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# A performance analysis of general packet radio service (GPRS) and narrowband internet of things (NB-IoT) in Indonesia

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## Abstract
Internet of Things (IoT) refers to a concept connecting any devices onto the internet. The IoT devices are able to not only use a service or server to be control at distance but also to do computation. IoT has been applied in many fields such as smart city, industries and logistics. The sending of IoT data can use the existing GSM networks such as GPRS. However, GPRS is not dedicated particularly for the transmission of IoT data in consideration to its weaknesses in terms of coverage and power efficiency. To increase the performance of the transmission of IoT data, Narrowband-IoT (NB-IoT), one alternative to replace GPRS, is offered for its excellences in coverage and power. This paper aims to compare the GPRS and NB-IoT technology for the transmission of IoT data, specifically in Bandung region, Indonesia. Considering that NB-IoT is a new technology, a preliminary feasibility study of this technology is needed, especially in Indonesia. This paper is the first paper to discuss the performance analysis of NB-IoT technology in Indonesia in terms of network performances. This research results can be useful for other further researches in NB-IoT area. The results obtained showed that the packet loss from clients for the GPRS network was at 68%, while the one for NB-IoT was at 44%. Moreover, NB-IoT technology was found excellent in terms of battery saving compared to GPRS for the transmission of IoT data. This then showed that NB-IoT was found more suitable for transmitting the IoT data compared to GPRS.

## 1. Introduction
Internet of Things (IoT) is a concept to connect any devices or appliances onto internet. An appliance will be seen as “Internet of Thing” if it is able to do a processing on the embedded processors or microcontrollers, communicate, and be controlled or use a server or service on Internet [1][2]. The structure of IoT consists of three components: hardware (sensor, actuator, embedded system, and communication), middleware (data processing from IoT, analytical) and presentation (visualization and interpretation) to users [2][3]. Based upon the architecture of IoT in [4], it requires an internet connection to connect things. The internet connection on IoT can use the networking technology that has been available in the today telecommunication network such as GSM technology. In essence, any network connections can be used for IoT data as long as their structure is compatible with the characteristics in IoT data.

One of GSM technology that can be used for the transmission of IoT data is General Packet Radio Service (GPRS). This technology, nevertheless, still has two weaknesses in its implementation regarding the use of high power and low coverage area. A solution offered is the network of Narrowband-IoT (NB-IoT), a protocol proposed by 3GPP to replace GPRS protocol [5]. NB-IoT can use a little part of LTE network [6] and has a gain of 20dB in an indoor environment (such as in a tunnel) in comparison to GPRS. In addition, NB-IoT is more power saving for being designed to the low power devices, off-the-grid / dependent upon the battery and has a network performance resembling GPRS [5].

The use of Narrowband-IoT has widely been applied on the smart metering or smart grid application [7][8][9][10][11]. Other Narrowband-IoT-based applications include smart parking [12][13], smart cities [14][15][16][17][18][19][20][21]. Any applications that can be employed using NB-IoT network need to adjust with the regulation of its deployment area. In Indonesia, not all base-stations support the NB-IoT network. To make IoT application can be used well in the NB-IoT network, then there is a need for a study on the properness in the usage of the network for the IoT data transmission.

There are some performance evaluations from other works that analyze the performance of NB-IoT. The research [22] compared the performance and the power characteristic between 4G LTE and GPRS network. The research used smartphone mobile networks for its testing environment. The result for TCP test using parameter of Round Trip Time (RTT) from the LTE technology resulted in median value around 69.5 ms, from the raw data ranging from 25 ms to 120 ms. Meanwhile, from the 3G technology, the result of RTT value ranging from 200 ms to 400 ms, and the median value was around 110 ms.

The average of LTE throughput for uplink and downlink are 12.74 Mbps and 5.64 Mbps. Although LTE has capability of high throughput, it scales with power consumption. For 5 Mbps downlink, LTE consumes power around 1700 mW, for 5 Mbps uplink, it consumes around 3400 mW, twice the consumption power of downlink. Base power consumption of LTE is 1060 mW. Average 3G throughput are 2.5 Mbps and ≤ 1 Mbps for downlink and uplink respectively. Power consumption for 500 Kbps downlink, is 850 mW and 1250 mW for 500Kbps uplink. Base power consumption of 3G is 601 mW.

*Table 1. Energy Usage Compared to Data Size in LTE and 3G*

| Data Size (B) | LTE uplink (µJ/bit) | LTE downlink (µJ/bit) | 3G uplink (µJ/bit) | 3G downlink (µJ/bit) |
|---|---|---|---|---|
| 10000 | ~10 | ~5.9 | ~13.1 | ~8.1 |
| 100000 | ~3 | ~1.5 | ~7 | ~5.8 |
| 1000000 | ~1.8 | <0.5 | ~6.5 | ~5.5 |
| 10000000 | <1.5 | <0.1 | ~6.4 | ~4.8 |

Table 1 depicts that LTE is not suitable for transferring small data and staying in an idle state. The advantage of 3G and 4G depends on the application. 4G is wasted in power usage, but its capability of high throughput is suitable for high definition urban security camera that is always connected to main power. 3G is may suitable for remote application that is powered by a battery that is intermittently charged from other power sources (such as solar panel) and needs adequate throughput to do its function properly.

The other study [20][23] analyze power consumption and battery life from NB-IoT. The goal of the study is to measure power usage when transmitting the signal. The study also estimates the battery life when the device sends a signal using NB-IoT. The result is NB-IoT commercial device consumes 716 mW to transmit a 23 dBm signal. Other studies [24] focus on signal coverage analysis from Sigfox, LoRa, GPRS, and NB-IoT. The testing purpose was to measure the failure rate from uplink and downlink from the signal transmission. The result from the study showed that NB-IoT had a failure rate below 5% for downlink and uplink connectivity in indoor and outdoor coverage. The last, a study presented in [25] compared signal coverage between LTE-M and NB-IoT in the rural area. The goal was to measure the coverage signal in an indoor and outdoor location. The result was NB-IoT could coverage 95% use in a deep indoor location.

Based on previous studies, no other studies focused on performance analysis of NB-IoT and GPRS in data transmission based on the network condition. This paper presents a performance test on the properness of the usage of NB-IoT network in Indonesia – particularly in Bandung. This test can be seen in terms of latency, throughput, packet loss, and power usage.

The paper is organized as follows: Section 2 describes the research method, Section 3 describes the simulation, result, and discussion of performance evaluation and Section 4 explains the conclusion and future works.

## 2. Research Method

In this research, the performance test from GPRS and NB-IoT was conducted to compare the network in transmitting the data from device onto cloud server. GPRS and NB-IoT are a mobile network requiring Base Transmission Station (BTS) from a cellular operator for communication. The mobile network applies a mechanism of radio wave to build a network in transmitting the data. The radio wave is used to provide the service of mobility and capacity to cover a wide area [5][26][27]. The longer the transmitted radio wave, the larger the delay. Delay occurs when the transmission can be influential in the throughput of a network. Therefore, the measurement of performance towards the throughput is very important as the parameter of performance in mobile network [26][28].

Radio wave also has the uplink or downlink when transmitting a data. The transmission of uplink occurs between device and BTS tower; on the other hand, the downlink transmission occurs between BTS and device [5][26]. Each transmission of uplink and downlink also brings an effect on the performance of data transmission. The Round Time Trip (RTT) of the data sent from a device to a BTS and then forwarded to the server and returning to the device through BTS is the parameter of performance of uplink and downlink of a mobile network [26][29].

In addition, the power usage in device brings an effect on the transmission of uplink and downlink on mobile network. The radio wave transmitted by the device is also determined by the electrical power existing in the device. The longer the transmission of radio wave in the device, the larger the power required [20][23].

Based on the justification of the measurement methods above, then the performance test was conducted to achieve the following Key Performance Indicators (KPI):

1. The measurement of throughput for the performance of the network in data transmission.
2. The RTT measurement to measure the time between the transmission and receipt of data package.

3. The measurement of power consumption to measure the power use when the device transmits the data.

Once KPI had been determined from the measurement to be done, then a test scenario was made. In this research. It began by explaining the coverage area from the network of NB-IoT and GPRS existing in Bandung area, Indonesia. The information about the coverage was used to find out to what extent the coverage area from the network of NB-IoT and GPRS to make it possible to be used as the reference of the mobility of the test. Subsequently, two scenarios of test on the network performance of the analysis were defined consisting of test towards the throughput and RTT from the data transmission. To figure out the power consumption of GPRS and NB-IoT when transmitting the data, then the test scenario of the power consumption was made.

### 2.1. Coverage Area

Prior to measure the performance of mobile networks on GPRS and NB-IoT it was necessary to know the coverage area of the two technologies, as seen in Table 2. The test was conducted in the campus area of Telkom University, Bandung, Indonesia. The first thing to do to find out the coverage area was to measure the signal strength in the test area. Signal strength on mobile networks is commonly measured by using the units of dBm (decibel-milliwatts). Signal strength is the representation of how much signal is received from cellular networks (downlink mode) [24][25].

*Table 2. Signal Strength Condition Standard from 2G and 3G Network*

| RSSI | Signal Strength | Description |
|---|---|---|
| ≥ -70 dBm | Excellent | Strong signal with maximum data speeds |
| -70 dBm to -85 dBm | Good | Strong signal with good data speeds |
| -86 dBm to -100 dBm | Fair | Fair but useful, fast and reliable data speeds may be attained, but marginal data with drop-outs is possible |
| < -100 dBm | Poor | Performance will drop drastically |
| -110 dBm | No signal | Disconnection |

There are two scenarios of measurement in the network measurement to be done. The first measurement was related to the throughput of GPRS and NB-IoT networks. In the tests conducted, measurement of throughput was calculated using Equation 1.

$$T = \frac{\sum nKbit}{s} \tag{1}$$

Throughput refers to the actual bandwidth measured by time units and certain network conditions to send data with a certain size. Based on Equation 1, the throughput test was carried out by sending a certain amount of data carried out over a certain period of time. The transmission was made from the device to the server via GPRS and NB-IoT networks. The second measurement was related to RTT from GPRS and NB-IoT networks. In the tests carried out, RTT measurements were calculated using Equation 2.

$$RTT = tA - tD \tag{2}$$

From Equation 2, the RTT test was to measure the time range between the time of data transmission and the time of arrival of the transmitted data. Test was to calculate the RTT of data sent from the device to the server and returned to the device.

### 2.2. Power Consumption Analysis

In the test of power consumption, two testing categories of testing were analysed. First, it was regarding the overall power usage on the device when using GPRS and NB-IoT networks. Second, the device utility was analysed when transmitting data on GPRS and NB-IoT networks. In the utility test, the measurement of power consumption estimation on the battery usage when transmitting and using the GPRS and NB-IoT was also done. The overall measurement of power usage on GPRS and NB-IoT networks used the Joule unit. In the measurement of overall power consumption performed on GPRS and NB-IoT was calculated using Equation 3.

$$J = \frac{W}{s} \tag{3}$$

Testing using Equation 3 measured the overall power usage of the device. The overall measurement of power consumption included power usage when using GPRS / NB-IoT networks and reading data from sensors.

The measurements of GPRS and NB-IoT usage were conducted using two scenarios. First, power consumption was measured when the device transmitted the data. Second, the time estimation towards the power in the battery was measured. Those two measurement scenarios were expected to illustrate the power usage used by devices with GPRS or NB-IoT mobile networks. In the first utility measurement, the power consumption was measured when the device transmitted the data. The measurement was conducted on GPRS and NB-IoT and calculated using Equation 4.

$$PC = \frac{T}{Tp} \quad (4)$$

From Equation 4, the power consumption was measured based upon the size of the throughput generated at one time data transmission. The size of the throughput was compared to the transmit power when transmitting or receiving data. The measurement of power consumption when the device transmitted the data was conducted on GPRS and NB-IoT and calculated using Equation 5.

$$Estimated\ Time = \frac{\frac{Transaction * data\ length\ (byte)}{Transaction\ interval\ (s)} * Transmit\ power\ (W/byte)}{Battery\ capacity\ (Ws)} \quad (5)$$

Based on Equation 5, the measurement would be focused on power usage when transmitting the data only using the network of GPRS or NB-IoT. The measurement was initially done to the data transaction to be transmitted. Furthermore, the measurement was combined with the amount of power consumption in each data transaction. This was then continued by comparing the battery power used to turn on the device.

## 3. Results and Discussion

This section explains the environment used for testing in this research. The topology from the network used for testing is describing in point 3.1.

### 3.1 Feasibility Design

Narrowband-IoT employs traditional GSM topology, Figure 1 is the simplified version of the network topology.

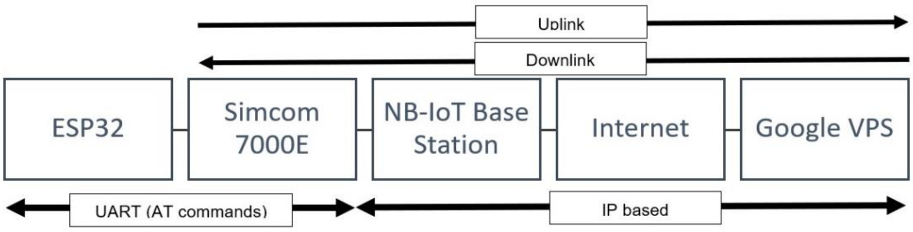


*Figure 1. Topology Diagram*

The detail from the testing scenario and environment is describing in point 3.1.1 and 3.1.2. The pseudocode from the network performance equation that used for testing is described in point 3.1.3.

#### 3.1.1 Test Scenario and Parameters

These lists are test parameters, devices specifications, and location.

a) Devices and equipment
   a. ESP32 WROOM (4 MB flash, 512 KB RAM)
   b. Waveshare SIMcom 7000E module
      Specification and capabilities [30] :
      - Frequency bands: GSM (900 Mhz / 1800 Mhz), LTE-M1, LTE-NB1
      - GNSS for geolocation data
      - Operating voltage: 3.3 volts – 4.03 volts (module built in with 3.3 volt to 5 volt regulator)
      - Transmit power:
        - GPRS: 2 W (EGSM 900), 1 W (DCS1800)
        - EGDE: 0.5 W (EGSM 900), 0.4 W (DCS1800)
        - LTE: 0.25 W

- Data transmission speed:
  - LTE-NB1 : 34 Kbps DL, 66 Kbps UL
  - LTE CAT-M: 300 Kbps DL, 375 Kbps UL
  - GPRS: multi-slot class 12
  - EDGE: multi-slot class 12
- UART interface (115200 bps)
- USB interface

c. Laptop/Tablet as debugging/terminal display
d. SANFIX DM-888 multimeter for power usage measurement.
e. Google cloud VPS as test server
- Runs ASP.net core 2.0 web API server
- Python 3.0 for UDP server
- Located in Singapore

b) Test location and signal coverage
a. Jalan Telekomunikasi, Universitas Telkom, Bojongsoang, Bandung
b. GPRS signal strength: -71 dBm
c. NB-IoT signal strength -87 dBm

### 3.1.2 Data Payload:

a. TCP using HTTP:
- Upload: 5 KB
- Download: 10 KB
- Time out: 60 seconds

b. UDP:
- Send: 1 KB
- Receive: 1 KB (echo)
- Time out: 10 seconds

c. Test iteration: 50 times
d. eDRX configuration for NB-IoT: 5.52s (1st cycle)

### 3.1.3 Pseudocode

a. Downlink throughput

```
function Download(N, iteration) → real
    Dt ← []
    Time1 ← 0
    for (I ← 0 to iteration) do
        Time1 ← millis()
        // request dummy data with N bytes
        If(Http.Get("http://testserver.com/api/value/"+N)) then
            Time2 ← millis()
            Dt.append(N / (Time2-Time1))
        Else
            //timeout
            Dt.append(0)
    Return Dt.average()
```

b. Uplink throughput

```
function UploadTest(N, iteration) → real
    Dt ← []
    // create dummy array, fill it with As
    dummyData ← new char[N]
    memset(dummyData, 'A', N)
    Time1 ← 0
    for (I ← 0 to iteration) do
        Time1 ← millis()
        //send that array, we assume that server only sent empty response,
        //because we're only measuring uplink throughput
        If(Http.Post("http://testserver.com/api/value/"+N,dummyData,length)) then
            Time2 ← millis()
```

```
                Dt.append(N / (Time2-Time1))
          Else
                //timeout
                Dt.append(0)
    Return Dt.average()
```

### 3.2 Performance profiling

Table 3 depicted the result of RTT TCP benchmarking for GPRS and NB-IoT. This research used TCP protocol in the transport layer and used the HTTP protocol in the application layer. Table 3 measure HTTP Round Trip Time by uploading 1 KB upload payload and 10 KB download payload. Round Trip Time did not include timed out of a transaction. Maximum transaction time was 60 seconds; otherwise it was counted as “timed out” or “fail”. For each upload and download did as much 50 times. The fail attempt is the number of fails to upload a payload (received an empty response) and download a payload (sent empty request).

*Table 3. RTT TCP Benchmark for GPRS and NB-IoT*

| Network | Round Trip Time | Fail Attempt (Upload) | Fail Attempt (Download) |
|---|---|---|---|
| GSM/GPRS | 17422.875 ms | 13 | 9 |
| NB-IoT | 8007.96 ms | 7 | 17 |

In Table 4, UDP Round Trip Time was measured by sending a 1 KB UDP echo message to reach the server and back in a certain time period. Round Trip Time did not include timed out transaction. Maximum time to receive echo message was 10 seconds; otherwise it is counted as “failed.” Fail Attempt was represented the number of UDP packet that did not reach the server or client.

*Table 4. RTT UDP Benchmark for GPRS and NB-IoT*

| Network | Round Trip Time | Fail Attempt (Payload did not reach server) | Fail Attempt (Echo payload did not reach client) |
|---|---|---|---|
| GSM/GPRS | 1531.814 ms | 1/50 | 33/50 |
| NB-IoT | 1434.091 ms | 0/50 | 28/50 |

In Table 5, throughput from HTTP was measured by uploading 1 KB payload and downloading 10 KB payload in a certain period. Based on the experiment, the average throughput for uploading from GPRS and NB-IoT had similar result. Furthermore, parameter of average download from NB-IoT throughput was smaller than GPRS, and the value was not too far adrift with the throughput when uploaded.

*Table 5. Throughput HTTP Benchmark for GPRS and NB-IoT*

| Network | Average Upload | Average Download |
|---|---|---|
| GSM/GPRS | 347.3 B/s (2.776 Kbit/s) | 2593.280 B/s (20 Kbit/s) |
| NB-IoT | 350.760 B/s (2.806 Kbit/s) | 348.839 B/s (2.7907 Kbit/s) |

From the HTTP test, it was concluded that NB-IoT has smaller RTT compared to GPRS. NB-IoT was also not suitable to download big files (in this case, downloading more than 10 KB data). In UDP test, NB-IoT has marginally smaller RTT than GPRS but having better reliability.

Meanwhile, the energy usage for both GPRS and NB-IoT was measured in the operating voltage of 3.3 volts. The device sent 50 KB (1 KB each) UDP packets during the transmit power test. Transmit power was also measured within 20 seconds timeframe. This benchmark measured from modem power consumption. The result is depicted in Table 6.

*Table 6. Energy Usage of GPRS and NB-IoT*

| Network | Start up | Idle & Connected | Idle | Transmit |
|---|---|---|---|---|
| GSM/GPRS | 7 J (0.35 W) | 4.7 J (0.235 W) | 6.15 J (0.307 W) | 14.75J (0.737 W) |
| NB-IoT | 8.25 J (0.412 W) | 5.1 J (0.225 W) | 5.05 J (0.252 W) | 8.1 J (0.405 W) |

Small power consumption improves the device battery life. As seen in Figure 2, the power consumption of transmitting power from NB-IoT was smaller than GPRS in the uplink mode. But the power consumption of transmitting power from NB-IoT was bigger than GPRS in the downlink mode, as seen in Figure 3.

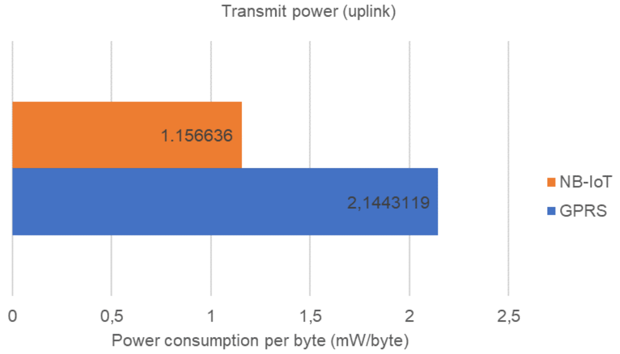


*Figure 2. Uplink Transmit Power (Smaller = Better)*

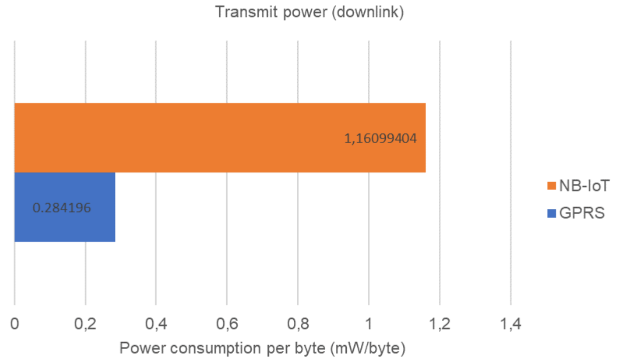


*Figure 3. Downlink Trasnmit Power (Smaller = Better)*

Figure 4 shows estimated common 18650 Li-Ion battery life with capacity 2560 mAh or 8.448 W/h [31]. This estimation does not include external component other than the modem itself.

Further, the estimated battery life was calculated using formula in Equation 5. The scenario used to compute the estimated battery life was: transaction interval was every hour, data length was 512 Byte, and battery capacity was 8.448 W/h.

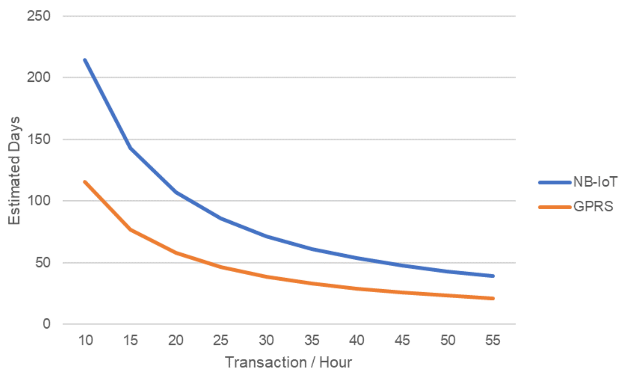


*Figure 4. Estimated Battery Life*

From Figure 4, we can conclude that where if the number of transactions increases, the power usage will decrease for both of GPRS and NB-IoT technology. The GPRS consumed more energy more than NB-IoT for the same number of transactions, which means that NB-IoT is better than GPRS in the aspect of energy savings.

## 4. Conclusion

IoT data can be sent using GPRS and NB-IoT technology. This paper compared the GPRS and the NB-IoT technology for sending IoT data using TCP and UDP protocols. The coverage area used in the deployment was Bandung, Indonesia. From the results, we can conclude that throughput, packet loss, and energy usage are superior to the NB-IoT network compared to GPRS. This result means that NB-IoT is more feasible to send IoT data better than GPRS.

Research development can be done by utilizing both technologies for real IoT applications, for example, smart tracking, smart cities, or smart transportation. Thus, the performance of both technologies can be seen better when they are used in real applications.

## Notation

T : Throughput (Kbps)
nKbit : The number of data (Kbit).
s : Time (s).
RTT : Round Time Trip from device to server (ms).
tA : Arrival time of echo data from server to client (ms).
tD : Departure time of echo data from client to server (ms).
J : Total power consumption from device (Joule).
W : Power from device (mW).
Tp : Transmit Power (W/byte).
PC : Power Consumption (mW/byte).

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