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Evaluating 4G Network Performance at UTeM Campus to Facilitate 5G Implementation in Malaysia

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ABSTRACT

As Malaysia transitions to 5G technology, evaluating 4G coverage performance is essential for preparing the groundwork for advanced networks. This project focuses on assessing the radio communication link performance of 4G systems at the University Technical Malaysia Malacca (UTeM) campus. The goal is to assist Mobile Broadband (MBB) service providers in developing efficient long-term strategies for Malaysian university campuses and enhancing 4G coverage. The study conducted measurement campaigns and real-time performance analysis using the G-Net Track app, recording key metrics such as minimum RSRP (-115 dBm off-peak, -117 dBm peak), RSRQ (-18 dB for both off-peak and peak periods), and average SNR (11.178 dB off-peak, 11.003 dB peak). Signal quality varied with 25.3% excellent and 4.5% poor in normal weather, and 21.8% excellent and 5.8% poor in rainy conditions. Proximity to the base station showed the best RSRP of -68 dBm at 56m and the worst at -110 dBm around 915m away. The study concludes that mobile network operator (MNO) performance is influenced by traffic load, weather conditions, and distance from the base station. Understanding these dynamics can help MBB service providers enhance coverage, reliability, and overall user experience on university campuses and beyond. Future research considering additional KPIs and environmental factors will further enrich these insights, supporting robust network planning and management.

1. Introduction

The advancement of mobile communications and their incorporation into everyday life has significantly impacted recent social and economic growth [1]. This influence has increased the demand to improve radio communication links for the 4G LTE network, especially as Malaysia transitions to 5G technology [2]. Assessing 4G coverage performance is vital for identifying areas that require enhancements, facilitating the implementation of 5G networks that depend on existing infrastructure [3]. Despite Malaysia's development towards 5G network technology and efforts to increase internet connectivity, certain Malaysian universities continue to face access issues that may obstruct digital learning experiences and plans for implementing smart campuses. Universities

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require dependable and seamless connectivity for labs, classroom equipment, student mobile phone coverage, and access to apps and search engines [4,5]. However, the quality of services (QoS) provided by the 4G system's radio communication link is impacted by the growing number of wireless devices on campus and the demand for high-speed access to digital devices, online learning, and collaboration [6]. The uneven load from weak LTE performance causes congestion in the cellular system, leading to a negative user experience [7-9].

The key performance indicators (KPI) measurements are critical to determining the discrepancy between network operators' claimed consumer expectations and the actual performance of mobile broadband (MBB) services. Physical impairments and channel conditions in the specific region where MBB performance is measured significantly impact this difference. This research paper [10] discusses the comparative analysis of predicting path loss using propagation models such as the Cost231Hata model, Okumura–Hata model, Hata short-range devices model, extended Stanford University interim model, and standard propagation model. The radio propagation model is calculated before drive test data collection to predict the signal strength and coverage of the network. This helps in adjusting network parameters and optimizing performance, including cell coverage radius, propagation pattern, transmitter (TX), and receiver (RX). The radio connection quality of 4G LTE systems is mainly affected by the propagation model, power supply, distance from transmitter to receiver, height of the base station (eNB), and other factors. Next, a comparison of 4G and 3G networks with the performance of each mobile network operator (MNO) in different Malaysian cities, including Klang Valley in Selangor, Johor, Sabah, and Sarawak, is discussed [10]. Mobile Broadband (MBB) service performance measurement was based on four KPIs relevant to the quality of user experiences (QoE): coverage, latency, satisfaction, and speed. The performance metrics for cellular signal strength indicate the RSRP, determining the overall network connectivity and page loading ability.

Another study has analyzed KPIs such as SINR, RSRP, RSRQ, RSSI, and data throughput using Genex Prove V16 and Genex Assistance V16 equipped with a 4G LTE modem for data transmission and reception, GPS equipment, and a personal computer for densely populated smart city and suburban environments [11]. Additionally, the measured KPIs include web-browsing services such as channel quality indicator (CQI), signal level (RSRP), signal quality (RSRQ), ping, downlink (DL) and uplink (UL) data throughput, and handover rate [12]. The data collection was based on four urban and suburban cities, comparing two mobile network operators, X and Y. Higher CQI indicates higher RSRQ levels, as it is the fundamental indicator in LTE networks for determining the relationship between radio link conditions and throughput. Furthermore, a study focused on the performance analysis of the Quality of Services (QoS) for 4G wireless communication among network providers supported in campus areas, specifically Digi and U-mobile, using Nemo Outdoor tools and software to analyze the data signal for the 4G system along the routed map of the campus [13]. Another study provided an extensive performance evaluation of five national MNOs in Malaysia conducted in a smart city with good technology infrastructure. "G-NetTrack" was used as a drive test tool that can be easily installed on any Android mobile device [14].

This paper carefully compared different applications for data collection and decided that G-NetTrack is suitable because it can customize test sets, similar to the consumer experience of MBB access, and be tested on the local device. Additionally, the application does not require handset modification to function. The application runs test continuously in the testing cycle, minimizing interaction between the tester and the phones, making the testing process more practical and convenient by reducing distractions, improving accuracy, and speeding up testing procedures. Moreover, mobile network parameters such as bandwidth, frequency band, cell information, data rate, and so on can be monitored and logged using the application without the need for specialized equipment like an RF scanner.

Finally, an indoor network coverage study for mobile broadband networks in West Malaysia found that Celcom had the best indoor coverage, followed by Maxis and Digi. Indoor coverage was affected by factors such as building materials, partition types, and interior design. The study recommends that network operators focus on improving indoor coverage to meet the increasing demand for mobile data services [15]. According to the study, outdoor network coverage analysis focuses on predicting coverage in open areas, while indoor network coverage analysis focuses on predicting coverage inside buildings. Outdoor coverage analysis considers factors such as terrain, vegetation, and weather conditions, while indoor coverage analysis takes into account factors such as building materials, interior design, and partition types between offices [16].

Despite extensive efforts to improve mobile network performance, there remains a significant gap between the claimed capabilities of network operators and the actual experiences of users, particularly in university settings. The growing number of wireless devices and the demand for high-speed access in educational environments highlight the need for more reliable and seamless connectivity. This research addresses this gap by providing a comprehensive analysis of 4G LTE performance, identifying areas for improvement to facilitate the transition to 5G technology. The findings of this study are expected to guide network operators in optimizing their services, ultimately enhancing the quality of digital learning experiences and supporting the implementation of smart campuses in Malaysia.

2. Methodology

This section outlines a comprehensive methodology to evaluate the coverage, efficiency, and performance of 4G networks at UTeM, focusing on Celcom, U Mobile, and Maxis. The evaluation combines real-time data collection and crowdsourcing using G-Net Track Pro, OpenSignal, Google Earth, Network Cell Info, and CellMapper.

2.1 Region Route

The region route was predefined to cover accessible areas at Kampus Induk, UTeM, Durian Tunggal, Melaka. Factors such as population, geography, terrain, buildings, distance between base stations, and MNO availability were considered. Special attention was given to high-traffic areas like student colleges, university offices, faculties, and libraries to ensure comprehensive performance measurements. Figure 1 illustrates the experimental testbed (measurement area) where data measurements were conducted along the designated route.

Fig. 1. Tacking route within the measurement area at UTeM

2.2 Test Tools

To comprehensively evaluate the performance of the 4G network at UTeM, a strategic approach leveraging multiple Android applications were adopted. These apps were chosen for their ability to capture and analyse essential metrics crucial for assessing network quality and coverage.

i. G-Net Track Pro**:** Used for on-site data logging and real-time network performance monitoring. The app records cell information, neighbor cells, measurements, and driving speed. Calibration settings were set to "4G" to ensure accurate data. Log parameters were configured to record data at specific intervals, and data sequence settings were used to measure network throughput. KML export settings enabled logging measurements in .txt and .kml files.
ii. Google Earth Pro**:** Used to visualize data distribution and coverage areas. RSRP, RSRQ, and SNR levels were mapped to identify cell tower locations and signal strengths.
iii. CellMapper**:** Located cell towers and coverage areas using crowdsourced data. LAC-eNB-Cell ID details were used to identify base stations
iv. Network Cell Info Lite**:** Estimated tower locations and provided real-time signal strength and cell information.
v. OpenSignal**:** Provided signal strength mapping, network speed testing, and tower locator features.

2.3 Drive Test

Drive tests adhered to a 30 km/h speed limit on campus, ensuring safety and accurate data collection. The drive test begins by establishing several parameters such as ping upload time, URLs for data rate tests (down/upload), and 1 GB files for testing. Once these parameters are set, the drive test will begin recording data measurements from the starting to the ending points of the route. Signal levels and quality are continuously measured throughout the drive test, capturing events such as cell reselection and handovers. All measurements are timestamped and geo-tagged with GPS coordinates (longitude and latitude). Table 1 presents the specific measurement parameters stored in the log file.

Table 1
Measured parameters from log files of Gnet-Track

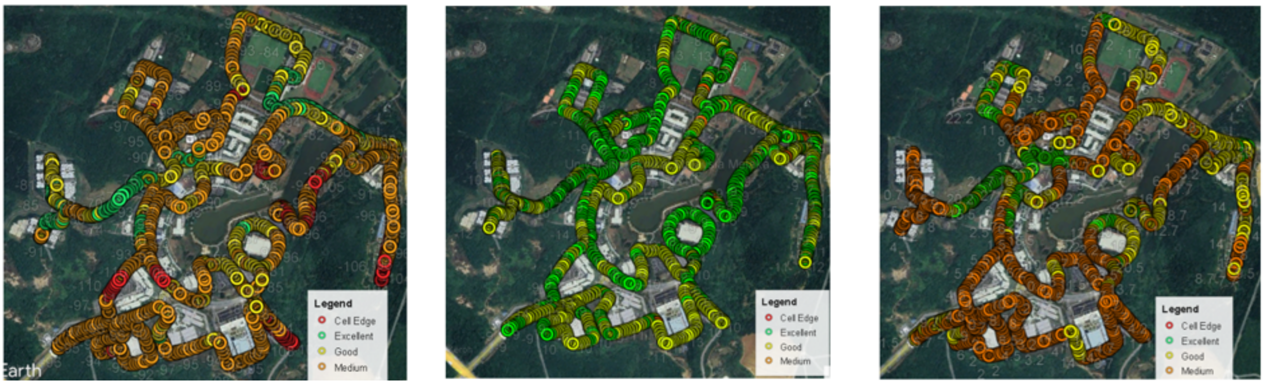
Parameters	Description
CGI	Cell global identity of a serving cell
CELLID	Cell ID of serving cell
MODE	Current network mode
TECHNOLOGY	Current technology – 2G, 3G, 4G
eNB / Node	Radio network controller - eNodeB ID on 4G cell
TAC	Tracking Area Code of serving cell
LAC	Location Area Code of serving cell
Level	Current signal strength in dBm – RSRP for 4G
Qual	Signal quality of the network - RSRQ for 4G
SNR	Signal to noise ratio
ARFCN	Absolute Radio Frequency Channel Number (radio channel ID)
DL_bitrate	Current data cell uplink data transfer speed in kbps
UL_bitrate	Current data cell downlink data transfer speed in kbps
Longitude	Location longitude in decimal format of the current data
Latitude	Location latitude in decimal format of the current data
Altitude	Data GPS measured altitude
Height	Ground level height
Accuracy	Accuracy of the data cell GPS location
Distance	Device distance from serving cell
Bearing	Serving bearing

3. Results

This section provides an analysis of 4G network performance metrics at UTeM, examining RSRP, RSRQ, SNR, and throughput for Celcom, Maxis, and U Mobile during off-peak and peak periods. Visualizations and statistical summaries illustrate performance variations influenced by subscriber demand, rainy weather, and distance from eNodeB.

3.1 Off-peak and Peak Period Scenarios

Measurements were taken during two distinct periods: off-peak and peak periods for all mobile network operators (MNOs) including Celcom, Maxis, and U Mobile. The off-peak period coincided with semester breaks when fewer students were on campus, while the peak-period measurements were conducted during semesters, reflecting higher subscriber demand and increased cell load traffic. Figure 2 illustrates the visualized KPIs of one MNO, with colours indicating signal levels.



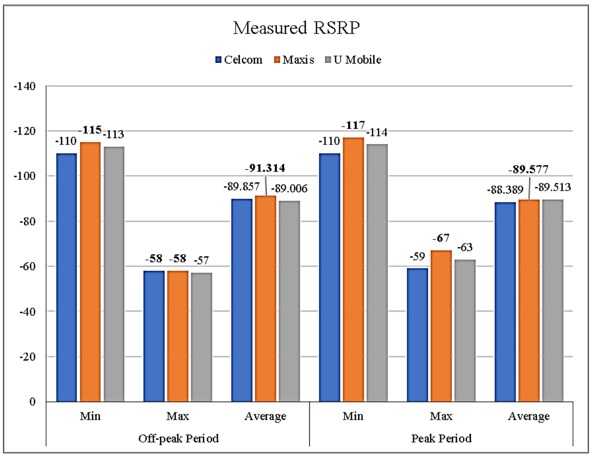
(a) (b) (c)

Fig. 2. Example of data visualization based on performance metrics for one operator: (a) RSRP, (b) RSRQ, and (c) SNR

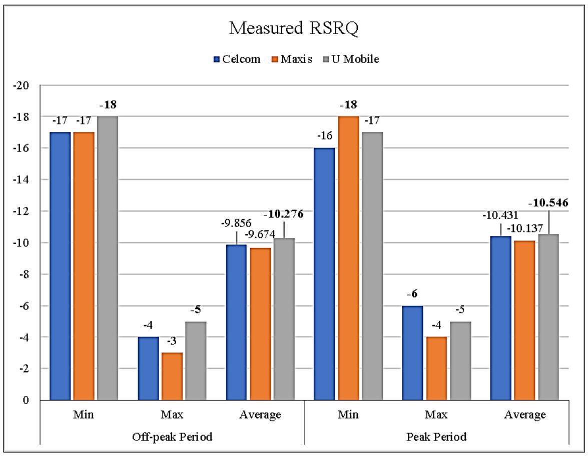
Figure 3(a) presents the histogram plots of RSRP values for Celcom, U Mobile, and Maxis during off-peak and peak periods. Celcom showed the strongest signals with the highest minimum RSRP values of -110 dBm during both periods, and the highest maximum RSRP values, reaching -59 dBm during peak periods and -58 dBm during off-peak periods. This indicates Celcom provides the most reliable signal strength overall. U Mobile had competitive performance, with higher minimum, maximum, and average RSRP values during off-peak periods compared to peak periods, showing strong performance when traffic is lower. Maxis, however, demonstrated a narrower range of RSRP values, with minimum values of -115 dBm and -117 dBm during off-peak and peak periods, respectively. Maxis's RSRP values were more variable, suggesting challenges in maintaining consistent signal strength, particularly during off-peak hours.

Figure 3(b) shows the RSRQ values for all MNOs under study during off-peak and peak periods. Generally, RSRQ values were better during off-peak hours, indicating poorer signal quality during peak hours due to increased network congestion [17]. Maxis achieved the highest minimum and maximum RSRQ values at off-peak periods, reaching -17 dB and -3 dB, respectively. Maxis’s RSRQ was the most stable across both periods, although its minimum RSRQ during peak hours was not as strong as Celcom’s, which recorded -16 dB. U Mobile’s maximum RSRQ was consistently -5 dB in both periods, but its average RSRQ values were the lowest, at -10.3 dB off-peak and -10.6 dB peak. This suggests U Mobile needs improvement in signal quality. Celcom showed greater fluctuation in RSRQ values compared to Maxis, which could lead to occasional drops in signal quality.

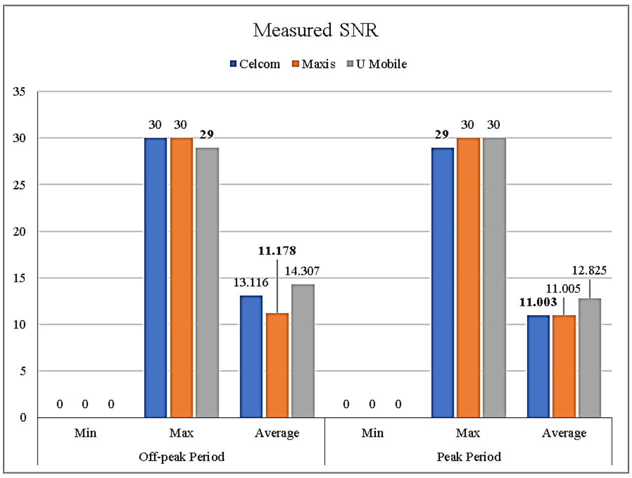
Figure 3(c) highlights the SNR values for Maxis, Celcom, and U Mobile during off-peak and peak periods. Maxis exhibited the most stable SNR, with consistent average values of 11.01 dB peak and 11.18 dB off-peak, and maintained a maximum SNR of 30 dB for both periods. This suggests Maxis provides a dependable signal quality within the campus. Celcom also reached 30 dB off-peak and 29 dB peak, but its average SNR fluctuated more between periods (13.12 dB off-peak and 11.00 dB peak), indicating noticeable variations in signal strength that could impact user experience during peak times. U Mobile showed the highest average SNR among the three MNOs, with 14.31 dB off-peak and 12.82 dB peak, implying strong signal quality, though with some variability during peak periods. Table 2-4 summarize the key parametric output values for all MNOs during off-peak and peak period.



(a)



(b)



(c)

Fig. 3. Measurement testing during Off-peak and peak period for all MNOs (a) RSRP, (b) RSRQ and (c) SNR

Table 2
Summary of RSRP in off-peak and peak period for all MNOs

MNO	Period	RSRP (dBm)			
		Min	Max	Average	Std. Dev
Celcom	Off-peak	-110	-58	-89.857	9.046
	Peak	-110	-59	-88.389	9.705
Maxis	Off-peak	-115	-58	-91.314	10.084
	Peak	-117	-67	-89.577	9.931
U Mobile	Off-peak	-113	-57	-89.006	9.196
	Peak	-114	-63	-89.513	8.771

Table 3
Summary of RSRQ in off-peak and peak period for all MNOs

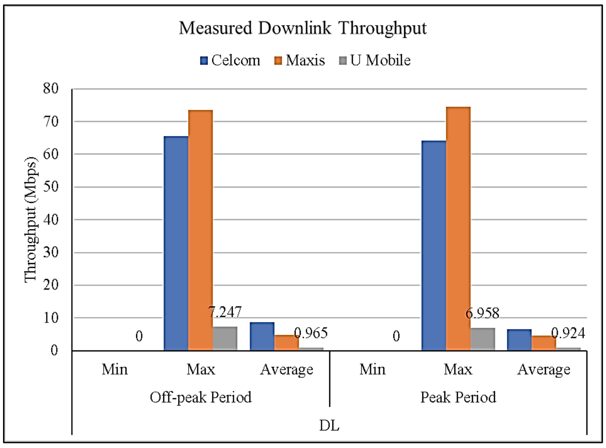
MNO	Period	RSRQ (dB)			
		Min	Max	Average	Std. Dev
Celcom	Off-peak	-17	-4	-9.856	2.018
	Peak	-16	-6	-10.431	1.900
Maxis	Off-peak	-17	-3	-9.674	1.897
	Peak	-18	-4	-10.137	1.646
U Mobile	Off-peak	-18	-5	-10.276	2.199
	Peak	-17	-5	-10.546	2.144

Table 4
Summary of SNR in off-peak and peak period for all MNOs

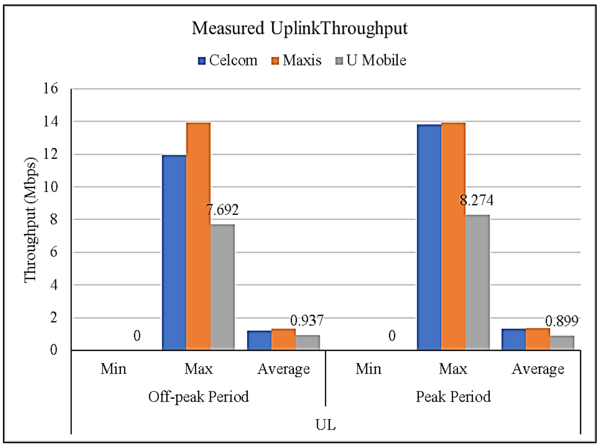
MNO	Periods	SNR (dB)			
		Min	Max	Average	Std. Dev
Celcom	Off-peak	0	30	13.116	6.710
	Peak	0	29	11.003	7.822
Maxis	Off-peak	0	30	11.178	6.678
	Peak	0	30	11.005	7.045
U Mobile	Off-peak	0	29	14.307	7.283
	Peak	0	30	12.825	7.166

3.2 Throughput (Downlink and Uplink Data Rate)

Based on Figure 4(a) and (b), the lowest downlink (DL) throughput during off-peak periods is 7.2 Mbps for maximum values and 0.97 Mbps for average values. During peak periods, the DL throughput decreases to 6.96 Mbps for maximum values and 0.92 Mbps for average values. For uplink (UL) throughput, the lowest values during off-peak periods are 7.7 Mbps for maximum values and 0.94 Mbps for average values. During peak periods, the average UL throughput decreases to 0.9 Mbps. This indicates that high user demand negatively impacts not only signal level and quality but also throughput [18]. The results also show that lower RSRQ values affect both DL and UL throughput. The lowest RSRQ and throughput values are observed for U Mobile, suggesting that this MNO lags behind others. Table 5 and 6 summarize the results for DL and UL throughput during both off-peak and peak periods.



(a)



(b)

Fig. 4. Measured data rate during off-peak and peak period for all MNOs for (a) downlink, and (b) uplink

Table 5
Summary of DL throughput in off-peak and peak period for all MNOs

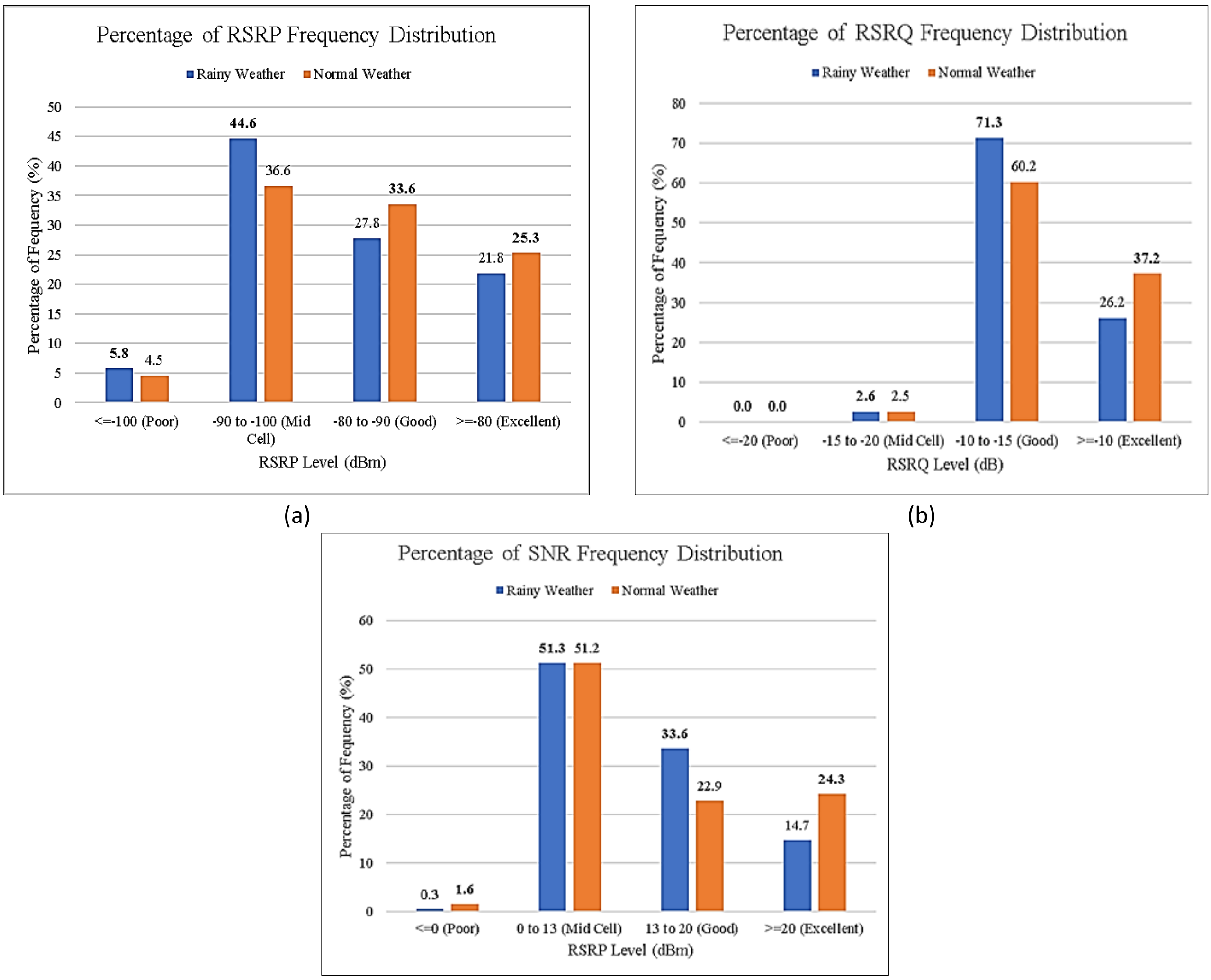
MNO	Period	DL throughput (Mbps)			
		Min	Max	Average	Std. Dev
Celcom	Off-peak	0	65.589	8.656	16.131
	Peak	0	64.1320	6.6060	7.822
Maxis	Off-peak	0	73.482	4.801	9.848
	Peak	0	74.394	4.556	7.045
U Mobile	Off-peak	0	7.247	0.965	1.525
	Peak	0	6.958	0.924	7.166

Table 6
Summary of UL throughput in off-peak and peak period for all MNOs

MNO	Period	UL throughput (Mbps)			
		Min	Max	Average	Std. Dev
Celcom	Off-peak	0	11.953	1.214	2.596
	Peak	0	13.822	1.333	2.732
Maxis	Off-peak	0	13.950	1.309	2.775
	Peak	0	13.950	1.371	2.833
U Mobile	Off-peak	0	7.692	0.937	1.731
	Peak	0	8.274	0.899	1.730

3.3 Rainy Weather Scenarios

The study analyses both normal and rainy weather conditions to assess their influence on performance metrics such as RSRP, RSRQ, and SNR as depicted in Figure 5(a), (b), and (c) under normal and rainy weather conditions selected for U Mobile operator. In normal weather conditions, 25.3% of RSRP signals are classified as excellent, with only 4.5% categorized as poor. Conversely, during rainy weather, the percentage of excellent signals drops to 21.8%, while the percentage of poor signals increases to 5.8%.



(a) (b) (c)

Fig. 5. Comparison for rainy and normal weather scenarios for (a) RSRP, (b) RSRQ, and (c) SNR

This trend is supported by the CDF analysis shown in Figure 6, where the probability of receiving a weak signal (below -100 dBm) is 0.07 under normal conditions and 0.15 during rainy weather. For RSRQ, rainy weather shows 26.2% of signals as excellent and 2.6% as mid-cell, compared to 37.2% excellent and 2.5% mid-cell signals in normal weather. In terms of SNR measurements, rainy weather records 14.7% excellent signals and 0.3% poor signals, whereas normal weather shows 24.3% excellent signals and 1.6% poor signals. Overall, rainy weather negatively impacts signal quality, resulting in a higher percentage of poor RSRP, RSRQ, and SNR signals compared to normal weather conditions.

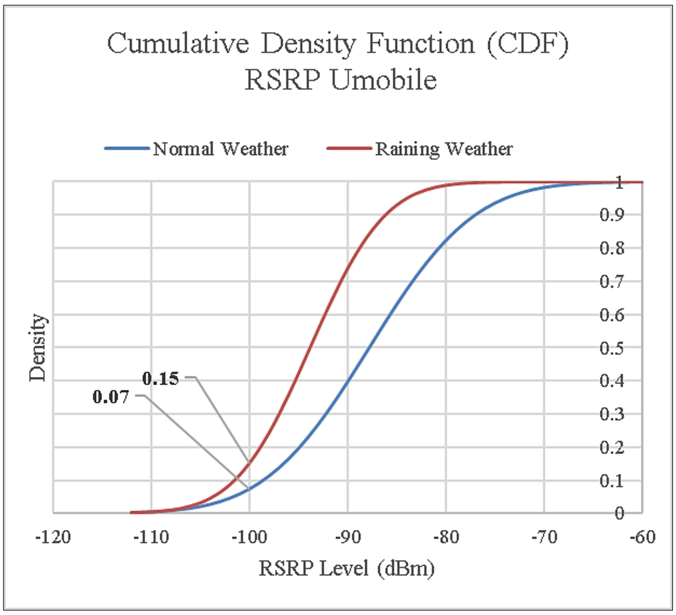


Fig. 6. CDF distribution of RSRP level during normal and rainy weather scenarios

3.4 Distance of User Equipment (UE) *to eNodeB*

Figure 7 illustrates the impact of distance on RSRP measurements during both off-peak and peak periods. The distance between the UE and the tower site significantly affects the performance metrics of each MNO. The scatter plot demonstrates that radio wave attenuation increases as the distance traveled by the UE increases. For instance, when the UE is closest to the eNB at 56 meters, the RSRP measures -68 dBm, classified as 'excellent'. As the UE moves further away, the RSRP transitions into the 'mid-cell' range, reaching -93 dBm. The weakest RSRP recorded is -110 dBm at a distance of 915 meters, approaching 1 km.

During drive tests, as the UE moves farther from the sites, especially during peak periods, it receives significantly weaker signals. This phenomenon is influenced by various factors such as neighbor cell load, frequency range, bandwidth, and the type of clutter, all of which play roles in LTE cell coverage [19-21].

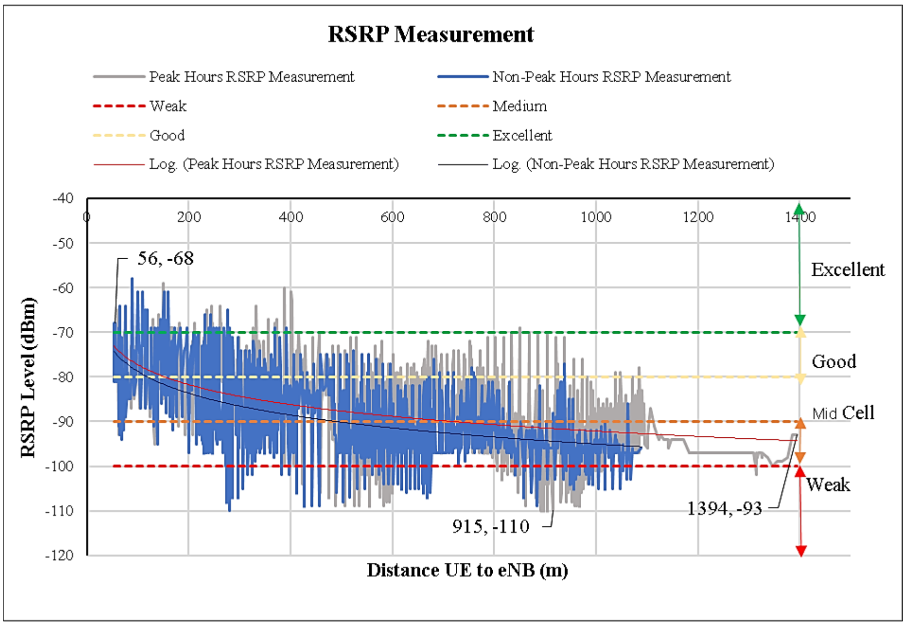


Fig. 7. RSRP measurements over distance during off-peak and peak period

Additionally, RSRP is crucial for determining the handover rate [22], which directly impacts signal strength. Higher handover rates within the same network (intra-eNB) can lead to increased call dropouts, slower data speeds, and longer service downtime, posing challenges in 4G networks. Efficient handover procedures in LTE networks ensure uninterrupted communication as mobile devices move between base stations (eNBs), highlighting its importance in maintaining network performance and reliability. Understanding handover rates can offer valuable insights into optimizing RSRP, RSRQ, SNR, and throughput for future network enhancements.

4. Conclusions

In conclusion, this study demonstrates that Mobile Network Operators' (MNOs) performance is closely tied to traffic load. Analysis of performance metrics through statistical models reveals that fluctuations in signal strength significantly affect Quality of Service (QoS), particularly for call quality and data speeds, especially during peak usage times. Variations in signal strength can lead to dropped calls, buffering, and slower internet speeds. Moreover, signal strength and quality are notably impacted by rain attenuation, which diminishes broadcast signal amplitude through absorption and dispersion, reducing communication link availability, reliability, and performance. Furthermore, signal strength weakens with distance from the tower. As vehicles move, frequent handovers occur due to weaker signals at greater distances, leading to connectivity issues. Drive testing confirms that moving away from cell towers reduces RSRP (Received Signal Reference Power) for all MNOs due to radio wave attenuation, resulting in higher handover rates that may compromise data and call performance. To optimize coverage and minimize handovers for seamless 4G experiences and eventual deployment of 5G, MNOs should consider variables such as clutter, frequency allocation, and distance. Future research should explore additional Key Performance Indicators (KPIs) like CQI (Channel Quality Indicator), RSSI (Received Signal Strength Indicator), handover rates, and ping loss to gain a comprehensive understanding. Factors such as temperature, humidity, and driving speeds should also be evaluated to further elucidate their impact on network performance.

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