs) of operational 4G wireless networks in Jos, Plateau State, Nigeria. Twenty-two base stations distributed across five representative clusters were investigated using Transmission Evaluation Monitoring System (TEMS) tools and mobile test terminals. The assessed KPIs included Radio Signal Level (RSL), Received Signal Code Power (RSCP), packet loss, Energy per Chip to Noise ratio (Ec/No), receive level (RxLev), receive quality (RxQual), speech quality index (SQI), and uplink/downlink throughput. The findings show that rainfall considerably impairs network performance. Rainy conditions led to significant decreases in RSL, RSCP, Ec/No, and throughput as compared to clear-sky conditions, along with noticeable increases in packet loss. It was shown that data services were more vulnerable to attenuation caused by rainfall than voice services, with downlink throughput dropping by more than 80% and packet loss rising to as high as 88% in some clusters. These results highlight the necessity for weather-aware network design and adaptive optimization techniques to enhance QoS in semi-temperate parts of Nigeria and comparable settings, as well as the susceptibility of microwave backhaul links to unfavourable weather.

Keywords:
Wireless networks,
Key Performance Indicators,
Drive Test Measurements,
Rain Attenuation,
Quality of Service,
Network Optimization.

INTRODUCTION

Modern telecommunications systems cannot function without wireless networks, which offer connections for a wide range of uses, from high-speed data transfer to voice conversations. Network operators must constantly assess and evaluate the functioning of their networks due to the growing demand for uninterrupted connection and high-quality services (Shakir et al., 2023; Zhimwang et al., 2022; Bilo et al., 2014). Over the years, wireless networks have evolved significantly, transitioning from analog to digital technologies and from 2G to 5G networks (Liu et al., 2017; Tikhomirov et al., 2018). In network optimization and operation, new intricacies and difficulties are introduced to every generation. Strong and dependable wireless networks are becoming increasingly necessary as mobile devices become more common and bandwidth-intensive activities like online gaming and video streaming become more prevalent (Farid et al., 2013; Zhimwang et al., 2022) hence the purpose of this study.

Metrics identified as Key Performance Indicators (KPIs) are used to assess coverage, capacity, dependability, and quality of service, among other elements of network performance. These indicators assist in pinpointing areas in need of improvement and offer insightful information about the network's general health. Signal strength, signal-to-noise ratio, call drop rate, handover success rate, data throughput, and latency are typical KPIs in wireless networks. KPIs are essential for evaluating the performance and efficacy of wireless networks (Shakir et al., 2023; Igbekele et al., 2019). Even though KPIs are important, effectively analyzing them presents several difficulties. Due to their inherent dynamic nature, wireless networks are susceptible to various external elements, including weather, topography, and interference from other devices. Furthermore, network performance can change dramatically based on variables like location, user density, and time of day (Nnochiri, 2015). Traditional methods of KPI evaluation, such as network simulation and laboratory testing, may not capture the real-world performance of the network accurately. Therefore, this study focuses on evaluating wireless network KPIs using drive test measurements. As wireless networks continue to evolve with the introduction of technologies such as 5G, Internet of Things (IoT), and edge computing, research on KPI evaluation becomes even more necessary (Yunisa et al., 2022). Understanding network performance metrics is essential for successfully deploying and operating these emerging technologies, ensuring their seamless integration into existing wireless infrastructures (Hamad-ameen, 2008).

The process of gathering data from a moving vehicle fitted with specialized equipment that monitors different network properties is known as a drive test measurement. Operators may obtain extensive information on network performance in real-world scenarios by doing vehicle tests at various times and locations. Drive test measurements offer useful information on signal strength, coverage areas, handover performance, and other KPIs. This information helps operators find coverage gaps, optimize network settings, and enhance overall performance (Igbekele, 2019; Zhimwang et al., 2023).

According to (Ahmed et al., 2017) the ability to make accurate predictions for cellular throughput would fundamentally alter how apps are developed and run. Video streaming is one of the many cellular applications that incorporate logic that tries to assess the available throughput and modify their behavior accordingly. They used statistical machine-learning approaches to perform an initial investigation of throughput prediction in a cellular setting. They investigate how prediction error changes with prediction horizon and available data granularity using simulations and real-world trials. Specifically, their simulation results demonstrate that combining network and end device measurements can greatly minimize the prediction error for mobile devices. According to their findings, achievable throughput up to 8 seconds in the future can be properly predicted when the 50th percentile of all faults is less than 15% for mobile devices and 2% for static devices.

Shakir et al (2023) examines the KPIs that track and influence the LTE cellular networks' performance from the perspective of big data statistical analysis and evaluation. The KPI data measurements were collected using the driving test methodology while moving at a speed of 30 km/h. Through a 20 MHz bandwidth, their work illustrates Long Term-Evolution (LTE) data measurements and performance analysis of the KPI at the 2100 MHz frequency band for three Iraqi mobile providers. Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), Signal Interference and Noise Ratio (SINR), Received Signal Strength Indicator (RSSI), and Downlink Throughput (DL Throughput) were among the metrics that were the focus of the data measurements. The relationship and dependence between these parameters for the three operators described can be seen by examining their analysis behavior and the probability distribution function (PDF) for the KPIs. For network management, evaluation, and appropriate requirements for cellular network operators for voice and data services, these KPIs offer valuable information.

According to the TETRA standard, the set of KPIs suggested Unidas (2013) provides an adequate metric to evaluate the effectiveness of a mobile radio network and the caliber of services that system users require. To meet customer demands and objectives, which are set as design targets during the system planning stage, network operators can use these indicators as a fundamental tool to create convergence between the four viewpoints of QoS. They claimed that if an evaluation of the indicators is not conducted after the monitoring procedure, it is impossible to determine the extent of conformity with the intended quality levels. To assess the validity of the given quality levels during the examination of QoS reports, a set of target values for each suggested KPI must be defined. However, it is difficult to identify any reference values and conditions that could be used as appropriate decision thresholds because these metrics are not commonly employed in TETRA networks.

MATERIALS AND METHODS

Experimental Site and Drive Test Measurements

The study was conducted in the Plateau State capital Jos. The plateau has both tropical and temperate weather, and what is known as a semi-temperate climatic zone. Nonetheless, due to the uneven topography, there are notable variations in the state's meteorological conditions and, therefore, in the features of precipitation across different regions, in contrast to the majority of Nigeria. The study location was grouped into clusters [PLA010 (9^o, 56'N, 8^o, 53'E), PLA011 (9^o, 57'N, 8^o, 53'E), PLA012 (9^o, 55'N, 8^o, 53'E), PLA024 (9^o, 58'N, 8^o, 53'E), PLA048 (9^o, 56'N, 8^o, 55'E)] and each cluster had a different Altitude.

The drive test is a key RF optimization exercise required to analyze radio parameters in the mobile network. It involves the collection of measurement data from a live network for the analysis and evaluation of the test result for performance improvement. Transmission Evaluation Monitoring Sets (TEMS) equipment was used to investigate base station radio-related issues such as network inaccessibility and retain ability arising from poor carrier-to-interference (C/I) ratio, high radio channel interference, overshooting cell sites, radio blind spots, amongst others. The study took measurements at different elevations within Plateau State. Drive test measurements were conducted at various locations from each cell location of the base transceiver station (BTS) and node bearer (Node-B) for twenty-two 3G and 4G sites. Figure 1 depict the drive test configuration for mobile stations' key performance indicator (KPI) parameters for optimization and the outdoor and inside units for radio signal attenuation measurements. For every measurement round, two sets of the driving test were conducted as follows:

The network parameters alignment based on the ITU-R link budget, both for the transmission microwave links and the cell sites for the study centers was carried out for comparative study analysis.

At testing locations throughout Plateau State, the experimental drive tests (DT) for the study were conducted in clear weather conditions with varying intensities of rain. Using both field DT tools—such as Transmission Evaluation Monitoring Sets (TEMs) test phones and six mobile (voice and data) test phones for call tracing—and the graphical user interface (GUI) from the network management center/radio network optimization (NMC/RNO) monitoring servers for the real-time QoS data capturing and analysis, the necessary radio parameters were obtained from the corresponding cell sites and the backhaul links.

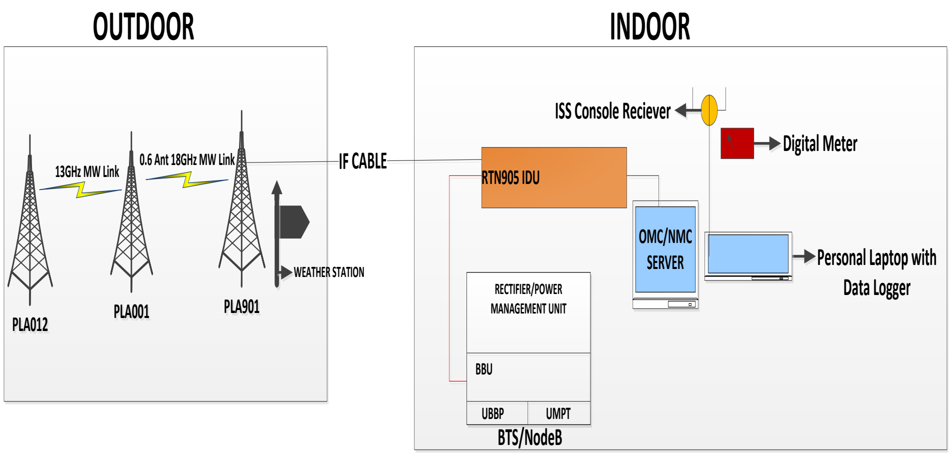

Figure 1: Radio Signal Attenuation Measurements: Outdoor and Indoor Units

The drive test was used to compare the performance of the cellular network during rain and normal clear sky weather conditions. The statistics generated from drive tests were used to assess the performance of mobile network services in terms of KPI. Transmission Evaluation Monitoring System (TEMS) tools were used to collect RF log files from the live cell sites. The analysis of the results was based on the target KPIs standard as defined by the Nigerian Communications Commission (NCC). A location-based optimized link budget (LB) is formulated to address the signal degradation suffered on the microwave backhauling of the RF cell sites to resolve problems identified in the course of the study.

RESULTS AND DISCUSSION

The drive test results clearly demonstrate that atmospheric conditions significantly affect wireless network performance in Plateau State. Under clear-sky conditions, most of the drive-test traces exhibited green colour distributions, indicating acceptable network performance and compliance with the NCC-recommended KPI thresholds. Strong received signal levels, negligible packet loss, and relatively high throughput values suggest that the investigated networks were adequately dimensioned for normal propagation conditions. However, under rainy conditions, substantial deterioration in network quality was observed across all investigated clusters. The deterioration was characterized by lower Radio Signal Levels (RSL), poorer Received Signal Code Power (RSCP), increased packet loss, degraded Ec/No values, and significant reductions in uplink and downlink throughput. These observations confirm that rainfall-induced attenuation adversely affects microwave backhaul links and consequently impacts end-user service quality.

For data services, RSL values decreased from clear-sky levels of between −29.20 dBm and −42.60 dBm to rainy-condition values ranging from −44.20 dBm to −55.10 dBm. Similarly, RSCP deteriorated from approximately −52 to −57 dBm during clear weather to values as low as −96 dBm during rainfall. Packet loss increased substantially, reaching 88% at PLA010, while downlink throughput reduced from peak values of 5.43 Mbps to approximately 1.52 Mbps or less. Uplink throughput also decreased markedly, dropping from 1.22 Mbps to as low as 0.03 Mbps. These findings indicate that rainfall has a more pronounced effect on data-intensive applications, which depend heavily on stable signal quality and adequate signal-to-interference margins. Voice services exhibited relatively better resilience to rainfall effects. Although reductions in RSL and increases in packet loss were recorded, the deterioration was generally less severe than that observed for data services. For example, while data service degradation became evident at RSL values around −30 dBm to −38 dBm, voice quality impairment was only observed at lower thresholds of approximately −48 dBm to −53 dBm. This difference may be attributed to the lower bandwidth requirements and error-tolerance mechanisms inherent in voice communication systems.

The findings of this study agree with those reported by Igbekele et al. (2019), who demonstrated that persistent rainfall in Jos significantly degrades terrestrial mobile links through increased propagation losses. The present study extends their work by quantifying the corresponding effects on multiple KPIs obtained through real-time drive testing and by distinguishing the differential impacts on voice and data services.

Similarly, the observed reductions in RSCP, Ec/No, and throughput support the findings of Shakir et al. (2023), who reported strong interdependence among LTE KPIs and emphasized that deteriorating signal quality directly translates into reduced user experience. While Shakir et al. focused primarily on statistical characterization of LTE measurements across different operators, the current study introduces environmental variability as a critical determinant of KPI performance. The results also corroborate the assertions of Farid et al. (2013), who emphasized that QoS in wireless networks is highly susceptible to external environmental factors. However, unlike earlier studies based predominantly on simulations or controlled evaluations, this investigation provides empirical evidence derived from field measurements conducted under actual weather conditions. Consequently, the findings contribute practical insights for network operators seeking to improve service reliability in regions with pronounced rainfall activity.

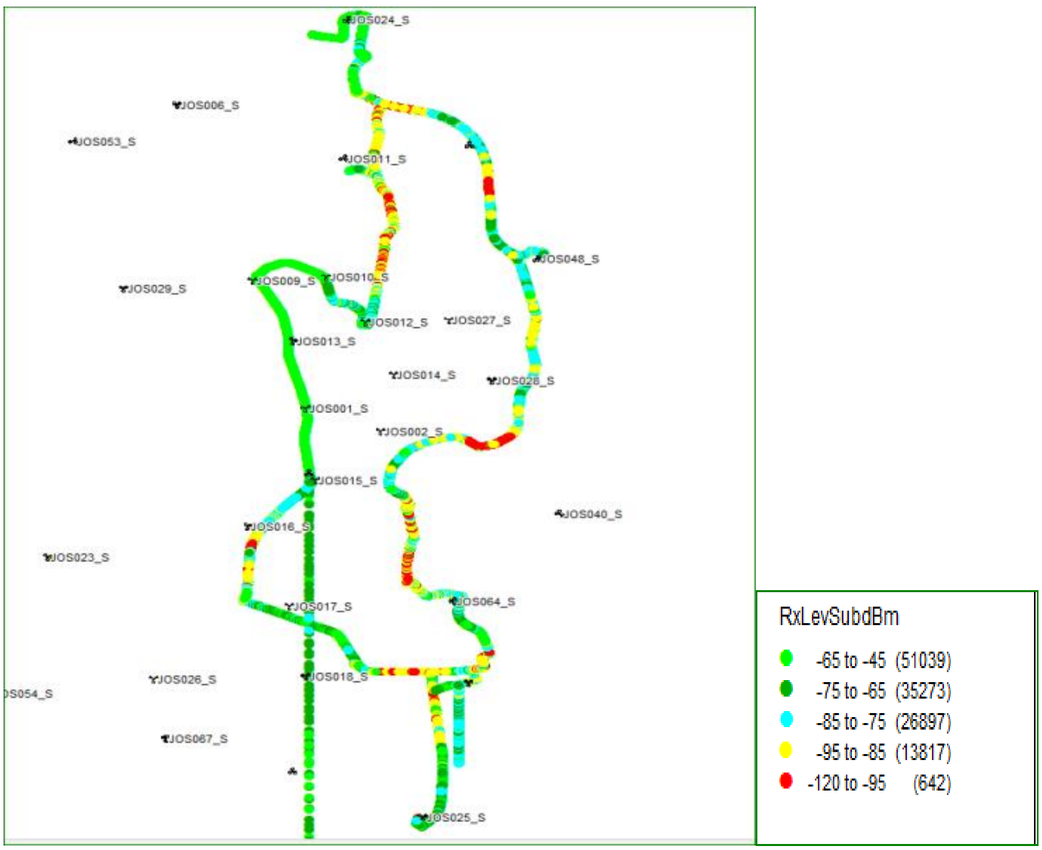

Figure 2: Drive Test under Clear Sky

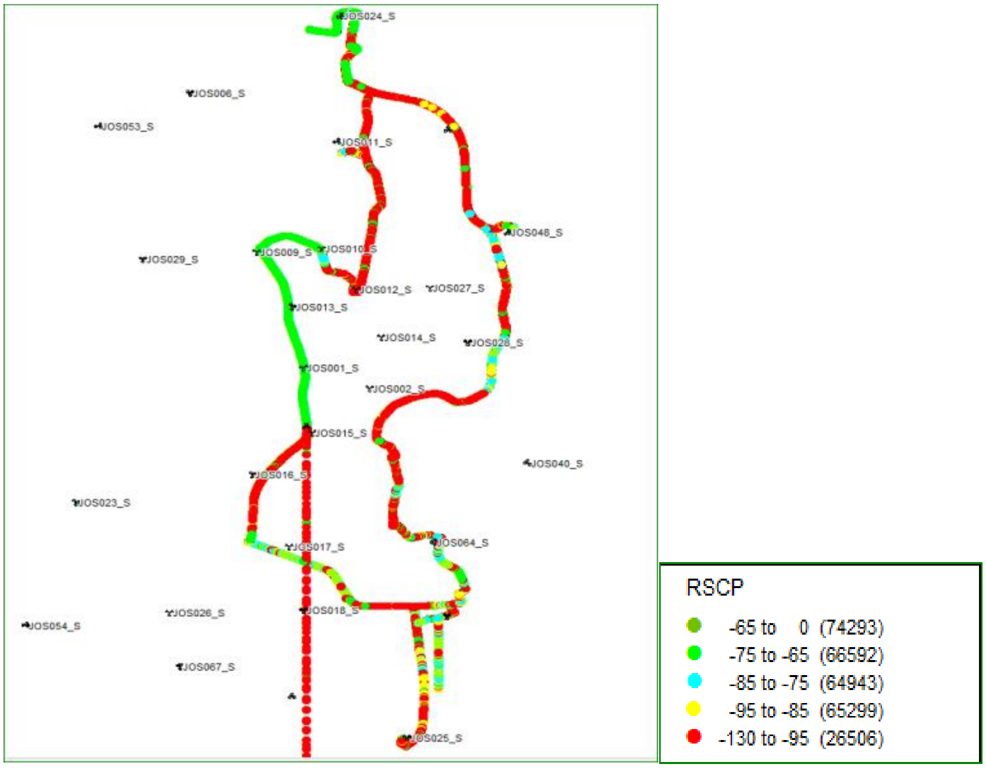

Figure 3: Drive Test during Rainfall

Table 1: Radio Parameters for Data Service in the RF Cell Sites

Site Code	DT Type	µ-Tx Power (dBm)	Radio Link RSL (dBm	Packet Loss (%)	RSCP (dBm)	ECNO	DL (Mbps)	UL (Mbps)	DT Radius (m)
PLA024	Clear Sky	+20.00	-31.95	0.00	-53.00	3.00	4.31	1.22	450.00
	Rain	+20.00	-48.20	30.00	-93.00	-16.00	1.52	0.42	450.00
PLA011	Clear Sky	+20.00	-33.20	0.00	-57.00	-3.00	3.31	1.22	450.00
	Rain	+20.00	-49.70	42.00	-96.00	-16.00	1.52	0.42	450.00
PLA012	Clear Sky	+20.00	-29.20	0.00	-52.00	-3.00	5.43	1.22	450.00
	Rain	+20.00	-44.20	25.00	-92.00	-16.00	1.52	0.42	450.00
PLA010	Clear Sky	+20.00	-42.60	4.00	-94.00	-4.00	1.11	0.72	450.00
	Rain	+20.00	-55.10	88.00	-96.00	-19.00	0.21	0.03	450.00
PLA048	Clear Sky	+20.00	-32.29	0.00	-56.00	-3.00	4.10	1.22	450.00
	Rain	+20.00	-49.40	33.00	-94.00	-16.00	1.22	0.42	450.00

Table 2: Radio Parameters for Voice Service in the RF Cell Sites

Site Code	DT Type	µ-Tx Power (dBm)	Radio Link RSL (dBm	Packet Loss (%)	Rx Level (RxL)	Rx Quality (RxQ)	Speech Quality Index (SQI)	DT Radius (km)
PLA024	Clear Sky	+20.00	-31.95	0.00	-50.00	2.00	+25.00	1.00
	Rain	+20.00	-36.95	0.00	-47.00	1.00	+25.00	1.00
PLA011	Clear Sky	+20.00	-33.20	0.00	-51.00	2.00	+20.00	1.00
	Rain	+20.00	-39.20	12.00	-48.00	1.00	+20.00	1.00
PLA012	Clear Sky	+20.00	-29.20	0.00	-51.00	2.00	+25.00	1.00
	Rain	+20.00	-34.28	0.00	-48.00	1.00	+25.00	1.00
PLA010	Clear Sky	+20.00	-42.60	4.00	-91.00	4.00	+25.00	1.00
	Rain	+20.00	-46.95	55.00	-59.00	2.00	+20.00	1.00
PLA048	Clear Sky	+20.00	-32.29	0.00	-50.00	2.00	+25.00	1.00
	Rain	+20.00	-37.65	40.00	-47.00	1.00	+25	1.00

CONCLUSION

This study evaluated the performance of operational wireless networks in Jos, Plateau State, Nigeria, using drive test measurements obtained under clear-sky and rainy conditions. The investigation demonstrated that environmental conditions, particularly rainfall, significantly influence wireless network KPIs and consequently affect users' Quality of Service. The comparative analysis revealed that rainfall caused noticeable degradation in both voice and data services through reductions in Radio Signal Level, Received Signal Code Power, Energy per Chip to Noise ratio, and uplink/downlink throughput, while simultaneously increasing packet loss. Although both service categories were affected, data services exhibited greater vulnerability to rainfall-induced attenuation than voice services. This finding is particularly important in the era of increasing dependence on broadband applications such as video streaming, cloud services, and real-time communications. The study provides empirical evidence that conventional network planning based solely on clear-weather assumptions may not guarantee satisfactory performance throughout the year in regions characterized by intense rainfall and complex terrain. Therefore, mobile network operators should integrate weather-aware optimization approaches into network design and operation. Such approaches may include enhanced microwave link budgeting with adequate fade margins, adaptive modulation and coding schemes, dynamic traffic management, antenna diversity techniques, and proactive performance monitoring using real-time KPI analytics. Beyond its local relevance, this study contributes to the broader understanding of environmental impacts on wireless network performance in tropical and semi-temperate climates. The findings can serve as valuable references for network planners, regulators, and researchers involved in the deployment and optimization of current and future wireless systems.

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