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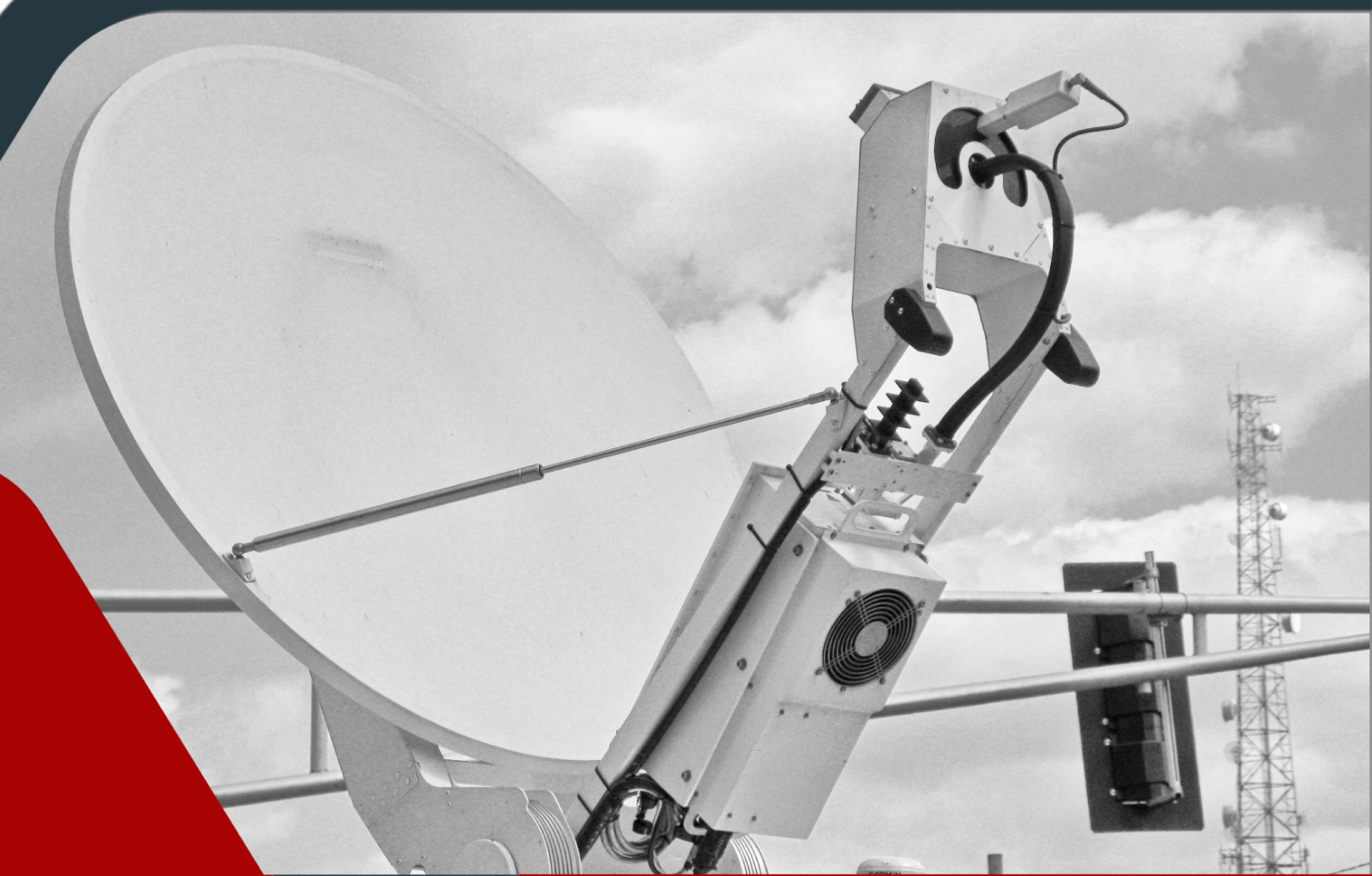

Solo, Indonesia
November 3-5, 2022

ISBN : 978-1-6654-6030-9

Institut Teknologi Telkom Purwokerto

IEEE ComSoc — IEEE Communications Society

IEEE Indonesia Section

AESS — Indonesia Section IEEE AESS / GRSS Chapter — GRSS

Co-Host : USM

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

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2022 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT) | 978-1-6654-6030-9/22/$31.00 ©2022 IEEE | DOI: 10.1109/COMNETSAT56033.2022.9994332

Abstract—The business and industrial worlds are implementing the Internet of Things (IoT) more and more, which affects the utilization of cellular networks as a connectivity provider platform. The presence of the 5G network provides a solution by offering the flexibility to establish a public or personal network to enhance vertical industry needs.

The objective of this study is to generate a private 5G network in the Jababeka Industrial Area, with an area of 35 km^2. In determining the optimal number of gNodeB, this study administered a planning method depending on capacity and coverage at 2300MHz and 40MHz BW to obtain the best number of gNodeB needs when applied by the Private 5G Network. In accordance with the capacity analysis, formulating up a private 5G network requires in downlink are 69 gNodeB and in uplink are 65 gNodeB. As for coverage, it requires 44 gNodeB for uplink and 69 gNodeB for downlink. These findings indicate that 69 gNodeB is the ideal number of nodes demanded for the Jababeka industrial region. With these results, the coverage analysis employing Atoll revealed the SS-RSRP value was-92, 76 dBm, falling under the "Good" category and the SS-SINR value is 6.94, falling under "Normal." Furthermore, the value for the need of traffic demand was 2688 Mbps/km2, possessing 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, gNodeB, vertical industry

I. INTRODUCTION

The Industrial Revolution 4.0 is a transformation effort towards the advancement by integrating the industry's online world and production lines. All production processes operate with the internet as the primary support. Connectivity becomes the prior issue in encouraging digitalization and product services in the industrial revolution 4.0 era. [1]. 5G technology plays a pivotal role in this connectivity integration as more extensive variety of relevant communication patterns are targeted by 5G technology, in various fields encompassing the production, automotive, transportation, agriculture, and health industries [2][3]. More specifically, 5G provides assistance with connectivity of IoT, in which it owns the capacity to alter numureous parts of the economy and fulfill the society's needs for digitization [4].

In the application of Industry 4.0, the mobile network is acknowledged as an excellent platform for "wire-free networking" in implementing the automated warehouses, logistics, and autonomous vehicles in the setting of a university, as well as in manufacturing and other forms of application (use cases). One of the development options to escalate interest in industries or companies is to produce a cellular 'private network,' i.e., a cellular network that possesses an exclusive administration for a particular company wherein a closed network segment incorporates all connected devices. From the data released by GSMA, 25% - 40% of small and medium enterprises in 2023-2025 will be able to be served by employing a private mobile network [5][15].

The development of 5G services in smart factories, which demand optimized operation development, resource management, and infrastructure to be available flexibly, will depend significantly on private networks. In terms of resource redistribution, reconfigurability, connect-compute latency, dependability, and governance management associated with components and elements of the 5G Network, the Private 5G Network will provide agile solutions to be effectively applied in operating heterogeneous use cases [6][14]. While research [2] conducts modeling to operate private 5G networks, research [1] has discussed employing 5G-enabled non-public networks to corroborate the ecosystem for industrial revolution 4.0.

Based on the aforementioned issue and the results of this research, a Private 5G Network will be constructed in the Jababeka industrial area. The analysis is conducted by employing scenario analysis, forecasting, and technical analysis of capacity and coverage at Frequency of 2300 MHz, Bandwidth of 40 MHz. The analysis is in accordance with the calculation of the site's amount that will be required by referring to the conditions of the existing 4G network. This study will first forecast the number of users by examining traffic demand and data rate requests in the research object region. Then, the capacity and the Maximum Allowable Path Loss (MAPL) are determined . Calculation analysis refers to the value of traffic demand in accordance with the needs of the case and throughput in the form of the service's data rate (use case). The number of gNodeB demanded in the Jababeka region will be examined by the final conclusion, which is based on capacity calculations and coverage analyses. The result determines the most appropriate resource plan and network roll-out plan for the industry in designing a Private 5G Network.

This paper emobodies 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 demonstrated in Part III. The analysis and examinition findings are illustrated in Part IV. Finally, part V embodies the conclusion of this study.

II. 5G TECHNOLOGY AND PRIVATE 5G NETWORK

A. 5G Technology

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

- Massive machine-to-machine communications (mMTC), incorporates and connects billions of objects on a scale never previously acquired without human intervention, as understood as Internet of thing (IoT). As a result, it is able to transform contemporary industrial applications and processes in industries encompassing manufacturing, agriculture, and corporate communications.
- Ultra-reliable low latency communications (URLLC) is communication between devices by administering low latency to open the latest 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 providing more rapid data rates and noticeably more capacity. The latest applications incorporate fixed wireless home internet connectivity and great connectivity when the user moves or travels.

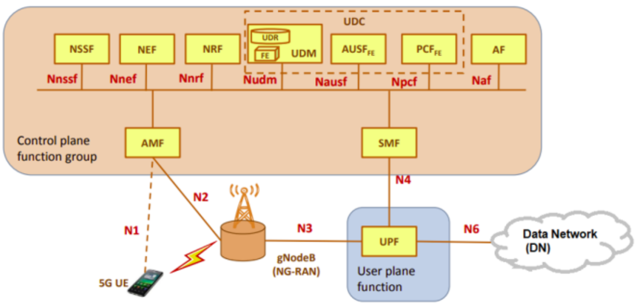

Fig. 1. 5G Architecture [8]

Figure 1 demonstrates how the 3GPP specifies the 5G Network Architecture. The architecture comprises of several elements, which is NR acknowledged as gNodeB, User Plane Function (UPF), Core Access and Mobility Management Function (AMF), Unstructured Data Storage Function (UDSF), and Session Management Function (SMF). 5G architecture generates a dynamic, coherent, and flexible framework of advanced technologies to enhance a variety of applications. In the architecture, a 5G Core incorporating 8 parts to perform control functions also exists [8].

B. Private 5G Network

A private 5G network is a type of network infrastructure employed merely by devices that end users have provided permission to access. This infrastructure is useable in one or more locations possessed or occupied by end-user organizations in accordance with 5G networks [2][19]. Private Networks merely serve devices that the user has determined, thus, there are no concerns about how the user affects the number of connected devices, throughput gained, or other network performance indicators.

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

1. Developing a physically-isolated Private 5G network which 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 establishes the private 5G network.
2. Building a Private 5G network by sharing resources with 5G network operators. In this scenario, the operator builds a Private 5G network for the company/industry.

Figure 2 below presents both forms.

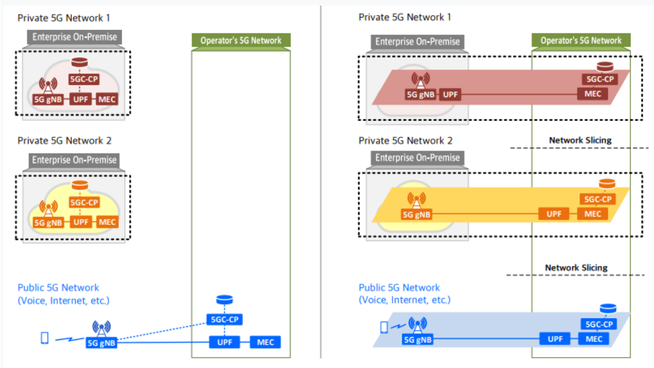

Fig. 2. Forms of Private 5G Network Development [8]

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

III. METHOD

The objective of this study is to determine and design gNodeB needs on the Private 5G Network in the Jababeka industrial area, by employing forecasting methods and calculation analysis in accordance with coverage area and capacity in frequency of 2300 MHz with a 40 MHz bandwidth. The obtained data to administer the simulation was from one of the Indonesian telecommunications operators in the Jababeka industrial area, incorporating the coordinates of the existing site parameters, the transmitter parameters, the number of the existing 4G network subscribers, and the users' assumption 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.

In accordance with the calculation of capacity and coverage, two scenarios were conducted. First, the calculated coverage area considers the number of the existing 4G network sites (eNodeB), which is 41 eNodeB, and signify the calculation of the link budget and Maximum Allowable Path Loss (MPAL). The calculation of gNodes required is from the obtained coverage value. Analysis in accordance with capacity employs the assumption of traffic needs during peak hours (Busy Hour Call Attempt). In a trial in the Jababeka region in May 2022, the 5G throughput achieves 300 Mbps, and calculations of the data rate was employed to determine the number of gNodeBs needed. In order to determine the ideal gNodeB number calculations for designing a private 5G network in the Jababeka industrial area, the researcher compared and examined the two computations. The Private 5G Network Design Flow Diagram in Figure 3 displays the Private 5G Network Design stages.

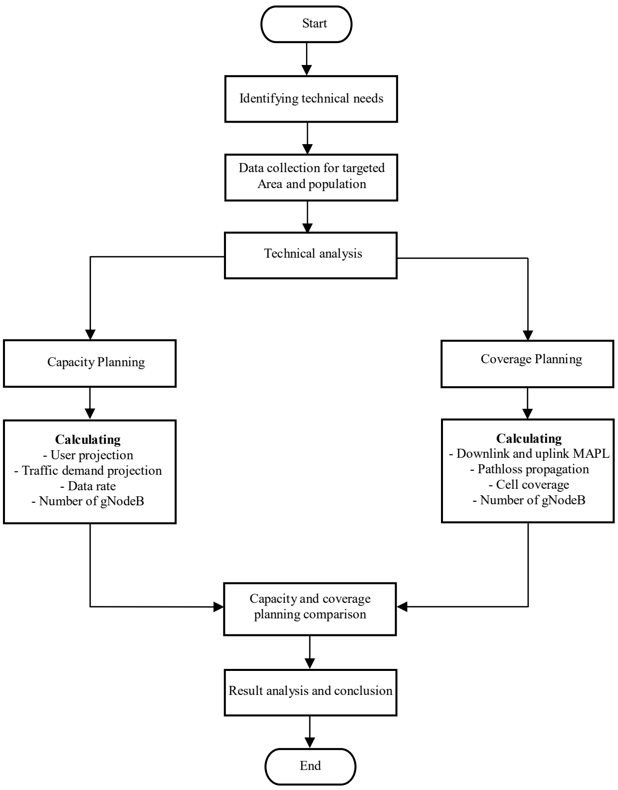

Fig. 3. Research Flowchart

A. *Capacity of Private 5G Network Planning*

Capacity of Private 5G Network Planning is a network planning technique in estimating the number of sites (gNodeB) in accordance with 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 which also possess 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 crucial for examining the traffic capacity or estimating traffic needs on the 5G network. The ODV formula is demonstrated in the following equation [9] [13][20]:

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

Table I displays 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 employed in predicting the type of service utilized by customers, Table II demonstrates the penetration of cellular services based on the ITU standard [9].

TABLE II. SERVICE PENETRATION [9][13]

Services	DL bit rate (Kbps)
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 examine the speed rate that the network can acquire and illustrates each cell's information capacity. For instance, the calculation based on 3GPP TS 38.306 administered to determine the data rate in 5G is [4]:

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

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

In accordance with the value of ODV and throughput or capacity of the cell, the cell coverage area calculation is by employing equation [9]:

$$L = \frac{Information\ Capacity\ of\ Each\ Cell}{Offered\ Data\ Volume\ (ODV)} \quad (3)$$

$which : L\ is\ Large\ of\ area$

Thus, the equation below can be administered 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 occupies is understood as coverage planning. The design based coverage of Private 5G planning estimates the number of sites required to provide services, considering factors as antenna gain, interference margin, receiver sensitivity, also others. The determination of the link budget is an essential stage in planning coverage. The parameters calculated in the coverage planning are as follows:

- Propagation Model and Link Budget

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

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

In which 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'_{BP} and $PL_{Uma-LOS}$ is the path loss (dB).

Equations (6) and (7) can be employed to obtain the values of d_{2D} and d'_{BP} :

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

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

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

The estimated coverage associated with the link budget calculation is calculated by employing the maximum coverage of each site. The coverage distance of each site affects how many gNodeBs are required. The following equation is utilized to measure each site's coverage area :

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

The amount of gNodes with in design region is determined utilizing the provided 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 required for capacity calculation encompasses the number of 4G subscribers in the Jababeka Area until June 2022 who may possess a 5G network of 1800 subscribers. Table V demonstrates the value of traffic requirements required 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 measured in accordance with equation (1), and the ODV value is 2688 Mbps/ km²

- gNodes amount based on Capacity Analysis

The calculation of capacity is a factor required to be considered. Other factors affecting system capacity are site usage, frequency spectrum, and sectorization. The capacity calculation of each cell by employing equation (2), in which the antenna selected is 8T8R with modulation of 64 QAM, hence, 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 corroborate calculating the L value under UL and DL conditions as in equation [3], hence, the number of gNodes generated follows the capacity design in the Jababeka area, as demonstrated in Table VI.

B. Coverage Analysis

- *Link Budget Analysis*

Link budget calculations are employed in coverage analysis to calculate the MAPL value that is received by the antenna both uplink and downlink. The frequency range utilized in the design is the first calculation parameter. Next, the parameter values for numerology and the link budget calculation are determined. For instance, the frequency and bandwidth employed by this Private 5G Network design are 2300 MHz and 40 MHz, respectively. Table VII provides a list of all the inputs administered by creating 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
Subscarrier 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 employed to calculate the link budget by utilizing the Table VII parameters, hence, the results acquired for the propagation model, as illustrated 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)
$h'bs$	$h'bs$	24 (m)	24 (m)
$h'UT$	$h'UT$	0.5 (m)	0.5 (m)
Speed of Light	c	$3x10^8$ (m/s)	$3x10^8$ (m/s)
Breakpoint Distance	d'_{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

Utilizing Atoll software, the RSRP value is calculated at a bandwidth of 30 MHz and a frequency of 2300 MHz. Therefore, the total number of gNodeB by administering the calculation results of the optimum number of sites obtained is 69 sites, with 41 sites emploiying 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 displayed in Figure 5 below. Based on the coverage simulation by employing Atoll software, the results are that with the number of needs for gNode 69 sites, the mean SS-RSRP value was -92.76, and in accordance with Table III, it was in the "Good" range.

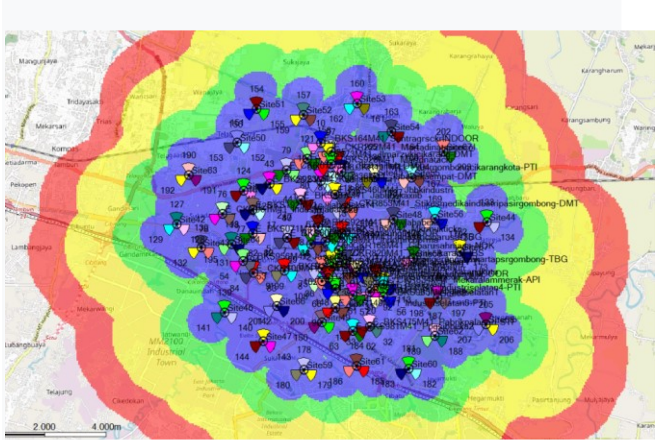

Fig. 4. SS-RSRP Coverage with Frequency of 2300 MHz, BW 40 MHz

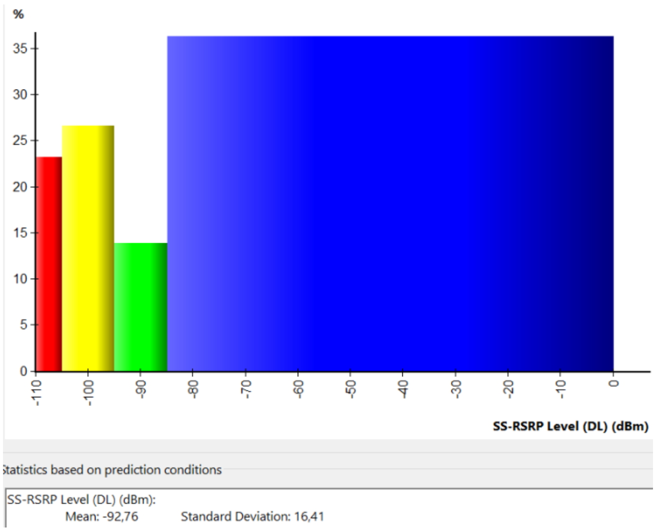

Fig. 5. SS-RSRP Value Jababeka on Frequency of 2300 MHz, BW 40 MHz

- SS-SINR Parameter

The SS-SINR values in this study is obtained from the Atoll planning software at 2300 MHz and BW 40 MHz. The signal strength is divided by the noise and interference of users to generate the SS-SINR result. Based on this paper, the simulation employs Atoll software. Figures 6 and 7 illustrate the results.

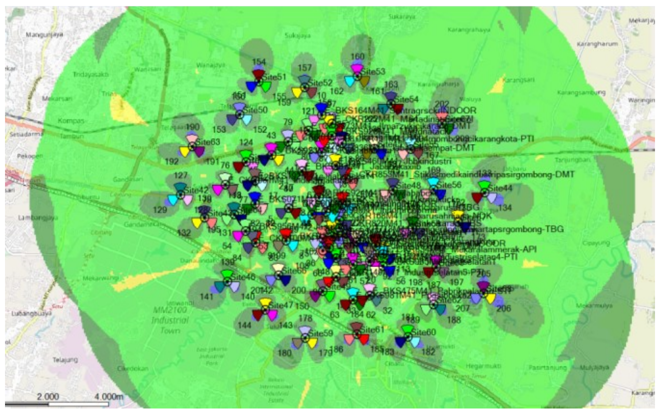

Fig. 6. SS-SINR Coverage with Frequency 2300 MHz, BW 40 MHz

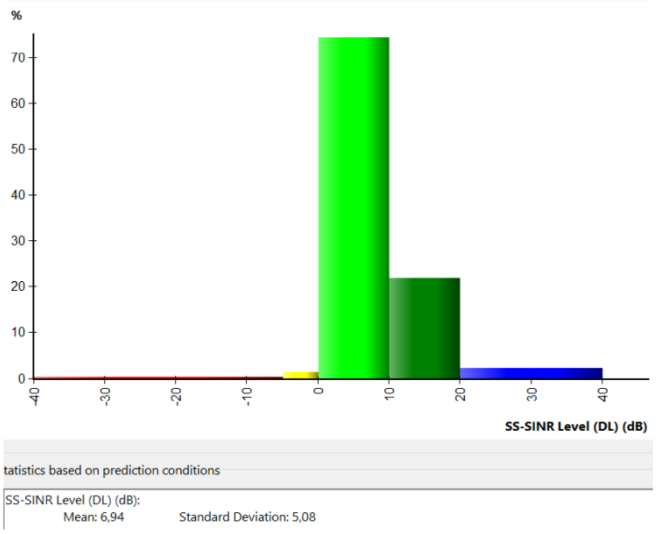

Fig. 7. SS-SINR Value Jababeka with Frequency 2300 MHz, BW 40 MHz

The mean SS-SINR value obtained from the coverage simulation of Atoll software is 6.94, which is within the "Normal" range as presented in Table IV. The comparison between the amount of gNodeB demand based on simulation in research is illustrated in Table IX, as follows.

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 follows the highest numbers for gNodeB in accordance with 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.

V. CONCLUSION

According to the capacity planning computation findings for generating a private 5G network in the Jababeka region, 65 gNodeB are required for UL and 69 gNodeB are required for DL. In order to establish a private 5G network in the Jababeka area, which encompasses 1800 users over a 35 km2 area, 44 gNodeB are highly required for the UL and 69 gNodeB for DL, according to coverage planning calculations. With a total of 69 gNodeB and a traffic demand region of 2688 Mbps/km2, the ideal number of gNodeBs will follow the highest numbers for gNodeB based on projections from capacity and coverage planning.

ACKNOWLEDGMENT

The authors expresses their deepest gratitude to Politeknik Negeri Jakarta for the funds and facilities provided during the research, to Telkomsel and to team of Institut Teknologi Telkom Purwokerto for their assistance, support, and recommendations in completing this research, in which Alfin Hikmaturokhman is the corresponding author.

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