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A performance of radio frequency and signal strength of LoRa with BME280 sensor

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ABSTRACT

LoRa is a Radio Frequency module that can send packet data up to 3 km in FSPL.LoRa has 3 different Frequency Radios i.e, 915 MHz, 868 MHz, and 433 MHz. LoRa testing is based on different distances, BME280 provides Barometric Pressure, Temperature, and Humidity data. An analysis from the results of the Received Signal Strength to the distance (m) to the farthest point to prove and provide QoS data from LoRa 915 MHz. Sensor nodes are built using ADR and Automatic sleep mode algorithms. Communication systems between nodes are built dynamic sensor nodes in mesh networking. Monitoring signal transferring on the 915 MHz Frequency waveform is carried out using the Textronix Spectrum analyzer. Based on the BME280 Data packet transmission from the LoRa 915 MHz Transmitter to the Receiver Receiver at a distance of 100m is -84 dBm and at a distance of 500m is -107 dBm. The LoRa Internet Gateway has 2 types of settings, i.e, application, and gateway, this setting is to find out the location of the gateway with longitude and latitude. Furthermore, the gateway holds Sensor data from the End node, while the Application Server displays sensor data in the form of Graphics in realtime.

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1. INTRODUCTION

The internet of things (IoT) technology is growing rapidly, the development of radio frequency or module e.g., GPRS, Narrowband-IoT, SigFox, and LoRa. the development of Internet gateway devices technology (LoRa Gateway, Digi Zigbee Gateway, Raspberry Pi Gateway, etc.), Security type [1], protocol type, node sensor technology, power consumption that supports lifetime of sensor nodes, routing protocol, long rangeability on radio frequency or frequency band is very influential in the development of the internet of things (IoT) technology, at present the company's demand (DSM) on LPWAN [1] and the internet of things (IoT)-based technology is increasing [2], this study is detailed in research [1]. In research [3] surveyed the differences between LoRa and NarrowBand-IoT, survey parameters included QoS, latency, reliability, and range. therefore, In research [4] the comparison of radiofrequency modules such as GPRS, Narrowband-IoT, SigFox, and LoRa was tested at a very long distance of 7800 km^2, proving that Radio module capability is capable of reaching very long distances. In research [5] LoRa communication was built to make smart energy Campus Testbed [5-7]. So that an appropriate architecture is needed to handle complex sensor node connections in the internet of things (IoT) and how to build architecture in various systematical domains [8]. Not only in indoor capabilities and short distances such as using bluetooth RN42 [9] which shows the transferring of data from the transmitter to the receiver is 20 meters then supported by the Raspberry Pi 3 Model B as an Internet gateway. furthermore, In research [7] the Raspberry Pi is used as a web server in monitoring the energy of LPWAN [10] on each sensor nodes supported by Linux script and radio module under testing, the testbed's components parameter includes the App inventor App on the tablet to create a GUI on a tablet based on blockly programming. In research [1] using the same board, Raspberry Pi, which is built security level method using the ARSy Framework on communication between Raspberry Pi 3 Model B and DS18B20 sensor, from this research we can determine the level of security of data in the Wireless Sensor Network. In research [11, 12], the radio frequency used is Zigbee with the farthest range of 120 meters [13], so a long-range frequency radio is needed to cover the outdoor area. So it is necessary to expand the capacity of the RF signals to the outdoor. For this reason, this research was made, namely analyzing the ability of the LoRa 915 MHz module in sending BME280 data at distant distances and locations. therefore, a scope on this research is transferring the BME280 data packet at LoRa transmitter to LoRa receiver at frequency 915 MHz which will produce receiver signal strength (RSS) value in -dBm at different distances. In research [14] One important reason for IoT is the Power consumption factor. e.g, LoRa and the global positioning system (GPS) require high power consumption, one method that can be used to reduce power consumption is fingerprint positioning method. The sender and receiver program on LoRa uses C language on the Arduino integrated development environment (IDE). accordingly, Problems that occur when sending packet data using the LoRa radio frequency module is the presence of obstacles in the form of mountains, buildings, trees, etc. which causes a greater percentage of the attenuation signal (-dBm).

2. RESEARCH METHOD

2.1. Research architecture

Figure 1 shows the overall research architecture, there are 3 parts shown in Figure 1. On the left (case_analytic_1) is an analysis of ADR (adaptive data rate) algorithm [15] which aims to maximize the lifetime of sensor nodes and the effectiveness of the overall networking if added with a large number of nodes, in the center (receiver sensitivity), transmitting multi-point data signals Tx node LoRa to Rx Node LoRa produces an analysis of the budget link consisting of transmission power, antenna gain, connector loss, factor fresnel zone equation, etc (Case_Analytic_2) [16]. In Case_Analytic2 the analyzed signal is Chirps (compressed high-intensity radar pulse) [17-19]. furthermore, Case_Analytic_3 is the result of an internet gateway analysis consisting of an internet server and application server and its analytic data, i.e, uplink and downlink which can be analyzed in detail.

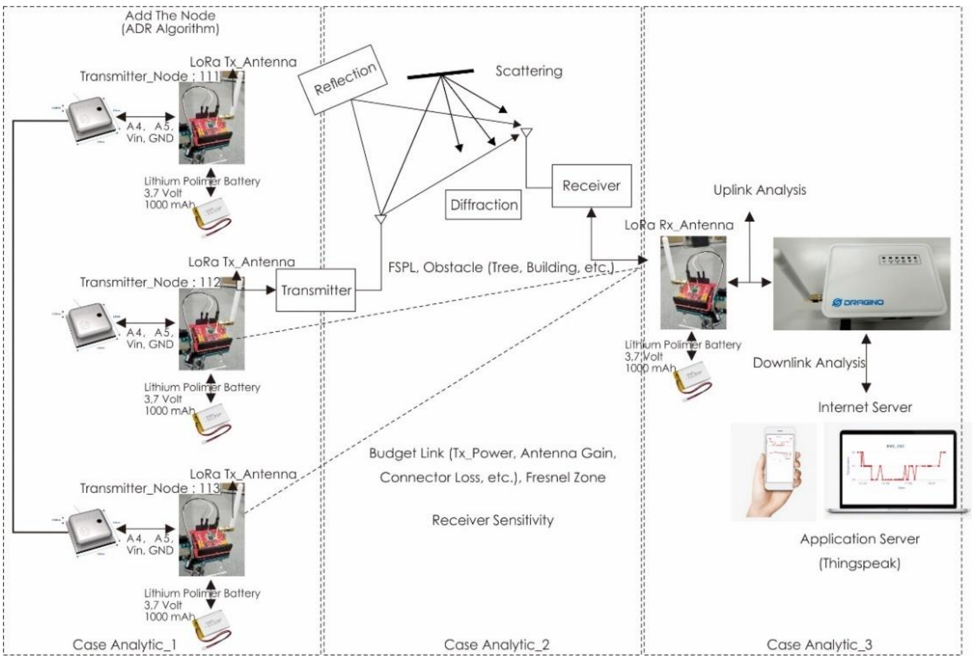


Figure 1. The architecture of this research

The flow diagram of Figure 1 shows the process of beginning to the end of this research, therefore, three parts of the flowchart are interrelated ie, end nodes/mote/end devices of LoRa and this transmitter will be added up so that the data rate will increase for that it needs an algorithm that maintains network stability and maximizes the lifetime of the sensor node using the ADR algorithm. Adaptive data rate (ADR) the algorithm focused on the algorithm used in the internet of things radio frequency LoRa communication system, this algorithm is used as an approach in handling data transmission rate on the network (LoRaWAN) [20] that is being built and has many sensor nodes that are being built interconnected, this has to do with how to increase the effectiveness of IoT-based networks and maintain the level of life-time for sensor nodes on complex networks. In this case, all end nodes/endpoints or motes can dynamically adjust the data rate that will be sent in the process of transmitting uplink and downlink data. If the end point/end node/mote is in ADR Active mode, the Server will be able to determine the data rate via the ADR (adaptive data rate) as documented in LoRaWAN [21, 22]. ADR algorithm parameters include RSSI (dBm) and SNR (dB), uplink and downlink processes between the application server and the server node. furthermore, three transmission parameters [23, 24] in adaptive data rate (ADR) i.e, spreading factor (SF), bandwidth (BW), and transmission power (dB). Further explanation of the ADR Algorithm can be seen in the flowchart of ADR algorithm in Figure 2 (b).

2.2. Hardware spesification and equation

2.2.1. BME sensor

The BME280 Sensor in Figure 3 is a multi-sensory and applied in the health care application (e.g. Spirometry). in previous research, health care application using different sensors in research [11, 20, 25, 26] i.e, blood pressure and pulse sensor. In research [27] the sensors used are the electrocardiogram (ECG) sensor, body temperature sensor, pulse rate, and oxygen saturation signal using MySignals and LoRa. There are 3 data on the BME280 sensor i.e. atmospheric pressure (hPa), temperature (DegC) and humidity (%). Atmospheric pressure (hPa) is the pressure at any point in the Earth's atmosphere. Almost the same as the hydrostatic pressure caused by the weight of the air above the measurement point. The formula for calculating atmospheric pressure is following the formula 2. Log10 P≈ 5-(h -15500), where the value of P is pressure (Pascal) and h is the height (meters). Furthermore, the temperature has the default unit Degree Celcius. the BME280 sensor, the unit used is degree celsius and detects conditions in the environment and results in precision. furthermore, to change to Kelvin (K), Reamur (ºRé) or Fahrenheit (°F) C language is used in the Arduino IDE. If the DegC value is known, to be changed to another temperature unit to r=c * 4/5; f=(c * 9/5) +32; k=c + 273.16; furthermore, humidity (%) is the amount of water vapor in the air that is not visible to the human eye, this amount of water vapor will determine rainfall, dew or fog. Furthermore, Figure 3 describes the BME280 sensor diagram block, There is a Pressure and temperature sensing element that is converted from analog to digital using analog to digital converter (ADC) to logic gate and continues to 6 output pins ie.SDI, SDO, SCK, CSB, VDD and GND, and just 4 pins used i.e. SDA, SCL, VDD (3.3 volt) and GND.

2.2.2. RFM95W/96W for dragino LoRa

The LoRa type used is the Dragino LoRa 915 MHz, which is compatible with the Arduino UNO Board. therefore, on the Dragino LoRa 915 MHz, the chip device used is RMF96, the transmit power is 20 dB, as shown in Figure 4 and the hardware specification in Table 1.

2.2.3. RSSI of LoRa

The RSSI stands for received signal strength indicator which is expressed in mW and dBm (when measuring), the RSSI range is -30 dBm (strength signal) and -120 dBm (weak signal). In this research, RSSI of LoRa radio signals will be analyzed within a distance of the free space area and obstacle area (tree, building, and hill). This Obstacle will cause attenuation of the signal due to three factors, i.e, diffraction, detailed reflection and scattering will be explained further. RSSI is also caused by SNR (signal noise ratio) [8] which is expressed in units of dB. The SNR range is -20 dB and +10 dB. A signal that is close to +10 dB, signal reception becomes poor or slightly corrupted. furthermore, In general, the RSSI formula is shown in (1).

$$\text{RSSI (dBm)}=-10n \log10(d) + A \tag{1}$$

Where value A is the signal strength at a distance of 1 meter in units of dBm and n is the value of path loss exponent value [28]. moreover, This RSSI can be developed in cases of research such as the coal mine underground locomotive [4], the reason for taking cases in this research is because the poor environment of coal mine underground, so that it is difficult to determine the position of locomotive so that it can be solved with an approach to positioning algorithm. The RSSI approach to path loss (PL) can be seen in (2).

$$\text{PL}\ (d) = PL\ (d_0) + 10\ x\ n\ x \log\frac{d}{d_0} + X\sigma \tag{2}$$

Where $PL\ (d)$ is a path loss from transmitter to receiver at a certain distance (d), d_0 is a reference distance at 1 meter. Xσ is a gaussian distribution random variable, where the mean or average is 0 and the standard deviation is σ (4-10). furthermore, From the PL formula above, it can be seen that the value of RSSI of node at distance d is as in (3).

$$RSSI\ (d) = P_{send} + P_{amplify} - PL\ (d) \tag{3}$$

P_{send} is a Power Transmitter, $P_{amplify}$ is a gain of antenna [29, 30]. and the RSSI formula is the same as looking for the value of A (4).

$$A = P_{send} + P_{amplify} - PL\ (d) \tag{4}$$

Where A is the RSSI value at a distance of d_0 or a distance of 1 meter. So to get an estimate of the distance (d) between nodes of the RSSI parameter and A, it can be seen in (5). The value of n is path loss exponent 2-5, each environment is different [28], for example, Free Space, n value is 2.

$$d = 10^{((A-RSSI-X\sigma)/10n)} d_0 \tag{5}$$

2.2.4. Energy and power signals

On a signal *x(t)* can be known the average value of energy signal E with range $0 < E < \infty$, as in (6).

$$E = \int_{-\infty}^{\infty} |x(t)|^2\, dt \tag{6}$$

And to get a power signal x(t) $0 < P < \infty$ for average power, stated in (7).

$$P = \lim_{T=\infty} \frac{1}{2T} \int_{-\mathrm{T}}^{\mathrm{T}} |x(t)|^2\, dt \tag{7}$$

2.2.5. PathLoss (dB) and attenuation signal

Linear path loss can be stated with (8), where a P_t devided a P_r.

$$P_r = \frac{Pt}{Pr} \tag{8}$$

Path Loss can also be defined as dB, where the dB value is not negative, as in (9)

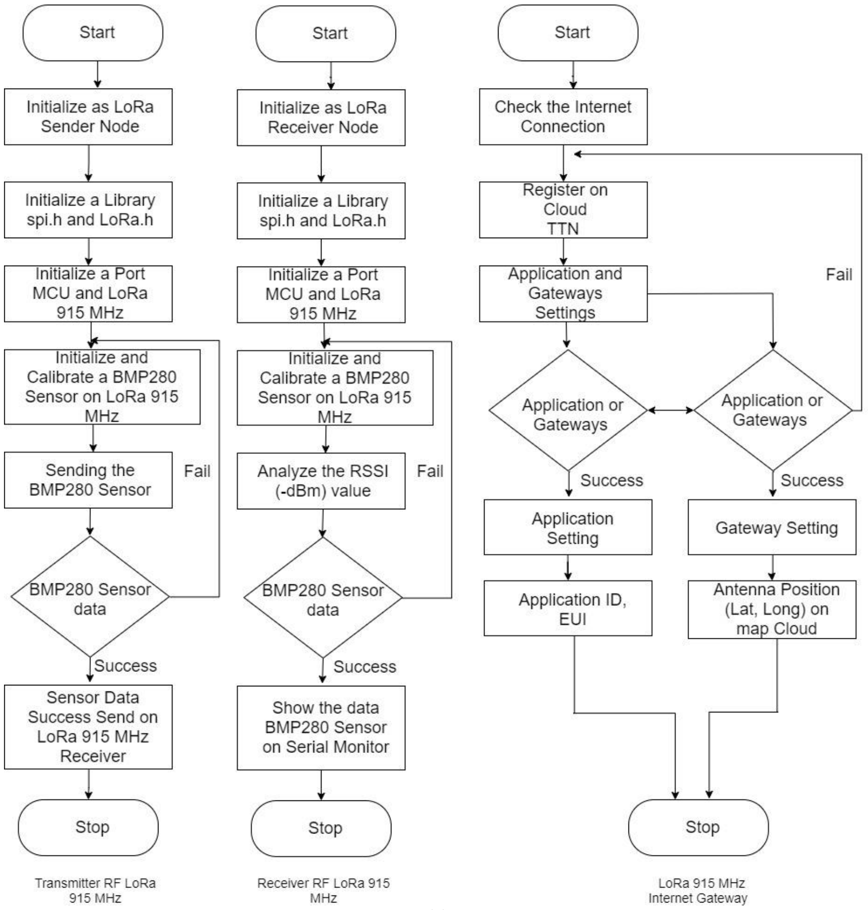
$$P_L\ dB = 10 \log_{10} \frac{Pt}{Pr}\ dB \tag{9}$$

Free space equation can be expressed as friss free space as in (10),

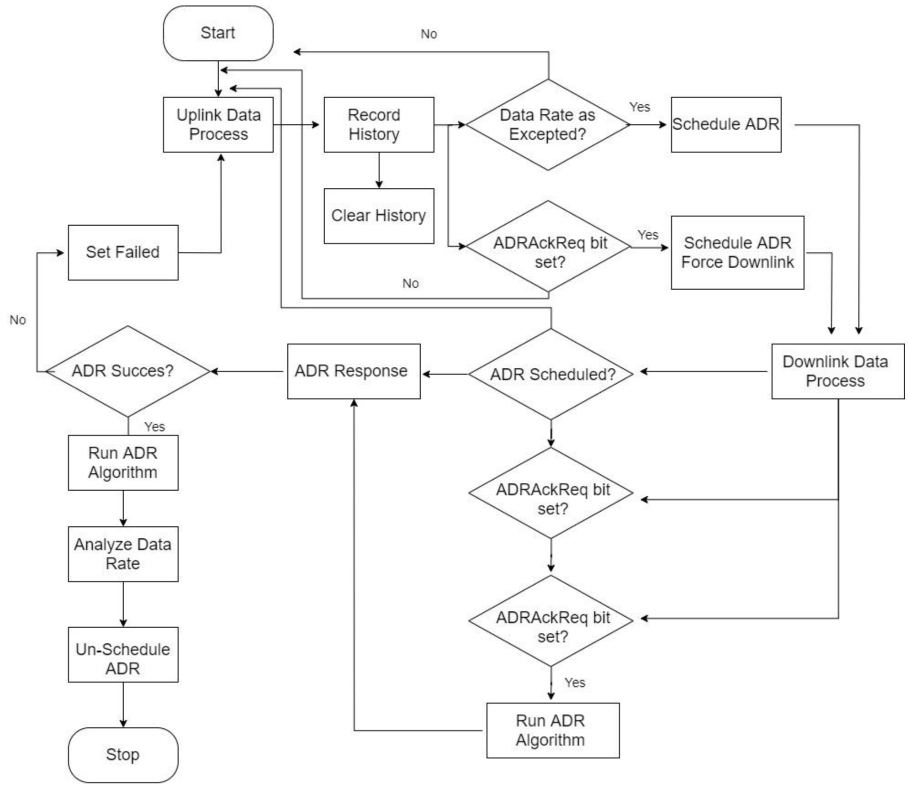
$$P_r = P_t G_t G_r \frac{\lambda^2}{(4\pi d)^2} \tag{10}$$

a distance (d) affects a signal strength at the Receiver (Rx). [29, 30] accordingly, the receiver signal strength is expressed by the parameter P_r (mW) or dB. In (11), the size of the power receiver (P_r) is determined by the power transmitter (P_t), gain on the transmitter (Gt) and receiver gain (Gr) and the length of the direct line-of-sight (LOS). in (11) there are 2 conditions where d ≥ ds (cross over) and d < ds (cross over).

$$P_r = \begin{cases} \frac{G_t\, G_r\, \lambda^2}{(4\pi d)^2 l} & \text{if } d < d_s, \\ \frac{P_t\, G_t\, G_r\, h_t{}^2 h_r{}^2}{d^4} & \text{if } d \geq d_s, \end{cases} \tag{11}$$



(a)



(b)

Figure 2. (a) Flowchart of the research (b) Flowchart of ADR algorithm

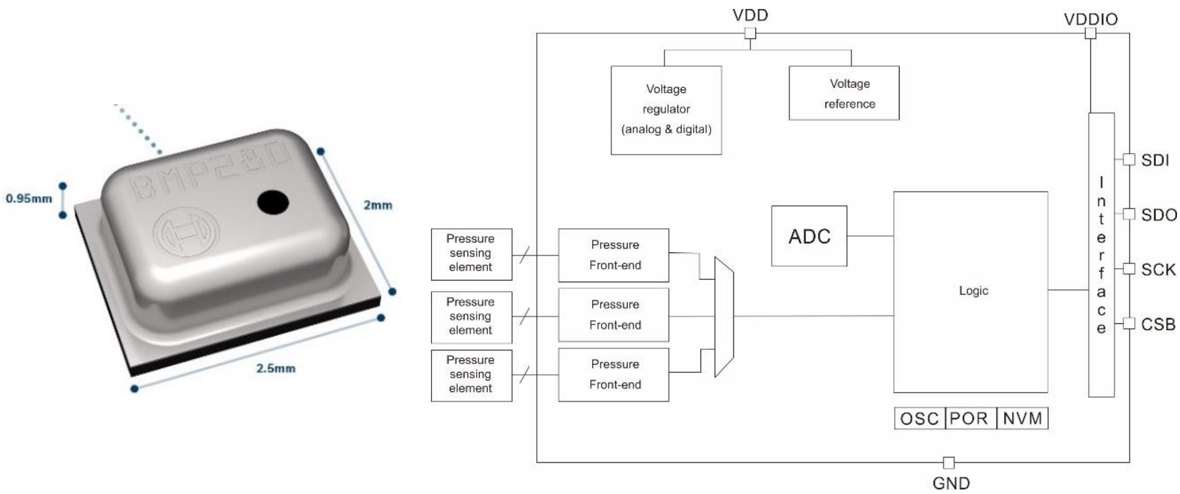


Figure 3. BME280 sensor and block diagram of BME280 sensor

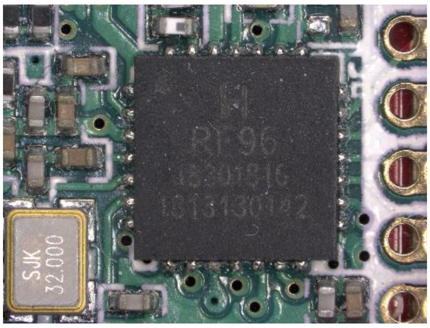


Figure 4. RF96 chip for LoRa 915 MHz from MeRL keyence VHX digital microscope

Table 1. RFM95W spesification

Parameter	Details
Link Budget	168 dB (Maximum)
Constant RF Output vs V.Supply	+20 dBm–100 mW
Low RX Current	10.3 mA, 200 nA register retention
Modulation type	FSK, GFSK, MSK, GMSK, LoRa Tm and OOK modulation
Dynamic Range RSSI	127 dB
Packet engine	256 bytes with CRC

2.2.6. Signal to noise ratio (SNR) of LoRa

Signal to noise ratio (SNR) of LoRa is the amount of signal received or signal strength (dB) compared to noise level. SNR can be used to classify signal strength. Therefore, SNR equation can be seen in (12).

$$\text{SNR\_1}=\frac{Receive\ Signal\ Power\ (dB)}{Noise\ Power\ (dB)} \tag{12}$$

and the magnitude of SNR is also influenced by Channel gain, the amount of channel gain depends on the frequency of the radio wave transmitter (Hz) and distance (d). In (13) explains about the channel gain.

$$Channel\ gain\_1=10\ log_{10}\left(\frac{\lambda^2}{4\pi^2}.\frac{1}{d^2}\right)\ dB \tag{13}$$

From (13), furthermore develop to (14).

$$Channel\ gain\_2 = 10\ log_{10}\ \left(\frac{\lambda^2}{4\pi^2}\right) - 20\ log_{10}\ (d)\ dB \quad (14)$$

In (12), receive signal power (dB) is equal to transmit power multiply channel gain, therefore, the equation becomes to (15).

$$SNR\_2 = \frac{Transmit\ Power\ .Channel\ Gain\ (dB)}{Noise\ Power\ (dB)} \quad (15)$$

Therefore, from (14), it can be concluded that SNR is influenced by the magnitude of radio wave frequency (Hz) and distance. The farther the distance between Tx and Rx, the greater the signal to noise ratio (dB) value means the greater the interference that occurs in the signal or the lower the signal reception (RSSI) (dBm). In this case, RSSI (dBm) is affected by the Noise value and signal interference.

2.2.7. LoRa parameters packet

Lora Packet is initialized with explicit header and implicit header mode, explicit header consists of preamble, header, payload, and payload CRC, while implicit headermode consists of preamble, payload and payload CRC. Other important parameters owned by LoRa are spreading factor (SF), bandwidth (BW) and code rate (CR), the value of CR is 1-4. SF value is 7-12, this value is given to LoRa when transmitting data based on factor distances (m). Bandwidth is also called RC (Chip Rate) LoRa consists of 500 kHz, 250 kHz and 125 kHz. furthermore, the process of transmitting LoRa data in 1 second expressed by T_S, T_S calculation can be seen in (16).

$$T_S = \frac{2^{SF}}{BW} \quad (16)$$

Furthermore, LoRa data transmission can be determined per 1 second, with different spreading factor values that will produce different data transmission. The next parameter is the symbol rate (R_S). R_S is formulated as in (17).

$$R_S = \frac{BW}{2^{SF}} \quad (17)$$

Therefore, from (17) a symbol rate can be generated. Symbol rate values differ based on bandwidth width (KHz) and spreading factor (SF). The next parameter is R_b, R_b is the data rate or bit rate (bps), this parameter is very important in the analysis of LoRa data transmission in (18) and (19), by analyzing the value of R_b means that it can find out the Quality of Services (QoS) of LoRa data transmission.

$$R_b = SF\ x\ \frac{BW}{2^{SF}}\ x\ CR \quad (18)$$

$$Rb = SF\ x\ \frac{\left[\frac{4}{4+CR}\right]}{\left[\frac{2^{SF}}{BW}\right]}\ x\ 1000 \quad (19)$$

$$\text{ToA or } T_{Packet} = T_{Preamble} + T_{Paylaod} \quad (20)$$

ToA or time on air (ms) is the sum of time preamble and time payload in second units. And to get the value of $T_{Preamble}$ can be seen in (21).

$$T_{Preamble} = (n_{Preamble} + 4.25\ )T_s \quad (21)$$

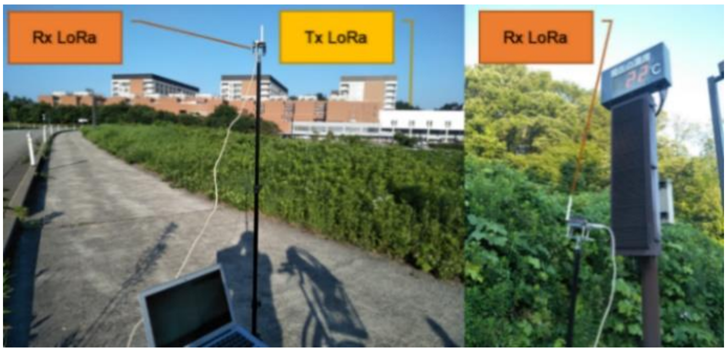
as for $T_{Paylaod}$, it can be formulated in (22).

$$T_{Payload} = T_s\ (8 + \max(\text{ceil}((8PL-4SF+28+16CRC-20H)/4(SF-2DE))\ (CR+4),0)) \quad (22)$$

2.2.8. Packet BME280 sensor data delivery

The BME280 sensor data transmission is done in 2 ways, the free space path loss (FSPL) method and obstacle, obstacle here e.g, tree, building, hill or mountain, for the resulting output is the receiver signal strength indicator (RSSI (-dBm) parameter)), for more details, add the SNR (signal noise ratio (-dB)) parameter. furthermore, sensor data BME280 e.g, temperature (DegC), barometric pressure (hPa), and humidity (%). The output is obtained from the Arduino serial monitor on the transmitter, receiver, and application server IoT (Thingspeak). Figure 5 (a) is sending Tx LoRa 915 MHz data at free space path loss (FSPL) and Figure 5 (b) is sending Tx LoRa 915 MHz data when obstacles are present.

(a)



(b)

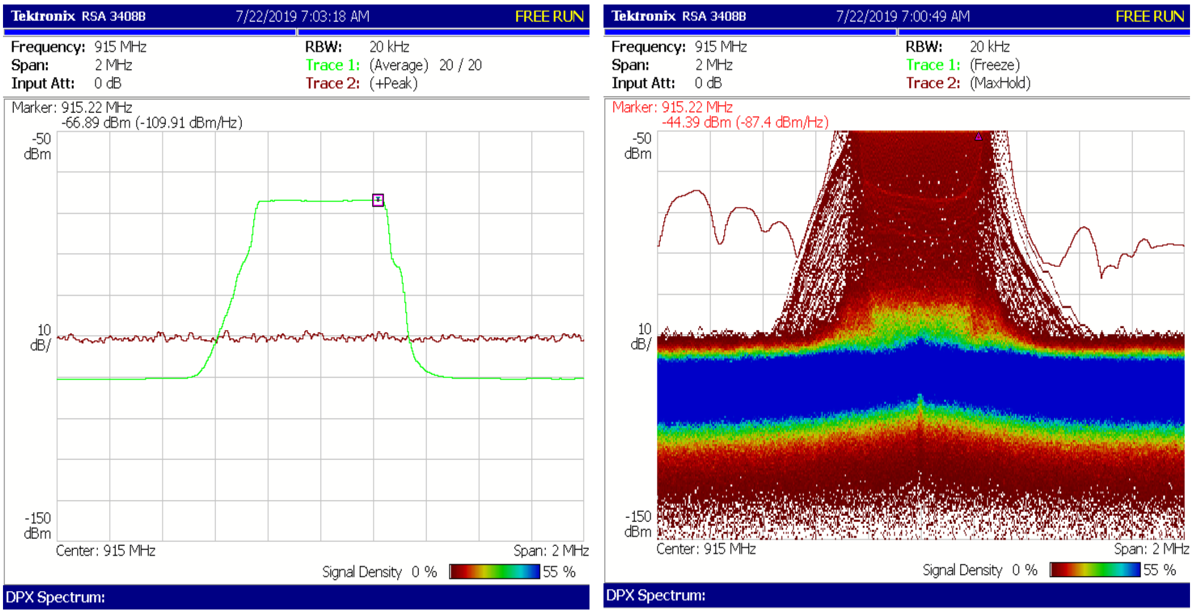
Figure 5. (a) Communication Tx and Rx LoRa 915 MHz on FSPL,
(b) Communication Tx and Rx LoRa 915 MHz on Obstacles

3. RESULTS AND ANALYSIS

3.1. Radio frequency LoRa 915 MHz with signal analyzer

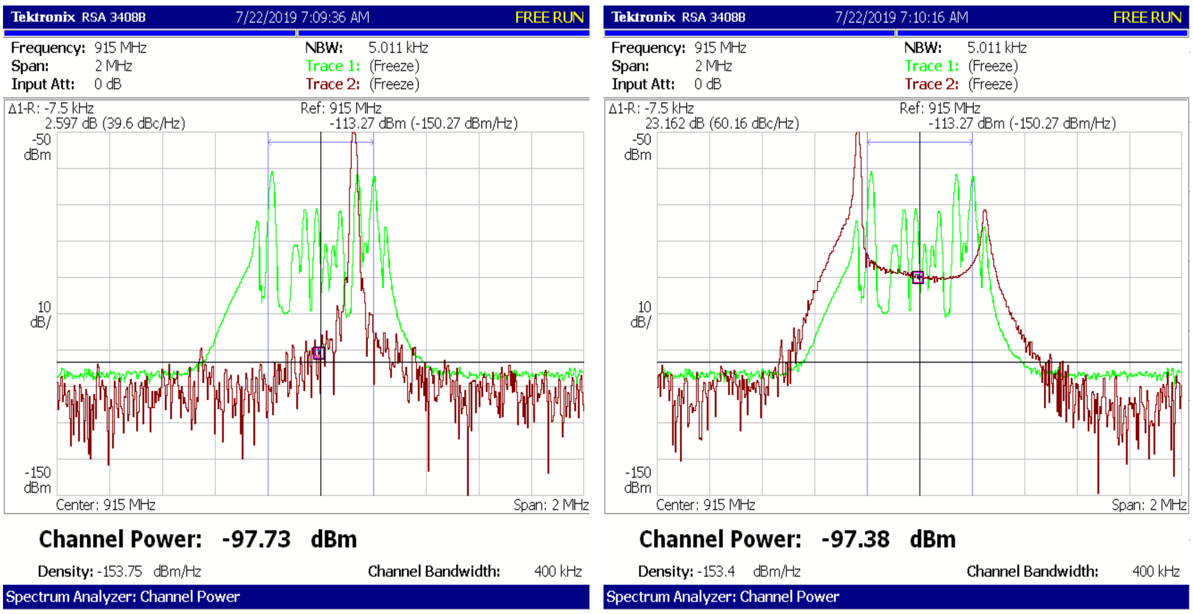
Figures 6 (a), 6 (b), 7 (a), and 7 (b) are various outputs of the RSA 3408B Realtime Spectrum Analyzer DC-8 GHz DPX technology electronic analyzer, signal LoRa E32915T20D at frequency 915 MHz as center value. Therefore, the analyzer records LoRa transmitting data activity at frequency 915 MHz as center frequency, this signal shows signal LoRa with receiver sensitivity (dBm) value and signal noise ratio (dB) value.

Data rate or Bit rate (Br) is also determined by the Spreading Factor, from the Spreading Factor (SF) parameter another parameter can be obtained e.g, Payload, data rate, bit rate, and receiver sensitivity. More fully, about LoRa Spreading Factor and Data Rate can be seen in Figure 8 (a, b) shows the relationship between LoRa Bandwidth and Spread Factor which determines the speed of transmitting LoRa data or time on air (ms) and determines the bit rate (bps). In Figure 8(a) can be seen that the 125 kHz Bandwidth has the longest Time on Air of 2465.79 ms on Spreading Factor 12, and the bandwidth of 500 kHz is 534.53 ms. meaning that the wider the bandwidth the faster the data transmits even though it is in Spreading Factor 12. In this case, Bandwidth determines the quality of the receiving signal from tx to Rx, the greater the bandwidth, the better the quality of the signal produced. The value of Time on Air is shown in (20). furthermore, Thingspeak Application Server, in the Application server important data that can be used as a key is the Application Programming Interface (API), i.e, Write API and Read API. therefore, the sensor data output can be seen in Figure 9. moreover, RSSI (-dBm) shows a value of -34 dBm at a distance of 1 meter, for further analysis a Receiver Receiver will be placed at a distance of up to 1 Km, to ensure the strength of LoRa at a great distance, and to the Free Space area (Figure 5(a)) and Obstacle (Tree, Building, Hill, etc.) (Figure 5(b)). From the comparison signals in 3 conditions, i.e. Free Space, Building Obstacle and Hill+Tree Obstacle, it was concluded that Building and Hill had a great value in terms of attenuation. Free Space is the lowest at a distance of 1 when it is compared to the obstacle, this is influenced by the Reflected signal factor, diffraction signal, and scattering signal during data transmission from Transmitter to Receiver in Figure 5.



(a) (b)

Figure 6. (a) Signal LoRa 915 MHz with peak setting, (b) LoRa 915 MHz signal with trace bitmap



(a) (b)

Figure 7. (a) Signal LoRa with a normal setting, (b) Signal LoRa with intermediate surges

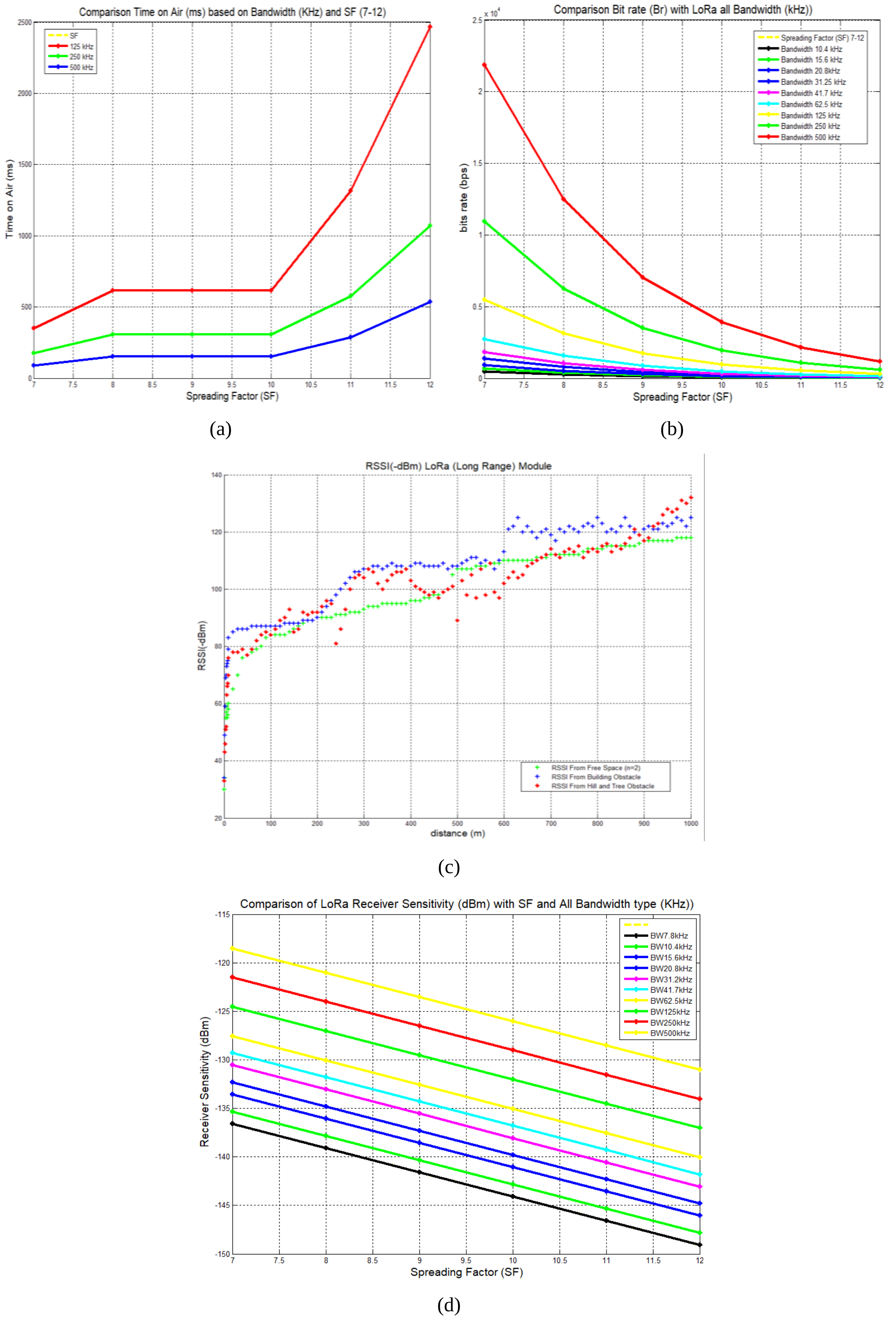


Figure 8. (c) RSSI (-dBm) comparison result from 3 conditions propagation,
(d) LoRa Receiver Sensitivity (dBm) NF=6 dB (continue)

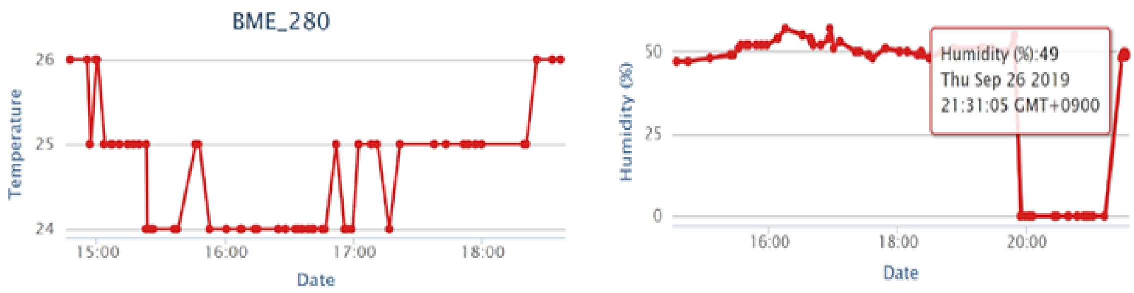


Figure 9. Output temperature (C) and humidity (%) of BME280 sensor on application server

4. CONCLUSION

The process of sending BME280 sensor data uses long range 915 MHz radio frequency at a distance of more than 1 km in the Kakuma-Machi-Ishikawa Kanazawa mountain range-Japan has difficulties due to tight obstacle problems, but the research can be carried out in 3 different conditions (free space area, building obstacle and hills and tree obstacle) that produce different values, where building obstacle gives a greater attenuation (-dBm) value. And free space is the best condition for sending BME280 sensor signals using LoRa at a distance of > 1 km. moreover, the LoRa 915 MHz signal can be analyzed using the signal analyzer and produces a signal strength value (-dBm). Signal LoRa 915 MHz can also be analyzed using signal analyzer. But this research needs to be developed with a more complex communication system, i.e, mesh networking uses 915 MHz LoRa with multi-sensor nodes, parameters of quality of service (QoS) are added to add quality and contribution to paper, budget link parameters such as byte rate, throughput, packet loss, air data rate, etc. The BME280 sensor output can be sent via sensor nodes to the graphical internet via the LoRa internet gateway, with the halpeak application server. The analysis process is on the internet of things (IoT) system and data analysis on the LoRa internet gateway and analysis on uplink, downlink processes and quality of service (QoS) on the internet gateway.

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