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Techno-Economic Analysis of LoRa WAN Deployment for Typical Massive IoT Applications in Urban and Suburban Areas

[1]Muhammad Imam Nashiruddin, [2]Amriane Hidayati

[1,2] Center for Regulation and Management of Telecommunication, Telkom UniversityBandung, Indonesia
[1]imamnashir@telkomuniversity.ac.id, [2]amriane.hidayati@gmail.com

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Abstract

LoRa WAN is a connectivity option candidate for typical massive IoT applications like a smart city, metering, smart manufacturing, environmental monitoring, and so forth. LoRa WAN is an unlicensed Low Power Wide Area (LPWA) networks that can potentially address the challenge of massive IoT deployment. It is designed to optimize battery lifetime, capacity, range, and cost. LoRa has an enormous advantage concerning cost when compared to 3GPP technologies because the given spectrum for LoRa is free. Although LoRa is a technology adopted from IoT, LoRa also has limitations related to massive deployment. This paper aims to provide techno-economic analysis of LoRa WAN for typical large-scale IoT application and what factors that give impact to the success of the implementation. The urban and suburban areas were chosen to see the differences between those two scenarios.

Keywords; *Internet of Things, LoRa WAN, Long Range, IoT, LPWA, Low Power, Wide Area.*

I. INTRODUCTION

Long Range (LoRa) Wide Area Network (WAN) is one of the leading Low Power Wide Area (LPWA) networks solutions that works in unlicensed band. LPWAN is a group of wireless technology that is developed to meet the needs for wide-range, low power, and low-cost connectivity [19]. The typical applications are small data volumes that transmitted over long distances with infrequent data transfer from varying environments [17]. LoRa WAN has an advantage in technology's long-range capability. LoRa WAN has a substantial link budget and processing gain. It enables decoding signal powers below the noise floor while making it invulnerable to multipath fading, Doppler Shift, and narrowband interference [12]. A single gateway of LoRa WAN can cover entire cities, thus with a minimal amount of infrastructure, entire wide area, or cities can be included [17].

In general, the IoT can divide into 2 (two) typical applications : (1) massive IoT, and (2) critical IoT.

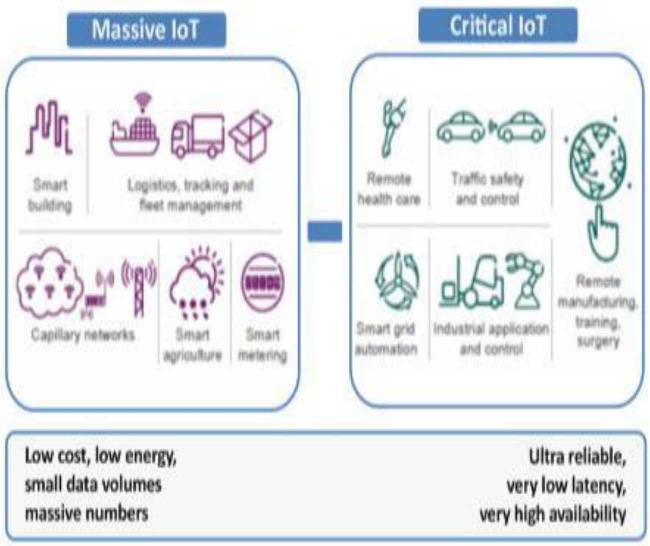

Figure 1. Different requirements for Massive and Critical IoT [4]

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In typical massive IoT applications, to make business case feasible, sensors that report to the cloud regularly must

be at low cost. Therefore, the requirement of typical massive IoT should be low-cost with low power and good coverage

1. Small data volumes and a large number of devices will be the main requirements of this typical IoT applications. On the other hands, in critical IoT applications, reliability, availability, and low latency will be a high demand [4].

Wibisono et al. [20] study the technical and economic aspects of LoRa WAN deployment at Perusahaan Listrik Negara (PLN) in Bali, Indonesia. Based on their analysis result, LoRa WAN is a potential candidate for communication technology to support smart meter reading implementation as application that categorized into massive IoT. The considerations are not only how to meet the requirements, but also the readiness of technology and its ecosystem. Wibisono et al. [20] offer several business models that depend on the priority of PLN as the owner of the smart meter implementation itself. This research limited the area of deployment only in Bali and did not consider the difference of profiles area and the density of connected devices.

In this paper, the implementation of the typical massive IoT application using LoRa WAN technology will be analyzed using two different scenarios based on the density of devices. Cost-benefit analysis (CBA) as a techno-economic tool is used to analyze and prescribe the feasibility of this project deployment. Accordingly, it can be used to assist decision-makers in making a rational investment decision of LoRa WAN deployment while considering the importance of technical aspects.

II. OVERVIEW OF LORA TECHNOLOGY

LoRa WAN is an LPWAN technology developed by Semtech Corporation [14] which defines the communication protocol and system architecture. LoRa is a term for the physical layer that utilized to form the long-range communication. It is supported by the chirp spread spectrum (CSS) modulation technique that maintains similar characteristics as Frequency Shift Keying (FSK) modulation, that considerably will increase the communication range

[17]. Communication of gateways and end-devices using various frequency channels and data rates provides a trade-off between communication range and message duration.

A. LoRa WAN Network Architecture

In a LoRa WAN, multiple gateways typically receive the data from a node. Thus end-devices are not linked with a particular gateway. Each gateway will forward the packet from the device to the network server via some backhaul (either cellular, Ethernet, satellite, or Wi-Fi). In this part, the redundant packet will filter, security checks, and schedule acknowledgements will be performed [17].

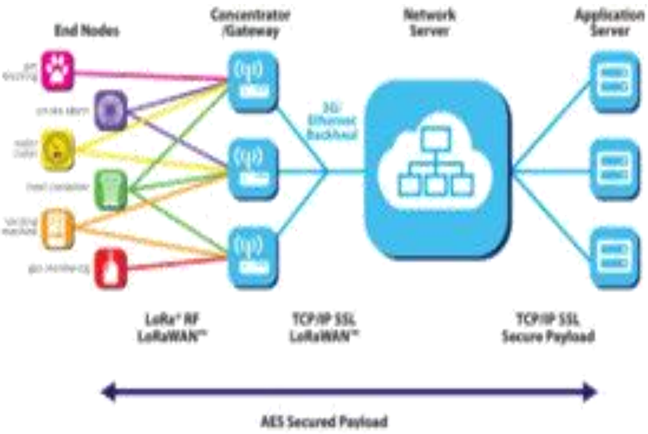

Figure 3. Long Range (LoRa) Wide Area Network (WAN) Architecture [17]

The end devices in a LoRa WAN network are asynchronous and communicate only when they have data ready to send whether event-driven or scheduled. This type of protocol usually referred to as the Aloha method [17]. In the synchronous network like cellular, the nodes have to synchronize with the network and check for messages regularly. This synchronization scheme consumes significant

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energy, and it is the primary driver of battery lifetime reduction in LoRa WAN [17].

The industry is considering to deploy LPWA networks because there is a feasible immediate deployment. The cost of LoRa WAN deployment requires much less capital than other leading LPWA technology that works in the licensed band. LoRaWAN has significant cost savings in the implementation compared to existing systems. Comparing to 3GPP-Standard technology; the LoRaWAN specifications differ slightly based on various regional spectrum allocations and regulatory requirements.

B. LoRa WAN End-devices Classes

In LoRa WAN, there are three different classes of end devices to answer the various needs of the IoT applications.

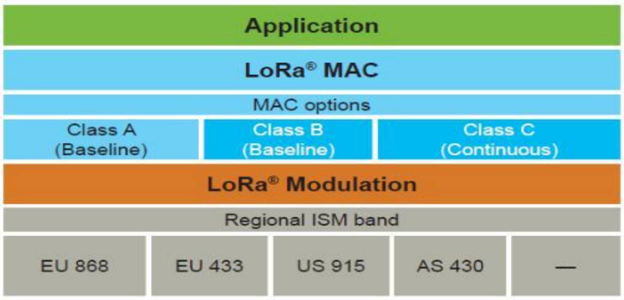

Figure 4. LoRa WAN Device Classes [17]

The trade-off of the device classes is the battery lifetime versus network downlink latency. In several applications like control application, downlink latency is an important factor that must be a concern. Figure 5 shows the trade-off by classes between battery lifetime and downlink latency.

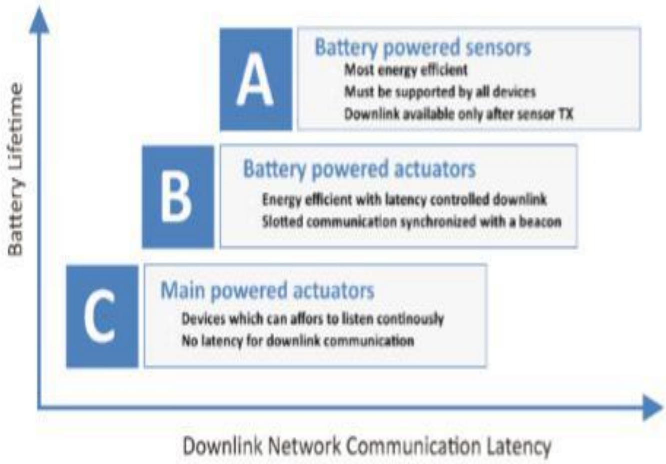

Figure 5. LoRa WAN Device Classes Downlink Latency vs Battery Lifetime [17]

a) *Class A*. Class A is a basic LoRa WAN class and it allowbidirectional communications. Class A offers basic functionality for all LoRa WAN devices. Two short downlinks follow each end-devices uplink transmission receive windows. This class-A operation utilizes the lowest power for applications.

b) *Class B (scheduled receive lots)*. Class B devices openadditional receive windows at regular times. It is an addition to the Class A random receive-windows. It gets a time-synchronized beacon from the gateway. The server will notice when the end-device is listening.

c) *Class C (maximal receive slots)*. Class C has almostcontinuously open receive-windows; it only closed when transmitting at the expense of excessive energy consumption. Higher-class end devices is a general term used for classes other than class A.

III. RESEARCH METHODOLOGY

A. Research Area and Density of Connected Devices

In this research, we are using two different typical areas to represent different scenarios as a case study.

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First, Kota Bandung as the high-density area, which represents urban scenario. Second, Kota Tasikmalaya as the low-density area, which represents a suburban scenario. The density calculates based on the number of population per kilometres. We classify Kota Bandung into a densely populated area, with the people about 2,404,589 people and a total area of 167.67 km^2. While Kota Tasikmalaya is a low-density city with a population of about 692,567 people and a total area of 171.61 km^2 [6]. We are using those two areas to analyze the deployment of LoRa WAN in this research. Figure 6 shows the population density map of West Java, Indonesia.

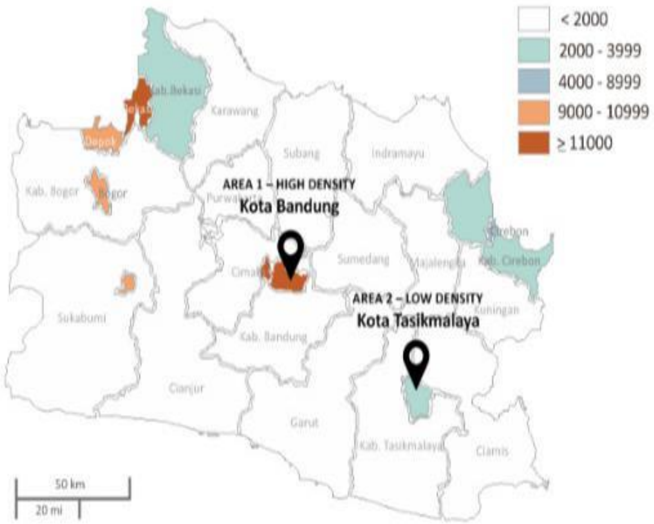

Figure 6. Population Density Map of West Java, Indonesia [6]

Based on population density data, we assume that the number of devices would be 30% – 35% of the number of people in a defined area. The detail calculation is in Table I.

TABLE I. Population And Devices Data For Defined Area

Parameters	Urban Area: Kota Bandung	Suburban Area: Kota Tasikmalaya
Coverage Area	167.67 km^2	171.61 km^2
Population (people)	2,404,589	692,567
Number of Devices	820,000	240,000
Device Density	4,891 meter / km^2	1,399 meter / km^2

B. Defined Scenario

We use two scenarios in this research, and we also conduct the Cost-Benefit Analysis (CBA).

TABLE II. Proposed Scenario

Scenario	Description
Scenario 1	LoRa WAN in Urban Scenario: Kota Bandung
Scenario 2	LoRa WAN in Suburban Scenario: Kota Tasikmalaya

C. Technical Assessment

The technical assessment consists of capacity assessment to determine the number of LoRa WAN gateway and coverage assessment to obtain proper sites by calculating link budget and predicting coverage.

1) Capacity Assessment

The network capacity can be estimated based on inputs taken from the packet Time on Air (ToA) or transmission time for the various data rate.

Figure 7. Time on Air (ToA) Illustration [14]

The LoRa packet comprises several elements, as shown in Figure 8 below.

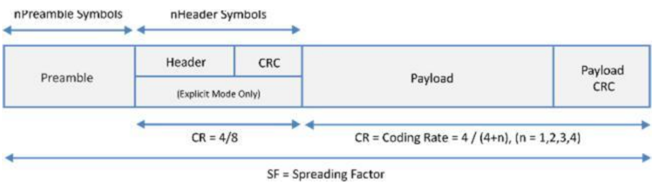

Figure 8. LoRa Modem Packet Formatting [14]

Capacity calculation objective is to determine the total required capacity. Time on Air (ToA) can be used to calculate required capacity. The transmission bandwidth options of LoRa is 125 KHz, 250 KHz, and 500 kHz. Indonesia uses 125 KHz [18].

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According to Semtech [14][9], Time on Air (ToA) is structured of a preamble and the packet payload and is given by equation [1-4] below :

$$\text{Time on Air (ToA)} = T\_Preamble + T\_Payload \quad (1)$$

$$T\_Preamble = (n\_preamble + 4.25).\ T\_sym \quad (2)$$

$$T\_Payload = payloadSymbNb\ .T\_Sym \quad (3)$$

$$payloadSymbNb = 8 + \max\left(\text{ceil}\ \frac{8PL-4SF2816-20H}{4\ SF-2DE}\ (CR+4), 0\right) \quad (4)$$

Note:

- n_preamble is 8
- 4.25 in equation (2) is symbol added by radio
- T_sym : 2SF / Bandwidth (BW)
- PL: the number of payload bytes.
- SF: the spreading factor
- H : 0 the header is enabled and H = 1 no header
- DE: low data rate optimization, DE = 1 for enabled, DE = 0 for disabled.
- CR: the coding rate from 1 to 4 (1 corresponds to CR 4/5, four corresponds to CR 4/8)

LoRa Limitation: Duty Cycle. Network size LoRa is limitedby the duty cycle. It is related to regulatory constraints; the value defined by the authority of the regulatory body in the government. It defined as the fraction between the time the LoRa packet sent to the packet delivery period. It represents the percentage of time an end-device occupies a particular channel. Its common in many countries to use duty cycle 1%. In this research, the duty cycle was not included first to see the real technical limits of LoRa.

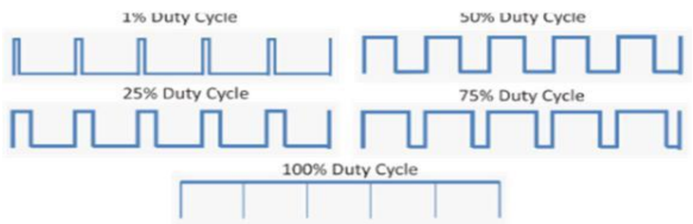

Figure 9. Duty Cycle Visualization

Time on Air (ToA) can be calculated to obtain a single gateway capacity. LoRa end device throughput will depend on the transmission mode. Where can be specified by a combination of bandwidth (BW), spreading factors (SF), and coding rates (CR) [22].

- **Coverage Assessment**

The Free Space Path Loss (FSPL) model serves as a baseline for coverage calculation. According to the estimate of path loss, and using the maximum coverage of the site. Thus, the number of gateways required to cover an area can be known. Simulation of coverage prediction was done using radio network planning tools Forsk Atoll 3.3.2, which provides LPWA module for LoRa WAN technology.

This research classified the area into 2 (two) types, namely the urban and suburban area.

a) *Urban Area (Kota Bandung).* The urban area is an areawhere buildings are close together and characterized by higher population density in comparison to surrounding areas. By using Hata channel model for the city, an equation (5) is used to calculate the distances between a gateway and a device [3].

$$PL = 69.55 + 26.16\log 10\ f - 13.82\log 10\ hB - CH + [44.9 - 6.55\log 10\ hB]\log 10\ d \quad (5)$$

Note:

hB = height of gateway's antenna (meters)

hM = height of device's antenna (meters)

f = transmit frequency (MHz)

CH = antenna height correction factor

d = distance from a gateway to the device (km)

b) *Suburban Area (Kota Tasikmalaya).* The Hata model forsuburban environments applies to the transmissions area out of the cities that has buildings and structures but not as high as in the cities.

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$$L_{su} = L_u - 2\left(\log_{10}\frac{f}{28}\right)^2 - 5.4 \qquad (6)$$

Note:

LSU = path loss in suburban areas (dB)

LU = average path loss from the small city version of the model (above) (dB)

f = frequency of transmission (MHz).

For conducting coverage prediction, some parameters need to be defined as shown in Table III below :

Table III. Configuration Parameters

Parameters	Value	References / Remarks
Frequency Band	923 – 925 MHz	TTN Radio Regulation Summary (AS923-925) [18]
Min RX Sensitivity	-137 dBm	For DR0, Spreading Factor (SF) = 12 (Highest)
Cable Loss	1 dBm	Based on Assumption
Effective Isotropic Radiated Power (EiRP)	16 dBm	LoRaWAN 1.1 Regional Parameters [7]

The received signal level should be identified first to see the minimum required level of coverage at the cell edge.

$$RSSI = EiRP - Pathloss \qquad (7)$$

The next step is setting the RSSI to the minimum sensitivity. -137 is sensitivity for spreading factor 12. Then, it can obtain the maximum distance of a single gateway and also the total number of gateway needed to cover the entire area.

-137= 16 – Pathloss ->Pathloss = 16 + 137 = 153 dBm

- **Projected Customer Growth**

In this research, we consider the projected customer growth. Refer to the average growth of the utility company; the value is assumed to be 6%. It became the baseline for calculating projected customer growth and will include in calculation after the implementation phase.

D. Economic Assessment

We calculate the economic aspects for ten years period. This research uses a 5-year deployment period until the initial investment is complete. Operational lifetime is started in year 2 and ended after year 10.

- **Business Model Determination**

According to reference [20], there are several feasible business models to support the implementation of typical massive IoT (e.g., smart metering). For LoRa WAN, the workable business model is Build Operational Transfer (BOT). BOT is considered a cost-effective model compare with other models. Especially during the initial period of development and operation, save capital expenditure, and reduce operational risk to sensitive development process [20].

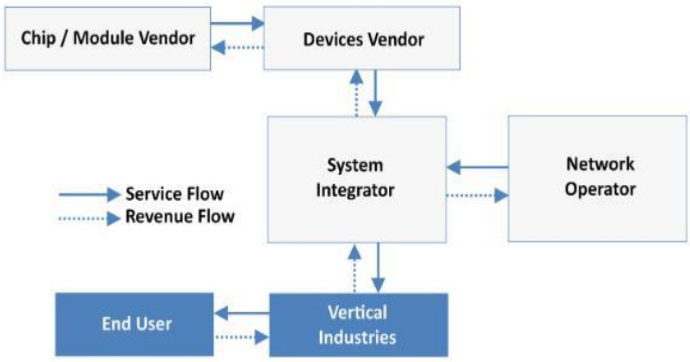

Figure 10. Business Model for LoRa WAN Deployment

Mainly referred to [21], figure 10 shows the value chain and business model of typical massive IoT, including the flow of service and revenue for each party. In LoRa WAN, an available business model built between vertical industries (e.g., utility company, manufactures, and so forth) and system integrator company. System integrator company plays a role in designing hardware and software by making a prototype before being commercialized. After that, they collaborate with the network operator to produce industrial design and mass production of the devices.

- **Cost and Benefit Structure**

The total cost of massive IoT deployment is the sum of capital expenditure (CapEx) and operational expenditure (OpEx). Figure 11 and 12 show the structures of cost and benefit, respectively.

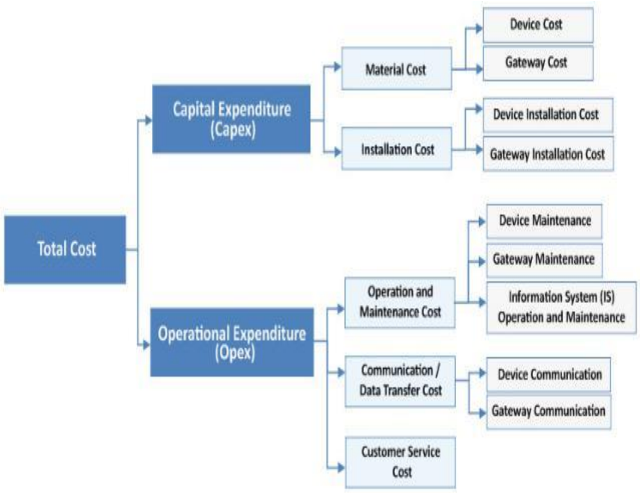

Figure 11. Cost Structure [11][1]

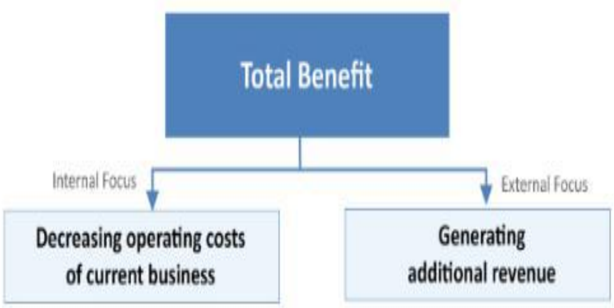

Figure 12. Benefit Structure [2]

The capital expenditure (CapEx) consists of material and installation cost. The operational expense (OpEx) includes operation and maintenance (O&M) cost, data transfer cost, and customer service cost. The cost element calculates per unit based on reference and assumption.

Table V. Capex elements (USD)

Capex Elements		Details	Cost / Unit	Ref
Material Costs	Device	Dumb device	7	[5,11]
		LoRa WAN module	10	[13]
	Gateway	LoRa WAN (overlay)	100-1000	[5,11,14]
	Spectrum	Free	Free	[1]
Installation Costs	Device installation cost		5	[11]
	Gateway installation cost		50	[11,16]

The dumb device is a term for a device that non-internet-enabled physical devices. Market players of IoT are the major user of the cloud with reason to reduce the cost and complexity in delivering IoT solution. Therefore, the Information System (IS) is considered to include into OpEx.

Table VI. Opex Elements (USD)

Opex Elements	Details	Period	Cost / Unit	Ref
Operation & Maintenance	Meter maintenance	Yearly	10% of Capex	[5]
	BS maintenance	Yearly		
	IS maintenance	Monthly	30 - 100	[5]
Communication / Data transfer		Monthly	15	[16]
Customer service		Monthly	10	-

The value of network O&M is 10% of the total CapEx [5]. The breakdown cost paid to application platform vendor for IS O&M is assumed, as shown in Table VII.

Table VII. Is Operation And Maintenance Costs

Area	Subscription Cost	Data Storing Cost	Total Cost
Bandung	82	14.75	96.75 (~100)
Tasikmalaya	24	4.32	28.32 (~30)

The benefit can be measured in two ways by (1) decreasing operating costs of current business and or (2) generating additional revenue [17]. These two factors help to consider whether the solution will have an internal or external focus.

a) Decreasing Operating Costs (Internal Benefit)

Annual savings can represent by internal benefit such as decreasing the meter reading costs, data

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entry costs, faster fault meter detection, technical loss reduction, etc. [8]. To quantify the benefit, it refers to the techno-economic study of smart meter implementation in Bali Indonesia [20], the average annual savings for all calculated scenarios are 3.82% of the total cost. With assumption based on it [20], the internal benefit approach made by calculating 4% of the total cost.

b). Additional Revenue (External Benefit)

The implementation of typical massive IoT is expected to generate additional revenue for the vertical industries. External benefits collected from devices and services price paid by consumers. The average service price per device per month is assumed USD 0.92 [15]. This number is still in an acceptable level, where based on reference [10], in general, there are majority research respondents (38%) willing to pay IoT subscription price between USD 3 – 7 per month.

E. Net Present Value (NPV)

With the data of CapEx and OpEx, further analysis can be conducted to find the Net Present Value (NPV) of the investment. By assuming the discount rate (r) 6%, The NPV can be calculated using the below formula:

$$NPV = \sum_{0}^{t} \frac{B_t - C_t}{(1+r)^t} \quad (8)$$

Note

- NPV is Net Present Value
- Bt is the benefit at time t
- Ct is the cost at time t,
- r is the discount rate *F. Sensitivity Analysis*

In this research, a sensitivity analysis is also presented to determine the parameters that could be subject to change or have a high level of uncertainty. The purpose is to outline, which are the most critical factors in deployment success.

IV. RESULTS AND ANALYSIS

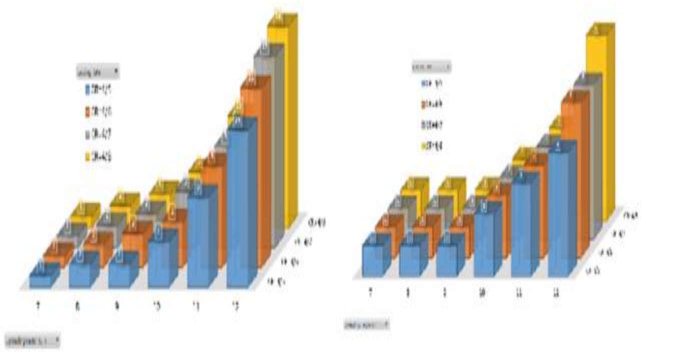
A. Capacity and Coverage Results

The calculation of capacity and coverage were conducted using fix 125 kHz bandwidth, a different spreading factor from 7 to 12, and various coding rate from 1 to 4. 20 bytes as typical massive IoT payload. The required capacity is obtained based on general traffic characteristics of the massive IoT devices. The total required packet per day for urban and suburban areas presented in Table VIII below.

Table VIII. Total Required Packet Per Day

Scenario	Number of Required Packets / Day
Urban Area	7,728,500
Suburban Area	2,262,000

Figure 11 shows the calculation results of the first number of LoRa WAN gateways for fixed 125 kHz bandwidth, different coding rate, and varied spreading factor. The value of the spreading factor (SF) and Coding Rate (CR) strongly influence the number of gateways for both areas. The change of SF shows significant difference than the change of CR. We required more gateways at high SF because of the higher the spreading factor will handle smaller capacity. For the simulation to obtain coverage prediction, its show that SF12 as the highest SF and CR4 as the most reliable forward error correction (FEC).



Urban Scenario **Suburban Scenario**

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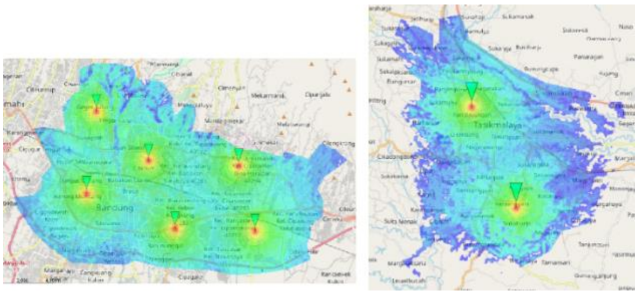
Figure 11. Initial Number of Gateways for Urban and Suburban Area

B. Coverage Prediction Results

According to equation (7), propagation prediction models can be used to determine the distance from the gateway at which path loss will occur. By using equation (5) and (6), we can obtain the distance for urban and suburban areas. Figure 12 shows the coverage prediction of LoRa WAN network for both regions.



(a) (b)

Figure 12. Coverage Prediction for (a) Urban and (b) Suburban Scenario

Based on coverage prediction results, all areas already can be covered. For ranges above 25 km, the best signal level is around -115 to -135 dBm for both regions, still within an acceptable level, while the receiver sensitivity is -137 dBm.

C. Cost and Benefit Analysis (CBA) Results

Based on the calculation of Net Present Value (NPV), it shows that investment in 10 years is not feasible, because it has negative NPV value for all scenarios. Sensitivity analysis is conducted to see optimal results based on several assumptions. Table IX shows parameters subject to change for sensitivity analysis.

Table IX. Parameters for sensitivity analysis

Parameters	Assumption and Baseline	Pessimistic Value	Optimistic Value
Customer growth	6 %	± 1 %	
Material cost (USD)	19	No change	10
Internal benefit	4 %	± 2 %	
External benefit (USD)	0.92	0	1.75
Discount rate	6 %	± 1 %	

In the pessimistic and baseline scenario, the cash flow for non-discounted and discounted (NPV) is negative, as shown in Figure 13 and 14. It means the deployment is not feasible because the investment is not returned yet during ten years of lifespan. After considering some changes in several parameters into an optimistic scenario, the NPV changes to a positive value for overall alternatives since year 5.

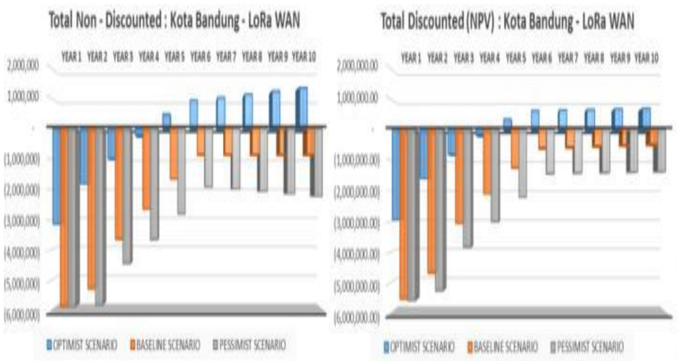


Fig. 13. Total cash flow at the urban scenario for non–discounted and discounted (NPV)

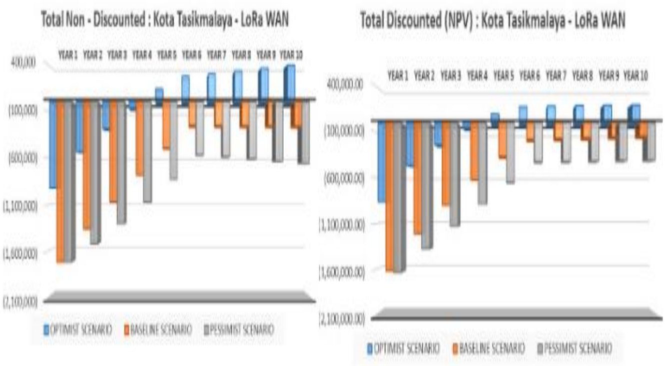


Figure 14. Total cash flow at the suburban scenario: non – discounted and discounted (NPV)

Material cost and external benefit are the most critical factors that influence the change of NPV. They represent the most significant proportion of capital spending for the massive IoT deployment. Besides technical and economic aspects, we need to consider the sustainability of technology lifespan. Research by Nashiruddin [10] shows that Indonesia experiences a high turbulence business environment.

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Moreover, the crucial element that can not be ignored to deal with this situation is the importance of regulations that can accommodate the sustainability of the technology.

V. CONCLUSION

The analysis of technical and economic aspects of typical massive IoT deployment using LoRa WAN technologies has been carried out. LoRa WAN is appropriate for typical massive IoT application that potentially deploys in wide-scale. LoRa WAN also offers high coverage. The capacity in terms of gateways needed for the urban and suburban areas influenced by the value of the bandwidth, spreading factor (SF) and Coding Rate (CR). The change of SF shows significant difference than the change of CR. The analysis of economic aspects has been done to see the feasibility of LoRa WAN deployment. From the NPV calculation and sensitivity analysis, positive results obtained after changing several critical parameters that have a high level of uncertainty into an optimistic scenario. Material costs and external benefit are the essential parameters to bring successful deployment since the variations and changes in those two parameters in massive implementation will bring a significant impact on turning NPV into a positive value.

VI. ACKNOWLEDGEMENT

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REFERENCES

[1]. Actility (2018). LoRaWAN and Cellular IoT (NB-IoT, LTE-M) How do they complement each other?

[2]. Calculate your ROI, learn how M2M can transform your business. Internet : https://www.ingenu.com/portfolio/calculate-m2m-roi/.

[3]. Cooper, N. The Things Network. (2016). Estimating The Service Radius. Internet : https://www.thethingsnetwork.org/community/Oxford/post/estimating-the-service-radius.

[4]. Ericsson (2016, Jan). Cellular Networks for Massive IoT. In Ericsson White Paper Uen 284 23-3278.

[5]. Kalalas, C., Ning, L., Zhang, R., Wu, Y., Laya, A., Markendahl, J., &Höglund, A. (2014). Techno-economic study on capillary networks and cellular technologies for machine-to-machine communications.

[6]. KepadatanPendudukProvinsiJawa Barat. BPS. Internet: https://id.m.wikipedia.org/wiki/Berkas:Kepadatan_penduduk_Provins i_Jawa_Barat.png [Accessed May 2019]

[7]. LoRa Alliance (2017). LoRaWAN 1.1 Regional Parameters.

[8]. Mekki, K., Bajic, E., Chaxel, F., & Meyer, F. (2018). A comparative study of LPWAN technologies for large-scale IoT deployment. ICT Express.

[9]. Mikhaylov, K., Petaejaejaervi, J., &Haenninen, T. (2016, May). Analysis of capacity and scalability of the LoRa low power wide area network technology. In European Wireless 2016; 22nd European Wireless Conference (pp. 1-6). VDE.

[10]. Nashiruddin, M. I. (2018). Understanding the Turbulence of Business Environment in Telecom Industry: Empirical Evidence from Indonesia [MemahamiTurbulensiLingkunganBisnispadaIndustri Telekomunikasi: BuktiEmpirikdari Indonesia]. BuletinPosdan Telekomunikasi, 16(2), 75-90.

[11]. Pillai, R. K., Bhatnagar, R., &Thukral, H. (2016, December). AMI rollout strategy and cost-benefit analysis for India. In Sustainable Green Buildings and Communities (SGBC), International Conference on (pp. 1-6). IEEE.

[12]. Pop, A. I., Raza, U., Kulkarni, P., &Sooriyabandara, M. (2017, December). Does bidirectional traffic do more harm than good in LoRaWAN based LPWA networks?. In

GLOBECOM 2017-2017 IEEE Global Communications Conference (pp. 1-6). IEEE.

[13]. Ray, B. (2018, June). NB-IoT vs. LoRa vs. Sigfox. Internet: NB-IoT vs. LoRa vs. Sigfox

[14]. Semtech Corporation. (2013, July). LoRa Modem Designer's Guide AN1200.13.

[15]. Suryanegara, M., Arifin, A. S., Asvial, M., Ramli, K., Nashiruddin, M. I., &Hayati, N. (2019). What are the Indonesian Concerns About the Internet of Things (IoT)? Portraying the Profile of the Prospective Market. IEEE Access, 7, 2957-2968.

[16]. Tabbane, S. (2016, December). IoT Network Planning: Developing the ICT ecosystem to harness IoTs ". ITU ASP COE Training.

[17]. Technical Marketing Workgroup 1.0. LoRa Alliance. (2015, November). LoRaWAN, What it is? Technical overview of LoRa® and LoRaWAN™.

[18]. The Things Network. LoRaWAN Frequency Plans and Regulations byCountry. Internet : https://www.thethingsnetwork.org/docs/lorawan/frequencies-by-country.html#i

[19]. Varsier, N., &Schwoerer, J. (2017, May). Capacity limits of LoRaWAN technology for smart metering applications. In 2017 IEEE International Conference on Communications (ICC) (pp. 1-6). IEEE.

[20]. Wibisono, G., Saktiaji, G. P., & Ibrahim, I. (2017, November). Techno-economic analysis of smart meter reading implementation in PLN Bali using LoRa technology. In 2017 International Conference on Broadband Communication, Wireless Sensors and Powering (BCWSP) (pp. 1-6). IEEE.

[21]. Wibisono, G., Permata, S. G., Awaludin, A., &Suhasfan, P. (2017, December). Development of advanced metering infrastructure based on LoRa WAN in PLN Bali toward Bali Eco-smart grid. In 2017 Saudi Arabia Smart Grid (SASG) (pp. 1-4). IEEE.

[22]. Yousuf, A. M., Rochester, E. M., Ousat, B., & Ghaderi, M. (2018, June). Throughput, Coverage, and Scalability of LoRa LPWAN for the Internet of Things. In 2018 IEEE/ACM 26th International Symposium on Quality of Service (IWQoS) (pp. 1-10). IEEE.