



Evaluation of 5G NR NSA Deployment on FR1 (Sub-6 GHz) in Bukittinggi

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ARTICLE INFORMATION

Received: November 23, 2025
 Revised: March 03, 2026
 Accepted: April 09, 2026
 Available online: May 31, 2026

KEYWORDS

5G NR NSA, RSRP, RSRQ, SINR, Throughput

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A B S T R A C T

This study evaluates the deployment of 5G New Radio (NR) Non-Standalone (NSA) operating on Frequency Range 1 (FR1) Sub-6 GHz in Bukittinggi, Indonesia. Field measurements were conducted using drive test methods to assess key performance indicators, including RSRP, RSRQ, SINR, and throughput. The results show that all measured RSRP values exceed -95 dBm, indicating good signal coverage across the test area. Approximately 71% of SINR samples are above 0 dB and 80% of RSRQ values exceed -17 dB, reflecting relatively stable channel conditions. However, 77% of throughput measurements remain below 10 Mbps, suggesting that achievable data rates remain moderate despite good signal quality. The analysis indicates that SINR has a stronger impact on throughput compared to RSRP and RSRQ. Although 5G NR NSA demonstrates superior signal quality compared to LTE, 4G LTE achieves higher data speeds at the measurement location. These findings highlight the influence of NSA architecture, bandwidth limitations in FR1 Sub-6 GHz, and network optimization factors on overall 5G performance.

INTRODUCTION

The rapid growth of mobile data traffic and digital service consumption has accelerated the global deployment of fifth-generation (5G) mobile networks. Compared to fourth-generation Long-Term Evolution (4G LTE), 5G New Radio (NR) provides improvements in spectral efficiency, bandwidth flexibility, latency reduction, and network capacity, enabling enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low-Latency Communication (uRLLC), and massive Machine-Type Communication (mMTC) services [1], [2].

In its early deployment phase, 5G NR is commonly implemented using the Non-Standalone (NSA) architecture, where LTE functions as the anchor for control signaling while 5G NR provides additional data capacity [3], [4]. Although this approach accelerates rollout and reduces infrastructure costs, NSA architecture may introduce performance constraints, particularly in terms of throughput efficiency and resource scheduling under real network conditions [4], [5].

Field-based performance evaluation is essential to assess the practical behavior of 5G networks beyond theoretical specifications. Previous measurement studies indicate that key performance indicators (KPIs) such as Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), Signal-to-Interference-plus-Noise Ratio (SINR), and throughput are strongly influenced by propagation conditions,

interference levels, dual connectivity configuration, and bandwidth allocation in Frequency Range 1 (FR1) Sub-6 GHz deployments [6], [7]. Several studies also report that strong RSRP values do not necessarily guarantee high throughput, as SINR and channel quality stability often have a more direct impact on achievable data rates [8], [9].

Most empirical studies have focused on large metropolitan areas with dense infrastructure and advanced optimization [6], [7], [10], [11]. However, performance characteristics in mid-sized urban environments, particularly in developing regions, remain less documented [12]. Variations in site density, traffic distribution, spectrum allocation, and deployment maturity may result in distinct performance behavior compared to major cities.

To date, limited empirical studies have quantitatively examined the interplay between SINR behavior, bandwidth allocation constraints, and NSA architectural dependency in mid-sized urban deployments within developing regions. This gap motivates the need for a structured field-based evaluation under realistic traffic conditions.

Bukittinggi City, a tourism-centered urban area in West Sumatra, exhibits high mobility and concentrated digital activity, especially in central commercial and public zones. Evaluating 5G NR NSA performance in such an environment is important to understand how early-stage FR1 Sub-6 GHz deployments behave under realistic urban conditions.

Therefore, this study evaluates the performance of a 5G NR NSA network operating on FR1 Sub-6 GHz (Band n1, 2100 MHz) in Bukittinggi using drive test measurements. The analysis focuses on RSRP, RSRQ, SINR, and throughput to examine signal coverage, channel quality, and data rate performance. Furthermore, a comparative assessment with 4G LTE is conducted to identify performance differences under identical measurement routes. The results provide empirical insights into the relationship between signal quality parameters and achievable throughput in practical NSA deployment scenarios.

METHOD

This study employed a quantitative field measurement approach to evaluate the performance of a 5G New Radio (NR) Non-Standalone (NSA) network operating on Frequency Range 1 (FR1) Sub-6 GHz (Band n1, 2100 MHz) in Bukittinggi City, West Sumatra, Indonesia. The research was designed as an empirical drive test-based evaluation to analyze the relationship between signal quality indicators—Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), Signal-to-Interference-plus-Noise Ratio (SINR)—and downlink throughput under real urban network conditions. The overall research workflow is illustrated in Figure 1.

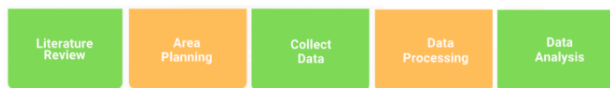


Figure 1. Research Block Diagram

The study began with a literature review of 5G NR performance metrics and their measurement principles, based on 3GPP standards. This stage established the theoretical foundation for the measurement configuration and data interpretation framework.

The measurement campaign was conducted in the Jam Gadang area of Bukittinggi City, selected due to its dense urban morphology, high user concentration, and significant commercial and tourism activities that generate substantial network traffic during busy hours. The measurement route was designed using Google Earth Pro to ensure representative coverage of commercial zones, public facilities, and main mobility corridors. The total route length was approximately ± 2 km, as shown in Figure 2.



Figure 2. Data Collection Route Designed in Google Earth Pro

Data collection was conducted in outdoor conditions using both drive test and walk test methods. The drive test was carried out at an average vehicle speed of 20–30 km/h, while walk tests were performed in high-density pedestrian areas. Measurements were taken during busy-hour periods to reflect realistic traffic load conditions. The sampling interval was configured at 1 second, resulting in 318 validated samples per parameter.

The recorded Key Performance Indicators (KPIs) included RSRP, RSRQ, SINR, and downlink throughput. The KPI definitions and interpretation follow standardized 3GPP NR performance specifications [13]. Furthermore, drive test methodology has been widely adopted in empirical cellular performance assessment to capture real-world network behavior under operational conditions [14].

To ensure data reliability, preprocessing procedures were applied, including the removal of incomplete or corrupted logs, filtering of samples affected by handover events, and verification of continuous NSA connectivity throughout the measurement period. Only validated data were included in the final dataset.

Descriptive statistical analysis was conducted to determine minimum, maximum, mean, and standard deviation values, as well as KPI distribution percentages. In addition, Pearson correlation analysis was performed to quantify the relationship between RSRP, RSRQ, SINR, and throughput. In addition, Pearson correlation analysis was performed to quantify the relationship between RSRP, RSRQ, SINR, and throughput. The Pearson correlation coefficient (r) was computed at a 95% confidence level to evaluate the linear dependency between radio parameters and throughput performance. Data processing and visualization were carried out using Microsoft Excel, TEMS Discovery, and MapInfo Pro.

RESULTS AND DISCUSSION

A total of 318 validated samples were analyzed after preprocessing and filtering. The statistical summary of the measured 5G NR NSA KPIs is presented in Table 1.

Table 1. Descriptive Statistics of 5G NR NSA KPIs

Parameter	Minimum	Maximum	Mean	Std. Dev
RSRP (dBm)	−93	−52	−69.78	12.70
RSRQ (dB)	−21	−11	−14.43	2.79
SINR (dB)	−5	11	2.97	4.39
Throughput (Mbps)	0.056	17.48	8.26	3.68

The results indicate that the deployed 5G NSA network provides strong signal coverage across the measurement route, with an average RSRP of −69.78 dBm. However, the average downlink throughput reaches only 8.26 Mbps, suggesting that capacity performance does not scale proportionally with signal strength.

Spatial Coverage Analysis (RSRP)

Figure 3 illustrates the spatial distribution of RSRP along the drive test route. The map is dominated by blue and green zones, indicating that the majority of measurement points fall within the Excellent and Good categories. This observation is quantitatively confirmed in Figure 4, where 78% of samples are classified as Excellent (≥ -80 dBm) and the remaining 22% as Good (-80 to -95 dBm).

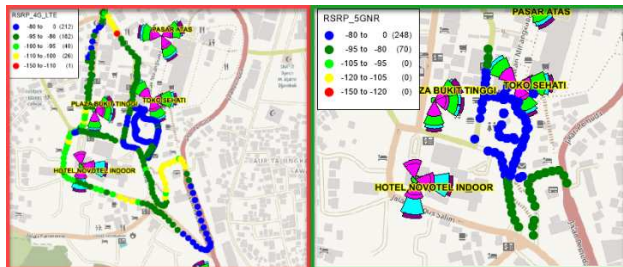


Figure 3. RSRP display for 4G LTE and 5G NSA

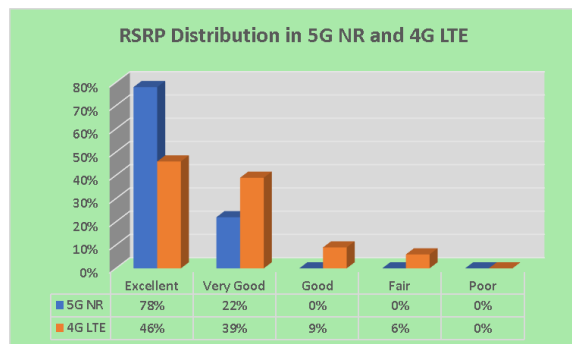


Figure 4. RSRP diagram for 4G LTE and 5G NSA

The absence of Fair and Poor categories indicates that no coverage gaps exist in the evaluated area. The relatively moderate standard deviation (12.70 dB) further indicates that coverage variation is limited across the urban route.

However, when correlated with throughput, RSRP shows almost no linear relationship ($r = -0.02$). This indicates that once sufficient signal strength is achieved, further improvement in RSRP does not significantly enhance data rate performance. Therefore, coverage is not the limiting factor in this deployment.

Channel Quality Evaluation (RSRQ)

The channel quality distribution shown in Figure 5 shows greater variation than RSRP. While large portions of the route are categorized as Good, several localized segments exhibit Fair and Poor conditions. The categorical distribution in Figure 6 shows that 54% of the samples fall into the Good category, 26% into the Fair category, and 20% into the Poor category.

The mean RSRQ value of -14.43 dB suggests acceptable but not optimal channel cleanliness. The presence of 20% Poor samples indicates interference or cell load effects in specific urban corridors.

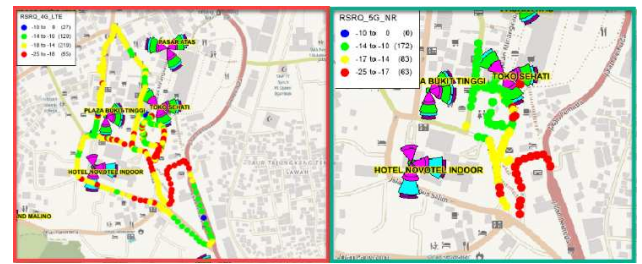


Figure 5. RSRQ display for 4G LTE and 5G NSA.

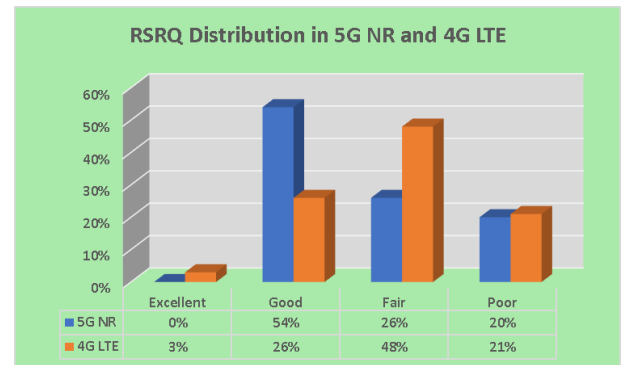


Figure 6. RSRQ diagram for 4G LTE and 5G NSA

Despite this variation, correlation analysis shows only a weak relationship between RSRQ and throughput ($r = 0.03$). This implies that although interference affects channel quality, it does not independently explain throughput fluctuations in this NSA deployment.

SINR Distribution and Its Impact

SINR represents the effective signal-to-interference condition and directly influences modulation capability. Figure 7 demonstrates that the spatial SINR distribution is dominated by yellow and green regions, corresponding to moderate channel conditions. Importantly, no red (Very Poor) areas are observed for 5G NSA, indicating stable interference management.

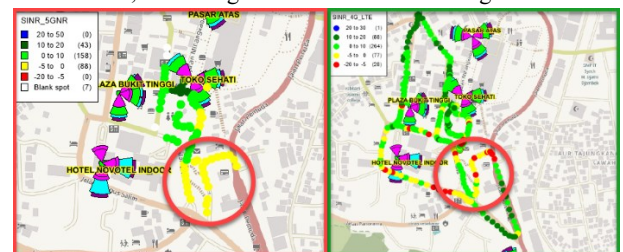


Figure 7. SINR display for 4G LTE and 5G NSA

The categorical distribution shown in Figure 8 confirms that approximately 71% of samples are above 0 dB. The mean SINR of 2.97 dB places the system within a moderate operating regime. This moderate SINR level suggests operation within lower modulation and coding scheme (MCS) regions, limiting sustained utilization of higher-order modulation such as 256-QAM. Consequently, achievable spectral efficiency remains constrained despite adequate coverage conditions.

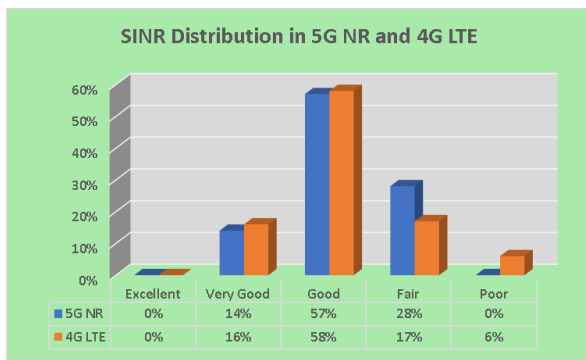


Figure 8. SINR diagram for 4G LTE and 5G NSA

In theory, higher SINR enables the use of higher-order modulation schemes and directly improves spectral efficiency. Statistical modeling and experimental studies confirm that SINR is typically the strongest predictor of throughput variability in operational 5G networks [15]. Indeed, segments with SINR values above 8 dB correspond to throughput peaks above 14 Mbps, as seen in Figure 10. The overall Pearson correlation between SINR and throughput indicates a weak linear dependency. Nevertheless, system-level modeling studies demonstrate that SINR remains the most structurally influential radio parameter in determining throughput variability, particularly when bandwidth and scheduling constraints are present [16].

This suggests that throughput is influenced not only by instantaneous radio conditions but also by higher-layer mechanisms such as scheduler behavior and dual connectivity overhead.

Throughput Performance Characteristics

The throughput map shown in Figure 9 reveals that most measurement points fall within the low-to-moderate data rate range. The distribution chart in Figure 10 confirms that 77% of samples are below 10 Mbps.

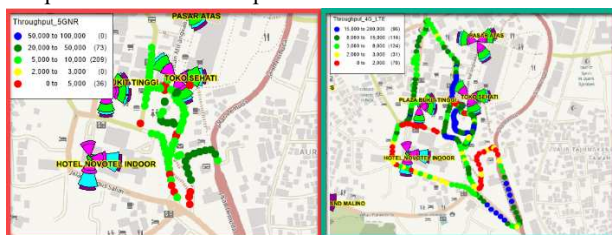


Figure 9. Throughput display for 4G LTE and 5G NSA

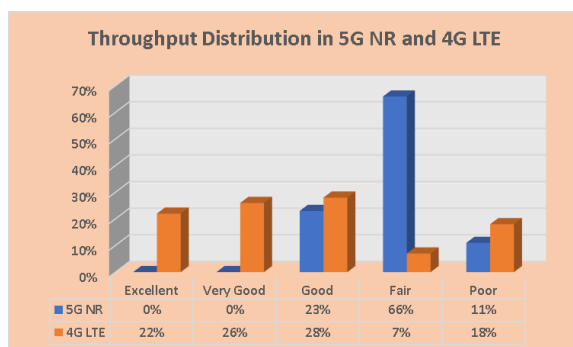


Figure 10. Throughput diagram for 4G LTE and 5G NSA

Although the maximum observed throughput reaches 17.48 Mbps, this peak occurs only in limited segments with favorable SINR and channel conditions. The moderate standard deviation (3.68 Mbps) indicates that throughput variability exists but remains bounded within a constrained range.

The discrepancy between excellent RSRP coverage and moderate throughput clearly illustrates that the evaluated 5G NSA deployment operates in a coverage-sufficient but capacity-limited regime. Similar behavior has been reported in early-stage NSA deployments, where bandwidth allocation and dual-connectivity overhead constrained achievable throughput despite strong signal indicators [17].

Integrated Interpretation

When integrating the findings from Figures 4–10, several patterns emerge:

1. Signal strength (RSRP) is consistently strong and not a limiting factor.
2. Channel quality (RSRQ) is generally acceptable but affected by localized interference.
3. SINR remains in the moderate range, restricting sustained high-order modulation.
4. Throughput performance remains moderate despite favorable coverage metrics.

These results indicate that the primary bottleneck lies in architectural and bandwidth limitations rather than propagation loss. Since the deployment operates under Non-Standalone (NSA) configuration with LTE as the anchor layer, user-plane data handling may introduce coordination overhead. Additionally, the use of FR1 Band n1 (2100 MHz) with limited bandwidth allocation restricts effective capacity gains. Theoretical and system-level analyses confirm that limited NR bandwidth significantly constrains achievable throughput, even under favorable propagation conditions [18].

Comparative observations with LTE measurements along the same route further support this conclusion. In several segments, LTE achieves higher throughput despite inferior RSRP values, indicating that network maturity and scheduling efficiency play a significant role in real-world performance. Comparable comparative evaluations in urban deployments report similar behavior, where LTE achieved competitive or even superior throughput due to mature scheduling mechanisms and optimized resource allocation [19].

Practical Implications and Future Directions

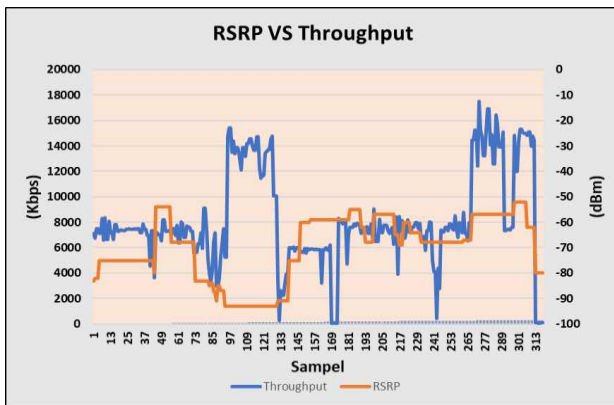
The findings suggest that further coverage densification alone would not significantly increase throughput in this area. Performance improvement strategies should prioritize interference mitigation, EN-DC configuration optimization, and bandwidth expansion. These strategies are particularly relevant for early-stage NSA deployments operating with limited FR1 bandwidth allocation. Prior studies emphasize that scheduler configuration and dual connectivity parameter tuning substantially influence user-plane efficiency in NSA deployments [20].

This study is limited to a single frequency band (n1, 2100 MHz), NSA architecture, and outdoor urban measurements. Future research should evaluate Standalone (SA) deployment, multi-band aggregation, indoor performance, and time-based traffic

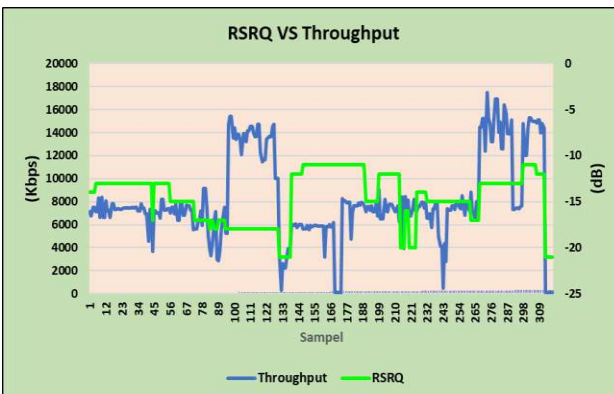
variation to provide a more comprehensive understanding of 5G performance evolution.

Analysis of the Impact of RSRP, RSRQ, and SINR on Throughput Performance

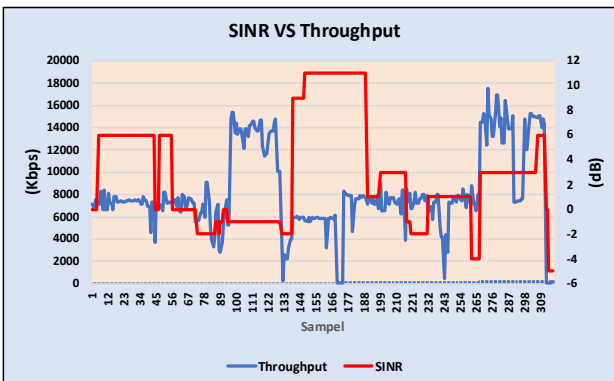
As illustrated in Figure 12, throughput exhibits a strong dependency on signal quality parameters, including RSRP, RSRQ, and SINR. In general, enhanced signal conditions, characterized by higher RSRP, improved RSRQ, and stable SINR values, contribute to higher user throughput performance. This observation is in agreement with established wireless communication theory, where transmission channel quality plays a critical role in determining achievable data rates in 5G networks.



(a)



(b)



(c)

Figure 12. Diagrams illustrating the influence of (a) RSRP, (b) RSRQ, and (c) SINR on throughput performance

Overall, the results indicate a positive relationship between radio signal quality and throughput performance. Figure 12(a) shows that as the RSRP curve increases toward stronger values, approximately -80 to -60 dBm, the throughput curve correspondingly rises and forms distinct performance peaks. Conversely, when the RSRP degrades to around -95 to -105 dBm, throughput drops sharply and remains in the lower range. This behavior is consistent with the fundamental principle of radio systems, where a stronger reference signal allows the network to apply higher modulation and coding schemes (MCS), thereby increasing effective channel capacity and user data rate.

A point-based analysis of Figure 12(a) further confirms this trend. The dominance of green and blue scatter points, representing good-to-excellent categories, is concentrated in areas where the RSRP exceeds -80 dBm, indicating that stronger signal conditions generally support higher throughput. However, several anomalies are also observed. For instance, sample 170 at coordinates (100.369444, -0.304762) records an excellent RSRP value (> -85 dBm) but achieves only 74 Kbps, while sample 317 at (100.369901, -0.304768) similarly shows excellent RSRP with throughput of only 131 Kbps. These cases demonstrate that RSRP alone is not sufficient to fully explain user data rate performance, as other factors such as SINR, RSRQ, traffic load, interference, scheduler decisions, and handover events also contribute significantly.

The analysis of Figure 12(b) shows that the RSRQ curve fluctuates within approximately -21 to -11 dB. In general, throughput tends to increase and become more stable as RSRQ improves from poor values (around -20 dB) toward better levels (approximately -13 to -11 dB). This trend reflects the role of RSRQ as an indicator of channel quality and inter-cell interference conditions. Nevertheless, the relationship is not always linear because throughput is also affected by RSRP, SINR, traffic load, and transient handover conditions. The highest throughput value of 17,481 Kbps was recorded at coordinates (100.369586, -0.305459), corresponding to sample 273, where the RSRQ was -13 dB and the RSRP was -57 dBm. This combination of strong signal strength and good channel quality enables the network to utilise higher-order modulation such as 256-QAM, producing optimal throughput performance.

These results confirm that RSRQ is highly sensitive to interference and cell density. Improved RSRQ is generally followed by increased and more stable throughput, although the final user experience still depends on the combined effects of RSRQ, RSRP, SINR, and network traffic conditions. Therefore, optimisation strategies such as inter-cell interference coordination (ICIC/eICIC), load balancing, and antenna tilt or azimuth adjustment are particularly important in route segments showing anomalous behavior.

Figure 12(c) demonstrates that the SINR curve fluctuates between approximately -5 and 11 dB, while throughput varies up to 18,000 Kbps. When SINR increases into the 8 – 11 dB range, throughput rises sharply and becomes more stable. Under moderate SINR conditions (0 – 5 dB), throughput remains acceptable but is more prone to fluctuations caused by dynamic channel conditions and user load. However, when SINR

approaches 0 dB or negative values, throughput drops significantly, often falling into the 0–500 Kbps range.

In summary, excellent SINR (10–12 dB) generally produces very high throughput ($\geq 14,000$ Kbps), while good SINR (3–9 dB) supports medium-to-high throughput (6,000–12,000 Kbps) suitable for data-intensive services. By contrast, poor SINR (≤ 0 dB) strongly correlates with low throughput ($< 1,000$ Kbps), which can substantially degrade the user experience.

Despite this clear trend, the relationship between SINR and throughput is not always strictly linear. Several route segments show moderate or good SINR while still experiencing low throughput. This can be explained by handover events in overlapping 5G NSA and 4G coverage areas, traffic congestion, weak RSRP that limits the selected MCS, poor RSRQ due to interference, and environmental obstructions such as buildings or trees. These factors increase retransmissions and reduce effective throughput, preventing direct proportionality between SINR improvement and user data rate.

Overall, the combined analysis confirms that RSRP, RSRQ, and SINR collectively determine throughput performance. RSRP provides the baseline signal strength, RSRQ reflects channel quality under interference, and SINR directly governs modulation efficiency and spectral utilisation. The highest throughput is achieved when all three parameters simultaneously exhibit good performance. Therefore, improving 5G NR network performance requires an integrated optimisation approach involving coverage enhancement, interference mitigation, channel quality improvement, and traffic-aware resource management.

CONCLUSIONS

This study provides an empirical evaluation of a 5G NR Non-Standalone (NSA) deployment operating in FR1 Band n1 (2100 MHz) in Bukittinggi City based on real-field drive test measurements. The results demonstrate that the network delivers strong and stable signal coverage, confirming that radio propagation and coverage planning in the evaluated area are technically sufficient.

However, the achieved throughput does not proportionally reflect the superior signal quality observed in RSRP, RSRQ, and SINR metrics. The findings clearly indicate that, in this early-stage NSA deployment, throughput performance is constrained more by architectural and bandwidth limitations than by coverage conditions. In particular, moderate SINR levels and reliance on LTE as the anchor layer limit the effective realization of 5G capacity gains.

A key contribution of this study is the evidence that improved signal indicators alone are insufficient to guarantee higher data rates in practical NSA implementations. While 5G NSA outperforms LTE in terms of signal quality metrics, LTE remains competitive—and in some segments superior—in actual throughput performance due to network maturity and scheduling efficiency.

These results highlight the need to shift optimization focus from coverage enhancement to capacity-oriented strategies, including SINR improvement, EN-DC parameter tuning, and bandwidth

expansion through additional NR carriers or aggregation mechanisms. Future work should investigate Standalone (SA) architecture and multi-band configurations to better assess the full performance potential of 5G in urban environments.

This study contributes empirical evidence from a mid-sized Indonesian urban deployment, highlighting the structural distinction between coverage sufficiency and capacity realization in early-stage 5G NSA implementation.

ACKNOWLEDGMENT

The author would like to express their sincere gratitude to Politeknik Negeri Padang. This research was funded through Politeknik Negeri Padang's Lecturer Research Programme, which is supported by the DIPA Research Grant.

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