Throughput and Coverage Evaluation on The Use of Existing Cellular Towers for 5G Network in Surakarta City

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ABSTRACT

Currently, telecommunication operators must deploy 5G networks to cope with the exponential growth in internet-access demand. To minimize capital expenditure, existing 4G cell towers are being used to install new 5G base stations (gNodeB). However, 5G has different key performance indicators (KPI), frequency and bandwidth values, and propagation models compared to 4G hence an evaluation of this approach's effectiveness is needed. This paper analyzes 5G network performance with frequency of 3.5 GHz, bandwidth of 100 MHz, and using existing cellular towers in Surakarta City. The city has a total area of 46.8 km^2, mostly flat topography and not many tall buildings therefore propagation models with line-of-sight urban macro (UMa) and urban micro (UMi) are representative. KPI parameters for throughput include 75% of the area served with at least 100 Mbps for downlink and at least 50 Mbps for uplink. KPI parameter for signal strength targets at least 90% of the area covered with -100 dBm or higher. Our Atoll simulations show that the optimistic scenario (UMa) produces average throughput of 153.59 Mbps (downlink) and 117.88 Mbps (uplink), 89.43% served with at least 100 Mbps (downlink) and 100% experience at least 50 Mbps (uplink), average signal strength is -83.99 dBm and 79.71% area covered with at least -100 dBm. The pessimistic scenario (UMi) predicts throughput of 141.32 Mbps (downlink) and 117.88 Mbps (uplink), 86.52% provided with at 100 Mbps (downlink) and 100% served with 50 Mbps (uplink), average signal strength of -90.73 dBm and 75.13% area covered with at least -100 dBm. It can be concluded that the 5G network installed at existing 4G towers can conform to KPI parameters on throughput but still experience drawbacks in signal coverage. A non-Standalone 5G network is suitable for early deployment, but gNodeB installation at new locations is needed in the following years.

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1. INTRODUCTION

The fifth generation of wireless access technology is referred to as 5G New Radio (5G NR). It has been created over the past few years by the Third-Generation Partnership Project (3GPP) to resolve the dilemmas that will arise due to advanced mobile technologies in the future. The primary demands of 5G are segregated into three usage scenarios for mobile communication: Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and Massive Machine Type Communications (mMTC) [1], [2]. eMBB delivers high-speed internet access capable of reaching speeds of 20 Gbps even in harsh environmental conditions [3]. URLLC on 5G networks ensures low latency with a target of under 4 milliseconds [4]. mMTC on 5G networks uses a machine-to-machine communication model, which prioritizes low-speed transmission to support massive device connectivity in IoT applications with large numbers [5], [6].

The demand for internet access is considerable and is further intensified by the emergence of new technologies such as artificial intelligence, the Internet of Things (IoT), and automation, resulting in a significant surge in data production. The surge in data production in this case means that the need for information sent from the server to the recipient requires high internet access speed, so that information can be sent in real-time without any interference such as delay and information data does not accumulate in the channel. The current 4G network infrastructure lacks the capacity to accommodate such a large volume of information and technology, hence necessitating fresh advances in mobile technology. Simultaneously, with the introduction of high-speed, large-capacity, and low-latency 5G technology [7]-[9].

5G technology has the potential to elevate numerous applications, including cloud-based traffic management, high-quality live-streaming video, and online gaming. The advances in 5G have the capability to revolutionize work environments, the global economy, and individual lifestyles. The maximum download speed possible with 5G network broadband services is up to 20 Gbps, it can transfer large amounts of data in cloud applications faster. In addition, 5G network broadband services allow users to perform high-quality live streaming video without buffering. With broadband services and low latency, it can be used for online gaming, so there is no lag when playing [10], [11].

At the World Radiocommunication Conference (WRC), the 3.5 GHz frequency band (3.3 - 4.2 GHz) is used worldwide in countries including the European Union, Latin America, Japan, and South Korea. The World Radiocommunication Conference (WRC) is important because it discusses regulations for deploying 5G networks. The conference established the 3.5 GHz frequency band as the globally optimal frequency and choice for 5G due to its high propagation quality and bandwidth potential, offering maximum coverage and capacity [12]-[15].

XL Axiata and Telkomsel are telecommunications companies that pioneered the deployment of 5G networks in Indonesia with trials in Jakarta using a frequency of 28 GHz and bandwidths of 100 MHz, 400 MHz and 800 MHz. The success of XL Axiata and Telkomsel's 5G network trial is used as a reference for other cellular operators and the government in providing new regulations for 5G networks in Indonesia [16]. 5G networks in Indonesia are recommended to use International Mobile Telecommunications-2020 (IMT-2020) technology and operate in the 2300 MHz or 2.3 GHz frequency band. This is because the 3.5 GHz frequency is still used for satellite communication systems [17], [18]. To date, 5G mobile networks have started operating using the 2.3 GHz frequency in various locations in Indonesia, including Jakarta, Bandung, Batam, Surabaya, Balikpapan, Makassar, Surakarta, Denpasar, and Medan [19], [20].

Telecommunications operators must prepare adequate infrastructure and investment funds for 5G networks, so that 5G networks can be of high quality and reach the entire community. The need for investment funds spent by cellular operators to buy frequency spectrum and bandwidth, build a cell tower, license, 5G devices and operational needs is very large, therefore the 5G network that can be implemented in Indonesia is a non-standalone model. This model is intended so that 5G networks can be supported by 4G technology and use existing cell towers. By utilizing 4G network infrastructure, it allows operators to roll out 5G networks faster because the time in building 5G network infrastructure is faster and the coverage is more evenly distributed. Users' smartphones that already support 5G will connect to the 5G network to get faster data speeds but will still use 4G's core network [21]-[23].

The signal coverage of 5G networks in the middle frequencies (2.3 GHz, 2.6 GHz, and 3.5 GHz) will not be much different from 4G networks due to the adjacent frequency bands, so the coverage can reach 3 km in each cell. The advantage of 5G networks in signal coverage is that there is a beamforming technique which is a technique in 5G by utilizing advanced antenna technology on mobile devices and cell towers to focus the direction of the signal beam in a certain direction. Whereas in the 4G network there is no beamforming technique, so the signal is transmitted in a wide area. The use of greater bandwidth in 5G networks will make the performance of 5G networks more optimal, so that they can produce faster data speeds with a target of 10x that of 4G networks [24]-[27].

The selection of the propagation model used in 5G network planning will affect the signal coverage generated at each gNodeB. In 5G network planning, three propagation models are used that have been standardized by 3GPP TR 38.901, namely Urban Marco (UMa), Urban Micro (UMi) and Rural Macro (RMa). The selection of propagation models is based on environmental conditions that are used in 5G network deployments. The UMa propagation model is more suitable for urban areas that do not have too many tall buildings and industries. The UMi propagation model is more suitable for urban areas that have tall buildings and dense industrial areas. The RMa propagation model is more suitable for rural areas that are sparsely populated and have uneven land contours [28], [29].

The planning of 5G network found literatures [19] commonly was done using greenfield. New gNodeB are installed at land coordinates without considering the real use of the locations, maybe it is middle of street or football field. Greenfield also does not take existing 4G cell towers into account. Despite producing optimum coverage and capacity, greenfield approach can be unrealistic for mobile network operators (telcos) since it requires very large capital expenditure (capex) to construct new 5G cell towers. To decrease capex, a better strategy is to use existing 4G cell towers as starting points for 5G sites. Telcos have installed 4G base stations at optimum locations to provide coverage and capacity for an area. The choice of locations commonly has fulfilled 4G network key performance indicators (KPI) to the customers. Considering that 5G has different modulation, coding scheme, signal to interference and noise ratio (SINR), operational frequency, bandwidth, and KPI, there is no guarantee that the use of existing 4G towers to install 5G base stations is adequate performance to conform 5G KPI. Therefore, a simulation and evaluation of this planning approach is needed.

This paper proposes two scientific contributions. Firstly, simulation and evaluation of 5G network performance utilizing existing 4G cell towers in Surakarta City with urban macro and urban micro propagation models. From results of this evaluation, we propose recommendation on 5G network deployment strategy for Surakarta City as this paper's second contribution. To the authors' best knowledge, there is no previous works touching these topics.

The rest of this paper is organized as follows. Section 2 present research framework, link budget, and KPI for 5G network. Section 3 summarizes and evaluates the simulation results on each KPI, from which recommendation and research limitation are also discussed. Finally, Section 4 concludes this paper.

2. METHODS

This section discusses three issues: research framework, simulation parameters, and simulation. Framework presents input, process, and output of this research. Simulation parameter values are used as estimation. Simulation devises performance metrics to evaluate the 5G network coverage.

2.1. Research Framework

The stages of the research framework are shown through the flow diagram in Fig. 1. Some inputs to this research are relevant information about Surakarta City area, frequency and bandwidth of 5G signal, propagation models, existing cellular towers owned by Telco X, and simulation parameters. Processes consist of three stages: Atoll simulations, and KPI evaluation which includes coverage based on signal level (SS-RSRP), signal quality (SS-SINR), and throughput. Based on KPI evaluation, this research outputs some recommendations on 5G network coverage design for Surakarta City.

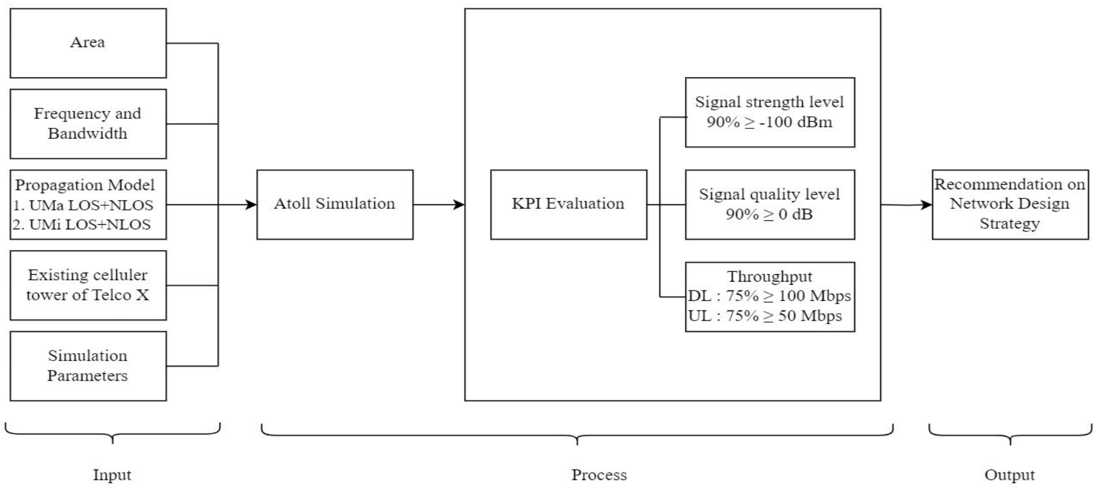
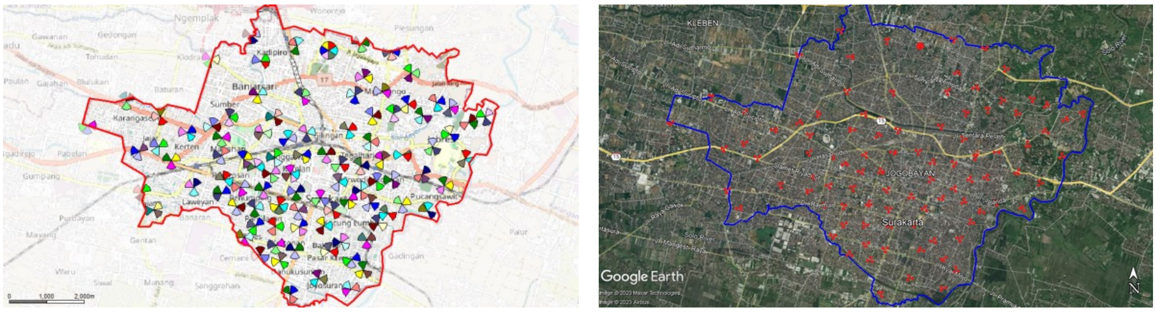


Fig. 1. Research Framework

2.1.1. Area

The determination of the 5G network planning area is the city of Surakarta with an area of 46.8 km^2. Surakarta City as one of the most populated cities in Central Java and the implementation of the smart city. According to the Surakarta City Population and Civil Registration Office, the population in 2022 is 579,212. Based on the total population, this city can be categorized as the urban area. The Atoll simulation requires several geo-data maps, namely digital terrain model (DTM), clutter class and clutter height, to determine the location and condition of the area. The digital terrain model (DTM) is a geographic data file representing the elevation of the ground over sea level. The clutter class geo data file describes land cover or land use. Clutter height maps describe the altitude of clutter over the DTM. Fig. 2 depicts the maps of Surakarta.



(a) (b)

Fig. 2. Map Surakarta City: (a) Map of Surakarta city administrative boundaries, (b) Position of Telco X cellular tower in Surakarta City

2.1.2. Frequency and Bandwidth

The 5G network in this paper is designed for 3.5 GHz band, with details presented in Table 1. This band is used globally in various countries, suitable for the 3GPP ETSI TR 38.901 propagation model, and considered one of ideal frequency bands for 5G due to its propagation properties and potential for greater bandwidth hence capable of providing maximum coverage and capacity. Resource block is a transmission block that is arranged based on the time and frequency domain. In 5G technology with 100 MHz bandwidth, the Sub-Carrier Spacing (SCS) used is 30 kHz. The peak data rate that can be achieved using a frequency of 3.5 GHz and a bandwidth of 100 MHz is a peak downlink data rate of 1753 Mbps and a peak uplink data rate of 625 Mbps.

Table 1. 5G Frequency Band [30]-[32]

NR Operating Band	Downlink	Uplink	Bandwidth	Sub-Carrier Spacing (SCS)	Resource Block
n78	3300-3800 MHz	3300-3800 MHz	100 MHz	30 kHz	273

2.1.3. Propagation Model

Surakarta city is an urban area with a few tall buildings and relatively similar land contours. Based on these characteristics, urban macro (UMi) and urban micro (UMi) with outdoor-to-outdoor and line of sight (LOS) + non line of sight (NLOS) conditions are representative to be used in coverage planning. Pathloss calculations based on 3GPP ETSI TR 38.901 propagation models for urban micro (UMi) and urban macro (UMa) [33], [34] are presented as follows.

a. Urban Micro (UMi)

Urban micro LOS model is suitable for densely populated areas full of high-rise buildings where the received signal is the sum of the direct signal and the dominant indirect signal. There are two pathloss formulas, i.e. PL_1 and PL_2. PL_1 is intended for a radius cell spacing (d_{2D}) between 10 m and the break point spacing (d'_{BP}) and can be calculated as:

$$10 \text{ m} \le d_{2D} \le d'_{BP} \rightarrow PL_1 = 32{,}4 + 21\, log_{10}(d_{3D}) + 20\, log_{10}(f_c) \tag{1}$$

PL_2 is used for a radius cell spacing (d_{2D}) between the break point (d'_{BP}) and 5 km which can be calculated as:

$$d'_{BP} \le d_{2D} \le 5 \text{ km} \rightarrow$$
$$PL_2 = 32{,}4 + 40\, log_{10}(d_{3D}) + 20\, log_{10}(f_c) - 9.5 log_{10}\left((d'_{BP})^2 + (h_{BS} - h_{UT})^2\right) \tag{2}$$

b. Urban Micro (UMi) NLOS

Urban micro NLOS model is suitable for densely populated areas full of high-rise buildings where the received signal is the sum of the direct signal and the dominant indirect signal with any obstacles. PL_3 is intended for a radius cell spacing (d_{2D}) between 10 m and 5km, pathloss formulas can be calculated as:

$$PL_3 = \max(PL_{UMi-LOS}, PL'_{UMi-NLOS})\, for\ 10m \le d_{2D} \le 5\, km \rightarrow \tag{3}$$

$$PL_3 = 35{,}3log_{10}(d_{3D}) + 22{,}4 + 21{,}3log_{10}(f_c) - 0{,}3(h_{UT} - 1.5)$$

c. Urban Macro (UMa) LOS
Urban macro LOS is propagation model intended for densely populated areas where the received signal is the sum of direct and indirect signals. Similar to UMi, UMa also has two pathloss values. PL_1 is used for a radius cell spacing (d_{2D}) between 10 m and the break point spacing (d'_{BP}), and calculated as:

$$10 \text{ m} \le d_{2D} \le d'_{BP} \rightarrow PL_1 = 28 + 22\ log_{10}(d_{3D}) + 20\ log_{10}(f_c) \quad (4)$$

PL_2 is used for a radius cell spacing (d_{2D}) between the break point (d'_{BP}) and 5 km, with formula:

$$d'_{BP} \le d_{2D} \le 5 \text{ km} \rightarrow$$
$$PL_2 = 28 + 40\ log_{10}(d_{3D}) + 20\ log_{10}(f_c) - 9\ log_{10}((d'_{BP})^2 + (h_{BS} - h_{UT})^2) \quad (5)$$

d. Urban Macro (UMa) NLOS
Urban macro NLOS is propagation model intended for densely populated areas where the received signal is the sum of direct and indirect signals with any obstacles. PL_3 is intended for a radius cell spacing (d_{2D}) between 10 m and 5km, pathloss formulas can be calculated as:

$$PL_3 = \max(PL_{UMa-LOS}, PL'_{UMa-NLOS})\ for\ 10m \le d_{2D} \le 5\ km \rightarrow$$
$$PL_3 = 13.54 + 39{,}08\ log_{10}(d_{3D}) + 20\ log_{10}(f_c) - 0{,}6(h_{UT} - 1{,}5) \quad (6)$$

In (1) to (4), the symbols represent, PL_i is the *i*-th pathloss value (dB), d_{3D} is the resultant value between h_{BS} and h_{UT} (m), h_{BS} is the base station height (m), h_{UT} is the height of user terminal (m), d'_{BP} is the break point distance (m), f_c is the frequency (GHz).

2.1.4. Existing Cellular Towers

The 5G network simulation was conducted using 95 existing 4G cellular towers owned by Telco X. The position of the 95 cellular sites is shown in Fig. 2. It can be observed that the site distribution is not even. Some areas have denser cells, other areas more bigger cells. This fact indicates that Surakarta City are served by a combination of microcells and macrocells to provide coverage and capacity needed at each area. The existing position of the cellular tower is used to determine the LOS and NLOS categories by looking at the existing position of the cellular tower through google maps and google earth to find out the obstacles around it. The number of existing cellular towers with LOS conditions is 64 site. Meanwhile, the number of existing cellular towers with NLOS conditions is 31 sites. Based on 3GPP ETSI TR 38.901, the UMa propagation model has a gNodeB height of approximately 25m and the UMa propagation model has a gNodeB height of approximately 10m.

2.2. Simulation Parameters

The 5G network simulation parameters are used to setup the Atoll simulation. The 5G network simulation parameter values are obtained based on 3GPP ETSI TR 38.901 data and several IEEE journals. Table 2 tabulates the details of link budget parameters for coverage planning using UMa and UMi models with outdoor-to-outdoor and LOS+NLOS.

Based on 3GPP ETSI TR 38.901, the gNodeB transmitter power parameter used as a standard in 5G network testing is 46 dBm which can be used in UMa, UMi and RMa propagation models with typical macro cell and mikcro cell. The parameters foliage loss, body block loss, interference margin and penetration loss are used as estimates of the signal power lost in the presence of an obstacle in the calculation of pathloss with outdoor to outdoor (O2O) and outdoor to indoor (O2I) scenarios. The standard values of foliage loss, body block loss and interference margin parameters for O2O and O2I scenarios differ depending on the area used for research.

Receiver sensitivity is the lowest level of signal strength that the UE can receive. The receiver sensitivity value from the calculation is -146.03 dBm which allows the throughput to still be achieved by the UE of 25 Mbps. For the UMa LOS+NLOS propagation model, the main radius that is possible as far as ≥ 1500 m. Meanwhile, for the UMi propagation model LOS+NLOS main radius is possible as far as ±1000 m.

Table 2. 5G Simulation Parameters [35]-[39]

Parameter	Formula	UMa	UMi
gNodeB transmitter power (dBm)	a	46	46
Resource block	b	273	273
Subcarrier quantity	c=12*b	3276	3276
gNodeB antenna gain (dBi)	d	8	8
gNodeB cable loss (dB)	e	2	2
Foliage loss (dB)	f	19.59	19.59
Body block loss (dB)	g	3	3
Interference margin (dB)	h	7	7
Rain/Ice margin (dB)	i	0	0
Slow fading margin (dB)	j	7	7
UT antenna gain (dB)	k	0	0
UT cable loss (dB)	l	0	0
Boltzmann constant(K) (mWs/K)	m	1.38×10^{-20}	1.38×10^{-20}
Temperature (Kelvin)	n	293°	293°
Bandwidth (MHz)	o	100	100
Thermal Noise(dBm)	p = 10 log (m*n*o)	-153.93	-153.93
UT noise figure (dB)	q	9	9
Demodulation threshold SINR (dB)	r	-1,1	-1,1
Penetration loss (dB)	s	26.85	26.85
Receiver sensitivity (dBm)	t = p+q+r	-146.03	-146.03

2.3. Simulation

Atoll application was employed to simulate the 5G network coverage in Surakarta City. This simulator facilitates propagation modeling, scenario creation, parameter setting, and 5G network performance analysis. In this paper, 5G network performance parameters include signal strength, signal quality, and throughput.

Actually, signal strength, quality signal, and throughput are interrelated. Throughput depends on modulation and coding scheme (MCS) used, and MCS is chosen based on SINR value. Larger SINR allows higher MCS to be chosen and then produces faster throughput. In the absent of interference, such as in the case of single cell without any neighboring cells, SINR value become signal to noise ratio (SNR). Noise power is equal to thermal power spectral density multiplied by signal bandwidth thus wider bandwidth produces larger noise power. In this situation, throughput is only determined by received signal strength, the signal strength is radiated power minus pathloss, and pathloss is determined by distance between transmitter and receiver. However, in cellular system, base stations and mobile stations receive signals not only from an intended cell but also from some other cells. Signal from neighbor cells can be regarded as interference.

In multicell simulation, as the case tackled by this paper, intercell interference can be considered significant hence SINR is more appropriate indicator for throughput. Throughput needs to be presented since it is sensible indicator directly-related to the customers' experience. Received signal strength provides information on the pathloss at the respective point. In multicell system, at location may receive signal from more than one base station thus its signal strength value also indicates which base station best serves the location. Therefore, we need the signal strength, signal quality, and throughput to analyze 5G network performance at area under study in order to get more comprehensive view on the situation and more meaningful course of action.

With the knowledge that signal strength, signal quality, and throughput are interrelated, threshold values for each KPI metric should be determined carefully. A telco considers to balance the three KPI parameters in the sense that unconformity of signal strength at a location correlate with unconformity of throughput requirement, and vice versa. As an example, receiver sensitivity for 10 Mbps is -110 dBm which requires SINR of 0 dB. At a location, the received signal strength is -100 dBm but its SINR is 2 dB and its corresponding throughput is 20 Mbps. Since SINR is influenced by noise and interference, this situation indicates that the interference lower that expected such that SINR is 2 dB higher. When this correlation does not hold at certain locations, maybe some irregularities in channel take place that need a deeper investigation. However, telcos normally set KPI metric threshold value based on their best practices.

2.3.1. Signal Strength

Signal strength level in 5G cell is indicated by secondary synchronization reference signal received power (SS-RSRP) which is calculated as the average power carried by the reference signal in the frequency range [39]. Table 3 shows 5G signal strength level indicator and range which are adopted from Telco X's 4G network.

Table 3. Indicators of Signal Strength Level

Range	Indicator	Color
-40 dBm to -80 dBm	Very Good	
-80 dBm to -95 dBm	Good	
-95 dBm to -100 dBm	Normal	
-100 dBm to -110 dBm	Poor	
-110 dBm to -140 dBm	Very Poor	

2.3.2. Signal Quality

Signal quality basically the ratio between the main signal emitted by the base station and the interference and noise that arise (mixed with the main signal), or shortly it is SS-SINR. In 5G, signal quality is represented by physical downlink shared channel carrier to interference noise (PDSCH C/(I+N)) in downlink channel and physical uplink shared channel and physical uplink control channel carrier to interference noise (PUSCH & PUCCH C/(I+N)) in uplink channel [40], [41]. Telco X's 4G signal quality indicator and range are adopted for 5G networks, as presented in Table 4.

Table 4. Indicators of Signal Quality Level

Range	Indicator	Color
> 20 dB	Very Good	
10 dB to 20 dB	Good	
0 dB to 10 dB	Normal	
-10 dB to 0 dB	Poor	
< -10 dB	Very Poor	

2.3.3. Throughput

Downlink and uplink throughputs are parameters used to determine the level of data speed transmitted by the base station [42]. Telco X's 4G network throughput indicator and range are adopted and adapted for 5G network as tabulated in Table 5.

Table 5. Indicators of Throughput Downlink and Uplink 5G

Range		Indicator	Color
Downlink	Uplink		
> 250 Mbps	> 100 Mbps	Very Good	
150 Mbps to 250 Mbps	75 Mbps to 100 Mbps	Good	
100 Mbps to 150 Mbps	50 Mbps to 75 Mbps	Normal	
50 Mbps to 100 Mbps	10 Mbps to 50 Mbps	Pretty Poor	
25 Mbps to 50 Mbps	5 Mbps to 10 Mbps	Poor	
0 Mbps to 25 Mbps	0 Mbps to 5 Mbps	Very Poor	

2.3.4. Key Performance Indicator

Key Performance Indicators (KPI) for evaluation criteria are shown in Table 6. Signal strength level, signal quality level, and throughput parameters are common performance parameter used in research and telecommunications companies for 4G and 5G networks coverage. Determining a high KPI is intended so that UEs with low specifications and located at the edge of the cell can still find neighboring gNodeB. In this paper, 5G network KPIs for signal strength level and signal quality level are chosen the same as the 4G network. Telco X determines its 4G network throughput KPI for downlink as 10 Mbps and uplink as 5 Mbps. Considering that 5G throughput is ten times 4G, this paper chooses the 5G network KPI for downlink throughput is 100 Mbps and uplink throughput is 50 Mbps [11], [45].

Table 6. KPI Values for 5G Network Coverage

Parameter	5G
Signal strength level	90% ≥ -100 dBm
Signal quality level	90% ≥ 0 dB
Throughput Downlink	75% ≥ 100 Mbps
Throughput Uplink	75% ≥ 50 Mbps

3. RESULTS AND DISCUSSION

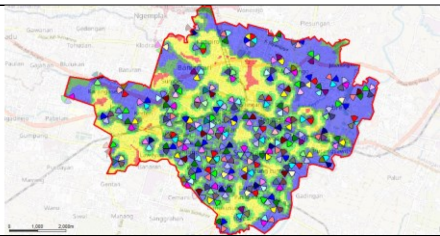
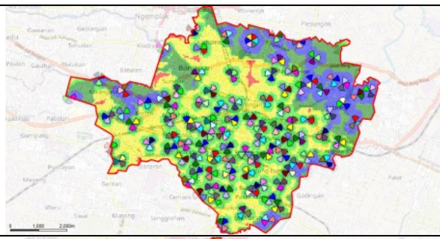
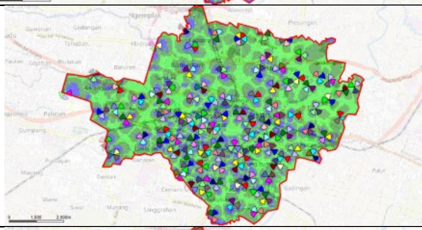
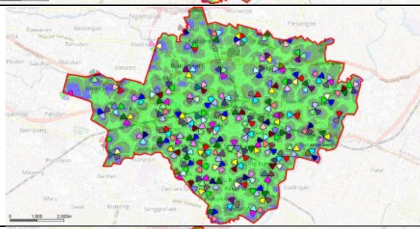
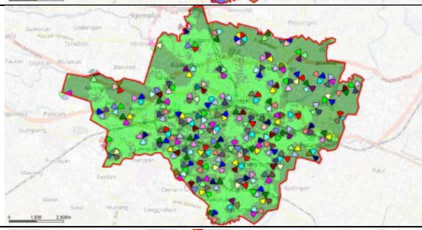
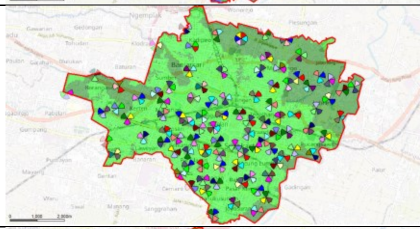
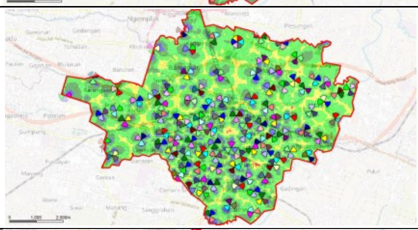
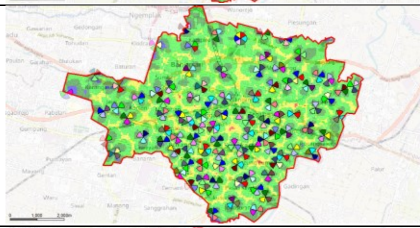
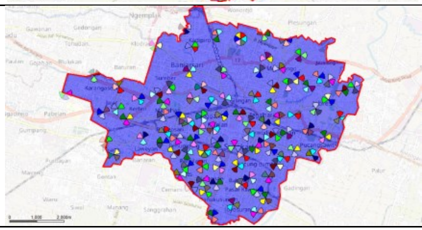
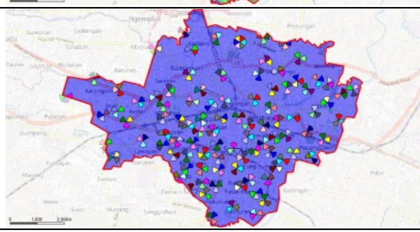
This section mainly consists of two parts: simulation results and overall performance evaluation. Subsection 3.1 presents the results of Atoll simulations on signal coverage, signal quality, and throughput.

Subsection 3.2 discusses KPI evaluation, comparison with previous works, recommendation, and limitation of this study.

3.1. Simulation Results on 5G Network Coverage

Atoll simulations results of 5G network coverage in Surakarta City based on Telco X's 95 existing towers are reported in this subsection. Each performance parameter is presented in color coded map and percentage for each KPI range. Table 7 shows the comparison of the simulation result maps for UMa and UMi propagation models on the parameters of signal strength, signal quality and throughput.

Table 7. Coverage-Map Comparison

KPI Parameters		**UMa**	**UMi**
Signal Strength	SS-RSRP		
Signal Quality	PDSCH C/(I+N)		
	PUSCH & PUCCH C/(I+N)		
Throughput	Downlink		
	Uplink		

Note: For all maps, colors indicated levels above threshold are light green (), dark green (), and blue ().

3.1.1. Signal Strength

Distribution of simulated signal strength is depicted in the first row of Table 7, according to color code defined in Table 3. Average SS-RSRP for UMa is -83.99 dBm with a standard deviation of 14.4 dB, whereas UMi has average SS-RSRP of -90.73 dBm with a standard deviation of 11.79 dB. Calculation of area and percentage of each SS-RSRP range as shown in Table 8. It can be observed that percentage of Surakarta City area with signal strength at least -100 dBm is 79.71% for urban macro model and 75.13% for urban micro model. Therefore, both models SS-RSRP coverage are less than 90% as required by KPI on signal strength.

Equations (1) to (6) state that baseline pathloss for UMa is 28 dB and UMi is 32.4 dB hence the difference is 4.4 dB. Atoll simulations shows that average signal strength values of UMa is 6.74 dB higher than Umi hence quite close to the 3GPP TR 38.901 prediction. Corresponding percentages of signal strength coverage differ 4.58%. UMi has significantly lower percentage of area with SS-RSRP above -80 dBm, as compared to UMa. The majority of area in UMi simulation has signal strength between -110 dBm to -80 dBm, while UMa mostly above -80 dBm. Space distribution of signal strength at the first row of Table 7 shows that east and north part of the territory achieve the highest level (blue) with not very dense cells. The central part of Surakarta is mostly dark green and blue, supported by denser cells. This situation indicates that north-east area has lower pathloss, and central part of Surakarta has more challenging propagation channel due to land contour or buildings. Areas with yellow and red color in the maps, at north-central and west, correspond to sparser cellular sites, may be due to small number of customers reside in those areas.

Table 8. The Result SS-RSRP of 5G Network

Range	Indicator	Color	Area (km^2)		Percentage (%)	
			UMa	UMi	UMa	UMi
-40 dBm to -80 dBm	Very Good		22.5	9.97	48.05	21.28
-80 dBm to -95 dBm	Good		10.62	16.26	22.68	34.72
-95 dBm to -100 dBm	Normal		4.21	8.96	8.98	19.13
-100 dBm to -110 dBm	Poor		8.7	1.16	18.58	23.83
-110 dBm to -140 dBm	Very Poor		0.8	0.49	1.71	1.04
KPI 90% > -100 dBm			**37.33**	**35.19**	**79.71**	**75.13**

3.1.2. Signal Quality

Simulated downlink signal quality is measured through PDSCH C/(I+N), or downlink SS-SINR, as shown at the second row of Table 7, presents downlink signal quality map for urban macro and urban micro. The maps are PDSCH C/(I+N) values coded in color according to Table 4. Downlink SS-SINR for UMa has average of 15.69 dB and standard deviation of 8.22 dB, while UMi has average value of 14.06 dB and standard deviation of 6.61 dB. Furthermore, Table 9 shows that downlink signal quality coverage for UMa is 100% and for UMi is 100%. Both coverage values conform KPI criterion that require 90% area has signal quality > 0 dB.

Table 9. The Result PDSCH C/(I+N) of 5G Network

Range	Indicator	Color	Area (km^2)		Percentage (%)	
			UMa	UMi	UMa	UMi
> 20 dB	Very Good		11.34	8.35	24.2	17.8
10 dB to 20 dB	Good		22.5	23.48	48.1	50.1
0 dB to 10 dB	Normal		12.97	15.1	27.7	32
-10 dB to 0 dB	Poor		0	0	0	0
< -10 dB	Very Poor		0	0	0	0
KPI 90% > 0 dB			**46.8**	**46.8**	**100**	**100**

Simulated uplink signal quality is measured from PUSCH & PUCCH C/(I+N) or uplink SS-SINR as shown at the third row of Table 7. The maps in the figure basically are uplink SS-SINR coded in color according to Table 4. Uplink SS-SINR for UMa has average value of 10.1 dB and standard deviation of 0.43 dB, whereas UMi has average value of 9.9 dB and standard deviation of 2.14 dB. Table 10 summarize the coverage of uplink signal quality above 0 dB is 100% for UMa and 100% for UMi. Both values conform KPI criterion on signal quality as tabulated in Table 6. It can be observed at the second and third rows of Table 7, almost all points are colored blue, dark green, and green. Downlink SS-SINR exhibits better performance since its blue points is more evident than uplink SS-SINR. Uplink SS-SINR has more yellow points, especially for UMi. Both maps confirms that downlink and uplink SS-SINR requirements are fulfilled.

Table 10. The Result PUSCH & PUCCH C/(I+N) of 5G Network

Range	Indicator	Color	Area (km^2)		Percentage (%)	
			UMa	UMi	UMa	UMi
> 20 dB	Very Good		0	0	0	0
10 dB to 20 dB	Good		31,2	21.4	66.6	45.8
0 dB to 10 dB	Normal		15.6	25.4	33.4	54.2
-10 dB to 0 dB	Poor		0	0	0	0
< -10 dB	Very Poor		0	0	0	0
KPI 90% > 0 dB			**46.8**	**46.8**	**100**	**100**

3.1.3. Throughput

Table 7 at fourth row presents map of *downlink* throughput based on range and color code defined in Table 5. Downlink throughput for UMa shows average value of 153.59 Mbps and standard deviation of 63.77 Mbps, and UMi has average value of 141.13 Mbps and standard deviation of 53.35 Mbps. KPI criterion for downlink throughput is at least 75% area covered with at least 100 Mbps. Based on Table 11, coverage for UMa is 89.43% and UMi is 86.52%. Both propagation models conform KPI metrics on downlink throughput. These results are consistent with signal quality result. Downlink throughput is proportional with PDSCH C/(I+N) value.

Table 11. The Result Throughput Downlink of 5G Network

Range	Indicator	Color	Area (km^2)		Percentage (%)	
			UMa	**UMi**	**UMa**	**UMi**
> 250 Mbps	Very Good		4.99	2.23	10.65	4.74
150 Mbps to 250 Mbps	Good		13.79	13.88	29.43	29.6
100 Mbps to 150 Mbps	Normal		23.12	24.44	49.35	52.18
50 Mbps to 100 Mbps	Pretty Poor		4.91	6.24	10.48	13.32
25 Mbps to 50 Mbps	Poor		0.05	0.07	0.1	0.15
0 Mbps to 25 Mbps	Very Poor		0	0	0	0
5G DL KPI 75%> 100 Mbps			**41.9**	**40.55**	**89.43**	**86.52**

Simulated throughput in *uplink* side for urban macro and urban micro are shown at the fifth row in Table 7, with range and color code defined in Table 6. UMa shows an average value of 117.88 Mbps and standard deviation of 0.06 Mbps, while UMi has average value of 117.88 Mbps and standard deviation of 0.06 Mbps. KPI criterion for uplink throughput states that at least 75% of area experience at least 50 Mbps throughput. Table 12 presents that this criterion can be achieved by UMa which shows 100% has at least 50 Mbps and also by UMi with 100% throughput coverage. Uplink throughput value is proportional to PUSCH & PUCCH C/(I+N).

Table 12. The Result Throughput Uplink of 5G Network

Range	Indicator	Color	Area (km^2)		Percentage (%)	
			UMa	**UMi**	**UMa**	**UMi**
> 100 Mbps	Very Good		46.8	46.8	100	100
75 Mbps to 100 Mbps	Good		0	0	0	0
50 Mbps to 75 Mbps	Normal		0	0	0	0
10 Mbps to 50 Mbps	Pretty Poor		0	0	0	0
5 Mbps to 10 Mbps	Poor		0	0	0	0
0 Mbps to 5 Mbps	Very Poor		0	0	0	0
5G UL KPI 75%> 50 Mbps			**46.8**	**46.8**	**100**	**100**

At the fourth row of Table 7, UMa's throughput map is dominated by dark green and blue. At the center, there is yellow area which is served by three gNodeB. This part of area has green and dark green SINR but green to yellow signal strength indicating quite low signal strength. UMi has more yellow and red areas, but overall downlink and uplink throughputs conform the KPI.

3.2. Evaluation of 5G Network Simulation

This chapter discusses evaluation based on KPI, recommendations on 5G network design strategy (gNodeB placement), limitations on this research, and comparison with previous work.

3.2.1. KPI Evaluation

Table 13 summarizes Atoll simulation results on signal strength, signal quality, and throughput coverages, and compares the results with KPI criteria. If simulation result on a parameter conforms its related KPI metric, symbol "✓" is assigned; otherwise, KPI column for the parameter is filled with "✕". Urban macro and urban micro signal quality and throughput coverages, both in downlink and uplink, conforms their KPI criteria. However, signal strength coverage 79.71% for UMa and 75.13% for UMi, quite far from target (90%).

The KPI achievement of the five parameters shows imbalance fulfillment. As discussed in the Subsection 2.3, all KPI parameters (SS-RSRP, SS-SINR, and throughput) are actually interrelated. However, KPI criteria as listed in Table 6 shows that the target percentage values are different (signal strength and signal quality: 90%, throughput: 75%), and the threshold values (SS-RSRP: -100 dBm, SS-SINR: 0 dB, downlink throughput: 100 Mbps, uplink throughput: 50 Mbps) are different as well. The KPI criteria area devised from operators' best practice. We did not establish the equivalence of threshold values and target percentage among KPI parameters, i.e. -100 dBm SS-RSRP is equivalent with 0 dB SS-SINR and 100 Mbps downlink throughput and 50 Mbps uplink throughput. Nevertheless, these simulation results prove that 100 Mbps at downlink and 50 Mbps at uplink at 75% area can be achieved by installing 5G gNodeB at existing 4G sites in Surakarta City. However, bandwidth of 100 MHz at 3.5 GHz band actually can reach peak data rate of 937 Mbps at uplink and 1,752 Mbps at downlink [47]. If the throughput target percentages are increased to 90% and/or the threshold are enhanced to better reflect the potential of 3.5 GHz band and 100 MHz bandwidth, along with the drawback in signal strength coverage, some gNBs should be installed at new locations.

Table 13. Summary of KPI Achievements

KPI Parameters		UMa Mean	UMa Standard Deviation	UMa Area (%)	UMa KPI	UMi Mean	UMi Standard Deviation	UMi Area (%)	UMi KPI
Signal Strength	SS-RSRP (dBm)	-83.99	14.4	79.71	×	-90.73	11.79	75.13	×
Signal Quality	Downlink (dB)	15.69	8.22	100	✓	14.06	6.61	100	✓
	Uplink (dB)	10.1	0.43	100	✓	9.9	0.46	100	✓
Throughput	Downlink (Mbps)	153.59	63.77	89.43	✓	141.32	53.35	86.52	✓
	Uplink (Mbps)	117.88	0.06	100	✓	117.88	0.06	100	✓

Note: ✓ = fulfilling KPI criterion, × = not fulfilling KPI criterion

3.2.2. Recommendation

It is predicted that deployment of gNodeB at existing 4G sites are adequate to provide 100 Mbps at downlink and 50 Mbps at uplink for 75% of Surakarta City area as proved by optimistic scenario (UMa LOS+NLOS) and pessimistic scenario (UMi LOS+NLOS) in Atoll simulations. These results suggest that Telco X can start 5G deployment using their existing towers. There is no need to rush installing gNodeB at new locations.

However, target coverage of 75% area with 100 Mbps at downlink and 50 Mbps at uplink may be enough only at the beginning but quite risky at the following years. Once the customer experience 5G network and engaged in 5G use cases, their requirements on throughput increase exponentially which implies the need of higher percentage of coverage area and throughput threshold. This time, Telco X should install more gNodeB at new locations. The addition of new gNodeBs is also a must, considering that gNodeB installed at existing sites can only provide signal strength with 79.71% coverage (threshold: -100 dBm) for optimistic scenario (UMa LOS+NLOS) and 75.17% coverage at pessimistic scenario (UMi LOS+NLOS). It means that around 25% Surakarta City experience very low signal strength and put the risk of bad throughput experience.
In the future, Telco X is recommended to do these steps:

1. Study and revise KPI criteria to reflect 5G capabilities and customers' requirements of 5G network services in 2025 onwards.
2. Augment the existing sites with new gNodeB sites. This step another Atoll simulation and KPI evaluation.
3. Enhance the 5G network design not only for outdoor-to-outdoor but also for outdoor-to-indoor and indoor, especially at locations that requires high-capacity network service.

3.2.3. Research Limitation

Firstly, Atoll modeling and simulations conducted in this paper did not include real building data in Surakarta City. The simulation setup only utilized clutter data from which Atoll calculate pathloss value between transmitter dan receiver using (1) to (6). Atoll simulations conducted in this paper did not analyze electromagnetic wave using ray tracing in an environment hence some important parameters are not considered, such as multipath, power delay profile, small-scale fading phenomena, channel distortion (inter-symbol interference), and blocking effect by objects. The real signal strength, signal quality, and throughput and their dynamics at each location may be different from the results reported in this paper. Nevertheless, drive test conducted to measure signal strength commonly produce acceptable discrepancy with 3GPP TR 38.901 propagation models.

Secondly, this paper does not include capacity simulation. Therefore, the throughput results are considered valid if the cells do not reach their capacity limit. Atoll also facilitates capacity analysis employing

Monte Carlo simulations. Combined with coverage analysis, Atoll can be used as first stage approach in 5G network planning.

3.2.4. Comparison with Previous Works

A comparison of research on 5G networks, coverage and throughput performance is summarized in Table 14. Of the twelve publications on 5G network coverage and/or throughput analyses, simulation software employed includes Atoll [31], [44], [45], Mentum Planet [30], [35], [39], [42], [43], Matlab [32], [41], and Omnet++ [46]. In addition to simulation, two papers [31], [45] also conducted direct field measurements (drive test method) to verify the simulations. Both papers report a good agreement between the simulation results and field measurements hence adding the confidence of Atoll simulation accuracy in 5G network analysis and design.

The analysis and design of 5G networks for urban areas (industrial area) commonly use UMa and UMi propagation models [30], [35], [39], [42], [43], [44], [47]. Both propagation models are utilized to analyzed 5G network performance in an area to evaluate which model is more representative for that area's characteristics [39,44]. This paper employs UMa model as optimistic scenario and UMi model as pessimistic scenario a larger urban area (city cluster). The simulation complexity is higher than previous works [39], [44]. The optimistic and pessimistic scenarios are chosen in this paper to get the range of best and worst of 5G network performance that leads to more comprehensive evaluation and recommendation.

To do evaluation, KPI criteria are needed. Some papers [30], [35], [42], [43] use *average* values of SS-RSRP and/or SS-SINR. Average throughput values are utilized in [42], [43]. *Maximum* SS-RSRP, SS-SINR, and data rate become performance metrics in [39]. Other criteria are employed, such as network availability and reliability [32], as well as pathloss [30], [35]. While SS-RSRP, SS-SINR and throughput parameters are more common to be chosen as KPI parameters, the use of average or maximum values does not represent the real costumers' experience and network performance. KPI metrics based on SS-RSRP, SS-SINR, and throughput threshold values are used in [44],[45]. Percentage of area that achieve SS-RSRP, SS-SINR, and throughput above threshold is more representative. Although the performance analysis in [45] consider percentage of area that attain SS-RSRP, SS-SINR, and throughput values above threshold, its KPI does not state certain percentage of area as target in KPI thus it differs from this paper's KPI as presented in Table 6. The KPIs in this paper are taken based on Telco X's 4G KPIs with the addition of a minimum percentage of parameter performance limits, so that the performance of the 5G network is maximized.

Network planning, analysis, and evaluation also need scenario to see the range of possibilities that can happen to the area under study. Scenarios are created by choosing independent variables such as frequency, bandwidth, area, propagation model, and the method to place gNodeB sites, as well as dependent variables (measured parameters) that are related to KPI. Commonly, planning is done with automatic placement of gNodeB [30], [35], [39], [42], [43], [44], [45], [46]. This approach is done without considering whether a site location is suitable or realistic, e.g. in the middle of a street, and strongly related to deployment of totally new network, aka greenfield. This paper evaluates 5G network performance based on much more realistic situation, i.e. the placement of gNodeB on existing 4G cellular tower owned by Telco X.

Table 14 shows that 3.5 GHz band and 100 MHz bandwidth is reasonable and has been used in several studies. Studies of throughput at frequency band of 26 GHz with 200 MHz bandwidth produce the ratio of average throughput to peak data rate, the ratio of average throughput per km^2, and the ratio of site number per km^2 as the following: UMi LOS: 0.37, 40.59 Mbps/km^2, 8 site/km^2 and UMi NLOS: 0.17, 10.21 Mbps/km^2, 179 site/km^2 [42]. Result studies of throughput at frequency band of 2.6 GHz with 100 MHz bandwidth as the following: UMa LOS: 0.41, 24.87 Mbps/km^2, 1 site/km^2 and UMa NLOS: 0.29, 17.55 Mbps/km^2, 44 site/km^2 [43]. In this paper, result studies of throughput at frequency band of 3.5 GHz with 100 MHz bandwidth as the following: UMa LOS+NLOS: 0.47, 3.28 Mbps/km^2, 2 site/km^2 and UMi LOS+NLOS: 0.43, 3.02 Mbps/km^2, 2 site/km^2. Therefore, the achievable average throughput in this paper is comparable for better than other works. It can be noted that other papers employ greenfield automatic placement width average served area per cell is 0.2 km^2 or wider, while this paper is only 1 km^2. The value of average throughput/average area per cell achieved in this paper is higher than other works.

From the 12 papers compared in Table 14, only two papers provide recommendations on 5G network planning/deployment strategy. Planning method for 5G can adopt 4G planning method [31]. Extensive studies conducted by [41] suggest the use of larger number of antennas in BS in order to maximize the throughput. This paper utilizes optimistic-pessimistic scenarios and KPI involving five parameters, and then recommends that at early stage the network operator to deploy 5G network at their existing 4G sites. It is expected that outdoor-to-outdoor service can achieve throughput KPI. However, user may find difficulties to connect to the network at around 25% of Surakarta City area hence the next phase of network deployment should install gNodeBs at some selected new sites.

From discussion in this Sections, the notable uniqueness and advantages achieve by this paper are simulation results with UMa and UMi propagation models using existing cellular tower 4G Telco X which targets KPI SS-RSRP 90% ≥ -100 dBm, SS-SINR 90% ≥ 0 dB, Throughput 75% DL ≥ 100 Mbps and UL ≥ 50 Mbps for Surakarta City covering 46.8 km^2. Therefore, it can be concluded that this paper contributes in two main points: study of existing 4G towers for 5G network using comprehensive KPI criteria and optimistic-pessimistic scenarios, and recommendation of 5G network deployment strategy.

Tabel 14. Table of Comparison with Other Researches

Ref., Year	Frequency, Bandwidth	Area, Propagation Model	KPI Metrics	Scenario	Recommendation on Network Design Strategy
[30], 2019	3.5 GHz, 100 MHz	Pulogadung Industrial Estate (5 km^2), UMa LOS	1. Pathloss Downlink = 97.44 dB 2. Pathloss Uplink = 103.43 dB 3. Average SS-RSRP Downlink = -90.8 dBm 4. Average SS-RSRP Downlink = -97.17 dBm	1. gNodeB downlink and uplink 2. Mentum Planet Simulation result using UMa LOS and NLOS are compared 3. Outdoor to outdoor (O2O) and Outdoor to indoor (O2I). 4. The simulation employed Automatic Site Placement (ASP) to determine site position regardless of the existing data.	No recommendation
[31], 2020	3.5 GHz, 60 MHz	Australia, CrossWave	1. Average SS-RSRP = -91 dBm	1. Dense urban, CrossWave propagation model 2. Non-standalone model 3. Simulation result is similar with previous research 4. Difference between Atoll simulation and drive test is around 1 dB.	5G planning can adopt 4G planning method
[32], 2021	30 GHz, 80 MHz	Iowa State University, USA	1. Network availability=99.99% 2. Network reliability = 99%	1. Design with uniform phased array antenna with Matlab Simulator. 2. Network layout design with a group of cells. 3. Implementation of higher-order sectorization with appropriate antenna downtilt angle.	No recommendation

Ref., Year	Frequency, Bandwidth	Area, Propagation Model	KPI Metrics	Scenario	Recommendation on Network Design Strategy
[35], 2021	28 GHz, 100 MHz	Pulogadung Industrial Estate (5km^2), UMi LOS	1. Pathloss Downlink = 110.30 dB 2. Pathloss Uplink = 109.80 dB 3. Average SS-RSRP Downlink = -98.82 dBm 4. Average SS-RSRP Downlink = -99.54 dBm	1. gNodeB downlink and uplink. 2. Mentum Planet Simulation result using UMi LOS. 3. Outdoor to outdoor. 4. The simulation employed Automatic Site Placement (ASP) to determine site position regardless of the existing data.	No recommendation
[39], 2020	2,6 GHz, 100 MHz and 26 GHz, 100 MHz	Jababeka Industrial Estate (22.67 km^2), UMa LOS and NLOS, UMi LOS and NLOS	1. 2.6 GHz-band LOS (max., average, min.): (a) data rate (Mbps): 436.31, 171.15, 13.8; (b) SS-RSRP (dBm): -43.8, -96.01, -114.79; SS-SINR (dB): 17.18, 4.21, -8.36. 2. 26 GHz-band LOS (max., average, min.): (a) data rate (Mbps): 1828.9, 342.19, 57.88; (b) SS-RSRP (dBm): -61.55, -78.14, -94.61; SS-SINR (dB): 14.11, 0.46, -8.74. 3. 2.6 GHz-band NLOS (max., average, min.): (a) data rate (Mbps):436.31, 139.95, 13.8; (b) SS-RSRP (dBm): -40.84, -68.1, -84.74; SS-SINR (dB): 14.41, 2.64, -8.85. 4. 26 GHz-band NLOS (max., average, min.): (a) data rate (Mbps): 327.96, 69.58, 57.88; (b) SS-RSRP (dBm): -61.28, -71.11, -78.13; SS-SINR (dB): 1.71, -7.09, -11,73.	1. gNodeB downlink and uplink 2. Mentum Planet Simulation result using mid-band and high-band are compared. 3. The simulation employed Automatic Site Placement (ASP) to determine site position regardless of the existing data. 4. Outdoor to outdoor.	No Recommendation
[41], 2020	-	Modulation techniques such as QPSK and QAM (i.e., 16, 64, and 256)	No KPI for SNR and data rate	1. Analyze the throughput in terms of SNR Uplink (PUSCH) by varying system parameters (i.e., SCSs, modulation schemes, number of antennas at BS	Throughput can be maximized by the Utilization of larger number of BS antennas, even in very low SNR regime

Ref., Year	Frequency, Bandwidth	Area, Propagation Model	KPI Metrics	Scenario	Recommendation on Network Design Strategy
				and UE, and propagation channel models (CDL and TDL)).	
[42], 2020	26 GHz, 200 MHz	Karawang Industrial areas (5km^2), UMi LOS and NLOS	1. LOS (max., average, min.): (a) data rate (Mbps): 543.79, 202.95, 28.17; (b) SS-RSRP (dBm): -58.30, -86.67, -106.72; SS-SINR (dB): 8.68, 1.70, -7.27. 2. NLOS (max., average, min.): (a) data rate (Mbps): 304.99, 51.05, 28.17; (b) SS-RSRP (dBm): -56.78, -70.88, -85.24; SS-SINR (dB): 4.83, -4.52, -8.43.	1. Urban Micro (UMi) propagation model 2. Simulation software: Mentum Planet 7.3.0 3. The simulation employed Automatic Site Placement (ASP) to determine site position regardless of the existing data. 4. Outdoor to outdoor.	No Recommendation
[43], 2020	2.6 GHz, 100 MHz	Golden Triangle of Jakarta (7.2 km^2), UMa LOS and NLOS	1. LOS (max., average, min.): (a) data rate (Mbps): 436.314, 179.079, 13.808; (b) SS-RSRP (dBm): -51.033, -95.940, -116.983; SS-SINR (dB): 17.246, 4.714, -7.982. 2. NLOS (max., average, min.): (a) data rate (Mbps): 436.314, 126.400, 13.808; (b) SS-RSRP (dBm): -49.553, -65.873, -85.963; SS-SINR (dB): 16.101, 2.153, -8.896.	1. Urban macro (UMa) propagation model 2. Simulation software: Mentum Planet 7.3.0 3. The simulation employed Automatic Site Placement (ASP) to determine site position regardless of the existing data. 4. Outdoor to outdoor.	No Recommendation
[44], 2023	3.5 GHz, 100 MHz and 28 GHz, 200 MHz	Quito City, Equador (6.72 km^2), UMa LOS and NLOS, UMi LOS and NLOS	1. SS-RSRP > -90 dBm 2. SS-SINR > 10 dB 3. DL Throughput > 50 Mbps	1. Number of gNode based on calculation results. 2. The new sites are allocated according to the cell radius of the coverage distance. 3. The site allocation is set automatically using the Automatic Coverage Planning (ACP) tool. 4. Outdoor to outdoor (O2O).	No Recommendation

Ref., Year	Frequency, Bandwidth	Area, Propagation Model	KPI Metrics	Scenario	Recommendation on Network Design Strategy
[45], 2022	-, 100 MHz	Universitas Brawijaya Malang (0,60 km^2), Cost 231-Hata	1. SS-SINR > 0 dB 2. SS-RSRP > -130 dBm 3. SS-RSRQ > 0 dB 4. DL Throughput > 3000 Kbps	1. The number of gNodes is based on the calculation results of 7 sites. 2. Data drive test is used as a KPI. 3. Atoll simulation result using Cost 231-Hata for compare with data drive test.	No Recommendation
[46], 2019	28 GHz, 520 MHz	Yaman City (23.2 km^2), No propagation model as it uses Capacity Planning	1. DL Throughput = 6.5 Gbps 2. UL Throughput = 3.2 Gbps	1. The number of gNodeB is 223 sites, calculated based on population capacity 2. Network simulation OMNET++ result using mm-Wave technique are compared	No Recommendation
[47], 2021	3.5 GHz, 100 MHz	Jakarta City (662.33 km^2), UMa LOS	No KPI for coverage and data rate	1. Calculation of the number of gNodeB based on regional divisions in Jakarta 2. Comparison of data rate results and number of gNodeBs based on calculation diagrams	No recommendation
This paper	3.5 GHz, 100 MHz	Surakarta City (46.8 km^2), UMa LOS+NLOS, UMi LOS+NLOS	1. SS-RSRP ≥ -100 dBm for ≥ 90% area 2. DL & UL SS-SINR ≥ 0 dB for ≥ 90% area 3. DL throughput ≥ 100 Mbps for ≥ 75% area 4. UL throughput ≥ 50 Mbps for ≥ 75% area	1. gNodeB are deployed at 95 existing cellular towers. 2. Atoll simulation results using UMa LOS+NLOS (optimistic scenario) and UMi LOS+NLOS (pessimistic scenario) are compared. 3. Outdoor to outdoor.	First stage of 5G deployment can use existing 4G sites, KPI on throughput can be fulfilled but signal strength coverage cannot. Next, gNodeB should be installed at selected new sites to ensure the fulfillment of all KPI criteria, especially RSRP, and extension for indoor service.

4. CONCLUSION

This paper evaluates the performance of 5G network installed on existing 4G sites with optimistic scenario (urban macro, LOS+NLOS) and pessimistic scenario (urban micro, LOS+NLOS). The 5G network operated at 3.5 GHz and 100 MHz bandwidth is capable to provide 100 Mbps downlink throughput to 89.43% (UMa) and 86.52% (UMi) of Surakarta City. Uplink throughput of 50 Mbps can be provided to 100% (UMa) and 100% (UMi) of the city area. Therefore, the uplink and downlink throughput values surpass KPI criteria (75% area). Average throughput UMa in downlink is 153.59 Mbps and uplink is 117.88 Mbps. Meanwhile, average throughput UMi in downlink is 141.32 Mbps and uplink is 117.88 Mbps. Signal quality (SS-SINR) UMa in downlink produce average of 15.69 dB and reach 100% of area. Meanwhile, signal quality (SS-SINR) UMi in downlink produce average of 14.06 dB and reach 100% of area. Uplink signal quality for UMa serve 100% area with above 0 dB and average of 10.1 dB. Meanwhile, uplink signal quality for UMi serve 100% area with above 0 dB and average of 9.9 dB. Another KPI criterion which requires minimum 90% area covered with signal strength (SS-RSRP) at least -100 dBm. However, signal strength coverage only achieves 79.71% (UMa) and 75.13% (UMi). The average signal strength (SS-RSRP) is -83.99 dBm (UMa) and -90.73 dBm (UMi). Optimistic and pessimistic simulations conclude that 5G network deployed using existing 4G towers can provide the customer with the required throughput, at the beginning. At the following years, gNodeB should be installed at new locations to ensure that signal strength coverage reach 90% of area and higher throughput can be served to the customer.

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