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Performance Design and Evaluation of 4G LTE and 5G NSA Networks for LTE Home

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ABSTRACT

The rapid evolution of cellular telecommunications has enabled high-speed network services, yet coverage in densely populated and geographically challenging areas remains a significant hurdle. This study proposes the implementation of 'LTE Home' using Software-Defined Radio (SDR) to mitigate issues such as weak signals, high interference, and limited sectoral antenna coverage. Performance was evaluated through drive tests in the Siteba area, comparing 4G LTE and 5G Non-standalone (NSA) networks across Radio Frequency (RF) parameters—including RSRP, RSRQ, SINR, and throughput—and Quality of Service (QoS) metrics. Initial measures indicated that while the 4G LTE network maintained relatively stable performance, with 38.81% of RSRP readings classified as 'good', the 5G NSA network underperformed. Specifically, 84.06% of 5G SINR readings were in the 'fair' category, and 68.58% of throughput readings were classified as 'poor'. The implementation of LTE Home technology yielded a substantial enhancement in network quality, particularly at measurement points initially exhibiting weak signals. On the 4G LTE network, RSRP improved from -88.9 dBm to -60 dBm, while RSRQ rose from -14.9 dB to -8 dB. Furthermore, the solution significantly optimised QoS, reducing latency to 16 milliseconds and jitter to 30 milliseconds. These findings demonstrate that SDR-based LTE Home implementation effectively addresses coverage gaps and enhances the consumer network experience in challenging environments.

1.0 Introduction

Cellular telecommunications systems have become an integral part of modern society. As well as functioning as a means of communication, they support various safety systems. One example is the development of a car alarm system for child safety that utilises a GSM module. This system can quickly send alerts via text message (SMS) to the driver or parent's mobile phone when a dangerous condition is detected inside the vehicle (M. Ruzaimi Mat Juna, 2024). This shows that advances in cellular technology improve connectivity and play a significant role in creating responsive, efficient safety solutions.

As human mobility increases, all industries in the information and communications technology sector are competing to develop technology that can meet these demands. The cellular industry has experienced significant developments, ultimately resulting in the creation of 4G LTE (Long Term Evolution) technology as part of the 3GPP (Third Generation Partnership Project) initiative (Mantirri, Rohmah & Putri, 2018). Currently, internet networks, especially 4G

LTE networks, are in high demand because they offer high speeds, low latency and ease of use (Alfaresi, Ardianto & Kurniawan, 2025).

When LTE technology was first launched, the main problem was the lack of an adequate transmission network. The availability of this network prompted further research to optimize access speeds for home customers through LTE Home technology services based on CPE modems (Shodikin, 2021). LTE Home technology amplifies signals from LTE transmitter towers using CPE modem repeater devices installed in customers' homes. To address the shortcoming of LTE Home technology lacking its own signal transmission, this research proposes an LTE Home technology based on Open Radio Access Networks (ORAN).

One cellular technology that can be developed using Open RAN is the 4G LTE network. These networks provide high data rates and low latency, allowing for seamless connectivity between users without interruptions (L. Damayanti et al., 2023). An LTE Home system based on Open Radio Access Networks involves installing subscriber radio access devices or LTE Home transmitters in customers' homes. These devices are directly connected to the core network system via existing broadband transmission lines, either leased or independently deployed. One device that supports ORAN is the Universal Software Radio Peripheral (USRP). The USRP is cost-effective, highly adaptable radio hardware used for software-defined radio (SDR) that is compatible with 4G LTE technology (Yuliansyah et al., 2023).

Research on Open RAN on the current 4G LTE network requires a trial implementation of 5G cellular network infrastructure using software-defined radio (SDR). However, 5G NR performance analysis testing still uses simulations on the non-standalone (NSA) scheme. Performance testing is carried out to measure KPIs such as delay, packet loss, and packet success rate on the 5G cellular network under development. It is expected that 5G technology will fundamentally change the role of existing telecommunications technology in society, serving the digitalization needs of the connected world whenever and however needed via the Internet of Things (IoT). The 5G NSA scenario combines NR and LTE radio cells using dual connectivity to produce radio access to the core network (Kirang et al., 2023).

Another factor influencing the renewal of telecommunications equipment on base transceiver station (BTS) towers is the increase in users in residential areas (Ni Ketut et al., 2023). To prevent a decrease in network quality, telecommunication equipment on BTS towers must be updated (Ni Ketut et al., 2023). Troubleshoot VSWR if an alarm appears. Optimize the physical tuning of sectoral antennas on LTE networks using the Automatic Cell Planning (ACP) method. Various studies and optimization methods have shown that increasing the coverage area and performance of 4G-LTE networks is crucial, particularly in areas with geographical challenges or high population density.

However, areas far from urban centres often have weak signals or poor coverage, which disrupts community activities. Therefore, a solution is needed to improve cellular network signals in areas with weak signals, one of which is through signal boosters or LTE Home technology. In this study, the design and implementation analysis of LTE Home based on Open RAN were conducted, utilizing Software Defined Radio (SDR) HackRF as an active LTE transmitter and Mikrotik LTE-A modem as a CPE device on the customer side. The implementation was carried out on a 4G LTE and NSA 5G network, followed by system performance measurements by testing customer performance when using voice and data services. The 4G LTE network was optimized using the Automatic Cell Planning (ACP) method and Physical Tuning Antenna. The results obtained from this LTE Home design aim to measure and analyze the performance of the LTE Home implementation on the 4G LTE network to align with Key Performance Indicator (KPI) values. The objective of this research is to design and optimize 4G LTE and NSA 5G networks based on Open RAN using HackRF as the Open RAN eNodeB and Mikrotik LTE-A modem as

Customer Premises Equipment (CPE), thereby improving signal coverage and service quality in areas with low signal strength.

2.0 Methodology

Solving a problem is an exciting opportunity to apply a research method and achieve the researcher's objectives. Check out Figure 1, which shows the Performance Design Block Diagram for 4G LTE and NSA 5G Networks for SDR-based LTE Home.

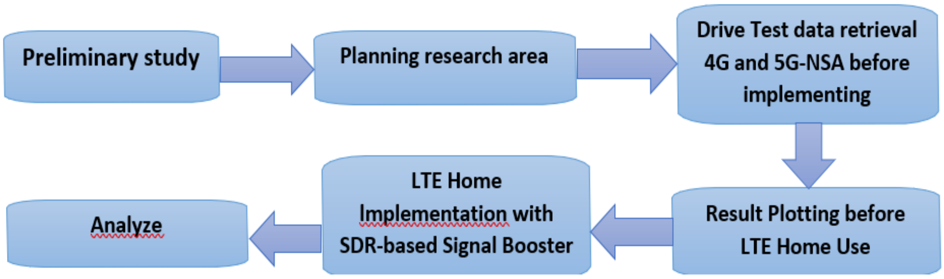


Figure 1: Block Diagram of 4G LTE and NSA 5G Network Performance Design for SDR-based LTE Home

A comprehensive literature review was conducted using journals relevant to 4G LTE, 5G networks, LTE Home, signal boosters, Open RAN, radio simulation (software-defined radio), and radio frequency (RF) parameters. A simulation scenario model was developed to analyse coverage and interference through voice and data services. The utilization of LTE Home as a signal booster has the potential to augment the coverage area of a site by employing a transmission pattern designed to mitigate signal weakness and interference between sectors.

The objective of this study is to determine the service area for network planning and to analyse the quality of 4G LTE and NSA 5G networks. The objective of this determination is to restrict the utilization of data on the enodeB. The research location is a densely populated area, namely Kurao Pagang and Surau Gadang villages (Siteba Padang area), Kampung Lapai, Khatib Sulaiman, and Gunung Pangilun villages with 4G LTE and NSA 5G BTS. The data collection process commenced with the delineation of the route utilizing Google Earth software. The measurement of signals was conducted via drive tests on the 4G LTE and NSA 5G networks in the areas along the aforementioned routes. The signal measurements were obtained through the utilization of the G-net track and the Tems pocket. The results or data obtained consist of radio frequency parameters prior to the implementation of LTE Home. The following paper will propose a design for the 4G LTE and NSA 5G cellular network for LTE Home. The equipment to be utilized includes a laptop, Tems Pocket device, G-Net Track device, Mikrotik LTE-A signal booster router, SDR devices, LTE modem with an outdoor LTE antenna, galvanized poles, and a power bank as a portable power source.

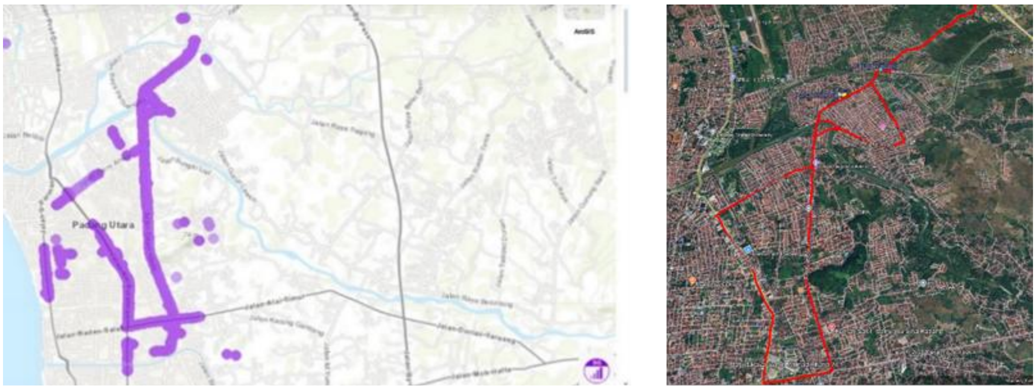
Figure 2: Design of 4G LTE and NSA 5G Networks for LTE Home

As illustrated in Figure 2, the PC device operates as a client for video and voice communication through a Wi-Fi network connected to the LTE Home network. The implementation of LTE Home, based on Software Defined Radio, is in accordance with the scenario created. This implementation measures Radio Frequency parameters and Quality of Service (QoS) parameters using the drive test method. The final stage of the process entails the analysis of the data using data processing applications (TEMS discovery) and the LTE modem device under evaluation. The results of the 4G LTE and NSA 5G network analysis will be optimized and evaluated in the future with higher bandwidth. This configuration is expected to yield an effective radio frequency (RF) network and satisfactory quality of service (QoS) metrics.

3.0 Discussion of analysis and findings

Data collection was conducted in the areas of Kurao Pagang and Surau Gadang (Siteba Padang area), Kampung Lapai, Khatib Sulaiman, and Gunung Pangilun. These areas are already covered by 4G LTE and 5G NSA networks. The 5G coverage in the city of Padang can be seen in Figure 1(a), and the planning and data collection route (drive test) using Google Earth can be seen in Figure 1(b). Measurement points were selected considering a spatially even distribution along the measurement route, while also paying special attention to areas known to have low signal quality based on previous data. This selection aims to ensure that the measurement results reflect the general network conditions while still accommodating evaluations at critical points.

The testing was conducted in the morning under clear weather conditions, which support signal propagation stability. All measurements were performed using the drive test method with the vehicle in motion, thereby representing network conditions in real-world user mobility scenarios. The design of LTE Home on the 4G LTE network was carried out at Telkomsel's eNodeB location with two sites serving the area, namely PAD448_Kurao Pagang and PAD073_Pasar Siteba, as shown in Table 1.



(a) (b)

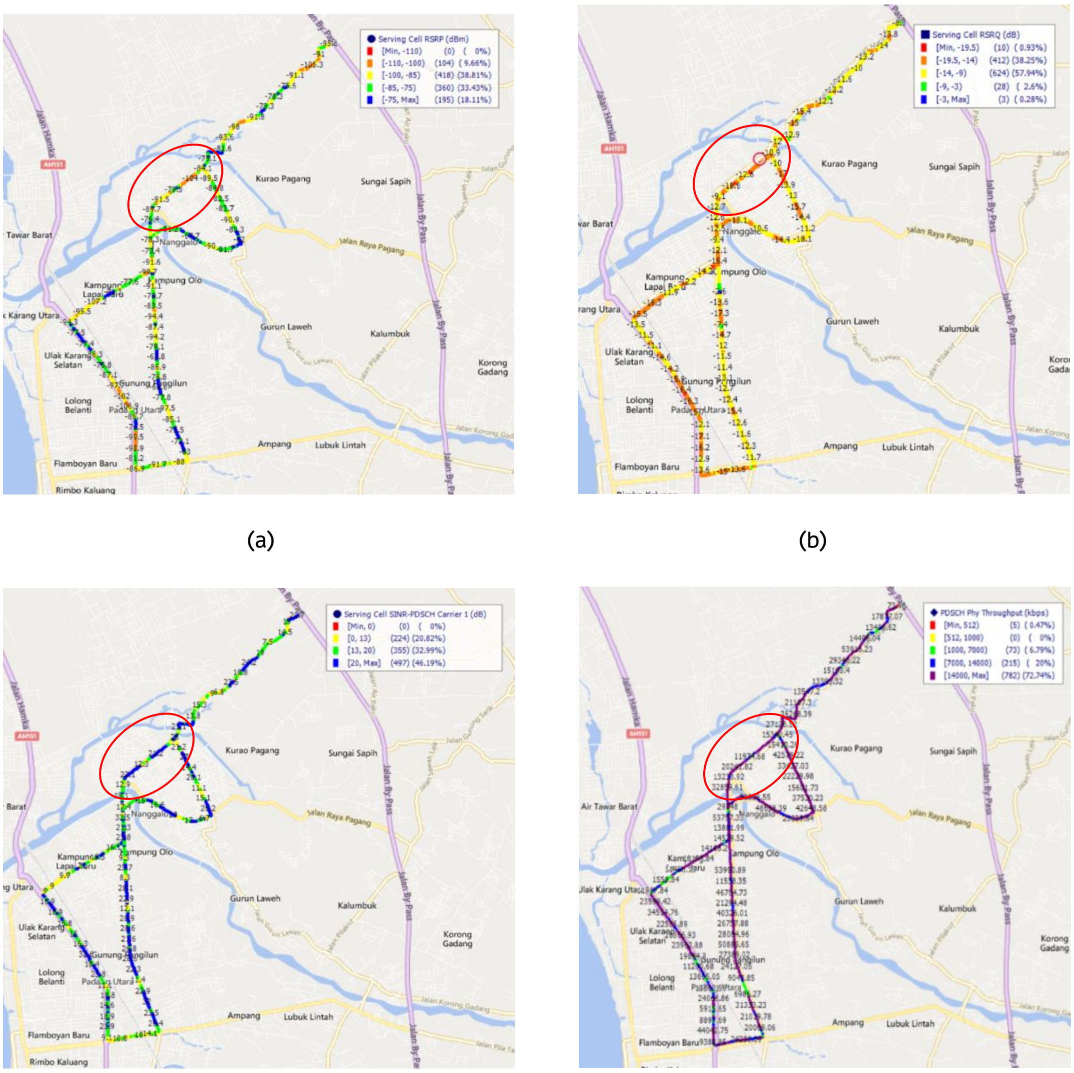
Figure 3: (a) 5G Network Measurement Route, (b) Drive Test Route Planning for 4G LTE and 5G NSA

Table 1 : Radio Parameter Data at the Siteba Area BTS

Site Name	Longitude	Latitude	Antena Height (m)	Azimuth	Mechanical Downtilt	PCI
Kurao Pagang	100,3702	-0,88708	15	0	0	195
Kurao Pagang	100,3702	-0,88708	15	115	0	196
Kurao Pagang	100,3702	-0,88708	15	240	0	197
Pasar Siteba	100,3659	-0,89121	39	30	0	63
Pasar Siteba	100,3659	-0,89121	32	130	0	64
Pasar Siteba	100,3659	-0,89121	39	240	0	65

3.1 Performance Measurement Results on 4G LTE Networks

The parameters used in this drive test measurement are RSRP, RSRQ, SINR, and DL Throughput. First, RSRP is a parameter that displays the signal strength (power) received by the user based on the BTS service. Figure 4(a) shows the RSRP results. Second, RSRQ is an important parameter in LTE and 5G networks used to measure the signal quality received by user equipment (UE). RSRQ represents the ratio between the reference signal strength (RSRP) and the total received power in a specific bandwidth (Received Signal Strength Indicator). Figure 4(b) shows the RSRP results. Third, the SINR parameter indicates the quality of the signal received by the user from the service provided by the BTS. Unlike RSRQ, SINR is the ratio between the desired signal power and the combined interference from neighbouring cells and thermal noise. Figure 4(c) shows the SINR results. The fourth parameter, throughput, indicates the speed and data transfer rate during download and upload. Figure 4(d) shows the download throughput results.



(a) (b) (c) (d)

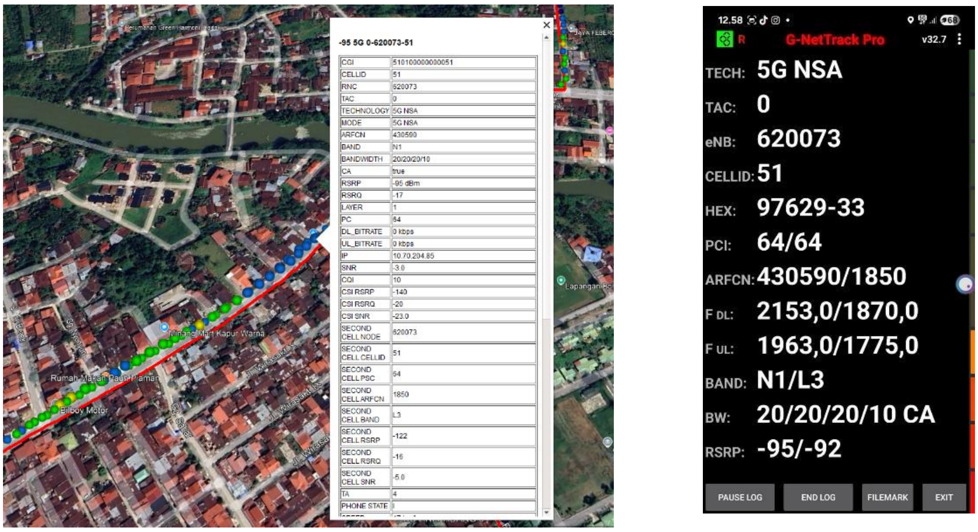
Figure 4: (a) Plotting Result Drive Test RSRP, (b) Plotting Result Drive Test RSRQ, (c) Plotting Result Drive Test SINR and (d) Plotting Result Drive Test Throuhgput DL

As illustrated in Figure 4(a), the RSRP parameter demonstrates an excellent performance rating of above -75 dBm, with a percentage of 18.11%, as indicated by 195 samples. The category designated as "very good" (-85 dBm to -75 dBm) comprises 360 samples, representing a percentage of 33.43%. The "good" category, defined as -100 dBm to -85 dBm, encompasses 418 samples, constituting 38.81% of the total. The fair category (-110 dBm to -100 dBm) comprised 104 samples, constituting a percentage of 9.66%. The poor category, which typically ranges from -150 dBm to -110 dBm, was not observed in this instance. In this measurement, the dominant value for the RSRP parameter of the 4G LTE network was in the yellow category, indicating a satisfactory performance. RSRP plays a crucial role in determining coverage areas, and this parameter is used as a benchmark for selecting priority areas for optimization (e.g., the red-circled areas in Figure 4 (a) by analysing the signal strength obtained during the measurement of 4G LTE KPI parameters in those areas.

In Figure 4(b), it can be seen that the RSRQ parameter performance in the excellent category (above -3 dB) has a percentage of 0.28%. The very good category (-9 dB to -3 dB) has a percentage of 21.10%. The good category (-14 dB to -9 dB) has a percentage of 59.22%. The fair category (-19.5 dB to -14 dB) accounts for 19.68%. The poor category (-20 dB to -19.5 dB) is not present. In this measurement, the dominant value for the RSRQ parameter of the 5G NSA network is in the yellow category, indicating good performance. For the SINR parameter of 5G NSA, the dominant category is fair (0 dB to 13 dB) with a percentage of 84.06%. For the throughput parameter of 5G NSA, the dominant category is poor (0 kbps to 512 kbps) with a percentage of 68.58%. Although the distribution of RSRP and RSRQ is predominantly in the good category, the dominant fair SINR (84.06%) implies a decrease in spectral efficiency (low CQI), resulting in the 5G NSA throughput being predominantly in the poor category (0–512 kbps) at 68.58%. This condition is most consistent with spectrum interference/congestion in the test cell.

3.2 Performance Measurement Results on 5G NSA Networks

The 5G NSA network is one of the implementation modes of the 5G cellular network, which is an evolution of 4G LTE technology. The NSA mode is the initial phase of 5G deployment, enabling network operators to leverage existing 4G infrastructure while adding radio parameters for 5G. The results of 5G network measurements using drive tests in the same area with G-NetTrack Pro can be seen in Figure 5.



(a) (b)

Figure 5: (a) Plotting Result Drive Test 5G NSA Network, (b) 5G NSA Network RF Measurement Results

The performance measurement parameters for 5G Non-Standalone Architecture (NSA) are RSRP, RSRQ, SINR, and Throughput. As illustrated in Figure 5, the RSRP (level) plot results are displayed on cell ID 51, frequency 1800 MHz (L3), PCI 64. The RSRP value is -95 dBm, the RSRQ is -17 dB, the SINR is -3 dB, and the throughput is 0 kbps. For further elucidation regarding 5G NSA measurement data, direct your attention to Figure 6, which presents a comparative analysis of RSRP histograms between 4G LTE and 5G NSA. As illustrated in Figure 6(a), the RSRP parameter performance is categorized as "excellent" (above -75 dBm) with a percentage of 5.29%. The category designated as "very good" (-85 dBm to -75 dBm) accounted for 22.76% of the total. The "good" category, which ranges from -100 dBm to -85 dBm, accounts for 55.40% of the total. The fair category, which ranges from -110 dBm to -100 dBm, exhibits a percentage of 10.41%. The category of poor performance, defined as levels ranging from 150 dBm to -110 dBm, accounts for 1.41% of the total. In this measurement, the dominant value for the RSRP parameter of the 5G NSA network is in the yellow category, indicating a satisfactory performance.

In Figure 6(b), the performance of the RSRQ parameter is categorized as excellent (above -3 dB) with a percentage of 0.28%. The very good category (-9 dB to -3 dB) accounts for 21.10%. The good category (from -14 dB to -9 dB) accounts for 59.22%. The "fair" category (-19.5 dB to -14 dB) accounts for 19.68%. The "poor" category (-20 dB to -19.5 dB) is not present. In this measurement, the dominant value for the RSRQ parameter of the 5G NSA network is in the yellow category, indicating good performance. For the SINR parameter of 5G NSA, the most common category is "fair" (0 dB to 13 dB) with 84.06% of the results. For the throughput parameter of 5G NSA, the most common category is "poor" (0 kbps to 512 kbps), accounting for 68.58% of the results.

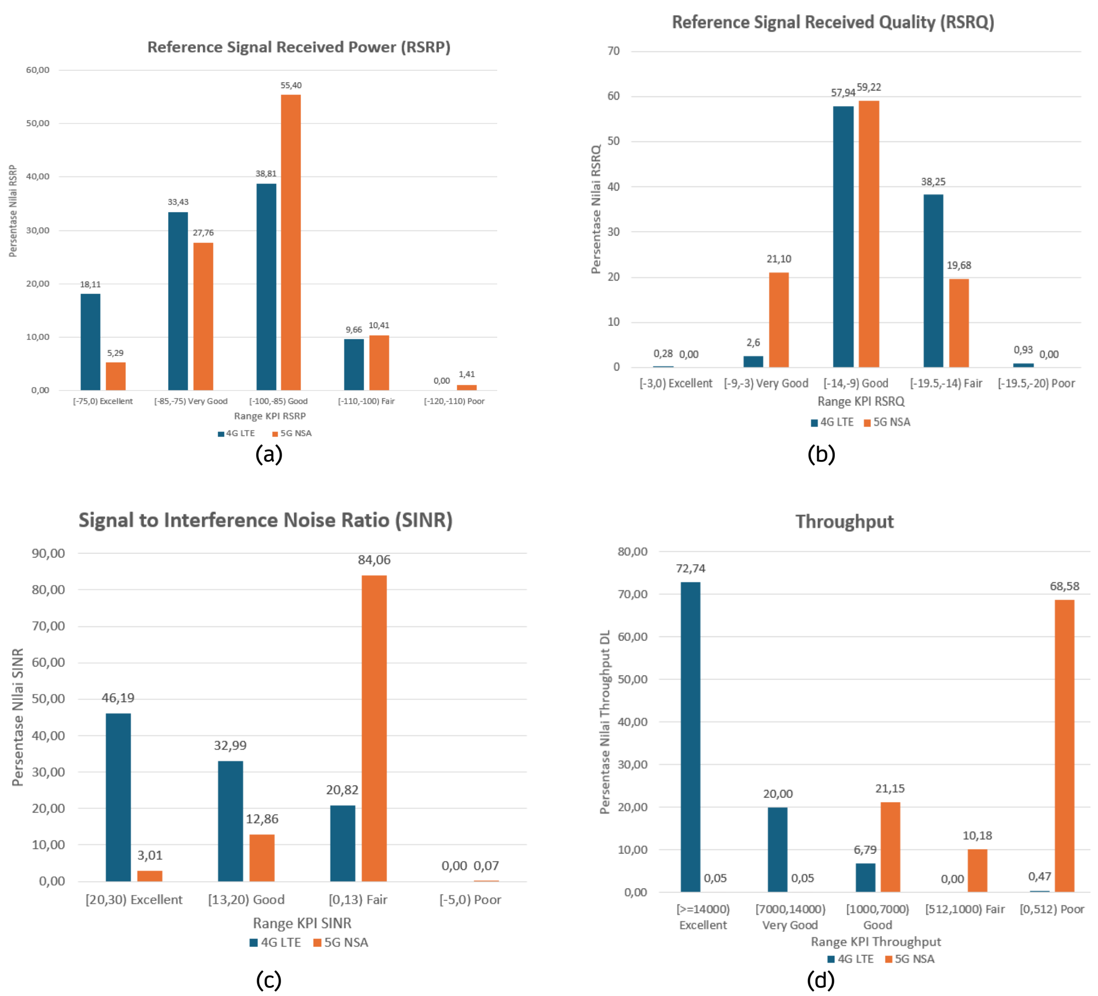


Figure 6: (a) Comparison Histogram RSRP 4G LTE and 5G NSA, (b) Comparison Histogram RSRQ 4G LTE and 5G NSA, (c) Comparison Histogram SINR 4G LTE and 5G NSA, and (d) Comparison Histogram Throughput DL 4G LTE and 5G NSA

It can be concluded that for the 5G NSA RSRP/RSRQ radio parameters, the majority are good, but the SINR is mostly fair, and the throughput is predominantly poor, due to suboptimal LTE anchor quality. NR 5G is rarely active or its contribution is small, and NR is not fully utilized. The channel quality (SINR) is low due to interference.

3.3 Measurement Results of LTE Home Implementation on 4G LTE Networks

The objective of this study is to assess the performance of the 4G LTE network utilizing the LTE Home technology. The assessment employs a combination of methodologies, including the use of user laptops and smartphones, Mikrotik outdoor routers, and a Software Defined Radio (HackRF One). The results of the measurements conducted on the LTE Home devices utilized are presented in Table 2 and Figure 7 below.

Table 2: Comparison of 4G LTE and 5G NSA RF Network

Parameter Site	Network Quality	RF KPI 4G LTE	KPI 4G LTE-A with LTE Home	RF KPI 5G NSA
PCI: 64	RSRP (dBm)	-88.9	-60	-79
Fre 1800 MHz (L3)	RSRQ (dB)	-14.9	-8	-11
PCI: 179	RSRP (dBm)	-93.6	-63	-96
Fre 2300 MHz (L40)	RSRQ (dB)	-13.7	-13	-16

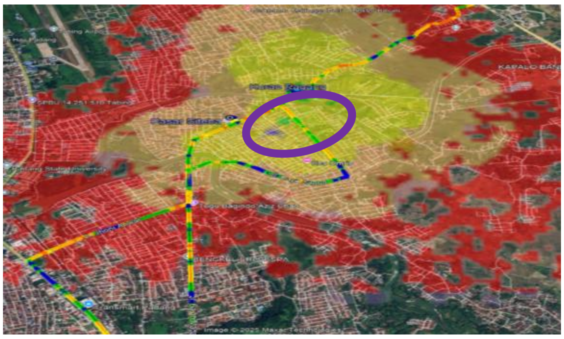


Figure 7: Application of SDR-based LTE Home in Bad spot Areas

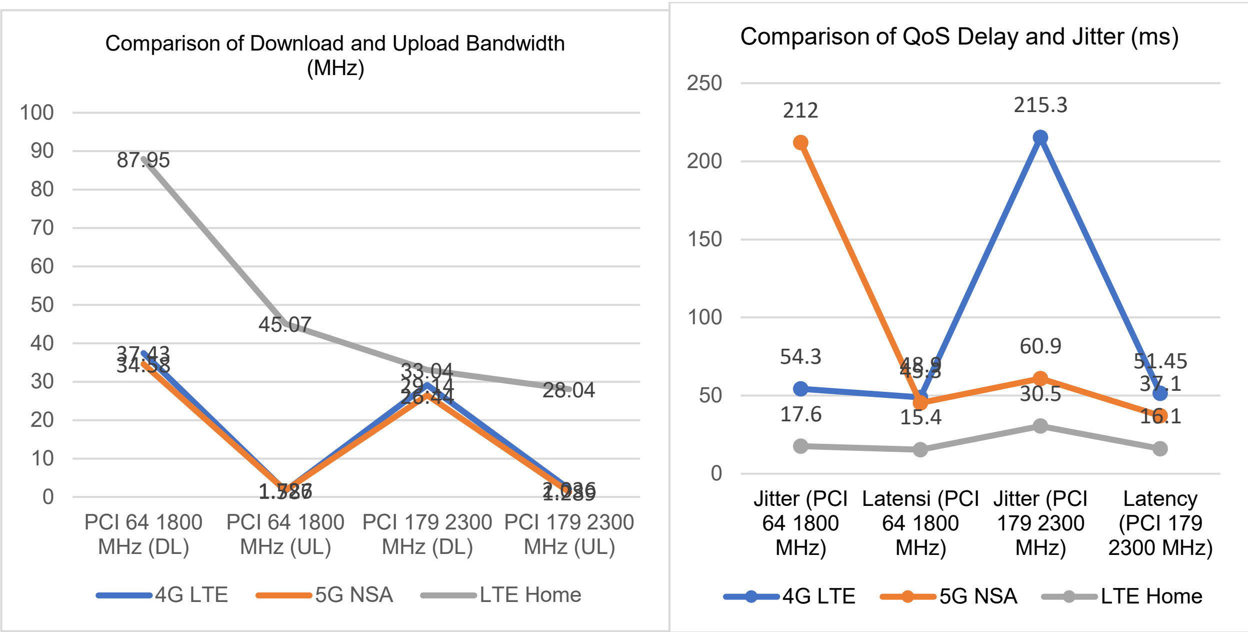
Figure 7 illustrates the implementation of LTE Home in a bad spot area, which is defined as an area with poor signal quality. In the context of 4G LTE and 5G NSA networks, low RSRP and RSRQ values are observed (see Figures 4, as well as Table 2). Additionally, the 5G NSA network exhibits poor SINR and throughput (see Figures 6.c and 6.d). The challenges experienced in these areas are attributable to various factors, including the presence of obstacles or barriers that impede the propagation of antenna signals, thereby leading to diminished signal strength within the designated regions. Poor signal quality is often attributable to interference from neighbouring sites and a high number of users in the area. A decline in performance is observed when utilizing download/upload services within this area, as evidenced by a decrease in throughput. Solutions to this issue include the optimization of the physical tuning of sectoral antennas on 4G LTE or 5G NSA networks. Alternatively, LTE Home can be implemented on 4G LTE networks based on SDR.

An investigation into the relationship between RF KPI measurements and network performance revealed a notable increase in the RSRP value of the 4G LTE network, with the addition of an LTE Home modem resulting in a rise from -88.9 dBm to -60 dBm. A similar trend was observed in the RSRP value of the 5G NSA network, which increased from -79 dBm. Conversely, the RSRQ on 4G LTE exhibited an enhancement from -14.9 dB to -8 dBm, while the RSRQ on 5G NSA registered at -11 dB at PCI 64. According to the results obtained from the PCI 179 measurement, the RSRP for the 4G LTE network was found to be -93.6 dBm, while the RSRP for the 5G NSA network was -96 dBm. The incorporation of the LTE Home modem resulted in an augmentation of the RSRP to -63 dBm. In a similar manner, the RSRQ for the 4G LTE network registered at -13.7 dB, while the RSRQ for the 5G NSA network was -16 dB, with the RSRQ increasing to -13 dB.

An evaluation was conducted to assess the performance and network performance evaluation of 4G LTE using LTE Home, employing the use of Software Defined Radio (SDR). The evaluation was based on Quality of Service (QoS) performance. The QoS parameters that were measured included bandwidth, delay, and jitter, with the measurements being conducted in accordance with TIPHON standards. The results of the Quality of Service (QoS) measurements on PCI 64 and 179 are presented in Table 3 and Figure 8.

Table 3: Comparison of Parameter QoS

Parameter Site	Parameter QoS	4G LTE Network	5G Network	4G LTE Network with LTE Home
Site name: Kura Pagang	Download	37.43 Mb/s	34.58 Mb/s	87.95 Mb/s
PCI: 64	Upload	1.587 Mb/s	1.726 Mb/s	45.07 Mb/s
Frekuensi : 1800 MHz (L3)	Jitter	54.3 ms	212 ms	17.6 ms
	Latensi	48.9 ms	45.3 ms	15.4 ms
Site name: Pasar Siteba	Download	29.14 Mb/s	26.44 Mb/s	33.04 Mb/s
PCI: 179	Upload	2.036 Mb/s	1.289 Mb/s	28.04 Mb/s
Frekuensi : 2300 MHz (L40)	Jitter	215.3 ms	60.9 ms	30.5 ms
	Latency	51.45 ms	37.1 ms	16.1 ms



(a) (b)

Figure 8: Graph of QOS Parameter Differences (a) Bandwidth, (b) Delay and Jitter

According to TIPHON, the average latency on the 4G LTE network on PCI 64 was 48.9 ms, categorized as good, and 5G was 45.3 ms, also categorized as good. Latency decreased by 15.4 ms when using LTE Home. The average jitter value was 54.3 ms on the 4G LTE network, which is categorized as good, and 212 ms on 5G, which is categorized as poor. Jitter decreased by 17.6 ms when using LTE Home. Similarly, on PCI 179, latency decreased by 16.1 ms and jitter decreased by 30.5 ms when using LTE Home.

4.0 Conclusion and Future Research

Drive test measurements indicate that, for the 4G LTE network, the RSRP value is predominantly in the "good" category at 38.81%. However, the RSRQ is also in the "good" category, though the channel quality indicates interference. In the context of a 5G Non-Standalone Access (NSA) network, performance metrics, such as Signal-to-Interference Ratio (SINR), exhibit a decline in performance when compared to those observed in a 4G Long-Term Evolution (LTE) network. This decline is particularly evident in the throughput values. While the RSRP and RSRQ remain within the acceptable range, the SINR predominantly falls within the fair category (84.06%), suggesting significant interference. The 5G Non-Standalone Access (NSA) throughput is predominantly in the poor category (68.58%), indicating that the actual data rate is low, even though the signal is detected. The findings indicate a strong correlation between the quality of the 5G NSA channel and the condition of the LTE anchor, as well as the integration of both technologies. The predominant challenges in the designated test area, such as Siteba, are attributed to geographical constraints and physical impediments. Obstacles such as tall trees and buildings cause weak RSRP, poor RSRQ, and low SINR, particularly when outside the sector antenna beam direction. The implementation of SDR-based LTE Home technology has been demonstrated to result in a substantial enhancement of signal quality. On the 4G LTE network, the RSRP value exhibited an increase from -88.9 dBm to -60 dBm, while the RSRQ demonstrated an improvement from -14.9 dB to -8 dB. Performance enhancements were also observed on the 5G Non-Standalone Access (NSA) network, with increases in Radio Resource Management (RRP) and Radio Resource Quality (RRQ) after the implementation of LTE Home. Furthermore, LTE Home reduced latency to 15–16 ms and jitter to 30 ms, thereby improving quality of service (QoS).

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Author Contributions

Siska A : Conceptualization, Methodology, Writing-Original Draft Preparation; **Ideva G**.: Data Collection, Data Analysis; **Sri Y**.:Data Validation, Supervision; **M. Putra P**.:Software Analysis, Writing-Reviewing; **Deri L. H**.: Writing-Reviewing and Editing.

Conflicts of Interest

The manuscript has not been published elsewhere and is not being considered by other journals. All authors have approved the review, agree with its Submission and declare no conflict of interest in the manuscript.

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