

Radio Propagation Modeling for KPI-Based Coverage Planning of 4G LTE Networks at 1800 MHz

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ABSTRACT

This research discusses 4G LTE coverage planning at 1800 MHz in the Cilacap City area using Atoll 3.3.0 software and link budget calculations. This study is needed because LTE network quality is affected by several factors, including distance from the antenna, propagation loss, interference, and the geographical conditions of the planning area. The research area covers 42,998 km², including residential areas, public facilities, industrial areas, and transportation routes. The planning process was carried out by determining the research area, configuring the 1800 MHz frequency, calculating the link budget, applying the COST-231 propagation model, and analyzing the simulation results based on RSRP, RSRQ, RSSI, signal level, and throughput. The link budget parameters used in this study include 20 W eNodeB transmit power, 17 dBi eNodeB antenna gain, 2 dB feeder loss, 7 dB UE noise figure, 6,285 dB target SINR, 20 MHz bandwidth, and -100,8169 KTB value. Based on the simulation results, the average signal level is around -65 dB with a standard deviation of 10 dB. The average RSRP is -112.4 dBm, with a standard deviation of 17.7 dB, indicating that some areas still experience weak reference signal reception. The average RSRQ is -17.6 dB with a standard deviation of 1.12 dB, indicating that the signal quality is still affected by interference or coverage overlap. The RSSI values range from -60 to -80 dBm, with an average of -76.34 dBm and a standard deviation of 7.12 dBm. The throughput result also shows that the data rate decreases with increasing distance from the antenna. Based on these results, LTE network planning in Cilacap City still needs optimization, particularly by adjusting antenna tilt, evaluating transmit power, improving radio parameters, and increasing network density in weak-coverage areas.

1. Introduction

Science and technology are advancing rapidly, as reflected in the increasing number of modern, sophisticated devices on the market. These developments have also influenced society's needs and lifestyles, particularly in the field of communication. In the past, mobile phones were considered luxury items and were only regarded as tertiary needs. However, today, communication devices have become necessities for almost all levels of society. This trend is consistent with the growing adoption of cellular services in Indonesia, where the telecommunications industry continues to expand significantly and mobile device use has reached a very high level (Pembelian et al., 2024). The availability of telecommunications services is an important aspect of modern life. However, Indonesia still faces significant challenges, particularly in rural areas where service availability remains very low. This condition is reflected in the national tele density rate, which remains below 4%, indicating that public access to Information and Communication Technology (ICT) remains limited. The low level of ICT penetration suggests that many regions have not yet received adequate telecommunications services. In fact,

according to the ITU-T, every 1% increase in ICT penetration can drive economic growth by up to 3%. These findings highlight the importance of equalizing telecommunications infrastructure to support the social and economic development of communities across Indonesia (Ayu et al., n.d.; Pembelian et al., 2024).

1.1 Long Term Evolution (LTE)

4G LTE is an advanced generation of cellular communication technology designed to provide high-speed data access and more efficient network performance. LTE is a modern telecommunications standard capable of delivering uplink speeds of up to 50 Mbps and downlink speeds of up to 100 Mbps, making it a far more reliable solution than previous technologies, particularly in terms of speed, coverage, and network stability (Ayu et al., n.d.; Purnamirza et al., 2023). In practical implementation, LTE performance is determined not only by data-rate capability but also by the structure and operation of the radio access network. Previous research on 4G Radio Access Network simulation shows that LTE infrastructure consists of radio access network, core network, and transport network, which together support real network operation and maintenance scenarios (Novanana & Hikmaturokhman, 2023).

1.2 Frequency Allocation of 1800 MHz Band

The 1800 MHz frequency spectrum in Indonesia is allocated within the 1710–1785 MHz band for uplink transmission and the 1805–1880 MHz band for downlink transmission, as established by the 2003 World Radiocommunication Conference (WRC-2003). This frequency range is classified as part of International Mobile Telecommunications (IMT) for the provision of mobile telecommunications services. National regulations also specify that the 1710–1885 MHz band is designated for cellular services and has become one of the primary spectrum bands used in IMT-based mobile network implementations, including LTE. From a technical perspective, the 1800 MHz band has medium propagation characteristics. Its signal coverage is shorter than that of lower-frequency bands such as 700 MHz or 900 MHz, but it can provide greater capacity and better data quality. These characteristics make the 1800 MHz band widely used as a balanced spectrum between coverage and capacity, making it ideal for areas with moderate to high user density. In practice, this band is divided into several frequency blocks used by various national cellular operators. As a result, the 1800 MHz spectrum has become one of the most widely used frequency bands in Indonesia's cellular network infrastructure, particularly for LTE technology, which requires large bandwidth and optimal spectrum efficiency (Ariyanti & Perdana, 2015).

1.3 Coverage

In cellular network planning, coverage performance can be evaluated using several KPI parameters, including RSRP, RSRQ, RSSI, signal level, and throughput. RSRP shows the reference signal power received by the user equipment. RSRQ shows the quality of the reference signal received and is affected by interference and noise. RSSI shows the total received signal power within the measurement bandwidth. Signal level describes the strength of the downlink signal received by the user equipment. Meanwhile, throughput is the data rate that the network can deliver. In this study, SINR is used in the link budget calculation, while the main simulation output parameters are RSRP, RSRQ, RSSI, signal level, and throughput (Belo, 2021).

1.4 WGS 84 Universal Transverse Mercator Zone

WGS 84 is a global geodetic reference system widely used for mapping, navigation, and modern geospatial applications. This system provides an Earth model along with ellipsoid parameters that serve as references for determining geographic coordinates, including latitude (ϕ) and longitude (λ). For more precise mapping, WGS 84 coordinates are often converted to the UTM system, a cartographic projection based on the Transverse Mercator method. The UTM system divides the Earth's surface into 60 zones, each spanning 6 degrees

of longitude. Each zone is numbered from Zone 1 at 180° West Longitude to Zone 60 at 180° East Longitude, with each zone having a central meridian used as the reference for calculations. The UTM system is applied between latitudes 84° North and 80° South. To ensure that coordinate values remain positive, the system defines a False Easting of 500,000 meters in every zone and a False Northing of 10,000,000 meters for the Southern Hemisphere. In addition, the UTM projection uses a scale factor of $k_0 = 0.9996$ to reduce distortion along the central meridian (Morgaś & Kopacz, 2016).

2. Method

This study describes the analysis and planning of 4G LTE network coverage at 1800 MHz frequency in Cilacap City area by referring to the network Key Performance Indicator (KPI) targets, such as the minimum RSRP value for coverage thickness, RSRQ and SINR limits for service quality, and the percentage of areas that must achieve service availability standards according to operator provisions. The planning process is carried out using Atoll 3.3.0 software to model signal propagation, compile a cellular topology design that suits the geographical conditions of the area, and perform performance simulations based on technical parameters (Rahmi et al., 2022). Previous cellular network planning research has also used Atoll software to simulate coverage areas and evaluate signal quality parameters. Reza et al. (2024) applied Atoll 3.4.0 for 5G coverage planning using SU-MIMO and MU-MIMO scenarios, with SS-SINR and SS-RSRP as the main indicators for assessing signal quality and network coverage (Reza et al., 2024). The use of radio planning software such as Atoll has been widely applied in LTE and 5G network planning studies to simulate coverage, evaluate signal quality, and analyze key performance indicators such as RSRP, SINR, SS-RSRP, and SS-SINR (Larasati et al., 2022). Through this approach, the study aims to ensure that the network design meets operator KPIs and provides even coverage, stable signal quality, and reliable service performance throughout Cilacap City. The planning flow in this study can be shown in Figure 1.

2.1 Planning flow

The process flow begins with the Start, then continues with the Location Determination and literature study stages. At this stage, the boundaries of the research area are defined, such as the Cilacap area polygon, and various supporting data are collected, including topographic maps, land cover, user density distribution, frequency regulations, and references related to the propagation model and KPI. The next stage is Frequency Determination and network coverage analysis, which includes selecting the 1800 MHz frequency band, determining relevant propagation models such as COST231 or Hata, and implementing initial coverage simulations to obtain an overview of the RSRP, RSRQ, and SINR values in the study area.

The next stage is to calculate the Link Budget and Pathloss by calculating the link margin from the transmitter to the user using technical parameters such as effective transmit power, antenna gain, feeder losses, fading margin, and pathloss estimation. The results of this calculation are used to determine whether the signal meets the KPI threshold at critical points. In the fourth stage, Determining the number of sites, the simulation output and link budget calculation are used to determine the required number of eNodeBs, determine the coordinates of candidate sites, antenna height, azimuth/tilt direction, and frequency configuration to ensure area coverage according to the target.

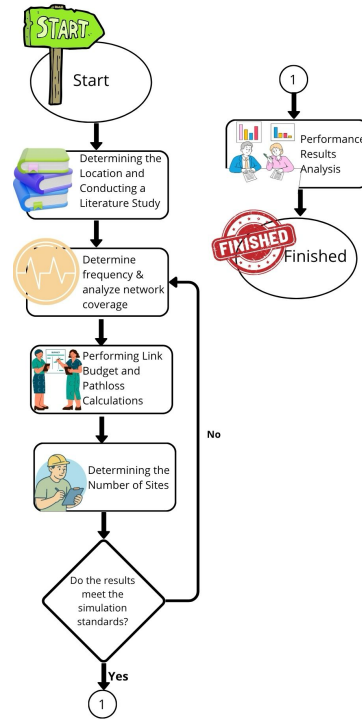


Figure 1. Flow Chart System

In the decision section "Do the results meet the simulation standards?", if the requirements are met, the process proceeds to the Performance Results Analysis stage. However, if the simulation results do not meet the standards, optimization steps are performed, including adjusting the number of sites, changing the antenna location or height, adjusting the power and tilt settings, and adjusting the propagation model. (Hikmaturokhman, 2024) Optimizing the LTE network in the Sario area of Manado City by adjusting parameters, making physical adjustments, and adding new sites, taking into account RSRP, SINR, and RSRQ parameters. After the optimization process is complete, simulations and calculations are repeated until all technical criteria are met, then the next phase proceeds.

The Performance Results Analysis involves a final review of KPIs, including the percentage of areas with RSRP values above the threshold, average RSRQ and SINR values, service availability rates, and capacity estimates. This analysis is validated using planning software and, if available, compared with field measurement data. The workflow concludes at the "Complete" stage once all metrics and KPIs have been met.

2.2 Geographical Area of Cilacap

The research area is shown in Figure 2, which depicts a computational zone bounded by a red polygon and covering approximately 42,998 km². This area covers various parts of Cilacap, including residential areas, public facilities, industrial areas, and transportation routes that are integral to community activities. This area was selected because it represents a variety of environmental conditions and is therefore relevant to the analysis of 4G LTE network coverage planning. The variety of land uses in this area helps provide a more comprehensive picture of signal propagation characteristics and network requirements according to planning parameters (Ardiansyah, 2020).



Figure 2. Geographical Area of Cilacap

2.3 Link Budget

This section presents the methodology adopted for coverage planning using Atoll, which comprises analytical formulations and parameter configurations to accurately model radio signal propagation, estimate coverage areas, and evaluate network performance. The approach integrates link budget analysis, propagation modeling, and key performance indicators to ensure that the designed network meets the required coverage and quality of service targets under the specified deployment scenario.

Table 1. Link Budget Parameters (D. A. Putri et al., 2024)

Link Budget Component	Unit	Downlink Calculation
ENB TX Power	Watt	20
ENB Gain	dBi	17
Feeder Loss	dB	2
TMA Insertion Loss	dBm	0,5
UE Antenna Gain	dBi	0
Body Loss	dB	0
KTb		-100,8169
UE Noise Figure	dB	7
Target SINR	dB	6,285
Bandwidth	MHz	20
Penetration Loss	dB	3
Fading Margin	dB	0
Interference Margin	dB	4
First Channel	Mhz	1805
Last Channel	Mhz	1825
Fdl -Low	Mhz	1805
Offset - DL		1200

Link Budget Component	Unit	Downlink Calculation
Fc	Mhz	1800
Htx	m	40
Hrx	m	1,5
CM	dB	0
N		75
Cluster	Cell	3
ENB TX Power	dBm	43,01029996

Link budget is a planning calculation used to determine the maximum allowed path loss (MAPL) and several other parameters. The path loss (PL) is calculated using Equation (Kiram et al., 1800):

$$PL = \frac{10 \log_{10} \text{enb}_{tx}}{1000} + \text{enb}_g + A_g - f_{loss} + TMA_{loss} - Bd_{loss} - p_{loss} - fn_{mrg} + 3.49 - SINR - I_{mrg} - KTB - N_{figure} \dots\dots\dots 1)$$

The parameter enb_{tx} represents the transmit antenna power, enb_g is the transmit antenna gain, A_g is the receive antenna gain, F_{loss} is the feeder cable loss, TMA_{loss} is the TMA loss, Bd_{loss} is the body loss, P_{loss} is the penetration loss, $F_{n_{mrg}}$ is the fading margin, SINR is the target SINR, I_{mrg} is the interference margin, and N_{figure} is the noise figure.

KTB is the thermal noise calculation using the parameters K = Boltzmann constant, T = temperature (in Kelvin), and B = bandwidth. The KTB value (in Watts) can be calculated using the following equation:

$$P = K \times T \times B \dots\dots\dots 2)$$

Where K = Boltzmann constant = 1.38×10^{-23} J/K. In this study, the temperature used is $300 \text{ K} = 26.85^\circ\text{C}$. In dBm units, the KTB equation becomes (D. A. Putri et al., 2024):

$$P(\text{dBm}) = 10 \log_{10} (1000 \times K \times T \times B) \dots\dots\dots 3)$$

The determination of the First Channel and Last Channel is performed by selecting a frequency range of 20 MHz (bandwidth) within the downlink (DL) frequency used in the planning. In this study, the frequency band employed is n3 (Band 3) with 20 MHz bandwidth, having a DL frequency range of 1805–1880 MHz. The selected frequencies are 1805 MHz for the First Channel and 1825 MHz for the Last Channel. These parameters are used to determine the EARFCN (E-UTRA Absolute Radio Frequency Channel Number) using the calculation in (H. Putri et al., 2024).

The propagation model used in this planning is an extension of the Hata model, namely the COST 231 model. The COST 231 model is considered suitable for this planning, as it is designed for carrier frequencies in the 1500–2000 MHz range. This propagation model is also used to determine the designed cell radius. The COST 231 model can be expressed as in (D. A. Putri et al., 2024).

$$PL = 46,3 + 33,9 \log_{10} (f_c) - 13,28 \log_{10} (h_t) - a(h_{rx}) + (44,9 - 13,28 \log_{10} (h_t) \log_{10} d + C_M) \dots\dots\dots 4)$$

where f_c is the carrier frequency, h_t is the transmitter antenna height, d is the cell radius, cm is 0 dB for suburban areas and 3 dB for dense urban areas, h_{rx} is the receiver height, and $a(h_{rx})$ is the correction factor for the receiver based on the coverage area. The equation to determine the value of $a(h_{rx})$ for suburban coverage is as follows:

$$a(h_{rx}) = (1,1 \log_{10}(f_c) - 0,7) h_{rx} - (1,56 \log_{10}(f_c) - 0,8) \dots \dots \dots 5)$$

Using Equation (4), the number of sites required for network planning with 3 sectors per site at a radius d can be determined using the following formula:

$$\text{Site area} = 2,6 \times r^2 \dots \dots \dots 6)$$

$$\text{Number of site} = \text{coverage area/site area} \dots \dots \dots 7)$$

where r is the site radius, or $\frac{d}{2}$, in km² (D. A. Putri et al., 2024).

2.4 Test Parameter

2.4.1 Reference Signal Receive Power

Reference Signal Received Power (RSRP) is defined as the linear average of the power contributions (in Watts) from resource elements carrying cell-specific reference signals within the considered measurement frequency bandwidth (Specification, 2017).

Table 2. RSRP Value Standards (Riswanto et al., 2024)

Category	RSRP Range Value
Very Good	≥ -89
Fair	$\geq -99; \leq -90$
Poor	$\geq -109; \leq -100$
Very Poor	$\geq -119; \leq -100$

2.4.2 Reference Signal Receive Quality

Reference Signal Receive Quality (RSRQ) represents the signal quality received by the User Equipment (UE). RSRQ is defined as the ratio between RSRP and the wideband power. It is also influenced by the signal, noise, and interference received by the UE. The unit of RSRQ is decibel (dB), and its value is always negative (since the RSSI value is always greater than $N \times \text{RSRP}$) (Farida & Nugraha, 2020).

Table 3. RSRQ Value Standards (Riswanto et al., 2024)

Category	RSRQ Range Value
Very Good	$\geq -7,5$
Good	$\geq -10,5; \leq -7,6$
Fair	$\geq -13,5; \leq -10,6$
Poor	$\geq -16,5; \leq -13,6$
Very Poor	$\leq -19,5$

2.4.3 Received Signal Strength Indicator

Received Signal Strength Indicator (RSSI) is the total signal power received by the user equipment in the measurement bandwidth. RSSI includes the signal from the serving cell, interference from other cells, and noise. Because of that, RSSI can be used to describe the received power condition, but it cannot be used alone to

determine LTE network quality. RSSI should be analyzed alongside RSRP and RSRQ, as RSRP indicates the reference signal strength, while RSRQ reflects the signal quality affected by interference and noise.

In this study, RSSI is discussed together with signal level because both parameters are related to received signal strength. The RSSI and signal level results indicate how strong the received signal is in the Cilacap City planning area.

2.4.4 Throughput

Throughput is the data rate transmitted through a network, typically expressed in bits per second (bps) or bytes per second (Bps). It refers to the amount of data carried by network traffic. Throughput is measured by calculating the number of bytes transmitted over a certain time interval. The length of the measurement interval can influence the observed network behavior (Sahal Fatah & Hikmaturokhman, 2025).

Table 4. Throughput Value Standards (Ayuningtyas et al., 2024)

Category	Throughput Range Value
Very Good	≥ 40.000
Good	30.000 - 40.000
Fair	20.000 - 30.000
Poor	10.000 - 20.000
Very Poor	0 - 10.000

2.4.5 Signal Level

The Signal Level parameter indicates the strength of the downlink (DL) signal received by the User Equipment (UE). Signal Level is commonly measured in decibels relative to milliwatts (dBm). Coverage based on Signal Level provides information on how well an adequate signal covers a particular area. The higher the Signal Level value, the stronger the signal received by the device, indicating better coverage (Purnamirza et al., 2023).

Table 5. Signal Level Value Standards

Category	Signal level Range Value
Very Good	≥ -70
Good	$\geq -77; \leq -71$
Fair	$\geq -84; \leq -78$
Poor	$\geq -91; \leq -85$
Very Poor	≤ -98

2.5 Validation Method, Evaluation Procedure, and Performance Criteria

The validation in this study was carried out by comparing the link budget calculation with the simulation result from Atoll. The link budget was used to assess the technical feasibility of LTE network planning based on parameters such as eNodeB transmit power, antenna gain, feeder loss, noise figure, target SINR, bandwidth, penetration loss, fading margin, and interference margin. After that, Atoll simulation was used to see the distribution of LTE performance in the Cilacap City planning area. The evaluation process was carried out in several steps. First, the Cilacap City area was defined as a polygon covering 42,998 km². Second, the LTE network was configured to use the 1800 MHz frequency and a 20 MHz bandwidth. Third, the link budget

calculation was performed using the parameters shown in Table 1. Fourth, the COST-231 propagation model was used to estimate path loss and coverage distribution. Fifth, the simulation results were analyzed using RSRP, RSRQ, RSSI, signal level, and throughput parameters.

The performance criteria were based on the KPI standard tables used in this study. RSRP was used to analyze the reference signal strength. RSRQ was used to analyze signal quality affected by interference and noise. RSSI and signal level were used to analyze the received signal power. Meanwhile, throughput was used to assess the network's data capacity. If the simulation results show weak signal strength, low signal quality, or uneven throughput distribution, then the network still needs optimization.

3. Result and Discussion

3.1. *RSRP Analysis Parameters*

The map in Figure 3 provides a comprehensive overview of signal distribution levels in the planning area. A blue-green distribution pattern dominates most of the area, indicating that signal intensity is in the medium category. Areas closer to the antenna exhibit stronger signal strength, while areas farther away experience lower intensity. This phenomenon occurs due to propagation attenuation and physical obstructions in the surrounding environment, such as dense buildings and vegetation.

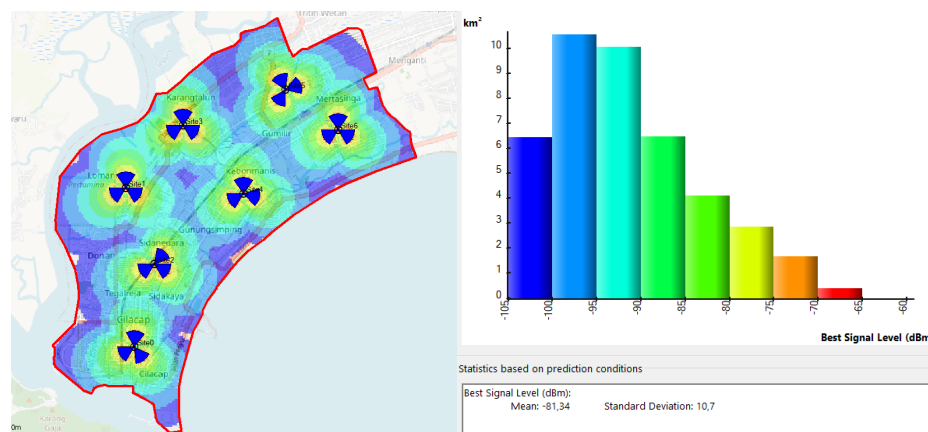


Figure 3. Results of Signal Level Parameters (a) in the Planning Area (b) in the Planning Histogram

The histogram on the right side of the diagram confirms this distribution. The data concentration appears to be in the medium-signal-level range, with the mean value hovering around -65 dB. The standard deviation is 10 dB, indicating significant signal variation at certain points. This pattern indicates that the network has consistent coverage in the central cell area, but some points near the planning area boundaries still require optimization. This can be addressed by adjusting the antenna tilt or evaluating the transmit power configuration to achieve even signal quality.

3.2. *RSRP Analysis*

The RSRP distribution in Figure 4 shows the reference signal quality received by the device. The color distribution on the map appears fairly even but still shows a decrease toward the region's boundaries, a common pattern in cellular systems. RSRP is a critical indicator of LTE performance because it determines a device's ability to maintain a stable connection.

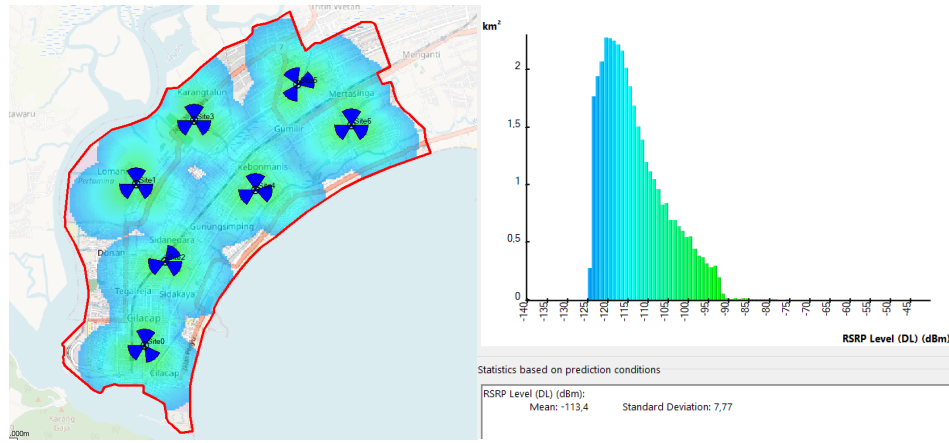


Figure 4. Results of RSRP Level Parameters (a) in the Planning Area (b) in the Planning Histogram

The histogram shows a pattern skewed around -100 dBm. The mean value is -112.4 dBm, with a standard deviation of 17.7 dB. These figures indicate that most areas experience poor signal conditions for basic LTE service, with some points reaching the lower signal quality threshold, affecting service stability and speed. The significant variation in the standard deviation indicates heterogeneity in signal quality across regions. This opens opportunities for improvements in antenna placement or increased cell density to achieve optimal coverage.

3.3. RSRQ Analysis

The RSRQ parameter in Figure 5 provides an overview of signal quality as affected by interference and channel efficiency. The color distribution on the map indicates that most areas are experiencing degraded quality, especially in areas between cell coverage or in areas exposed to signals from multiple directions. The histogram shows a distribution of RSRQ values concentrated in the low range, with a mean of -17.6 dB and a standard deviation of 1.12 dB. This value indicates less-than-ideal reference signal quality and the presence of quite strong interference in most of the coverage area. The tight distribution around the mean indicates that interference conditions are consistent and do not vary significantly between areas. These results indicate that the planning area requires radio configuration evaluation, cell parameter readjustment, or coverage overlap adjustments to maintain RSRQ within a better range.

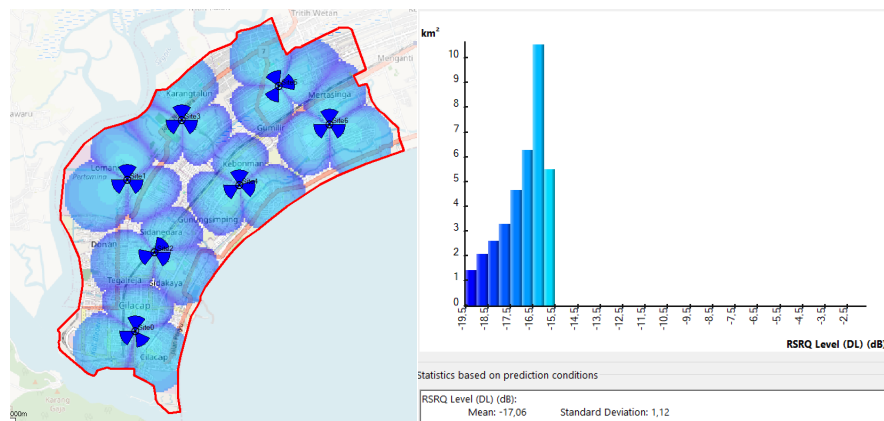


Figure 5. Results of RSRQ Level Parameters (a) in the Planning Area (b) in the Planning Histogram

3.4. RSSI Analysis

The RSSI map provides an overview of the total signal power received by the device. The green color distributed across most areas indicates that the received power remains at a satisfactory level. Conversely, the edges begin to decrease with increasing distance from the antenna. This difference in power intensity indicates the direct impact of propagation attenuation, environmental obstacles, and uneven line-of-sight (LOS) paths.

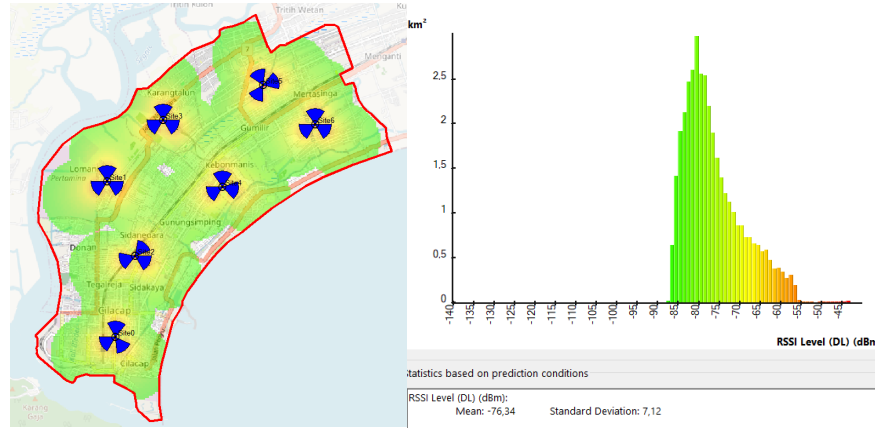


Figure 6. Results of RSSI Level Parameters (a) in the Planning Area (b) in the Planning Histogram

The histogram shows the distribution of RSSI values in the range of -60 to -80 dBm. The mean value was -76.34 dBm, with a standard deviation of 7.12 dBm, indicating stable reception conditions but significant variation in some areas. RSSI performance within this range remains sufficient to support daily communication services, but special attention is required in areas near the device's sensitivity threshold to avoid deterioration in the user experience.

3.5. Channel Throughput Parameters

The throughput parameter provides a clear picture of the channel's capacity to deliver data rates. Figure 7 shows that the highest throughput occurs around the antenna, which is the area with the most ideal signal quality and the most interference. The farther away from the signal source, the throughput value appears to decrease significantly. This pattern aligns with the characteristics of cellular communication systems, which are highly dependent on signal quality and environmental conditions.

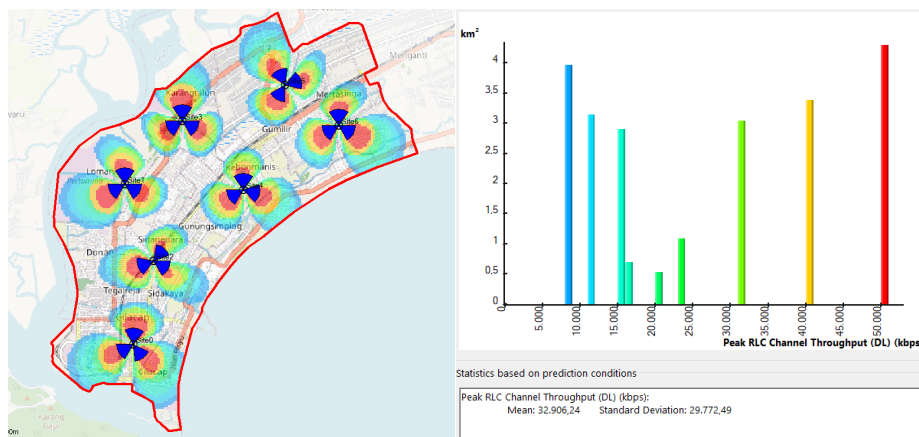


Figure 7. Channel Throughput Parameter Results (a) in the Planning Area (b) in the Planning Histogram

The histogram shows a wide throughput range, indicating significant performance variation between the cell's core and periphery. This distribution indicates uneven network capacity. Capacity can be increased through resource allocation optimization, QoS parameter reconfiguration, or the implementation of network densification techniques, such as small cells, to ensure more consistent throughput across the entire area. Overall, these results demonstrate that channel quality is heavily influenced by signal quality and interference, and improvements in both will directly increase throughput.

4. Conclusion

Based on the simulation results, the 4G LTE coverage planning at 1800 MHz in the Cilacap City area has not produced fully even network performance. The average signal level is around -65 dB with a standard deviation of 10 dB. This value indicates that the average signal condition is good, especially in areas near the antenna. However, the RSRP has an average of -112.4 dBm and a standard deviation of 17.7 dB, indicating that some areas still experience weak reference signal reception. The RSRQ has an average of -17.6 dB and a standard deviation of 1.12 dB, indicating that the signal quality is still affected by interference or coverage overlap. The RSSI values range from -60 to -80 dBm, with an average of -76.34 dBm and a standard deviation of 7.12 dBm. Meanwhile, the throughput results show that the data rate decreases as the distance from the antenna increases.

Based on these results, the planned LTE network still needs further optimization, particularly to improve RSRP, RSRQ, and throughput distribution. The recommended optimization steps are antenna tilt adjustment, transmit power evaluation, radio parameter reconfiguration, coverage overlap control, and network density improvement in areas with weak coverage. For future research, field measurements or drive-test validation is recommended to compare the simulation results with real network conditions in the Cilacap City area.

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