Private 5G Network Capacity and Coverage Deployment for Vertical Industries: Study Case in Indonesia

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Abstract— The business and industrial worlds are implementing the Internet of Things (IoT) more and more, which impacts the use of cellular networks as a connectivity provider platform. The presence of the 5G network provides a solution by offering the flexibility to build a public or personal network to support vertical industry needs. The goal of this study is to create a private 5G network in the Jababeka Industrial Area, with an area of 35 km^2. To determine the optimal number of gNodeB, this study applies a planning method depending on capacity and coverage at 2300MHz and 40MHz BW to get the best number of gNodeB needs when implemented by the Private 5G Network. According to the capacity analysis, setting up a private 5G network requires in downlink are 69 gNodeB and in uplink are 65 gNodeB. As for coverage, it takes 44 gNodeB for uplink and 69 gNodeB for downlink. These findings indicate that 69 gNodeB is the ideal number of nodes needed for the Jababeka industrial region. With these results, the coverage analysis using Atoll found the SS-RSRP value was-92, 76 dBm, falling under the "Good" category and the SS-SINR value is 6.94, falling under "Normal." Also, the value for the need of traffic demand was 2688 Mbps/km2, having a maximum data throughput for the uplink of 1.456 Gbps and the downlink of 1.361 Gbps.

Keywords—Private 5G Network, capacity planning, coverage planning, ODV, SS-RSRP, SS-SINR, Data Rate, vertical industry

I. Introduction

The Industrial Revolution 4.0 is a transformation effort towards improvement by integrating the industry's online world and production lines. All production processes run with the internet as the primary support. Connectivity has become the main thing to encourage digitalization and product services in the era of industrial revolution 4.0. [1]. 5G technology plays an important role in this connectivity integration because a wider variety of relevant communication patterns are targeted by 5G technology, in various fields such as the production, automotive, transportation, agriculture, and health industries [2][3]. More specifically, 5G provide assistance with connectivity of IoT, which it possesses the capacity to alter many parts of the economy and meet our society's needs for digitization [4].

In the application of Industry 4.0, the mobile network is an excellent platform for "wire-free networking" for applications in automated warehouses, logistics, and autonomous vehicles in the setting of a campus, as well as in manufacturing and other forms of application (use cases). One of the development options to increase interest in industries or companies is to create a cellular 'private network,' i.e., a cellular network that has exclusive use for a particular company wherein a closed network segment is comprised of all connected devices. GSMA estimates that at 2023 – 2025 as many as 25% - 40% of small and medium sized businesses could be supplied by can be served through a private 5G network[5][15].

Private networks will be crucial to the development of 5G services in smart factories that call for improved operation development, resource management, and infrastructure to be available flexibly. The Private 5G Network will offer agile solutions to be implemented effectively in operating heterogeneous use cases in terms of resource redistribution, reconfigurability, connect-compute latency, and dependability and governance management related to components and elements of the 5G Network [6][14]. Research [1] has discussed using 5G-enabled NPNs to support the industrial revolution 4.0 ecosystem, while research [2] conducts modeling to implement private 5G networks.

With the problem above, based on of this research, a Private 5G Network will be developed in the Jababeka industrial region. The analysis is carried out based on the calculation of the site's amount that will be needed by referring to the conditions of the existing 4G network, an approach of technical analysis of capacity and coverage at Frequency of 2300 MHz, Bandwidth of 40 MHz, by utilizing scenario calculations and the use of forecasting in the 2022 - 2023 time frame. First, by assessing traffic demand and data rate requests in the research object region. This study will forecast the number of users. Then, calculate the capacity and Maximum Allowable Path Loss (MAPL). Calculation analysis refers to the value of traffic demand according to the needs of the case and throughput in the form of the service's data rate (use case). The number of gNodeB required in the Jababeka region will be determined by the final conclusion, which will be based on capacity calculations and coverage analyses. The result will determine the most appropriate resource plan and network roll-out plan for the industry in designing a Private 5G Network.

This paper has several parts: Introduction Part I; Description of 5G Technology and Private 5G Network in Part II. The study methodology and computations for the configuration scenario in Private 5G Network Planning are presented in Part III. The analysis and examinition findings are displayed in Section IV. Finally, part V conveys the conclusions of this study.

II. 5G Technology and Private 5G Network

A. 5G Technology

5G is the 5th generation cellular network technology released by 3GPP, a significant evolution of the 4G LTE network. The design of the 5G is to meet today's modern society's massive data growth and connectivity, IoT-based for billions of connected devices and future innovations. A key benefit of 5G is its quick response time, or low latency, which is in addition to offering quicker connections and more capacity [5][18]. The three primary types of 5G use cases, namely mMTC, URLLC, and eMBB where the explanation of each is as follows [7] [17]:

- Massive machine-to-machine communications (mMTC), incorporates and connects billions of objects on a scale never previously achieved without human intervention, as known as Internet of thing (IoT). As a result, it can transform contemporary industrial applications and processes in industries including manufacturing, agriculture, and corporate communications.
- Ultra-reliable low latency communications (URLLC) is communication between devices using low latency to open a new world with with real-time device control, robotics in industrial uses, communication between vehicles, autonomous driving, and transportation network security.
- Enhanced mobile broadband (eMBB) maintains connectivity while offering faster data rates and noticeably more capacity. The latest applications include fixed wireless home internet connectivity and great connectivity when the user moves or travels.

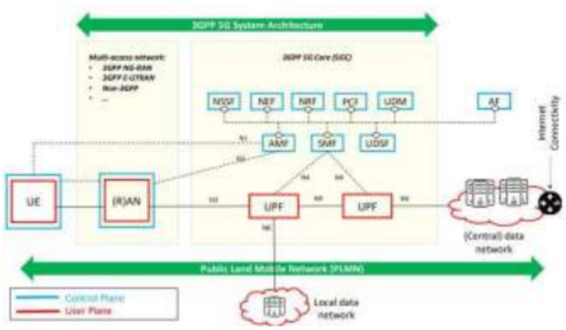

Fig. 1. 5G Architecture [8]

Figure 1 illustrates how the 3GPP specifies the 5G Network Architecture. The architecture consists of several elements, which is NR called gNodeB, User Plane Function (UPF), Core Access and Mobility Management Function (AMF), Unstructured Data Storage Function (UDSF), and Session Management Function (SMF). 5G architecture creates a dynamic, coherent, and flexible framework of advanced technologies to support a variety of applications. It also has 3GPP 5G Core that includes eight part that will be a controlling function that seem in that figure [8].

B. Private 5G Network

A private 5G network is a type of network infrastructure used only by devices that end users have given permission to access. This infrastructure is useable in one or more locations owned or occupied by end-user organizations based on 5G networks [2][19]. Private Networks only serve devices that the user has defined, so therefore, there are no concerns about how the user will affect the number of connected devices, throughput gained, or other network performance indicators.

Private 5G networks development is in 2 forms of implementation, namely [9]:

1. Develop a physically-isolated Private 5G network that does not depend on 5G networks from mobile operators (as if building a wired LAN or WLAN Wi-Fi in a company/industry). In this scenario, either the business/industry or the cellular operator can build the private 5G network.
2. Build a Private 5G network by sharing resources with 5G network operators. In this scenario, the operator will build a Private 5G network for the company/industry

Figure 2 below shows both forms.

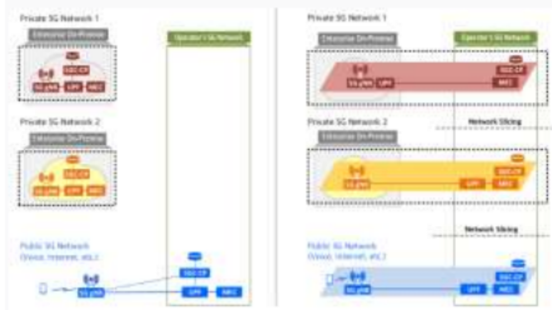

Fig. 2. Forms of Private 5G Network Development [8]

In its implementation, Private Networks with 5G technology provide a number of advantages over alternative choices such wired Ethernet, Wi-Fi, or unlicensed wireless. It includes offering device flexibility and deployment efficiency and utilizing 5G to deliver the necessary coverage and capacity with excellent quality and dependability, Low-Latency, Ultra-Reliable Communications [2][16].

III. Method

This study aims to analyze and design gNodeB needs on the Private 5G Network in the Jababeka industrial area, using forecasting methods and calculation analysis depending on coverage area and capacity in frequency of 2300 MHz with a 40 MHz bandwidth. The obtained data to perform the simulation was from one of the Indonesian telecommunications operators in the Jababeka industrial area, which includes the coordinates of the existing site parameters, the transmitter parameters, the number of existing 4G network subscribers, and the assumption of users of the private 5G network in 2023. The number of assumption of the 4G network subscribers capable of the network 5G is 1800 customers with an area of 35 km^2.

Based on the calculation of capacity and coverage, there are two scenarios. First, the calculated coverage area considers the number of existing 4G network sites (eNodeB), which is 41 eNodeB, and refers to the calculation of the link budget and Maximum Allowable Path Loss (MPAL). The calculation of gNodes needed is from the obtained coverage value. Analysis based on capacity uses the assumption of traffic needs during peak hours (Busy Hour Call Attempt).

The 5G throughput during a trial in the Jababeka area in May 2022 reaches 300 Mbps, and the number of gNodeBs required will be determined by calculations of the data rate. As the final results, the researcher will compare and analyze the two computations to obtain the ideal gNodeB number calculations for designing a private 5G network in the Jababeka industrial area. The Private 5G Network design stages are shown in the Private 5G Network design flow diagram in Figure 3.

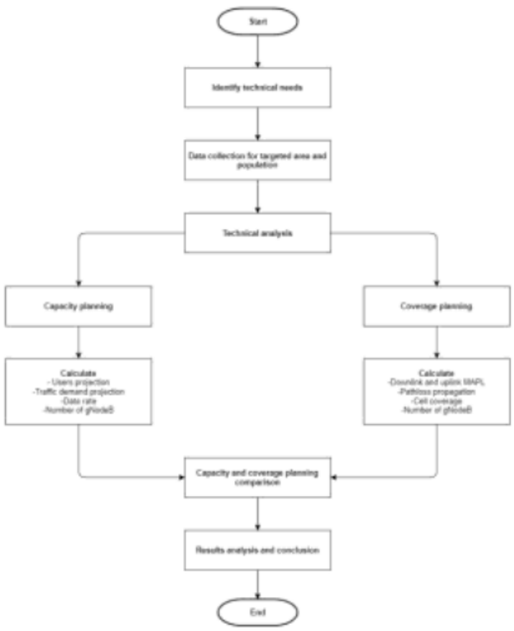

Fig. 3. Research Flowchart

A. *Capacity of Private 5G Network Planning*

Capacity of Private 5G Network Planning is a network planning technique to estimate the number of sites (gNodeB) based on the traffic needs of customers in an area, the type of service, service penetration, effective service user duration, and busy hour call attempt (BHCA). The following are the primary aspects that may also have an impact on the network design :

- *Offered Data Traffic* (ODV)

Offered Data Traffic (ODV) is the total bit throughput per km^2 during peak hours. It was usable for calculating the traffic capacity or estimating traffic needs on the 5G network. The ODV formula is shown in the following equation [9] [13][20]:

*ODV = BHCA * Service Penetration *Potential User * Service Throughput * Effective Call Duration* (1)

Table I shows the value of service throughput on cellular networks and the user bit rate classification for each type of service on the network for uplink and downlink [9][20].

TABLE I. USER BIT RAT FOR EACH SERVICE [9][13]

Services	DL *bit rate* (Kbps)	UL *bit rate* (Kbps)
Speech	16	16
Simple Message	14	14
Switched Data	64	64
Medium Multimedia	384	384
High Multimedia	2000	2000
High Interactive Multimedia	128	128

While the service penetration value is the estimated value used to predict the type of service used by customers, Table II shows the penetration of cellular services based on the ITU standard [9].

TABLE II. SERVICE PENETRATION [9][13]

Services	DL *bit rate* (Kbps)
a) Speech	73
Simple Message	40
Switched Data	13
Medium Multimedia	15
High Multimedia	15
High Interactive Multimedia	25

- *Throughput* (*Data Rate*)

The data rate calculation needs is to determine how much speed the network can achieve and shows each cell's information capacity. For example, the calculation based on 3GPP TS 38.306 used to determine the data rate in 5G is [4]:

$$\text{Data Rate (Mbps)} = 10^{-6} \cdot \sum_{j=1}^{J} \left(v_{Layers}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{max} \cdot \frac{N_{PRB}^{BW(j),\mu} \cdot 12}{T_s^{\mu}} \cdot \left(1 - OH^{(j)}\right) \right) \quad (2)$$

Which J stands for the Component Carrier, $v^{(j)}$ for the number of layers, $Q^{(j)}$ for the modulation order, $f^{(j)}$ for the scaling factor, N_{PRB} for the number of RB, and $OH^{(j)}$ for the Overhead

- Quantity Calculation of gNodeB

Based on the value of ODV and throughput or capacity of the cell, where the cell coverage area calculation is by using equation [9]:

$$L = \frac{\text{Kapasitas Informasi Tiap Sel}}{\text{Offered Data Volume (ODV)}} \quad (3)$$

So the equation below, can be used to determine how many gNodeB sites are necessary [10] :

$$Number\ of\ gNodeB = \frac{Large\ of\ area\ (km)}{Coverage\ of\ area\ (km)} \quad (4)$$

B. *Coverage of Private 5G Network Planning*

Network planning from the perspective of the area the network will cover is known as coverage planning. The design based coverage of Private 5G planning estimates the number of sites needed to provide services, considering factors as antenna gain, interference margin, receiver sensitivity, also others. The determination of the link budget is a crucial step in planning coverage. The parameters measured in the coverage planning are as follows :

- Propagation Model and Link Budget

The 5G network uses the 38.901 standard 3GPP propagation model, where the Jababeka area includes areas with UMa conditions (Urban/suburbs/dense urban macro), with the 3GPP model propagation standard equation 38.901 UMa LOS [10][11]:

$$PL_{UMa-LOS} = 28.0 + 30log(d_{3D}) + 20log(f_c) - 9log[(d'_{BP})^2 + (h_{BS} - h_{UT})^2] \quad (5)$$

Where d_{3D} is the resultant of h_{BS} and h_{UT}, h_{BS} is the gNodeB antenna height (m), h_{UT} is the user transmission height, the frequency carrier (Hz) is f_c, the breakpoint distance (m) is d^l_{BP} and $PL_{Uma-LOS}$ is the path loss (dB).

Equations (6) and (7) can be used to get the values of d_{2D} and d^l_{BP} :

$$d_{2D} = \sqrt{(d_{3D})^2 - (h_{BS} - h_{UT})^2} \quad (6)$$

$$d'_{BP} = 4 \cdot h'_{BS} \cdot h'_{UT} \cdot \frac{f_c}{c} \quad (7)$$

where d_{2D} is cell radius (m), h^l_{UT} is user transmission height – device height (m) and h^l_{BS} is the gNodeB antenna height – device height (m)

The estimated coverage based on the link budget calculation is calculated using the maximum coverage of each site. The coverage distance of each site affects how many gNodeBs are needed. The following equation is used to calculate each site's coverage area :

$$Coverage\ area = 2.6 \cdot (d_{2D})^2 \quad (8)$$

The amount of gNodes with in design region is determined using the given calculation as below :

$$Number\ of\ gNodeB = \frac{Large\ of\ area\ (km)}{Coverage\ of\ area\ (km)} \quad (9)$$

- SS-RSRP and SS-SINR Parameter

The values of the SS-RSRP and SS-SINR parameters are those generated by the coverage planning, indicated by the parameter values as follows [4][12] :

TABLE III. SS-RSRP RANGE [4][12]

Range SS-RSRP	Category
-140 ≤ SS-RSRP Level (DL) (dBm) < -120	Very Bad
-120 ≤ SS-RSRP Level (DL) (dBm) < -105	Bad
-105 ≤ SS-RSRP Level (DL) (dBm) < -95	Normal
-95 ≤ SS-RSRP Level (DL) (dBm) < -85	Good
-85 ≤ SS-RSRP Level (DL) (dBm) < 0	Very Good

TABLE IV. SS-SINR RANGE [4][12]

Range SINR	Category
-40 ≤ SS-SINR Level (DL) (dB) < -5	Very Bad
-5 ≤ SS-SINR Level (DL) (dB) < 0	Bad
0 ≤ SS-SINR Level (DL) (dB) < 10	Normal
10 ≤ SS-SINR Level (DL) (dB) < 20	Good
20 ≤ SS-SINR Level (DL) (dB) < 40	Very Good

IV. RESULT AND ANALYSIS

A. Capacity Analysis

- Traffic Demand Calculation

The data needed for capacity calculation includes the number of 4G subscribers in the Jababeka Area until June 2022 who can have a 5G network of 1800 subscribers. Table V shows the value of traffic requirements needed for the calculation.

TABLE V. TRAFFIC CALCULATION DATA

Selected Area	Jababeka Industrial Estate
Area (km²)	35 km²
Numbers of Costumers	1800 costumers
Service Penetration (kbps)	25 [9]
Service Throughput (kbps)	128 [9]
BHCA(kbps)	28

From the data, the ODV value is calculated according to equation (1), and the ODV value is 2688 Mbps/ km^2

- gNodes amount based on Capacity Analysis

The calculation of capacity is a factor that needs to be aware. Other factors that affect system capacity are site usage, frequency spectrum, and sectorization. The capacity calculation of each cell using equation (2), where the antenna chosen is 8T8R with modulation of 64 QAM so that the capacity value of each cell for UL is 1456.07 Mbps and DL is 1361.11 Mbps.

TABLE VI. GNODEB AMOUNT BASED ON CAPACITY ANALYSIS

Parameter	**Private 5G Network (2300MHz, 40 MHz)**	
	Uplink (UL)	**Downlink (DL)**
Sector	3	3
Bandwidth (MHz)	40	40
Cell Coverage (km²/site)	0,54	0.51
Large area (km²)	35	35
Amount of gNodeB	**65**	**69**

The results will help calculate the L value under UL and DL conditions as in equation [3] so that the number of gNodes generated follows the capacity design in the Jababeka area, as shown in Table VI.

B. Coverage Analysis

- *Link Budget Analysis*

Coverage analysis uses link budget calculations to estimate the MAPL value received by the antenna, both downlink and uplink. The initial parameter of the calculation is to determine the frequency range used in the design, then determine the parameter value for numerology and the value of the link budget calculation. For example, this Private 5G Network design uses a frequency of 2300 MHz and a bandwidth of 40 MHz. Table VII shows all the parameters used in calculating the link budget.

TABLE VII. PARAMETER LINK BUDGET FREQUENCY 2300 MHZ

Parameters (gNodeB)	Link Budget 2300MHz BW 40 MHz	
	Urban	
	Downlink (DL)	Uplink (UL)
Transmiter Power (dBm)	49	49
Number of RB	106	106
Subcarrier Spacing (kHz)	30	30
Antenna Gain (dBi)	2	2
Cable Loss (dBi)	0	0
Penetration Loss (dB)	19	19
Folliage Loss (dB)	19.59	19.59
Loss of Body Block (dB)	3	3
Interference Margin (dB)	6	2
Subscarrier Quantity	1272	1272
Rain/Ice Margin (dB)	0	0
Slow Fading Margin (dB)	7	7
UT Antenna Gain (dB)	0	0
Thermal Noise Power (dBm)	-157.9119	-157.9119
UT Noise Figure (dB)	9	9
Demodulation Threshold SINR (dB)	19.4	19.4

Equations (5), (6), and (7) can be used to compute the link budget using the Table VII parameters, so that the results obtained for the propagation model, as shown in Table VIII

TABLE VIII. PROPAGATION MODEL CALCULATION RESULTS

Propagation Model 5G NR Frequency 2300 MHz			
Parameters	Symbols	Propagation 3GPP 38.901 UMa-LOS	
		Urban	
		Downlink (DL)	Uplink (UL)
Path loss	PL_{UMa}	94.877 (dB)	94.877 (dB)
Height of Equipment	h_E	1 (m)	1 (m)
Transmission User Height	h_{UT}	1.5 (m)	1.5 (m)
Height of gNodeB	h_{BS}	25 (m)	25 (m)
$h^{I}bs$	$h^{I}bs$	24 (m)	24 (m)
$h^{I}UT$	$h^{I}UT$	0.5 (m)	0.5 (m)
Speed of Light	c	$3x10^8$ (m/s)	$3x10^8$ (m/s)
Breakpoint Distance	d^{I}_{BP}	368 (m)	368 (m)
BS-UT Distances/ Cell Radius	d_{2D}	442.05 (m)	556.80 (m)
Resultant of Distance Between h_{BS} dan h_{UT}	d_{3D}	442.68 (m)	557.303 (m)
Total gNode B		**69**	**44**

- SS-RSRP Parameter

Using Atoll software, the RSRP value is measured at a bandwidth of 30 MHz and a frequency of 2300 MHz. Therefore, the total number of gNodeB using the calculation results of the optimum number of sites obtained is 69 sites, with 41 sites using the coordinates of the existing 4G network eNode B. The results of the SS-RSRP coverage simulation are in Figure 4, and the SS-RSRP values obtained are shown in Figure 5 below.

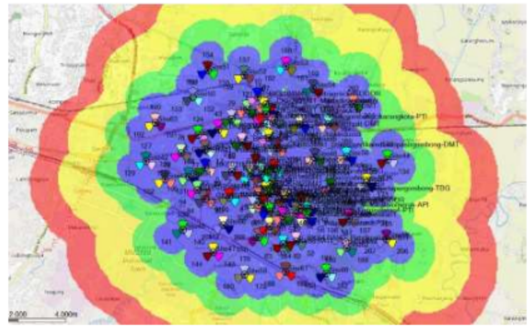

Fig. 4. SS-RSRP Coverage with Frequency of 2300 MHz, BW 40 MHz

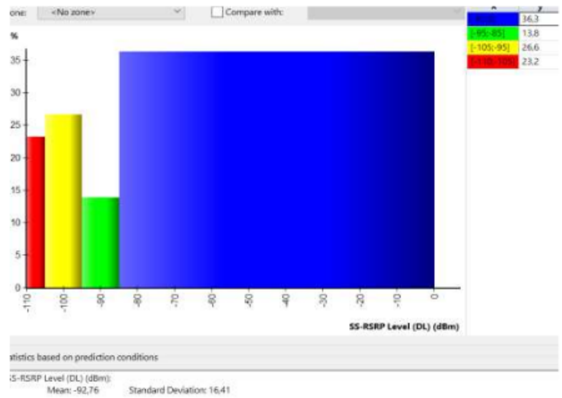

Fig. 5. SS-RSRP Value Jababeka on Frequency of 2300 MHz, BW 40 MHz

Based on the coverage simulation using Atoll software, the results are that with the number of needs for gNode 69 sites, the mean SS-RSRP value was -92.76, and according to Table III, it was in the "Good" range.

- SS-SINR Parameter

The SS-SINR values in this study is from the Atoll planning software at 2300 MHz and BW 40 MHz. The signal strength is divided by the user's noise and interference to produce the SS-SINR result. Based on this paper, the simulation uses Atoll software. Figures 6 and 7 show the results.

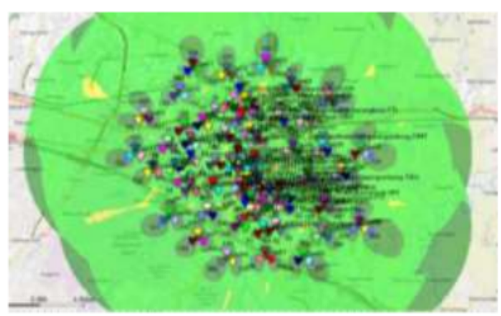

Fig. 6. SS-SINR Coverage with Frequency 2300 MHz, BW 40 MHz

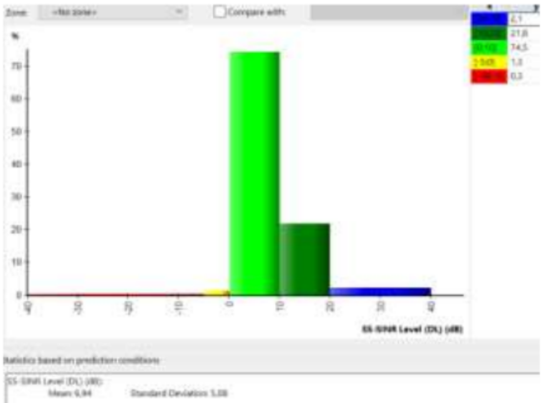

Fig. 7. SS-SINR Value Jababeka with Frequency 2300 MHz, BW 40 MHz

Using Atoll software's coverage simulation, the mean SS-SINR value is 6.94, and according to Table IV, it is in the "Normal" range.

C. Evaluate the number of gNodeBs by Coverage and Capacity Simulation

According to the capacity planning computation findings for setting up a private 5G network in the Jababeka region, 65 gNodeB are required for uplink and 69 gNodeB are required for downlink. They also cover 1800 users, with a traffic demand requirement of 2688 Mbps/km^2. According to the coverage planning calculations, 44 gNodeB are required for the uplink simulation and 69 gNodeB are required for the downlink simulation, in order to establish a private 5G network in the Jababeka area., which covers the Jababeka area with an area of 35 km^2. Table IX shows the findings of the comparison between the amount of gNodeB demand based on simulation in research, as follow

TABLE IX. COMPARATION ANALYSIS RESULT OF GNODE B NUMBER

Analysis	**Private 5G Network (2300MHz, 40 MHz)**	
	Uplink (UL)	**Downlink (DL)**
Capacity (Numb of gNode B)	**65**	**69**
Coverage (Numb of gNodeB)	**44**	**69**

The ideal number of gNodeBs for the Jababeka Private 5G Network design will follow the highest numbers for gNodeB based on the projections from capacity and coverage planning. The end result is a deployment option for a private 5G network in the Jababeka region with a total gNodeB of 69 gNodeB and a traffic demand region of 2688 Mbps/km2.

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