Selection of IoT-based technology for electric smart meter on PLN Disjaya

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Abstract. With so many platforms or protocols developed by several organizations or institutions, such as LoRa, NB-IoT and SigFox that have their own advantages and limitations. While it takes a large and long-term investment to deliver IoT technology. Apart from that, losses caused by the use of conventional meters on electricity customers cause a decrease in income by electricity supply companies. In this study aims to choose the internet-based technology of things for electricity smart meters in the PLN Disjaya region between three LoRa, NB-IoT and Sigfox technologies. This research is doing network design, coverage analysis, capacity analysis and network utilization, cost benefit calculation and analysis, data rate speed and proprietary. From the analysis results obtained SigFox superior in terms of coverage, capacity and network utilization, cost benefits (NPV, IRR, Payback Period, BCR, ROI), LoRa superior in terms of proprietary and NB-IoT superior in terms of data rate speed.

1. Introduction
Internet of things concept first introduce on RFID development committee in 2000 [1]. Since then, internet of things related to object detection, finding, and control every day through internet, using RFID [2], wireless network [3], wide area network or other equipment [4]. Based on International Telecom Union (ITU), key from IoT are connection, human and information [5]. Generally, basic structure internet of things technology divided by 3-layer that are physical layer, network or cloud layer and intelligence layer. Many independent studies forecasting number device and income from internet of things technology and machine-to-machine industry for the next ten years. Number M2M device will be connected and electronic customer will be passed number people that used mobile phone, personal computer, laptops and tablet by year 2020. Its predicted number of devices connected with IoT technology will reach 20 billion devices by year 2025 [6].

Basically, wireless technology that supports IoT requires several parameters such as low power consumption, low cost, measurable, reliable, low latency, wide range and secure. According to [7] wireless technology divided by two, which is Long Range and Fixed & Short Range. Fixed & Short Range, wireless technology with low coverage area connectivity, limited bandwidth and long battery usage. For example, Fixed & Short-Range technologies are RFID, Bluetooth, Zigbee and WiFi. Long Range is a connectivity technology with a wide range of areas by using a variety of bandwidth and battery. Long range technology is divided into two namely 3GPP Standard and Non-3GPP Standard. 3GPP standard uses cellular technology and frequency, for example the IoT technology included in the 3GPP Standard is LTE-M, NB-IoT and E-GSM. Non-3GPP Standard uses wireless technology and
un-license frequency. LoRa, SigFox and RPMA are examples of Non-3GPP Standard Long Range IoT technology. Figure 1 shows the distribution of IoT wireless technology.

![Figure 1](image1.png)

**Figure 1.** Shows the distribution of IoT wireless technology

One application of IoT technology is the application of the use of smart meters to electricity customers, which serves to record the consumption and use of electricity on a regular basis for monitoring and billing [8]. Figure 2 explains the comparison of traditional meter (electromechanical meter) systems with smart meters for electrical systems.

![Figure 2](image2.png)

**Figure 2.** Traditional meter vs smart meter

According studies done by Analog Device Inc. USA find that accuracy from traditional electricity meter getting worst with the age of the metering. This is caused by several factor, such as environment, corrosion and mis-calibrated. By using smart meter, several advantages such as eliminate monthly manual reading, monitor electricity system real time, give responsive data for balancing electricity load, decreasing electricity stolen and eliminate loss happened from traditional electricity meter. Beside advantage, smart meter has disadvantage such as additional capex, personal training and implementation time smart meter.

From that disadvantage smart meter and many platform or protocol develop by organisation or institution such as SigFox, LoRa and NB-IoT, need to be choose one technology that best suited to be implement in smart metering in PLN Disjaya area. This research will do network planning for these three technologies that can covered PLN Disjaya area. From planning result, will conduct analysis coverage network, capacity and utilization network, cost benefit analysis, data rate speed and proprietary.

2. **Research Methodology**

In this research methodology using quantitative and study case selecting of IoT technology for smart meter in PLN Disjaya area, based on cost benefit analysis, starting from data collection, such as working area PLN Disjaya to get information about clutter classification and contour. Number PLN subscriber, income and exogen data, to do regression method and forecast PLN Disjaya subscriber and income. Continue with coverage and capacity prediction for every technology NB-IoT, SigFox and LoRa using Atoll software. PLN subscriber growth prediction using regression method. Next, calculation all implementation cost and all prediction benefit after using smart meter for every
technology. Analysis compare IoT technology from coverage, capacity, cost benefit and economic evaluation.

3. Finding and Discussion
The research was conducted in 4 steps in order to find IoT based technology for electric smart meter in PLN Disjaya area, which is the aim of this study, several findings were obtained:

3.1. PLN data collection and prediction
First, PLN Disjaya working area that cover all DKI Jakarta Province, Kota Bekasi, Kota Depok and some Kota Tangerang Selatan until Kota Tangerang. Plot this map into digital map from Badan Informasi Geospasial to get data clutter and contour. Figure 3 shown the map of PLN Disjaya working area and digital map clutter and contour. This data needed to calculated coverage prediction, since signal loss of electromagnetic wave depend on contour and clutter classification.

![Figure 3. PLN Disjaya area map, contour and clutter classification](image)

After that, we collect data for subscriber number and income from PLN Disjaya area starting from 2010 until 2018, there are 6 classification type of subscriber which are rumah tangga, industri, usaha and others. Figure 4 shown the subscriber PLN Disjaya based on type from 2010 to 2018.

![Figure 4. Data subscriber of PLN Disjaya area 2010 – 2018.](image)
Figure 5 shown income PLN Disjaya based on type from 2010 until 2018. These data needed to forecast number subscriber and income PLN Disjaya area using multiple regression method.

![Figure 5](image_url)

**Figure 5.** Data income of PLN disjaya area 2010 – 2018 (in million IDR)

Beside data above, data exogen also needed, such as total population in Jakarta province, Tangerang Selatan City, Tangerang Kabupaten, Tangerang City, Bekasi City and Depok City. Beside data total population, several data exogen such as growth production index, number of MSMEs, inflation and economic growth can be seen in table 1.

| Data Exogen     | UoM    | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   | 2018   |
|-----------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Population      | Million| 241.8  | 245.1  | 248.5  | 251.8  | 255.1  | 258.4  | 261.6  | 264.6  | 267.7  |
| Production Index Growth | %     | 4.82   | 4.1    | 4.12   | 6.01   | 4.76   | 4.76   | 4.01   | 4.74   | 4.05   |
| MSMEs           | Million| 52.76  | 54.11  | 55.2   | 56.53  | 57.89  | 59.26  | 61.65  | 62.92  | 64.19  |
| Inflation       | %      | 6.96   | 3.79   | 4.3    | 8.38   | 8.36   | 3.35   | 3.02   | 3.61   | 3.13   |
| Economic Growth | %      | 6.22   | 6.17   | 6.03   | 5.56   | 5.02   | 4.79   | 5.02   | 5.07   | 5.06   |

Table 1. Variable exogen data

Simply linear regression model can be used to study relationship between two variables which are usually represented by y and x as representative of several population where y is the response variable or dependent variable and x is the control variable, the independent variable, or predictor variable. Simple equation in equation (1):

$$y = \beta_0 + \beta_1 x_1 + u$$  \hspace{1cm} (1)

In addition to linear regression, there also multiple regression that used to see the relationship between the response variable and the predictor variable in which the predictor variable is owned by more than one. The multiple regression equation can be seen in the equation (2):

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + u$$  \hspace{1cm} (2)

By predicting the parameter coefficient values, OLS is obtained for multiple regression as equation (3):

$$y = \hat{\beta}_0 + \hat{\beta}_1 x_1 + \hat{\beta}_2 x_2 + \cdots + \hat{\beta}_k x_k$$  \hspace{1cm} (3)

In this research, causal loop diagram of the relationship between each variable endogen and exogen can be shown in figure 6.
Figure 6. Diagram causal loop connection between endogen and exogen data

After running regression with below condition in eViews software except for customer type others forecast with simple linear regression. Equation (4) shown for number subscribe rumah tangga, equation (5) shown for number subscribe industri and equation (6) shown for number subscribe usaha, where all equation validated with R-Square above 70%.

\[
\ln A = 30.94804 - 1.337367 \ln G - 1.436916 \ln C \\
\ln B = 85.45697 + 0.20216 \ln H - 6.6603 \ln I - 2.093152 \ln K \\
\ln C = 29.67792 - 1.370846 \ln I + 0.015245 \ln J - 1.212393 \ln K
\]

(4)

(5)

(6)

Table 2 shown the forecast data for PLN Disjaya subscriber in the year 2019 until 2028 for rumah tangga subscriber using equation 4, industry using equation 5 and usaha using equation 6, and for others using simple linear regression.

| Tahun | Rumah Tangga | Industri | Usaha | Lainnya | Total |
|-------|--------------|----------|-------|---------|-------|
| 2019  | 4,274,513    | 6,113    | 317,017 | 58,078  | 4,655,722 |
| 2020  | 4,361,031    | 5,686    | 324,549 | 57,846  | 4,749,112 |
| 2021  | 4,452,798    | 5,304    | 333,197 | 57,615  | 4,848,914 |
| 2022  | 4,549,885    | 4,961    | 342,974 | 57,384  | 4,955,204 |
| 2023  | 4,652,375    | 4,654    | 353,902 | 57,152  | 5,068,083 |
| 2024  | 4,760,366    | 4,376    | 366,010 | 56,921  | 5,187,673 |
| 2025  | 4,873,966    | 4,126    | 379,336 | 56,690  | 5,314,117 |
| 2026  | 4,993,300    | 3,899    | 393,925 | 56,458  | 5,447,583 |
| 2027  | 5,118,501    | 3,693    | 409,832 | 56,227  | 5,588,253 |
| 2028  | 5,249,718    | 3,506    | 427,115 | 55,996  | 5,736,334 |

Equation (7) shown for income rumah tangga, equation (8) shown for income industri and equation (9) shown for income usaha, where all equation validated with R-Square above 70 %.

\[
\ln A_1 = -15.834 + 0.220 \ln B_1 + 2.867 \ln G - 0.002 \ln K \\
\ln B_1 = 119.392 + 0.432 \ln H - 8.859 \ln I - 4.157 \ln K \\
\ln C_1 = -17.880 + 0.323 \ln B_1 + 2.674 \ln I + 0.075 \ln J - 0.184 \ln K
\]

(7)

(8)

(9)
Table 3 shown forecast data for PLN Disjaya income in the year 2019 until 2028. All these data will be used to calculate number of smart meter than will be implemented (subscriber) and benefit of implemented smart meter (income).

**Table 3.** Forecast PLN disjaya income in 2019 – 2028 (in million IDR).

| Tahun | Rumah Tangga | Industri | Usaha | Others | Total |
|-------|--------------|----------|-------|--------|-------|
| 2019  | 13,882,564   | 5,675,076| 16,088,009 | 3,617,617 | 39,263,265 |
| 2020  | 14,509,525   | 5,375,616| 17,043,841 | 3,807,109 | 40,736,092 |
| 2021  | 15,172,921   | 5,114,701| 18,094,079 | 3,996,601 | 42,378,302 |
| 2022  | 15,874,699   | 4,887,194| 19,246,283 | 4,186,093 | 44,194,269 |
| 2023  | 16,616,930   | 4,688,820| 20,508,828 | 4,375,585 | 46,190,162 |
| 2024  | 17,401,808   | 4,516,005| 21,890,966 | 4,565,077 | 48,373,856 |
| 2025  | 18,231,664   | 4,365,754| 23,402,894 | 4,754,569 | 50,754,881 |
| 2026  | 19,108,971   | 4,235,547| 25,055,826 | 4,944,061 | 53,344,403 |
| 2027  | 20,036,346   | 4,123,259| 26,862,079 | 5,133,552 | 56,155,237 |
| 2028  | 21,016,568   | 4,027,094| 28,835,174 | 5,323,044 | 59,201,880 |

3.2. Coverage Planning

In coverage planning, parameter determine from level of signal receiving power on the device or received signal strength indicator (RSSI). Equation to calculated the received power level or RSSI level is like in equation (7):

\[ P_{rx} = P_{tx} + G_{system} - L_{system} - L_{channel} - M \] (7)

Where, \( P_{rx} \) is receive signal level (RSSI) in dBm, \( P_{tx} \) is transmit power into the antenna, \( G_{system} \) is a combined signal amplifier in the system, \( L_{system} \) is loss caused by the system, \( L_{channel} \) is signal propagation loss and finally \( M \) is Fading Margin.

To calculate the amount of loss caused by signal propagation the Cost-Hata equation is used. Cost-Hata loss propagation equation (8):

\[ L = 46.3 + 33 \log(f) - 13.82 \log(hB) - a(hR,f) + [44.9 - 6.55 \log(hB)] \log(d) + C \] (8)

Where, for dense urban and urban:

\[ a(hR,f) = \begin{cases} 8.29(\log(1.54hR))^2 - 1.1; & 150MHz < f < 200MHz \\ 3.2(\log(11.75hR))^2 - 4.7; & 200MHz < f < 1500MHz \end{cases} \] (9)

While for sub-urban or medium population density:

\[ a(hR,f) = (1.1 \log f - 0.7)hR - (1.56 \log f - 0.8) \] (10)

And while for rural or less dense population:

\[ L = L_{urban} - 2\left[ \log \left( \frac{f}{28} \right) \right]^2 - 5.4 \] (11)

Where \( L_{urban} \) is total loss propagation in urban area, \( hB \) is gateway antenna height, \( hR \) is receiver antenna height, \( d \) is propagation distance, \( f \) is frequency carrier and \( a(hR,f) \) is correction factor antenna height. Especially for very densely population, \( C \) is 3 dB.

Using above equation, data contour and clutter classification, coverage planning for each IoT technology can be calculate using AToll planning tolls with several adjustment parameter and specification from each technology as table 4.
### Table 4. Parameter coverage planning IoT

| Technology | Gateway Power Transmit (dBm) | Node Power Transmit (dBm) | Antenna Gain (dBi) | Node Gain (dB) | Antenna Height (m) |
|------------|----------------------------|---------------------------|-------------------|----------------|-------------------|
| NB-IoT     | 26                         | 23                        | 11                | 2              | 30-40             |
| LoRa       | 20                         | 14                        | 1.6               | 3              | 30-60             |
| SigFox     | 20                         | 14                        | 6                 | 2              | 30-60             |

The calculation result plan nominal coordinate gateway for each IoT technology can be shown in figure 7. From this result determine number of gateways needed to cover PLN Disjaya area, also average covered area for each technology gateway.

![Gateway Plan for PLN Disjaya Area](image)

#### Figure 7. Plan Gateway for PLN disjaya area for three technologies.

From table 5, shown that number of gateways needed SigFox less than NB-IoT and LoRa. Also, total area covered with RSSI uplink more than > -130dBm, SigFox higher than the others. This will be advantage, within the same covered area, the number gateway needed will be less.

### Table 5. Coverage planning summary for smart meter iot in PLN disjaya

| Technology | Covered Area (%) | Number of Gateway | Average Covered Area per Gateway (km) |
|------------|------------------|-------------------|---------------------------------------|
| NB-IoT     | 96.81            | 58                | 3.6                                   |
| LoRa       | 93.90            | 92                | 2.5                                   |
| SigFox     | 97.08            | 51                | 3.9                                   |

### 3.3. Capacity planning

In this research, each smart meter device sends data information with payload of 50 Bytes in an hour period. Network capacity should meet the requirement of spectrum for electricity smart meter in the area for the next ten years or 2028. Forecast number smart meter connected yearly can be used from table 5. Development full gateway assume need three years, where in first year 40% from total gateway and for the second and third year 30 % from total gateway needed.

For all three technology will depend on the number of devices connected in a network or gateway. From the number of devices serve in the network, knowing the maximum cell capacity and the number of cells, the utilization of the network can be known.

\[
\text{Utilization (\%)} = \frac{\text{Total devices}}{\text{max cell capacity} \times \text{no cell}} \ 
\]

(12)

Table 6 shown the maximum capacity network, number device connected, number gateway, and utilization yearly for three technology. From this table, SigFox has the biggest maximum capacity compare to others.
Table 6. Network capacity and utilization NB-IoT, LoRA and SigFox

| Year | Number PLN Customer | NB-IoT | LoRa | SigFox |
|------|--------------------|--------|------|--------|
|      |                    | Gateway | Total Devices Covered | Network Utilization (Uplink) | Gateway | Total Devices Covered | Network Utilization (Uplink) | Gateway | Total Devices Covered | Network Utilization (Uplink) |
| 2019 | 4,655,722          | 29      | 5,392,293 | 86.34% | 46      | 5,439,639 | 85.59% | 26      | 15,688,858 | 29.68% |
| 2020 | 4,749,112          | 46      | 10,809,913 | 43.93% | 74      | 9,863,217 | 48.15% | 41      | 27,829,094 | 17.07% |
| 2021 | 4,848,914          | 58      | 15,021,807 | 32.28% | 92      | 13,112,638 | 36.98% | 51      | 35,251,200 | 13.76% |
| 2022 | 4,955,204          | 58      | 15,021,807 | 32.99% | 92      | 13,112,638 | 37.79% | 51      | 35,251,200 | 14.06% |
| 2023 | 5,068,083          | 58      | 15,021,807 | 33.74% | 92      | 13,112,638 | 38.65% | 51      | 35,251,200 | 14.38% |
| 2024 | 5,187,673          | 58      | 15,021,807 | 34.53% | 92      | 13,112,638 | 39.56% | 51      | 35,251,200 | 14.72% |
| 2025 | 5,314,117          | 58      | 15,021,807 | 35.38% | 92      | 13,112,638 | 40.53% | 51      | 35,251,200 | 15.07% |
| 2026 | 5,447,583          | 58      | 15,021,807 | 36.26% | 92      | 13,112,638 | 41.54% | 51      | 35,251,200 | 15.45% |
| 2027 | 5,588,253          | 58      | 15,021,807 | 37.20% | 92      | 13,112,638 | 42.62% | 51      | 35,251,200 | 15.85% |
| 2028 | 5,736,334          | 58      | 15,021,807 | 38.19% | 92      | 13,112,638 | 43.75% | 51      | 35,251,200 | 16.27% |

With this result, SigFox has the lowest utilization compare to NB-IoT and LoRa, figure 8 shown the utilization graph yearly from 2019 – 2020 for three technology NB-IoT, LoRa and SigFox. This will be advantage to put more device beside electricity smart meter, such as health sensors, gas meter or water meter, since all three technologies capacity utilization still bellow 80% from maximum capacity to covered smart meter or sensor.

Figure 8. Utilization graph from 2019 – 2020 for NB-IoT, LoRa and SigFox.

3.4. Cost benefit analysis
In this research using cost benefit analysis, assuming 10 years (2019 until 2028) of implementation technology with forecasting using regression model for number of customers using data from 2010 until 2018. Several methods used in this research. Payback period (PP) method, this calculate how fast the return of the investment. Payback Period formula are shown as bellow

\[ PP = \frac{\text{CAPEX Investment}}{\text{Cash Flow}} \]  (13)
Return on Investment (ROI) method, where to calculate percentage benefit from a project compare to cost that has been spend. ROI method using bellow formula

\[
ROI = \frac{Total\ Benefit - Total\ Cost}{Total\ Cost}
\]  

(14)

Net Present Value (NPV) method, to calculate gap between investment value that has been spend with net profit upcoming years with set interest. NPV method using bellow formula

\[
NPV = \sum_{t=1}^{T} \frac{Net\ Profit}{(1+r)^t}
\]  

(15)

Where \( t \) is year’s period and \( r \) is interest.

Internal rate of return (IRR) method is to calculate the interest rate \( r \) which would equate the present value of the expected revenue received by the present value of the expenses for the investment project or when the NPV equal to zero. The value of IRR is calculated using a formula.

\[
IRR = i_1 + \frac{NPV_1}{NPV_1+NPV_2} (i_1 - i_2)
\]  

(16)

Depreciation method is to calculate the actual decrease in value of fair value of an asset, such as the decrease in value of factory equipment each year as it is used and wears, and second, the allocation in accounting statements of the original cost of the assets to periods in which the assets are used. In this research using straight line depreciation, where the formula as bellow.

\[
SL = \frac{Total\ Cost - Salvage\ Value}{Economic\ Life}
\]  

(17)

SL result can be shown as depreciation charge yearly.

In this research, benefit using smart meter compare to conventional meter, observe 396 existing customer using conventional metering, compare the monthly billing in February 2020 to March 2020 and discover that 33 customer has anomaly billing in March 2020 compare to February 2020. After that we check the existing conventional metering, found that 19 conventional metering not working properly. From these 19 customers, monthly billing in March 2020 less 1.23% from monthly billing in Feb 2020. This will be as based assuming benefit to be consider in the cash flow calculation 1.23% from income yearly PLN Disjaya. Where the forecast income in year 2019-2028 based on table 3.

Cost assumption will be divided by two, which is Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). Table 7 shown breakdown for CAPEX and OPEX for these three-technology based on [10]. With the assumption implementation will be for ten years (2019 until 2028) with customer forecast based on the table 2, three-year implementation for network development, with configuration 40% from total gateway in first year, 30% in second year and 30% in third year. Another assumption is depreciation using straight line, lifetime 5 years and salvage value remaining 10%. All investment cost in first three years using loan from bank with the interest 6%.

| Table 7. Cost assumption capex and opex technology iot |
|-----------------|--------|--------|--------|
| Cost                      | SigFox | LoRa   | NB-IoT |
| CAPEX                     |        |        |        |
| Equipment Cost            | 65,030,560 | 16,257,640 | 162,576,400 |
| Installation Cost         | 20,641,667 | 20,641,667 | 20,641,667 |
| Transmission Installation Cost | 8,128,820 | 65,030,560 |         |
| Smart Meter Cost          | 153,773  | 170,031 | 218,803 |
| Server & Application (Equipment & Installation) Cost | 1,427,494,000 | 1,427,494,000 | 1,427,494,000 |
| OPEX                      |        |        |        |
| Site Leased Cost (Monthly) | 10,000,000 | 10,000,000 | 10,000,000 |
| Electricity Gateway Cost (Monthly) | 1,250,000 | 1,250,000 | 1,250,000 |
| Gateway Connection Main & BackUp (Monthly) | 6,120,000 | 6,120,000 | 6,120,000 |
| Spectrum License Fee      |         | 2,354,400 |        |
| O&M Cost (include spare part) | 10%    | 10%    | 5%    |
With all those assumptions, then calculate for PP, NPV, BCR, ROI and IRR for these three technologies. Table 8 shown Comparison of Cost Benefit of IoT technology for Smart Meters at PLN Disjaya.

| Items             | UoM                  | NB-IoT                          | LoRa                           | SigFox                        |
|-------------------|----------------------|---------------------------------|--------------------------------|-------------------------------|
| NPV               | IDR                  | 891,110,453,323.56              | 1,091,142,456,200.17           | 1,440,159,425,136.23         |
| BCR               |                      | 2.65                            | 2.59                           | 2.81                          |
| IRR               | %                    | 16.30%                          | 22.60%                         | 29.83%                        |
| PayBack Period    | Years                | 7.23                            | 6.53                           | 5.88                          |
| ROI               |                      | 2.24                            | 2.02                           | 2.29                          |

From all those cost benefit parameters, found that SigFox technology has biggest NPV, BCR, IRR and ROI and the shortest Payback Period compare to LoRa and NB-IoT. One of the most influential factors in the cost benefit analysis is the price of the smart meter, this is because the number of smart meters used is very large, so a strategy is needed in implementing this smart meter.

4. Conclusion and Suggestions

4.1. Contribution

Based on all aspect data rate, coverage, capacity, network utilization and cost benefit analysis IOT technology from NB-IoT, LoRa and SigFox for electric smart meter IOT technology in PLN Disjaya area, SigFox technology has more advantage in coverage, capacity and cost benefit compare to NB-IoT and LoRa. NB-IoT only has advantage for the faster data rate and LoRa has advantage for proprietary (open source).

4.2. Suggestion

Additional smart meters that are used such as gas and water, or even sensors for health and other sensors. This is possible, because the predicted utilization of smart electricity meters in the 10th year of the three technologies is still less than 50% of the total network capacity if fully implemented in the third year. This can increase revenue for PLN Disjaya aside from the efficiency of electricity smart meters.

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