

5G network performance analysis and planning for the development of 5G services in Padang City

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ABSTRACT

The rapid deployment of fifth-generation (5G) mobile networks requires accurate performance assessment to support effective network planning. This study presents a combined field measurement and simulation approach, integrating drive test data with Atoll-based coverage planning to evaluate the early deployment of 5G non-standalone (NSA) in Padang City, Indonesia. Radio performance was assessed using reference signal received power (RSRP) and signal-to-interference-plus-noise ratio (SINR) obtained from drive tests using a Samsung Galaxy A26 5G and G-NetTrack Pro, while Atoll was used to analyze planned coverage. The results show that 64% of measurement points achieved very good RSRP (≥ -85 dBm) and 56% recorded very good SINR (≥ 10 dB), although several locations exhibited poor SINR despite strong RSRP, indicating interference associated with the NSA architecture. Atoll simulation showed that only 36.42% of the planned coverage area reached excellent RSRP, revealing gaps between measured and predicted performance. These findings demonstrate that integrating drive test measurements with propagation simulation provides a practical framework for identifying coverage deficiencies and supporting 5G network planning through interference mitigation, antenna parameter adjustment, and migration toward SA architecture.

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1. INTRODUCTION

Fifth-generation (5G) mobile communication is a key enabler of Information and Communication Technology (ICT), supporting smart-city services, IoT applications, and Indonesia's digital transformation through high-speed, low-latency, reliable wireless communication [1]. With data rates of up to 20 Gbps - about 20 times faster than 4G - 5G enables advanced applications such as IoT, augmented reality, and virtual reality [2]. Padang City was the first city in West Sumatra to receive commercial 5G, launched by Telkomsel in 2021 [3], making it an important case study for evaluating real-world network performance. Drive test studies show that signal quality varies considerably across locations, influenced by SINR, inter-cell handover, interference, physical obstacles, and weather [4]. These variations are influenced by SINR, inter-cell handover, signal interference, physical obstacles, and weather conditions [5]. 5G new radio (NR) supports high-frequency spectra such as mmWave for higher data rates at the cost of limited range [6], [7]. and achieves high architectural flexibility through network function virtualization (NFV) and software-defined networking (SDN) [8], [9]. Network slicing allows logical separation of the network to serve different service needs simultaneously - for example, prioritizing video streaming or IoT-based healthcare [10].

Beamforming and massive multiple-input multiple-output (MIMO) further increase capacity and signal quality by focusing transmission directly toward users [11]–[14]. Key implementation challenges include suboptimal high-frequency propagation, particularly at mmWave, which is easily obstructed by buildings and vegetation [15], as well as infrastructure readiness, regulatory adjustment, and investment requirements, especially in dense urban areas [16].

Two main deployment architectures have been standardized by 3GPP - non-standalone (NSA) and SA [17], [18], each with different trade-offs in coverage, adoption speed, and cost [19]. Drive tests remain essential to verify real-world performance, particularly for high-frequency spectrum vulnerable to obstruction [20], [21], and drive test data can further serve as training data for machine-learning-based network optimization [22], [23]. Beyond coverage, emerging services such as extended reality (XR) will place additional demands on latency and quality of experience in future mobile networks [24].

Recent studies have examined 5G NSA performance in medium-sized developing-country cities. A 2025 study on Bandung City applied the 3GPP TR 38.901 UMa propagation model and found only 30% of existing sites achieved adequate coverage, while a related 2024 study proposed a simulation model for 5G NSA deployment specifically for emerging countries. However, both were simulation-focused and conducted in larger metropolitan areas, leaving a gap for combined drive-test-simulation validation in medium-sized coastal cities such as Padang [25].

Previous studies have evaluated 5G performance using drive test measurements alone [26], [27], or propagation simulation alone [28], [29], but rarely both together, leaving the consistency between measured and simulated performance insufficiently understood for medium-sized Indonesian cities. This study therefore integrates drive test measurements with Atoll-based propagation simulation to evaluate the 5G NSA network in Padang City, validating simulation results against actual field measurements to provide practical insights for future 5G deployment and optimization in medium-sized urban environments.

2. RESEARCH METHOD

2.1. Research design

This study adopts an observational field-measurement approach combined with propagation simulation, integrating five stages: (a) drive test data acquisition, defining device configuration, scanning interval, and mobility speed; (b) data preprocessing, validating raw logs and extracting RSRP/SINR values with geospatial tagging; (c) RSRP - SINR correlation analysis using key performance indicator (KPI) thresholds to identify anomalous (interference) points; (d) Atoll-based simulation using an N78 configuration with beamforming modeling; and (e) performance evaluation, comparing drive test results with simulation outputs. Measurement routes were selected to represent residential, commercial, and arterial-road environments in Padang City, allowing real-time capture of radio parameters under mobility conditions. The tools and software used at each stage are summarized in Table 1. Research stage flow as shown in Figure 1.

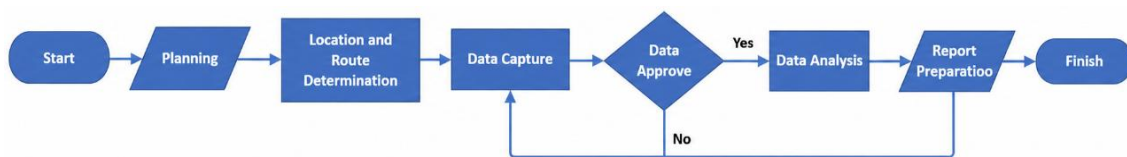


Figure 1. Research stage flow

Table 1. Software specifications

Software	Specifications	Use
G-NetTrack Pro	Gyokov Solutions v32.7; Android ≥ 6.0	Mobile network analysis/measurement (5G/4G/3G/2G)
Atoll	Forsk	Radio planning, simulation & optimization
Google Earth Pro	—	3D real-time field condition reference
Microsoft Excel	Microsoft 365, 2021	Data processing
Open Signal	v7.60 (2025)	Locating mobile tower points
Nperf	nPerf SAS; Android ≥ 5.0	5G coverage mapping & speed test

2.2. Measurement parameters

The KPIs evaluated are RSRP and SINR. RSRP indicates the strength of the received reference signal ($\text{RSRP} = P_{rs}$), where higher values (closer to 0 dBm) indicate a stronger signal. SINR indicates signal

quality relative to interference and noise, $\text{SINR} = S / (I + N)$, where S is the received signal power, I is interference power, and N is noise power; higher SINR reflects better quality. Based on the Telkomsel 5G NSA KPI standard, $\text{RSRP} \geq -92$ dBm and $\text{SINR} \geq 3$ dB are classified as good.

2.3. Drive test procedure and measurement route map

Data were sampled at 1-second intervals with vehicle speed of 20-40 km/h to balance measurement stability and realistic urban usage conditions. Two routes were surveyed: Route A (Jl. Kurao Pagang - Simpang Punggai - Berok Raya) and Route B (Lubuk Buaya - Air Tawar - Padang City Center), covering areas of varying building density and traffic, including Mount Pangilun, Kurao Pagang, Simpang Punggai, and Berok Raya. Recorded parameters included RSRP, SINR, CQI, utilized bandwidth, EARFCN, and gNodeB ID.

2.4. Synchronization between drive test and simulation

All drive test samples were georeferenced using GPS coordinates and matched to corresponding locations on the Atoll coverage map, focusing on points where both simulated and measured RSRP were available. SINR observations were analyzed together with simulated coverage to investigate discrepancies caused by interference, environmental obstruction, and practical deployment conditions, enabling a direct comparison between theoretical predictions and actual performance.

2.5. Simulation method (Atoll)

Radio propagation simulation was performed in Atoll to evaluate the planned 5G NR NSA coverage, employing the Cost-Hata propagation model to estimate path loss based on distance, frequency, and antenna height. The network operated in the N78 band (3300 MHz), with each macro site configured using a standard tri-sectoral antenna layout providing 360° azimuthal coverage. All transmitters were deployed without additional downtilt, reflecting the initial commercial rollout configuration, and were equipped with a 128×128 Massive MIMO array supported by the default beamformer model, consistent with typical 5G NR macro-layer deployment. Complete simulation parameters are summarized in Table 2, configured to approximate the actual commercial deployment observed during the drive test campaign.

Table 2. Atoll simulation parameters

Parameter	Value
Propagation model	Cost-Hata
Frequency band	N78 (3300 MHz)
Bandwidth	50 MHz (NR-ARFCN 621667)
Antenna height	30–39 m
Sector configuration	3 sectors/site (0°/120°/240°)
Downtilt (mech./elec.)	0°
Antenna array	128×128 (Massive MIMO)
Beamforming model	Default Beamformer
Noise figure	5 dB
Calculation radius	10 km
Grid resolution	50 m
Propagation model	Cost-Hata
Frequency band	N78 (3300 MHz)

3. RESULTS AND DISCUSSION

Of the 2,779 collected samples, 2,695 (97%) were connected to 4G LTE and 84 (3%) to the 5G NSA network, reflecting the still-limited commercial 5G coverage in Padang City, as summarized in Table 3. Detected 5G coverage was concentrated around Kurao Pagang and Lubuk Buaya, where LTE continued to operate as the anchor network under the NSA architecture. Overall, the measured RSRP and SINR values indicate satisfactory performance in most deployed locations, although several points exhibited degraded signal quality due to interference and environmental conditions, highlighting the need for further optimization; these findings are examined in detail in the following subsections.

Table 3. Total results measurement data

Type	Number of Points Drive Test
4G LTE	2.695
5G NSA	84
Total	2.779

3.1. 5G network behavior

Because G-NetTrack Pro defaults to displaying the LTE anchor of an NSA connection, the application shows the device as connected to LTE even where a 5G NSA session is active; carrier-aggregated LTE bandwidth configurations such as [20/20/20/10] MHz (70 MHz total) were observed at these points. In the NSA architecture, control and signaling continue to rely on the LTE anchor while user data is intended to be offloaded to the NR carrier, so points labeled “5G NSA” or showing “Unknown serving cell” entries indicate NR components not yet fully recognized by the measurement application. A representative anchor point recorded RSRP - 89 dBm, SINR 1.0 dB, CQI 2, and RSSI - 89 dBm - a stable LTE signal but relatively low SINR/CQI, values that can constrain download speed and latency and are consistent with the interference behavior analyzed in section 3.3.

3.2. Simulation on the atoll

Figure 2 presents the simulated RSRP coverage and its corresponding distribution for the 5G site area. The simulation results indicate that only 5.8% of the area reaches optimal signal (> -85 dBm) and 11.4% reaches good signal (-92 to -85 dBm), while 47.9% falls in the weak-to-medium range (-102 to -92 dBm) and 34.9% in the very weak range (-120 to -102 dBm); mean RSRP was -98.63 dBm (SD 7.45 dB). This shows that planned coverage generally follows the expected deployment scenario, although the large proportion of weak-RSRP area suggests further optimization is needed, consistent with previous Atoll-based planning studies [30], [31].



Figure 2. RSRP coverage of 5G site area and histogram of 5G site area

Figure 3 shows the corresponding SINR distribution. The best-quality area (blue) covers about 7.38 km² (20%), better-quality areas (green/yellow) cover 16.23 km² (43.9%) and 8.58 km² (23.2%), and low-quality area covers 4.82 km² (13%); mean SINR was 5.56 dB (SD 6.19 dB), indicating that overall simulated signal quality is generally low and variable.

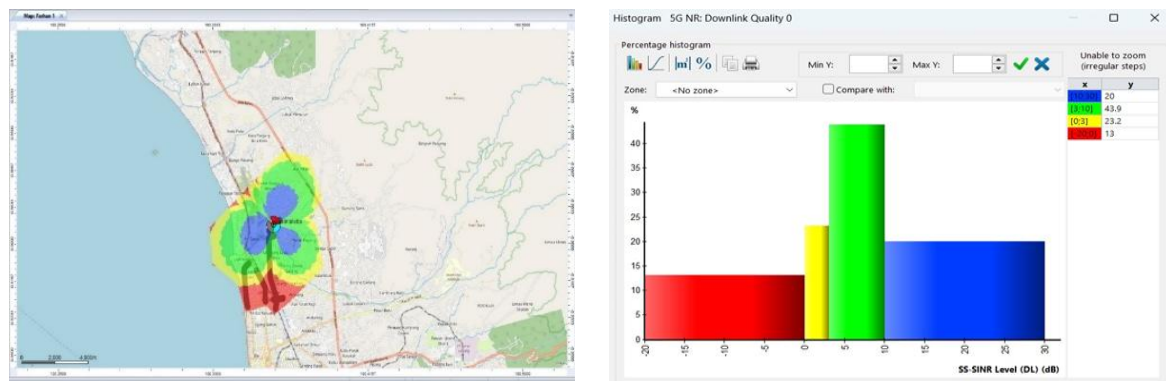


Figure 3. SINR coverage and histogram of 5G site region

3.3. SINR bad but RSRP good

Filtering the drive test data for points with good RSRP but poor SINR identified six locations, listed in Table 4. These results indicate that strong received signal power alone does not guarantee good signal quality; similar interference-driven SINR degradation despite adequate RSRP has been reported elsewhere [32], [33]. This suggests that improving interference coordination and radio resource management may yield greater performance gains than signal-coverage enhancement alone.

Table 4. SINR bad but RSRP good

Longitude	Latitude	RSRP (dBm)	SINR (dB)	Technology	Location
100.369177	-0.889396	-96	0	5G	Jl. Kurao Pagang
100.368955	-0.889639	-93	0	5G	Jl. Kurao Pagang
100.368898	-0.88972	-93	0	5G	Cod Cell Kurao
100.367029	-0.891174	-85	0	5G	Simp Punggai
100.366936	-0.891242	-85	0	5G	Jl. Simp Payakumbuh
100.366843	-0.891316	-84	-1	5G	Jl. Berok Raya

3.4. RSRP parameter analysis

Table 5 summarizes measured RSRP at 84 points against the Telkomsel KPI standard, computed as $\%Target = (\text{points meeting target} / \text{total points}) \times 100\%$. Of these, 54 points (64%) were Excellent (≥ -85 dBm) and 11 (13%) were Good (-92 to -85 dBm), while 19 (23%) were Pretty Good (-102 to -92 dBm) and none fell into the Bad category, giving 65 points (77%) with $RSRP \geq -92$ dBm. This indicates generally strong received power across the study area, consistent with previous urban 5G NSA drive test studies, although the lower values recorded at some points suggest that propagation loss and physical obstruction still affect coverage [34].

Table 5. Analysis of RSRP parameter results

Category	RSRP (dBm)	Number of points	Percentage
Excellent	≥ -85	54	64 %
Good	$-92 \leq RSRP \leq -85$	11	13%
Pretty Good	$-102 \leq RSRP \leq -92$	19	23%
Bad	$-120 \leq RSRP \leq -102$	0	0%
Total		84	100%
$RSRP \geq -92$ dBm		65	77%

3.5. SINR parameter analysis

Table 6 presents the corresponding SINR analysis. Of 84 points, 47 (56%) were Excellent (10-30 dB), 9 (11%) Good (3-10 dB), 15 (18%) Pretty Good (0-3 dB), and 13 (15%) Bad (-20 -0 dB), giving 56 points (67%) with $SINR \geq 3$ dB. While more than half of the measured area retains good signal quality, a meaningful share of points - consistent with the interference behavior identified in Section 3.3 - experience degraded quality despite adequate coverage.

Table 6. Analysis of SINR parameter results

Category	SINR (dB)	Number of points	Percentage
Excellent	$10 \leq SINR \leq 30$	47	56 %
Good	$3 \leq SINR \leq 10$	9	11 %
Pretty Good	$0 \leq SINR \leq 3$	15	18 %
Bad	$-20 \leq SINR \leq 0$	13	15 %
Total		84	100%
$SINR \geq 3$ dB		56	67%

3.6. Bandwidth

Table 7 summarizes the carrier-aggregation bandwidth configurations observed. On Band N1 (5G NSA), no points used the 20/20/20/20 MHz (80 MHz) configuration, while all 83 detected points used 20/20/20/10 MHz (70 MHz); LTE Band L1 recorded 421 points at 80 MHz and 186 at 70 MHz, and Band L3 recorded 751 points at 80 MHz and 51 at 70 MHz. This shows that, despite the 5G rollout, most current bandwidth usage still depends on the consolidation of stable, uniform 4G LTE channels, indicating a gradual NSA-to-SA transition.

Table 7. Bandwidth

Band	Sum 20/20/20/20 (MHz)	Sum 20/20/20/10 (MHz)
N1	0	83
L1	421	186
L3	751	51

Since NSA relies on the LTE anchor for signaling while only part of user data is offloaded to NR, throughput remains constrained where LTE bandwidth aggregation is narrower. Comparable studies report downlink throughput rising from below 200 Mbps to over 260 Mbps once band configuration was optimized, suggesting the limited N1 bandwidth observed in Table 7 may similarly cap achievable 5G throughput. Direct Mbps measurement was beyond this study's scope but is recommended for future work [25].

3.7. 5G development planning in Padang City

Figure 4 presents the simulated city-wide 5G RSRP coverage and its distribution in the Air Tawar–South Padang area. Figure 4(a) shows the simulated city-wide RSRP coverage, while Figure 4(b) shows the corresponding RSRP coverage histogram. The simulation uses the N78 band (50 MHz, NR-ARFCN 621667, ≈ 3308.34 MHz intermediate frequency) on the 5G NR Macro Layer with the default beamforming model. Table 8 quantifies this coverage: the Excellent category ($\text{RSRP} \geq -85$ dBm) covers 11.13 km^2 (36.42%), Good (-92 to -85 dBm) 8.10 km^2 (26.51%), Pretty Good (-102 to -92 dBm) 10.02 km^2 (32.81%), and Poor (-120 to -102 dBm) only 1.30 km^2 (4.26%), so that 62.93% of the 30.72 km^2 study area (19.4 km^2) achieves $\text{RSRP} \geq -92$ dBm, indicating generally good planned signal quality.

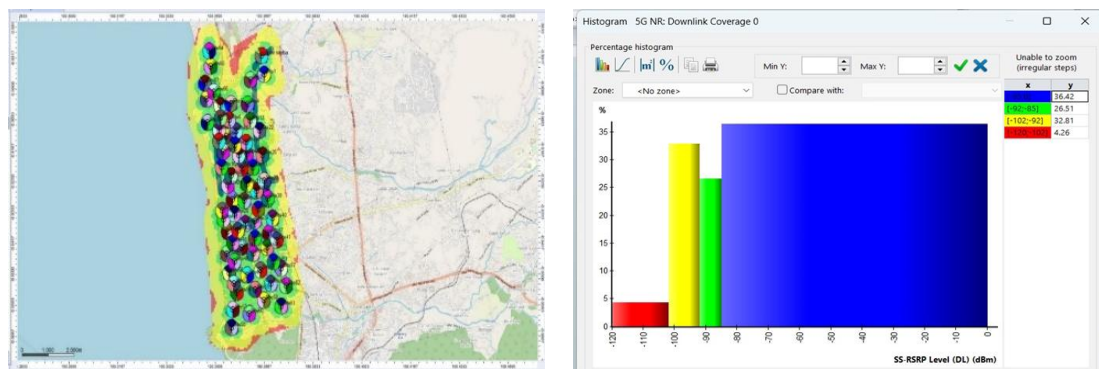


Figure 4. 5G RSRP coverage simulation results in the Padang City planning area (a) simulated city-wide RSRP coverage and (b) RSRP coverage histogram for the Air Tawar–South Padang area

Table 8. RSRP coverage results in the Padang City planning area

Category	RSRP (dBm)	Wide Coverage (km^2)	Coverage Percentage (%)
Excellent	≥ -85	11.13	36.42%
Good	$-92 \leq \text{RSRP} \leq -85$	8.1	26.51%
Pretty Good	$-102 \leq \text{RSRP} \leq -92$	10.02	32.81%
Bad	$-120 \leq \text{RSRP} \leq -102$	1.3	4.26%
Total		30.72	100%
$\text{RSRP} \geq -92 \text{ dBm}$		19.4	62.93 %

The Poor-category area lies mainly along the coastline, outside the main activity centers, and was therefore excluded from the primary optimization analysis; future deployment should prioritize densely populated urban areas while maintaining adequate surrounding coverage. Although the Atoll simulation generally reproduced the coverage trend observed during the drive test, minor differences between simulated and measured RSRP/SINR distributions were observed - expected, since drive test data reflect actual traffic load, inter-cell interference, buildings, and user mobility, whereas Atoll estimates propagation under predefined planning assumptions. The simulation therefore provides an effective tool for preliminary network planning, while field measurement remains essential for validating performance under real operating conditions.

This study has several limitations: measurements were conducted only in Padang City using a commercial 5G NSA network, limiting generalizability to other environments or 5G SA deployments, and the analysis focused mainly on RSRP and SINR, while other QoS/QoE metrics, and Atoll's reliance on available (rather than actual operator) planning parameters, were not comprehensively evaluated. Future work should validate the framework using larger datasets from different geographical environments, compare NSA and SA deployments, and incorporate additional QoS, QoE, and machine-learning techniques for more comprehensive 5G network planning and optimization.

4. CONCLUSION

This study evaluated the performance of a commercial 5G NSA network in Padang City by integrating drive test measurements with Atoll-based propagation simulation. The deployed network generally provides good radio coverage, with 77% of measurement points achieving $\text{RSRP} \geq -92$ dBm, although several locations experienced poor SINR due to interference. Combining field measurement and simulation provided a more reliable basis for assessing network performance than either method alone, confirming that interference management remains important for improving 5G service quality even where signal strength is adequate. Further optimization of radio resources and gradual expansion of 5G infrastructure are recommended to support future ICT development in Padang City.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal adheres to the Contributor Roles Taxonomy (CRediT) to clearly define individual author contributions, minimize authorship conflicts, and foster better collaboration.

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C : **C**onceptualization

M : **M**ethodology

So : **S**oftware

Va : **V**alidation

Fo : **F**ormal analysis

I : **I**nvestigation

R : **R**esources

D : **D**ata Curation

O : Writing - **O**riginal Draft

E : Writing - Review & **E**ding

Vi : **V**isualization

Su : **S**upervision

P : **P**roject administration

Fu : **F**unding acquisition

CONFLICT OF INTEREST STATEMENT

We declare that we have no conflict of interest in relation to the research and publication of this article.

DATA AVAILABILITY

This study did not involve the creation or analysis of new data; therefore, data availability is not applicable. No datasets were generated during the course of this research.

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