# Comparative study of low power wide area network based on internet of things for smart city deployment in Bandung city

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**ABSTRACT**

Smart city implementation, such as smart energy and utilities, smart mobility & transportation, smart environment, and smart living in urban areas is expanding rapidly worldwide. However, one of the biggest challenges that need to be solved is the selection of the appropriate internet of things (IoT) connectivity technologies. This research will seek for the best candidate low power wide area network (LPWAN) technologies such as long-range wide area network (LoRaWAN), narrow-band internet of things (NB-IoT), and random phase multiple access (RPMA) for IoT smart city deployment in Bandung city is based on IoT network connectivity between with six technical evaluation criteria: gateway requirements, traffic/data projection, the best signal level area distribution, and overlapping zones. Bass model is carried out to determine the capacity forecast. While in coverage prediction, LoRaWAN and NB-IoT use the Okumura-Hata propagation, and Erceg-Greenstein (SUI) model is used for RPMA. Based on the simulation and performance evaluation results, RPMA outperforms LoRaWAN and NB-IoT. It required the least gateway number to cover Bandung city with the best signal levels and overlapping zones.



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## 1. INTRODUCTION

Smart city is a concept of urban development consisting of economic, social, and environmental aspects that focus on citizens' quality of life. Health aging and welfare, energy, transportation, and the environment, an inclusive, innovative, reflective, and safe society will become global social challenges and even Indonesia. Information and communication technology (ICT) is the primary technology behind the smart city complex's development. Intelligent systems that connect things and the information world and provide an autonomous mode of operation are recognized as part of the solution [1].

The smart city is expanding and has become a contemporary trend in all metropolitan areas, considering all elements in completing a solution connected to urban infrastructure. Bandung city, which is categorized as an urban area, is one of the metropolitan cities in Indonesia that has launched a smart city development. However, the deployment of smart city is a significant challenge in urban areas due to without appropriate management or diverting the direction of needs would cause the operational costs to soar [2]. Bandung city is the capital city of west Java province with an area of 167.31 $km^2$ and an uneven topography; it consists of 30 districts in which 2.5 million people live. Bandung city is one of Indonesia's most populous cities with severe traffic jams, floods, and infrastructure maintenance. Based on the 2020-2024 national medium term development plan (RPJMN) of the republic of Indonesia, development policies and strategies in realizing a smart city can be done by utilizing reliable ICT in town services.

The low power wide area network (LPWAN)-based internet of things (IoT) is a new wireless trending technology to help people overcome global challenges. As for some of the IoT connectivity technology characteristics: low power and long-range, legacy wireless services that provide power: long-range (cellular technology: 3G/4G), low power and long-distance: short (ex: Bluetooth, Zig Bee, and WiFi), and low power wide area network (LPWAN), as illustrated in Figure 1. LPWAN-based IoT is a new wireless technology emerging to support the IoT paradigm with cheaper operation than traditional cellular network systems and better power efficiency [3]. Figure 1 shows that LPWAN is superior in cost, low power consumption, coverage, and geographic coverage penetration than cellular and short range device (SRD). However, LPWAN has low data throughput and delay.

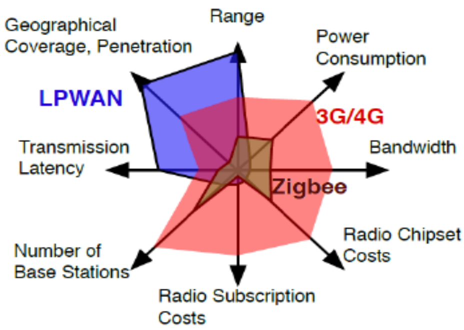



Figure 1. Wireless technology comparison [4]

LPWAN is divided into two licensing standards: the 3rd generation partnership project (3GPP) standard (licensed spectrum) and non-3GPP standard (free license spectrum). Under the Regulation of the director-general of resources and equipment of post and information technology (Perdirjen SDPPI) no. 3 in 2019, the LPWAN frequency band is 920-923 MHz [5]. Narrow-band internet of things (NB-IoT), long-range wide area network (LoRaWAN), extended coverage-global system for mobile communications (EC-GSM), long term evolution for machines (LTE-M), and Sigfox technologies apply frequency bands at 920-923 MHz, in contrast to random phase multiple access (RPMA) as shown in Table 1.

Table 1. LPWAN work frequency and spectrum standards for Asia [6]

| LPWAN | 3GPP Rel. 13 Standard | | | Non-3GPP Standard | | |
|---|---|---|---|---|---|---|
| | NB-IoT | LTE-M | EC-GSM | LoRaWAN | Sigfox | RPMA |
| 939.8 MHz | 939.8 MHz | 700-900 MHz | 900 MHz | 923 MHz | 920.8 MHz | 2.4 GHz |

The deployment of the LPWAN technologies is presented in Figure 2, with Figure 2(a) shows the NB-IoT and LTE-M deployment, Figure 2(b) presents the LoRaWAN deployment, Figure 2(c) illustrates Sigfox deployment and Figure 2(d) displays the RPMA deployment in Indonesia and around the world. LoRaWAN and Sigfox have the same frequency band and spectrum standards characteristics. However, NB-IoT uses a licensed spectrum, and RPMA is a non-3GPP LPWAN standard that uses an operating frequency of 2.4 GHz.

Previous studies have explored the use of NB-IoT and LoRaWAN network planning for several use cases, namely AMI in dense-urban [7], urban, and sub-urban [8], [9]. However, minimal information was found regarding the deployment of NB-IoT and LoRaWAN networks for AMI, supporting multiple use cases simultaneously in one network, especially in urban scenarios. Therefore, this study aims to explore NB-IoT and LoRaWAN technologies as network connectivity for smart city services in Bandung city, representing the urban area and special economic zone in Indonesia.

In particular, a design of study comparative LPWAN: LoRaWAN, NB-IoT, and RPMA based on capacity and coverage planning analysis. LPWAN technology is chosen based on work standards, working frequency, and development in Indonesia. Network planning for LoRaWAN, NB-IoT, and RPMA smart city is based on capacity and coverage analysis. The capacity analysis is the number of data sessions conducted in an area within a certain period, while the coverage analysis is the percentage of the geographic area (Bandung city). Furthermore, the authors will analyze the technology comparison in the distribution of LPWAN in Bandung city.

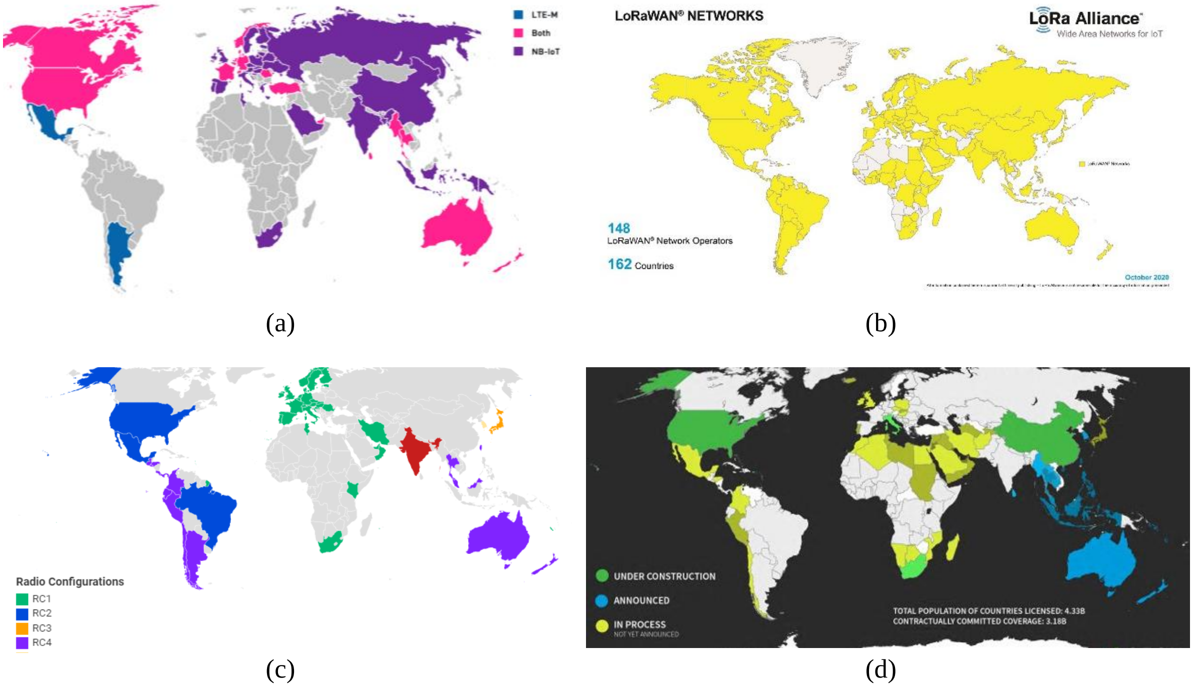



Figure 2. Deployment of LPWAN technologies: (a) NB-IoT and LTE-M, (b) LoRaWAN, (c) Sigfox, and (d) RPMA around the world

## 2. RESEARCH METHOD

Bandung city, which is the capital of West Java Province, has an area of 167.31 km$^2$. Bandung city's population is projected to have 2.5 million in 2019. Hence, before LPWAN-based IoT connectivity services are implemented in Bandung city it is crucial to project the initial value in future market projections. It can be done by projecting the number of devices that need to be predicted in this study's implementation of an effective network with a ten-year range. The coverage and traffic requirements are the basic requirements in deploying LPWAN network planning.

### 2.1. Capacity analysis

#### 2.1.1. Subscriber demand forecasting

Data/traffic requirements of LPWAN are another factor in the preparation or calculation of network deployment. This research was conducted from 2020 to 2030. Forecasting modeling the number of devices with the bass model [10], as in:

$$N(t) = M\frac{1-e^{-(p+q)t}}{1+\frac{q}{p}e^{-(p+q)t}} \tag{1}$$

$p > 0$ is the innovation coefficient which is the probability of an initial purchase at the start of new network deployment, and $q \geq 0$ is the imitation coefficient which refers to the group size of future users.

#### 2.1.2. Traffic requirements projection

Data/traffic requirements do not depend on the method of deploying the LPWAN. Data/traffic analysis in implementation is based on references [11]. One of the powerful features is the on-demand control requirements, in addition to scheduled controls or reads. Command-based requests require a network that listens and responds to on-demand commands promptly. So, bandwidth is not necessary since only latency is the most required. Therefore, IoT wireless connectivity must support two-way communication to ensure long service life and full functionality. Features and technical requirements of the smart city application in this study are shown in Table 2.

Table 2. Smart city technical requirements [12], [13]

| Use case | Event trequency | Payload | |
|---|---|---|---|
| | | Utility-Meter | Meter-Utility |
| Meter reading on-demand | 25 per 1000 meter per day | 200 | 800 |
| Meter reading scheduled | 1 per meter per 6 hours | 12,800 | 12,800 |
| Meter system events | 4 per 1000 meter per month | | 2,224 |
| Outage restoration and management (ORM) | 1 per meter per event | | 200 |
| Real time pricing (RTP) | 60 per 1000 meter per day | 800 | 200 |
| Time of use (ToU) pricing | 60 per 1000 meter per day | 800 | 200 |
| Service switch operation | 50 per 1000 meter per day | 200 | 200 |

## 2.2. Coverage analysis

Coverage planning analysis uses the link budget calculations. The results of coverage planning are anticipated to obtain the cell radius, which will then impact the coverage area, gateway or eNodeB configuration, and propagation models. In addition, link budget calculation obtains the maximum possible path loss estimation from the gains and losses of the antenna transmitter to the receiver, as formulated and illustrated in (2) and Figure 3 [14], [15].

$$P_{Rx} = P_{Tx} - L_{Tx} + G_{Tx} - L_{Path} + G_{Rx} - L_{Rx} \quad (2)$$

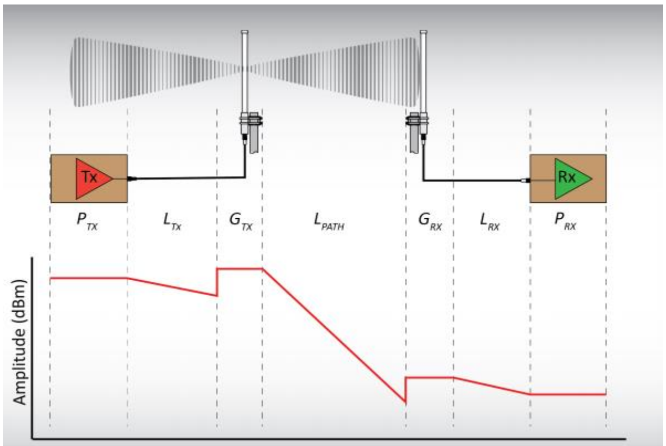



Figure 3. System’s gain-loss profile for a link budget calculation [16]

Path loss calculations are carried out between the transmitter and receiver using the propagation model and other radio waves propagation calculations such as diffraction and image fading. The propagation model is a mathematical representation of the average loss in signal strength over a distance. Diffraction loss and shadow fading margin are added to averaging these losses to obtain precise path loss values. The path loss matrix is calculated for each transmitter, and the results are used in calculating the coverage. The calculation method may differ depending on the analysis performed, as shown in Table 3.

Table 3. Default propagation model [17]

| Propagation model | Erceg-Greenstein (SUI) | Okumura-Hata |
|---|---|---|
| Frequency band | 1900-6000 MHz | 150-1500 MHz |
| Physical phenomena | $L(d, f, H_{Tx}, H_{Rx})$ | $L(d, f, H_{Rx})$ |
| Diffraction calculation method | Deygout (1 obstacle) | Deygout (1 obstacle) |
| Profile-based on | Digital Terrain Model | Digital Terrain Model |
| Profile extraction mode | Radial | Radial |
| Cell size | Macrocell & Minicell | Macrocell & Minicell |
| Receiver location | Street | Street |
| Use | RPMA | LoRaWAN & NB-IoT |

The Okumura-Hata formulas empirically describe the path loss as a function of frequency, transmitter-receiver distance, and antenna height for an urban area. This formula applies to flat, urban environments and a 1.5-meter LPWA antenna height. The path loss (Lu) is calculated in dB by using (3):

$$Lu = 69.55 + 26.16\log(f) - 13.82\log(h_{Tx}) + (44.90 - 6.55\log(h_{Tx}))\log d \quad (3)$$

The Erceg-Greenstein propagation model is a statistical model of path loss from experimental data collected at 1.9 GHz at 95 macrocells. This propagation model is very suitable for distances based on the frequency and height of the Gateway antenna. The line loss model applies antenna heights from 10 to 80 m, gateway distances from 0.1 to 8 km, and three terrain categories. The SUI model is divided into three types of terrain: A, B, and C, as shown in Table 4.

Table 4. SUI terrain types

| Model Parameter | Terrain A | Terrain B | Terrain C |
|---|---|---|---|
| A | 4.6 | 4.0 | 3.6 |
| b ($m^{-1}$) | 0.0075 | 0.0065 | 0.005 |
| c ($m$) | 12.6 | 17.1 | 20 |
| X | 10.8 | 10.8 | 20 |

The Erceg-Greenstein propagation model (SUI) formula is derived from (4)-(6):

$$PL = -7.366 + 26 \times \log_{10}(f) + 10 \times a(h_{Tx}) \times (1 + \log_{10}(d)) - a(h_{Rx}) \quad (4)$$

$a(h_{Rx})$ is the correction for a receiving antenna height different from 1.5 m. When the receiver antenna height is equal to 1.5 m, a $a(h_{Rx})$ approaches 0 dB regardless of frequency:

$$a(h_{Rx}) = 3.2(\log(11.75h_{Rx}))^2 - 4.97 \quad (5)$$

the modeling scenario used in determining the LPWAN coverage area uses a hexagonal approach:

$$S = \frac{3}{2}r^2\sqrt{3} \quad (6)$$

each gateway or eNodeB of the LPWA network connectivity technology system (LoRaWAN, NB-IoT, and RPMA) has its range, which will affect the coverage of the area served. The area can be calculated from six hexagonal equilateral triangles.

### 2.3. LPWAN comparative assessment

A comparative study is the primary multi-attribute decision-making tool DEXi because of the tremendous dimensional optimization problem. It evaluates and contrasts two or more items or ideas side by side. Furthermore, a comparative study is a study that demonstrates the capacity to assess, compare, and contrast subjects or ideas with other issues or ideas. Comparative research indicates how two problems are similar or distinct topics. In addition, the inputs to the analysis are the expressed different model attributes and domain ranges.

## 3. RESULTS AND DISCUSSION

### 3.1. Forecasting of IoT smart city penetration

Forecasting IoT device share is an early-stage analysis in processing projection data. It is commonly utilized for obtaining the fundamental demands of device needs of LPWAN-based IoT connection that is performed on the projected data. Additionally, this forecasts the penetration depth for the IoT operator when implementing the LPWAN technologies inside the designated study region. This research, later, provides an estimated number for the IoT device share required for smart city deployment in Bandung city as a result of its findings.

#### 3.1.1. Forecasting of IoT smart city devices needed

Bandung city is the capital of West Java. Bandung city is also known as a city for shopping and culinary tourism in the Republic of Indonesia. In 2019, there were 2,507,900 inhabitants. The total population of Bandung city in 2020 is 2,529,561 people. The number of connected IoT devices in the city must be prepared to determine LoRaWAN capabilities. Forecasting users of LPWAN-based IoT devices is done by using the geometric method. The number of IoT devices can be selected based on the traditional service users. The number of connected devices in Bandung City, as shown in Table 5. The number of LPWA-based IoT devices connected to smart city in Bandung city is 2,077,335. smart energy & utilities are the most significant connected devices is 53%, smart living is 0%, smart mobility & transportation is 43%, and smart environment is 4%, as illustrated in Figure 4.

Table 5. Bandung city's classifications type for smart city demographics projection area in 2020

| IoT smart city | Growth rate | Number of devices | | Density per sq. km |
|---|---|---|---|---|
| | | 2020 | 2030 | |
| Smart electricity metering | 3.30% | 1,022,690 | 11,675,333 | 69,782.64 |
| Smart water metering | 1.42% | 185,563 | 534,279 | 3,193.35 |
| Smart fuel metering | 3.30% | 295 | 3,401 | 20.33 |
| Smart gas metering | 3.30% | 99 | 1,164 | 6.96 |
| Smart lighting | 3.30% | 305,749 | 3,490,541 | 20,862.72 |
| Smart energy & utilities | 2.92% | 1,508,314 | 13,099,109 | 78,292.45 |
| Smart parking | 8.35% | 6,987 | 2,860,993 | 17,099.95 |
| Smart traffic light | 8.35% | 828 | 339,524 | 2,029.31 |
| Smart public transport | 8.35% | 18,206 | 7,454,327 | 44,553.98 |
| Smart mobility & transportation | 8.35% | 26,018 | 10,652,608 | 63,669.88 |
| Smart waste management | 0.19% | 381,461 | 439,828 | 2,628.82 |
| Smart air quality monitoring | 1.47% | 16,652 | 49,762 | 297.42 |
| Smart water quality monitoring | 1.42% | 309,302 | 890,549 | 5,322.75 |
| Smart environment | 1.03% | 529,836 | 1,139,849 | 6,812.80 |
| Smart disaster warning & alert systems | 1.03% | 13,167 | 22,257 | 133.03 |
| Total IoT device share | | 2,077,335 | 24,913,823 | 148,908.15 |

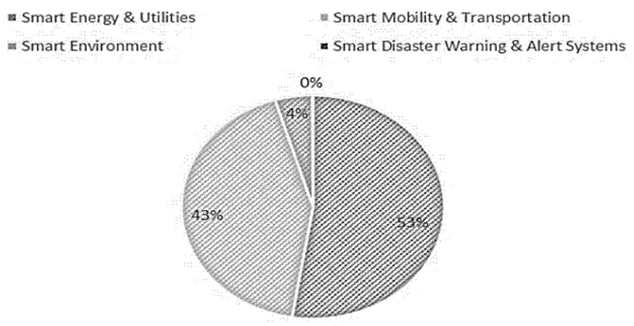



Figure 4. Percentage of smart city devices in 2030

**3.1.2. Forecasting of IoT smart city device share**

The number of devices connected to Bandung city is around 2,077,335. These devices form the basis for the projection of device shares. In order to meet the appropriate IoT network deployment needs, user/device projections need to be predicted. The projection of connected devices is analyzed using the bass model, as in (1). The same parameter values for p (0.00692) and q (0.04356), as done in a study to predict mobile broadband subscriptions in Thailand [10]. Previous research reports show a similar diffusion pattern for mobile broadband services in Indonesia and Thailand, strengthening comparative markets between the two countries. The saturation M (devices share) point occurs in the 73$^{rd}$ year, as illustrated in Figure 5.

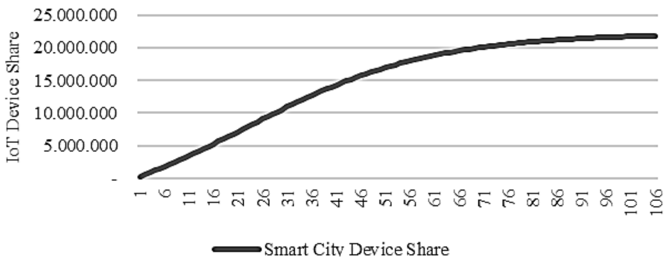



Figure 5. Saturation of IoT device smart city share

Figure 5 shows the market capacity saturation value in considering the components of device needs in Bandung City. According to the average device battery life standard, the predicted values are attained for the ten-year perspective, with 2020 as the base year. The number of adoptions needs for IoT devices per district is carried out to obtain the demand growth for IoT devices in the first year (2021) of deployment until the $10^{th}$ year (2030) according to the average IoT battery capacity, as illustrated in Figure 6.

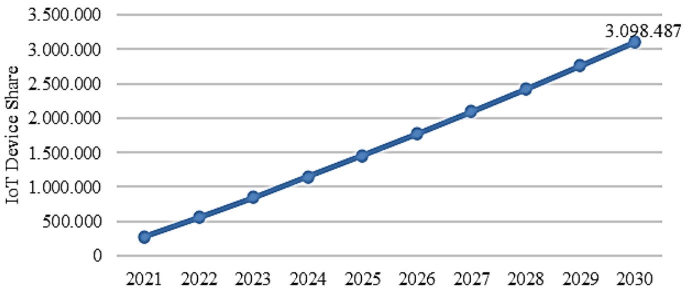



Figure 6. IoT smart city device share in Bandung city within the next ten years

#### 3.1.3. Data/traffic projection of IoT smart city needs

IoT smart city of data/traffic needs projection is the basis for capacity planning in deploying LPWAN. Characteristic requirements based on forecasting the share of IoT devices refer to the mobile broadband market. As explained in the previous chapter, the data/traffic characteristics of IoT smart city refer to the use case, the number of messages each day, and the payload. For each district in Bandung city, the requirements for the number of packages needed per day are shown in Table 6.

Table 6. Total packet per day for Bandung city's IoT smart city

| Use case | Number of end device (Unit) | Number of packets per day for one device | Num. of required packet (bps) |
|---|---|---|---|
| Meter reading on-demand | 77,462 | 1 | 77,462 |
| Meter reading scheduled | 3,098,487 | 4 | 12,393,946 |
| Meter system events | 1,126,722 | 0.042 | 46,984 |
| Outage restoration and management | 3,098,487 | 1 | 3,098,487 |
| Real time pricing | 185,909 | 1 | 185,909 |
| Time of use pricing | 185,909 | 1 | 185,909 |
| Service switch operation | 185,909 | 1 | 185,909 |
| Firmware updates | 6,196,973 | 0.0027 | 16,978 |
| Direct load control | 185,909 | 1 | 185,909 |
| Total packet per day | | | 16,377,494 |

The final calculation of the number of devices is obtained in Table 6. The number of packets per day for one device, burstiness margin, and security margin is obtained based on assumptions. The number of packets required (bps) is the number of end devices shared and packets per day for one device. Thus, the number of packages needed per day is 16 Mbps.

### 3.2. Capacity planning

LoRaWAN, NB-IoT, and RPMA are the leading technologies in the IoT industry in recent days [18]. LoRaWAN is an un-3GPP technology led by Semtech. LoRaWAN's transmission bandwidth options are 125 kHz, 250 kHz, and 500 kHz. According to regulations, Indonesia uses 125 kHz. 3GPP standardizes NB-IoT; NB-IoT's transmission bandwidth is 180 kHz as 1 LTE Physical Resource Block (PRB). RPMA uses the 2.4 GHz unlicensed universal band, which offers 80 MHz bandwidth. RPMA uses the 2.4 GHz unlicensed universal band, which offers 1 MHz bandwidth.

#### 3.2.1. LoRaWAN capacity planning

Networks are designed to be hassle-free and more effective. Therefore, the planned network capacity requirements must match the traffic requirements. LoRaWAN network capacity can be estimated from the input taken from time on air (ToA) packets or transmission times for data rate variations and distributions. The LoRaWAN package consists of several elements, as illustrated in Figure 7.

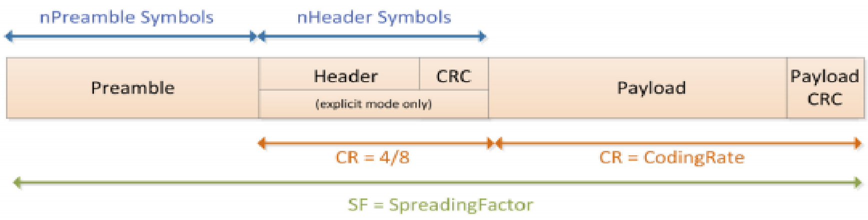



Figure 7. LoRaWAN modem packet

According to Semtech, the LoRaWAN frame duration, known as ToA or payload duration, consists of the actual opening and load of the packet, as described in (8)-(11):

$$ToA = T_{Preamble} + T_{Payload} \quad (8)$$

$$T_{Preamble} = T_{sym} \times (n_{Preamble} + 4.25) \quad (9)$$

$$T_{Payload} = payloadSymbNb \times T_{Sym} \quad (10)$$

$$payloadSymbNb = 8 + \max\left(ceil\left(\frac{8PL-4SF+28+16-20H}{4(SF-2DE)}\right)(CR+4), 0\right) \quad (11)$$

in order to enable the various IoT application optimizations, LoRaWAN uses several necessary design parameters, namely bandwidth, Spreading factor (SF), and Coding rate (CR). This parameter allows the trade-off between data rate optimization, occupied bandwidth, interference, and increased link budget. The required capacity is obtained based on massive IoT devices' traffic characteristics and technical requirements, as shown in Table 7.

Table 7. Single gateway with eight-channel capacity (packet per day) MAX APP THP

| Spreading factor (SF) | Coding rate (CR) | | | | Minimum capacity (Site) | | | |
|---|---|---|---|---|---|---|---|---|
| | CR=1 | CR=2 | CR=3 | CR=4 | CR=1 | CR=2 | CR=3 | CR=4 |
| SF7 | 14,285,714.29 | 14,594,594.59 | 14,594,594.59 | 14,594,594.59 | 2 | 2 | 2 | 2 |
| SF8 | 7,803,468.21 | 7,803,468.21 | 7,988,165.68 | 7,988,165.68 | 3 | 3 | 3 | 3 |
| SF9 | 4,192,546.58 | 4,192,546.58 | 4,299,363.06 | 4,299,363.06 | 4 | 4 | 4 | 4 |
| SF10 | 2,205,882.35 | 2,265,100.67 | 2,265,100.67 | 2,265,100.67 | 8 | 8 | 8 | 8 |
| SF11 | 1,074,840.76 | 1,074,840.76 | 1,102,941.18 | 1,102,941.18 | 16 | 16 | 15 | 15 |
| SF12 | 566,275.17 | 581,896.55 | 581,896.55 | 581,896.55 | 29 | 29 | 29 | 29 |

SF and CR influence the demand needed for LoRaWAN gateways on capacity. The LoRaWAN gateway requirement is based on the SF range from SF7 up to SF12. The capacity planning gateway requirements indicate that SF12 has more important gateway requirements than SF11, SF10, SF9, SF8, and SF7, resulting in 29 sites for Bandung city.

**3.2.2. NB-IoT capacity planning**

The required capacity is based on massive IoT devices' traffic characteristics and technical requirements. The scenarios can be developed based on the connected density, as shown in Table 8. The number of gateways required in the capacity analysis is strongly influenced by households' density per km$^2$ and devices. The analysis is based on 3GPP Rel.13 TR 45.820 V.2.1.0 [19], which supports 45,000 in every three sectoral cells. Therefore, the total gateway requirement in Bandung city is 23 sites.

Table 8. Device density assumption per cell (London model)

| Case | Urban |
|---|---|
| Household density per km$^2$ | 45,000 |
| Inter-site distance (ISD) (km) | 53 |
| Number of devices within a household | 40 |
| Number of devices within a cell site | 54,280 |
| Number of devices (Unit) | 3,098,487 |
| Number of cell needed (Cell) | 69 |
| Minimum capacity (Site) | 23 |

#### 3.2.3. RPMA capacity planning

The total application throughput calculates the RPMA capacity that the network can support. Therefore, the term total application throughput can be described as the acceptance rate of data on one part of the network's gateway infrastructure, as stated in Table 9. The values of the RPMA parameter formulate the RPMA capacity. Capacity planning is needed in obtaining the technical requirements for massive IoT device implementation. The RPMA capacity represents 3% of capacity planning (30/1000). Based on this, the required RPMA gateway is eight sites.

Table 9. Application throughput parameter of RPMA

| Parameter | | Value |
|---|---|---|
| PHY calculation | (1) link data rate | 960 |
| | (2) Number of Simultaneous Links | 1,200 |
| | (3) Sectorization links | 1 |
| | (4) PHY throughput | 1,152,000 |
| MAC calculation | (5) Repetition de-rate | 1 |
| | (6) Other cell interference de-rate | 1.4 |
| | (7) Half-duplex de-rate | 2 |
| | (8) Mac protocol de-rate | 3 |
| Total application throughput (bps)/MHz (4/(5*6*7*8*9)) | | 68,571 |
| Total packet per day * 3% (bps) | | 491,324.82 |
| Minimum capacity (Sites) | | 8 |

### 3.3. Coverage planning

#### 3.3.1. LoRaWAN coverage planning

Several parameters must be determined based on coverage planning, as shown in Table 10. First, the received signal level must be identified; this provides the closest to the extreme level of coverage. Therefore, in (12) and (13) are utilized to know the maximum propagation attenuation to avoid interference. After calculating the link budget, a coverage area analysis is needed to determine the LoRaWAN coverage capability based on area characteristics (urban). LoRaWAN coverage analysis used the Okumura-Hata propagation model based on (2) to obtain the LoRaWAN cell area. Coverage analysis was analyzed using Okumura-Hata propagation, as shown in Table 11. Due to the widest spreading, SF12 is used. Therefore, the number of gateways required is only one.

$$RSSI = -174 + 10\log(BW) + NF + SNR \tag{12}$$

$$MAPL = EiRP - RSSI \tag{13}$$

Table 10. Configuration of LoRaWAN parameters [14]

| MCI Regulation of the Republic of Indonesia 1/2019 | | LoRaWAN Parameter | | Height of Transmitter and Receiver | |
|---|---|---|---|---|---|
| Frequency band (MHz) | 920-923 | Bandwidth (Hz) | 125,000 | Height of Antenna for Urban Area (m) | 30 |
| | | Max Antenna Power (dBm) | 23 | Height of Receiver (m) | 1.5 |
| | | Gain Transmitter (dBi) | 5 | | |
| | | Gain Receiver (dBi) | 2 | | |

Table 11. LoRaWAN, link budget results, based on spreading factor (SF)

| SF | SNR | NF | Sensitivity | EiRP | MAPL | a(hR) | D (km) | Cell area (km$^2$) | Area (km$^2$) | Number of gateway (Site) |
|---|---|---|---|---|---|---|---|---|---|---|
| SF7 | -7.5 | 6 | -125 | 21 | 150 | 0.01687 | 4.7517 | 58.661 | 167.31 | 3 |
| SF8 | -10 | 6 | -127 | 21 | 153 | 0.01687 | 5.5953 | 81.338 | 167.31 | 3 |
| SF9 | -12.5 | 6 | -130 | 21 | 155 | 0.01687 | 6.5886 | 112.78 | 167.31 | 2 |
| SF10 | -15 | 6 | -132 | 21 | 158 | 0.01687 | 7.7583 | 156.38 | 167.31 | 2 |
| SF11 | -17.5 | 6 | -135 | 21 | 160 | 0.01687 | 9.1356 | 216.83 | 167.31 | 1 |
| SF12 | -20 | 6 | -137 | 21 | 163 | 0.01687 | 10.757 | 300.66 | 167.31 | 1 |
| SF7 | -7.5 | 6 | -125 | 21 | 150 | 0.01687 | 4.7517 | 58.661 | 167.31 | 3 |

#### 3.3.2. NB-IoT coverage planning

NB-IoT uses three-sectoral in eNodeB cells, as illustrated in Figure 8. Using the three-sectoral cell is to increases the range and capacity. ISD value is used to determine the area of the three-sectoral cell. ISD is a measure in classifying eNodeB density in cellular networks as stated in 3GPP TR45.820 [20]. The maximum allowed path loss (MAPL) calculation is based on the difference between the measured power level in the transmitting, receiving transmitting, and receiving antennas [7]. Cell power calculations follow 3GPP standards and MAPL. Several parameters are needed to predict coverage planning, as shown in Table 12.

The Okumura-Hata propagation model is used to describe the cell area's ability to be covered [21]. The Okumura-Hata propagation model analysis for NB-IoT technology is analyzed based on the classification of the type of area, as shown in Table 13. The configuration of parameters for each characteristic of an area indicates different coverage capabilities. For example, one site is one of the required numbers of eNodeB (NB-IoT) network designs for Smart City.

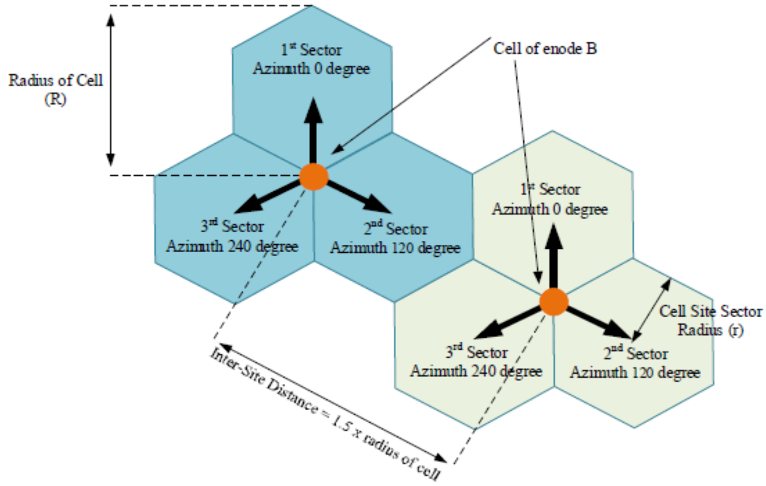



Figure 8. Illustration of three-sectoral cells in NB-IoT [20]

Table 12. NB-IoT link budget calculation

| Parameter | PUSCH | PDSCH |
|---|---|---|
| Frequency Based on Stand-alone (MHz) | 900 | 900 |
| Frequency Based on Operation (MHz) | 940 | 940 |
| Bandwidth Channel (Stand-alone) (kHz) | 200 | 200 |
| TRANSMITTER | | |
| Max Tx Power (dBm) | 23 | 43 |
| (a) Actual Tx Power (dBm) | 23 | 43 |
| Gain Antenna Tx (dBi) | 4 | 17 |
| Height of Antenna's Tx [Urban] (m) | 1.5 | 30 |
| RECEIVER | | |
| (b)Thermal Noise Density (dBm/Hz) | -174 | -174 |
| (c) Receiver Noise Figure (dB) | 3 | 5 |
| (d) Interference Margin (dB) | 0 | 0 |
| (e) Occupied Channel Bandwidth (Hz) | 15,000 | 180,000 |
| (f) Effective Noise Power = (b) + (c) + (d) + 10 log (e) (dBm) | -129 | -116 |
| (g) Required SINR (dB) | -12 | -5 |
| (h) Receiver Sensitivity = (f) + (g) (dBm) | -141 | -121 |
| (i) Rx Processing Gain (dBi) | 0 | 0 |
| (j) MAPL = (a) - (h) + (i) (dB) | 164 | 164 |

Table 13. NB-IoT eNodeB requirement based on coverage analysis

| Okumura-Hata | | Power (kW) |
|---|---|---|
| Link budget/MAPL (dBm) | | 164 |
| Gateway | hT (m) | 30 |
| Height of end device | hR (m) | 35 |
| Frequency | Frq (MHz) | 940 |
| Height of correction factor | a (hR) | 0.0176 |
| Range | R (km) | 11.6 |
| Inter-site distance (ISD) | | 17.5 |
| Cell site sector radius (km) | | 5.82 |
| Cell area (km$^2$) | | 352.30 |
| Area (km$^2$) | | 167.31 |
| Number of cell | | 1 |
| Number of eNodeB (Trisectoral) | | 1 |

#### 3.3.3. RPMA coverage planning

Table 14 shows several parameters that need to be determined based on coverage planning. First, the received signal level must be identified; this provides the closest to the outer level of coverage. Second, before knowing the coverage area capability of the RPMA, it is necessary to know the maximum propagation attenuation to avoid interference. Third, the RPMA frequency uses 2.4 MHz, so the RPMA coverage analysis is analyzed based on the Erceg-Greenstein (SUI) propagation model to explain the cell area. The Erceg-Greenstein (SUI) Terrain A propagation model for RPMA in Bandung city is shown in Table 15 [23].

The configuration parameters for each area's characteristic within a single area coverage capability related to the Erceg-Greenstein propagation model (SUI) show that the coverage capability is not much different in each region type classification. This is because the terrain of an area influences the Erceg-Greenstein (SUI) propagation model. Based on the coverage analysis, it was found that the number of gateways needed in planning the RPMA-based IoT network design for smart city services requires one site.

Table 14. RPMA link budget calculation [22]

| Parameter | | Transmitter | | Receiver | |
|---|---|---|---|---|---|
| Frequency/Frq Down (MHz) | 2.400 | (a) Max Antenna Power/Tx Power (dBm) | 36 | (c) Rx Gain (dBi) | 6 |
| Frequency/Frq Uplink (MHz) | 2.483 | (b) Antenna Gain/Tx Gain (dBi) | 9 | Height of End Device/hR (m) | 1.5 |
| Bandwidth (MHz) | 1 | Height of Gateway/hT [Urban] (m) | 30 | RF Sensitivity at radio module (dBm) | -135 |
| | | | | Losses | 5 |
| | | | | EiRP = (a) + (b) + (c) | 21 |
| | | | | Maximum Allowable Path Loss (dB) = (a) – RF Sensitivity + (c) | 177 |

Table 15. RPMA's gateway requirement based on coverage analysis

| Erceg-Greenstein (SUI) | Urban |
|---|---|
| Height of Transmitter Correction Factor | 4.795 |
| Height of Receiver Correction Factor | -1.34934 |
| Radius Cell (km) | 9.637536 |
| Cell Area ($km^2$) | 241.3148 |
| Area ($km^2$) | 167.31 |
| Number of Gateways (Sites) | 1 |

### 3.4. Gateway requirements

The number of gateways needed to meet the needs of IoT for smart city in Bandung city is obtained from calculating the capacity and coverage planning analysis. The LoRaWAN working specifications use SF7 to SF12 [24]. Therefore, the gateway requirements are based on capacity and coverage planning analysis, calculated using (14) [25].

$$GatewayReq = Max\{No.of\ Gateways\ (coverage), No.of\ Gateways\ (capacity)\} \tag{14}$$

Based on the capacity analysis calculation in Tables 8, 9, and 10. It is obtained that the minimum gateway requirements are 29 for LoRaWAN, 23 for NB-IoT, and eight for RPMA. While in coverage analysis calculation as shown in Tables 12, 14, and 16, the obtained result shows that only one gateway is required for all LPWAN technologies: RPMA = NB-IoT = LoRaWAN. By referring to (14), the number of gateways required to serve Bandung city is 29 for LoRaWAN, 23 for NB-IoT, and eight for RPMA. Therefore, the LoRaWAN technology requires a much larger gateway than NB-IoT and RPMA technologies, simplified into RPMA < NB-IoT < LoRaWAN as illustrated in Table 16.

Table 16. Comparison of LoRaWAN, NB-IoT, and RPMA's gateway requirements

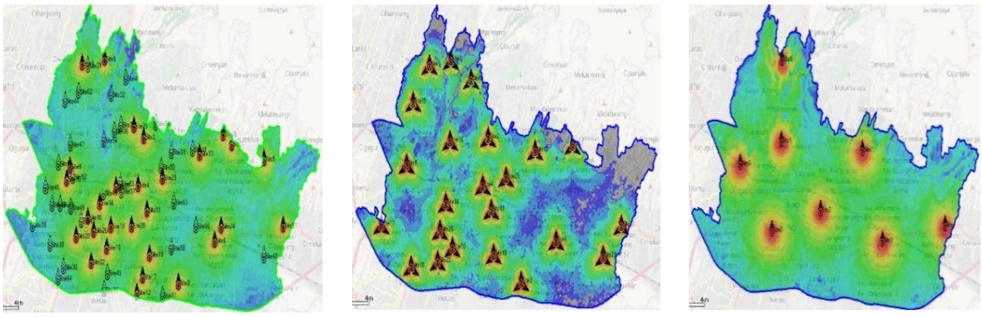
| Technology | Number of devices | Area ($km^2$) | No. of Gateway (capacity) | No. of Gateway (coverage) | Gateways requirements |
|---|---|---|---|---|---|
| LoRaWAN | 3,098,487 | 167.31 | 29 | 1 | 29 |
| NB-IoT | 3,098,487 | 167.31 | 23 | 1 | 23 |
| RPMA | 3,098,487 | 167.31 | 8 | 1 | 8 |

### 3.5. LoRaWAN, NB-IoT, and RPMA signal distribution prediction results

From calculating the capacity and coverage planning analysis, the number of gateways needed is acquired to meet the needs of smart city network deployment in Bandung city. Particularly for LoRaWAN technology since its gateway requirements are analyzed based on SF12. The LoRaWAN, NB-IoT, and RPMA gateway are positioned [26].

#### 3.5.2. The best signal level prediction results

Based on the prediction results, as illustrated in Figure 9, the steadiest LoRaWAN signal levels from -140 dBm to -65 dBm with a mean value of -84.38 dB. Therefore, the best LoRaWAN signal levels are -115 dBm to -110 dBm with a -15.94% distribution, as shown in Figure 9(a). On the other hand, the obtained NB-IoT signal levels are from -105 dBm to -100 dBm, with a mean value of -76.08 dBm. Hence, the most satisfactory NB-IoT signal levels are -95 dBm to -90 dBm with a 21.42% distribution, illustrated in Figure 9(b). Meanwhile, in RPMA, the attained signal levels are from -140 dBm to -65 dBm, with a mean value of -70.21 dBm. Thus, the optimum RPMA signal levels are -110 dBm to -105 dBm with a 17.33% distribution, as shown in Figure 9(c).



(a) (b) (c)

Figure 9. The optimum signal level distribution in Bandung city according to: (a) LoRaWAN, (b) NB-IoT, and (c) RPMA technologies

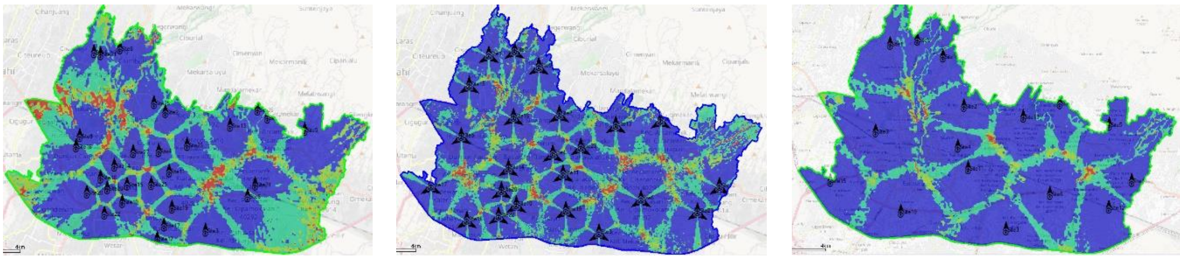
The prediction simulation results show that the best average signal level based on the capacity planning analysis in Bandung city is NB-IoT, followed by RPMA and LoRaWAN. Based on the prediction distribution from these three technologies. It can be concluded that LoRaWAN < NB-IoT < RPMA, as shown in Table 17.

Table 17. Percentage of LoRaWAN, NB-IoT, and RPMA's optimum signal level

| Best signal level (dBm) | Percentage | | |
|---|---|---|---|
| | LoRaWAN | NB-IoT | RPMA |
| [-140; -135] | 0.29% | - | 0.24% |
| [-135; -130] | 0.56% | - | 0.84% |
| [-130; -125] | 3.13% | - | 2.07% |
| [-125; -120] | 6.95% | - | 6.27% |
| [-120; -115] | 12.58% | - | 11.49% |
| [-115; -110] | 17.08% | - | 13.59% |
| [-110; -105] | 16.46% | - | 17.33% |
| [-105; -100] | 14.32% | 10.17% | 16.32% |
| [-100; -95] | 11.17% | 17.49% | 10.8% |
| [-95; -90] | 7.83% | 21.42% | 7.26% |
| [-90; -85] | 4.61% | 18.77% | 4.89% |
| [-85; -80] | 2.48% | 13.34% | 3.24% |
| [-80; -75] | 1.28% | 8.9% | 2.08% |
| [-75; -70] | 0.69% | 5.72% | 1.37% |
| [-70; -65] | 0.59% | 4.18% | 2.2% |

#### 3.5.1. Overlapping zones prediction results

Figure 10 shows the overlapping zones on the distribution of three LPWAN technologies, with Figure 10(a) presents the LoRaWAN overlapping zones, Figure 10(b) for NB-IoT overlapping zones, and Figure 10(c) for RPMA servers from one server to five servers across the whole Bandung city. The simulation prediction results show that the average number of overlapping zones on the server based on the capacity analysis on LoRaWAN is 1.39 servers, NB-IoT is 1.44 servers, and RPMA is 1.22 servers. Thus, the adequate number of overlapping zones can be concluded into RPMA < LoRaWAN < NB-IoT.



(a) (b) (c)

Figure 10. Three LPWAN technologies: (a) LoRaWAN, (b) NB-IoT, and (c) RPMA's overlapping zones distribution in Bandung city

The prediction simulation results show that the overlapping zones are based on capacity planning analysis. Therefore, it can be concluded that the optimum number of overlapping zones between LoRaWAN, NB-IoT, and RPMA servers is LoRaWAN<NB-IoT<RPMA, as shown in Table 18.

Table 18. Percentage of the LoRaWAN, NB-IoT, and RPMA's overlapping zones

| Overlapping zones (Servers) | Percentage | | |
|---|---|---|---|
| | LoRaWAN | NB-IoT | RPMA |
| [1-2] | 68.1% | 67.9% | 79.9% |
| [2-3] | 22.6% | 23.5% | 17.8% |
| [3-4] | 6.6% | 6.4% | 2% |
| [4-5] | 2.7% | 2.2% | 0.2% |

### 3.6. Summary of LoRaWAN, NB-IoT, and RPMA

The summary for determining the criteria for the technical aspects of each LPWAN technology is shown in Table 19. The gateway requirement for LoRaWAN is 29 sites, while NB-IoT requires 23 sites, and RPMA demands only 8 sites. Overall, the RPMA technology network implementation looks superior to LoRaWAN and NB-IoT for smart city in the Bandung city area. This is because RPMA necessitates the smallest number of sites for smart city deployment. Therefore, it can be inferred that RPMA, aside from being superior to the other two LPWAN technologies, also provides more optimal connectivity.

Table 19. Summary of LPWAN technologies for IoT smart city in Bandung city

| Technical Evaluation Criteria | LoRaWAN | NB-IoT | RPMA |
|---|---|---|---|
| Gateway Requirement | 29 sites | 23 sites | 8 sites |
| Traffic/Data Projection | 16,377,494 | 16,377,494 | 16,377,494 |
| The Best Signal Level | -84.38 dBm | -76.08 dBm | -70.21 dBm |
| Overlapping Zones | 1.39 servers | 1.44 servers | 1.22 servers |

## 4. CONCLUSION

This study contributed to comparing LPWAN-based IoT for Smart city in Bandung city. The comparison of LPWAN is aimed to determine the needs and selection of technology based on coverage and capacity network. The three LPWA technologies were selected based on the LPWAN coverage map, working frequency, and spectrum standards. Based on the analysis of the bass model, there were 3,098,487 devices shared in 2030. The analysis of network planning for smart city applications in Bandung city consisted of smart environment (4%), smart energy & utilities (53%), smart mobility & transportation (43%), and smart Living (0%).

Thus, the total number of packages required per day for smart city is 16,377,494 bps. The gateways required to serve Bandung city were 29 for LoRaWAN, 23 for NB-IoT, and eight for RPMA. The LoRaWAN technology requires a much larger gateway than NB-IoT and RPMA. Based on the simulation analysis results, the mean values representing the optimum signal level for LoRaWAN was -84.38 dBm, NB-IoT was -76.08 dBm, and RPMA was -70.21 dBm. Furthermore, 1.39, 1.44, and 1.22 servers were the average overlapping LoRaWAN, NB-IoT, and RPMA zones correspondingly.

LPWAN-based IoT results for smart city implementations showed that RPMA was preferred in gateway requirements, best signal levels, and overlapping zones than the other two technologies: LoRaWAN and NB-IoT. Simultaneously, NB-IoT, comprised of cell site and cell area, was superior in coverage capabilities. Since this research was focused on network connectivity, further study can be carried out, namely, cost-benefit analysis, sensors, and platforms aspects of getting an actual picture of smart city concepts in Bandung city

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