Development Education of Blind Adaptive Data Rate LoRaWAN Network on Mobile Node

Puput Dani Prasetyo Adi
Telecommunication Research Center
National Research and Innovation Agency (BRIN-RI)
corr. author: pupu008@brin.go.id
ORCID: 0000-0002-5402-8864

Yuyu Wahyu
Telecommunication Research Center
BRIN, Cisitu, Bandung, West Java
yuyuwahyusr@gmail.com

Dwi Arman Prasetya
Universitas Pembangunan Nasional Veteran Jawa Timur, Indonesia
arman.prasetya.sada@upnjatim.ac.id
ORCID: 0000-0003-0281-9928

J.M.Parenreng
Department of Computer Engineering
Universitas Negeri Makassar, Makassar, Indonesia
jparenreng@unm.ac.id
ORCID: 0000-0001-6803-7529

Gatot Suharto Abdul Fatah
Horticulture and Plantation Research Center, BRIN-RI
gsafatah@gmail.com

Fairuz Iqbal Maulana
Computer Science Department,
Bina Nusantara University
Jakarta, Indonesia 11480
fairuz.maulana@binus.edu
ORCID: 0000-0002-8740-1530

Volvo Sihombing
Department of Informatics Management
Labuhan Batu University
volvolumantoruan@gmail.com

Agoestina Mappadang
Faculty of Economics and Business
Budi Luhur University
Jakarta, Indonesia
agustina.mappadang@budiluhur.ac.id

Hastangka
The educational research center,
National Research and Innovation Agency (BRIN)
hastangka@brin.go.id
ORCID: 0000-0002-6513-7409

Abdul Wahid
Department of Computer Engineering
Universitas Negeri Makassar, Indonesia,
wahid@unm.ac.id

***Abstract*—Adaptive Data Rate is one of the essential mechanisms that continue to be developed for LoRaWAN. Adaptive Data Rate (ADR) is one of the mechanisms for saving energy and bit-rate efficiency of LoRaWAN. Using ADR is expected to increase throughput (bps) and minimize packet loss (bps), packets can be lost during data collisions, LoRaWAN networks are formed from several end-nodes that are connected to each other, can reach 100 nodes, and this causes collisions data if no settings are made with ADR. ADR talks about scheduling and set other parameters. The ADR method was developed on mobile nodes, ADR can handle the node's data rate condition in its movement, but this is also influenced by the distance (km). The farther the end-node is moving from its gateway, causing packet loss data can occur even in percentage (%) different. ADR development in the Blind ADR for mobile node includes Node-ADR and Net-ADR. from the experimental results of the estimation of battery usage (mAH), the average battery used in position 1 is 409 mAH, position 2 is 482 mAH, and position 3 is 992 mAH, this shows that the larger the SF, the greater the energy required.**

Keywords—LoRaWAN, Education of ADR, Blind ADR, LoRa Communication, Mobile Node

I. INTRODUCTION

Talking about LoRa and LoRaWAN will never end if we focus on developing the data transmitting method. LoRa works at 920-923 MHz frequency in Indonesia so that it can be adjusted according to the frequency of PT.TELKOM Indonesia, this is done so as not to interfere with the performance of other frequencies or frequency interference. LoRaWAN is an ad-hoc network that can transmit sensor data at a low bit rate to a LoRa Gateway or LoRa server [2,8,15]. The problem is if there are too many LoRa end-nodes and how to manage them if the data conditions collide, this will cause a system to be ineffective. Several methods continue to be developed for ADR [1,3,4,7,11,12]. So until now, ADR continues to grow according to the cases obtained, for example, multi-node monitoring in agriculture, medical [19,20], and water quality in ponds. The next thing is to determine the Time of Air (ToA) sensor data continuously sent from the end node to the LoRa Gateway. Using LoRaWAN, the Internet of things (IoT) [13,16,30] is rapidly growing. One of the significant contributions to this research is providing a quick analysis of changes in Bit-Rate or Packet Receive Ratio (%) in the movement of horses that are being monitored on their position and health with a new method, namely Blind-ADR.

II. THEORY

A. Adaptive Data Rate Introduction and Mechanism

Figure 1 is an overview of the Adaptive Data Rate [17,22,23,26] LoRaWAN Network in general [5,18,21,24,27], the connections between these components are connected to each other starting from end-nodes based on LoRa; these end-nodes are nodes that have sensors with low bit-rates such as temperature sensors, humidity sensors, pH sensors, etc., while the LoRa Gateway is in charge of capturing sensor data from all end-nodes from various sides, then displaying it to the Application server via Backhaul and LoRa Network Server. This is where the analysis comes in, how much data loss (bps) is recorded on LoRa gateways. Some researchers say that ADR can be done by adding LoRa gateways [32,35,38]. Moreover, the point is that data can be handled well by Gateways with the addition of gateways that are used to avoid data bottlenecks and avoid packet loss, and the second step is how to manage data by providing delay time (s) for each sending data sensors from the end-node or

2022 5th International Seminar on Research of Information Technology and Intelligent Systems (ISRITI) | 978-1-6654-5512-1/22/$31.00 ©2022 IEEE | DOI: 10.1109/ISRITI56927.2022.10052978

transmitter. Several parameters or factors that determine the quality of LoRaWAN data are Spreading Factor (SF), Bandwidth (BW), and sensitivity (s). Note the relationship between SF and sensitivity in Table 1 [33,34,36,37].

Table 1 shows that if the SF value increases, the sensitivity (s) is also more sensitive. Moreover, SF value increases, the ToA (ms) also increases, meaning that the time it takes to send sensor value data or messages (bytes) to the Receiver or gateway is getting longer (ms). For simplicity, Figure 2 and Figure 3 represent ADR conditions. If it is activated, then there are two parameters to consider at the end-node, namely data rate from end-node sensor types and Longes range, as in Figure 2; if SF7, then the ToA condition very fast (ms) and the bit-rate will also be affected. The data that will be displayed is in the form of sensor data with a low bit-rate; it can be in the form of graphs or table data set by time (time delay (s)). Meanwhile, in figure 3, we can see that the amount of data from the end node to the gateway must be ensured that the ADR is active. If ADR is involved, the end-node sensor data has a greater chance to enter the server without any significant packet loss.

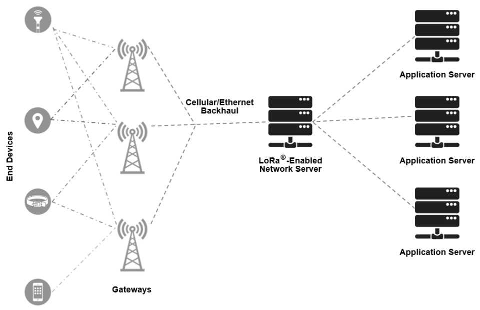

Fig. 1. Adaptive Data Rate LoRaWAN Network

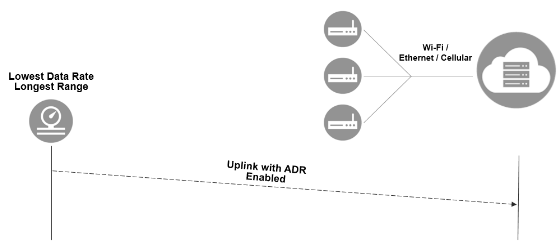

Fig. 2. Uplink process data with Adaptive Data Rate LoRaWAN

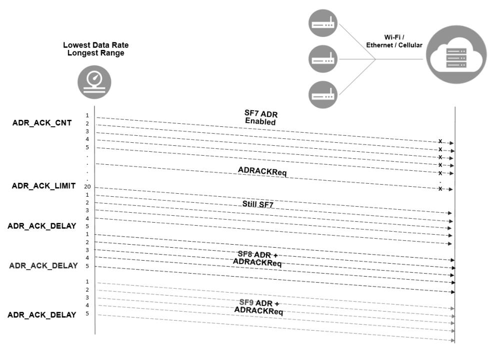

Fig. 3. Multiple data on the ADR mechanism

TABLE I. SF, Sensitivity, and ToA comparison

Spreading Factor (SF)	Sensitivity (s)	Time on Air (ms)
SF7	-123 dBm	41 ms
SF8	-126 dBm	72 ms
SF9	-129 dBm	144 ms
SF10	-132 dBm	288 ms
SF11	-134.5 dBm	577 ms
SF12	-137 dBm	991 ms

From the ADR Algorithm, the quality of the data rate generated from each set of the Spreading Factor (SF) can be determined. Kualitas data rate ini ditentukan dengan SF yang kecil. The development of this ADR can be seen in other ADR Algorithms. What is certain is that ADR regulates incoming data on the server, i.e., uplink and downlink, the uplink process, and data that comes out of the server to the end node, namely the downlink process. ADR is used for static conditions such as figure 2 and figure 3, but what if the node moves are familiar with the term Blind ADR? Now we are just getting started.

III. METHOD

B. Blind ADR Algorithm

The Blind ADR approach is a new method for unpredictable node movement, the LoRa parameters used are Power consumption, Link Budget, and Airtime of LoRa. Several essential parameters for LoRaWAN analysis are contained in the following formulas: equation 1 to equation 8. Equation 1 to 8 is the standard equation used for LoRaWAN analysis. At the same time, modifications can occur if there is a case study, such as monitoring the movement of horses, so that the GPS Module is integrated with LoRaWAN into real-time data that needs to be solved by analyzing the data transmission.

$$S = -174+10\ Log_{10}\ (BW)+NF+SNR_{Limit} \quad (1)$$

$$Time\ on\ Air\ (ToA) = T_{Preamble}+T_{Payload} \quad (2)$$

$$T\_p_{reamble} = Nb\ Preamble\ (8)+symbols\ added\ by\ radio\ (4.25)\ x\ T_{Symbol} \quad (3)$$

$$T_{Payload} = NbPayloadSymbol\ x\ T_{Symbol} \quad (4)$$

$$N_{Payload}=8+max(ceil\ |(8PL-4SF+28+16CRC-20IH)/4(SF-2DE)|(CR+4),0) \quad (5)$$

$$Link\ Budget\ (dB) = Tx\ Power - Sensitivity\ (s) \quad (6)$$

$$R_b=SF\ x\ (BW/2^{\wedge}SF)x\ CR \quad (7)$$

$$R_b=SF\ x\ (4/(4+CR))/((2^{\wedge}SF)/BW)\ x\ 1000 \quad (8)$$

In figure 3, multiple data using ADR is very regular; it can be seen from the accuracy of the schedule SF7 to SF12 in the data uplink process. Accordingly the theory, the bit rate or data rate is stable with a value that does not change (with a particular sensor type (bit)) and a predetermined distance, so the ToA (ms) value is permanently fixed. Moreover, the Bit Rate is approximately the same (bps) depending on the SF used, while in Figure 4. The data sent to this LoRa server has a value that varies depending on the distance (m) that will produce data at a certain distance, a specific RSSI value, and signal strength (-dB), especially the resulting data, so it is called Blind ADR.

Blind ADR is used, e.g., tracking car movement tracking Pets, such as the movement of dogs or cows, and of course, the data sent to the Gateway is GPS data; the settings can send data every few minutes and sleep and wake up again when the data must send messages or GPS information.

```
Blind ADR Algorithm
Input: SF7-12
Output: Bit Rate (bps) and Battery Estimate
Initialize: UL Transmission and ACK
               : end-node position or range
if  All Devices are on, ED and GW ON
    ADR_ACL_CNT Enabled, then SF ADR Enabled
    SF7 ADR Enabled, then ADR ACKReq Enabled
Then
    ADR_ACK_LIMIT, then Still SF7
    ADR use Different SF setting [6-10 step]
    ADR_ACK_DELAY then SF7ADR + ADRACKReq Run
    ADR_ACK_DELAY then SF10ADR + ADRACKReq Run
    ADR_ACK_DELAY then SF12ADR + ADRACKReq Run
    Every 60 minute SF12 send the sensor data
    Every 30 minute SF10 send the sensor data
    Every 20 minute SF7 send the sensor data
else
    ADR_ACK ERROR or use a different setting, or
    different SF Setting
    Analyzes of Data rate (bytes) produced with
    specific Time on Air (ToA) in ms
End
```

C. ADR and its comparison

In outline, several Adaptive Data Rate developments, e.g., ADR++ α best for IoT LoRaWAN, ADR for low mobility scenario use Net-ADR and Node-ADR, Comparison of ADR, ADR+, and New Dynamic (ND-ADR), FloRaWAN and OKUMURA-HATA, Comparison of ADR and Modified ADR for Network-Server side, Enhanced ADR for LoRaWAN networks with mobility, Using Enhanced-ADR (E-ADR) minimize transmission time, and energy consumption, Packet Loss, improve QoS, Feasibility Study of the LoRaWAN Blind Adaptive, Data Rate (BADR), and EARN: Enhanced ADR With Coding Rate Adaptation in LoRaWAN, EARN AM is better than ADR and FADR in terms of range. Several ADR development methods positively impacted Throughput, Packet Loss, Packet Receive Ratio (%), and reduced energy (mJ). However, Blind ADR has a match in the case study, namely Horses, due to the random positioning causes the data obtained to be random and erratic, while the patterns on the mobile network mostly have regularity, for example, a car being driven on a highway, namely the same point, for example from the point A to point B at a certain distance. But for the behavior of horses in captivity, no one can be sure which point will be chosen. So Blind ADR is preferred.

D. Blind ADR

From table 2, we can see that the condition of coverage quality determines the settings of the data rate, which is indicated by the SF Value and Battery capacity (approach on SF11, SF9, and SF8); battery capacity talks about the ability of LoRa end-nodes to send data to the gateway so that adequate battery capacity is needed to transmit data. Continuously or set using delay_time and sleep mode of end-node LoRa [10,14,28,29].

Figure 5 is an example of setting the Spreading Factor (SF) at a certain time, for example, 60 minutes; in 60 minutes, there is a Spreading Factor of 7 of 3 times data transmission, an SF of 10 of 2 times of data transmission and Spreading Factor of 12 of 2 times of data transmission. This is done to manage the three parameters, namely Power consumption, and effective data rate. Figure 5 shows SF12 once every hour, SF10 twice an hour, and SF7 three times an hour. GPS data estimation is 46-50 bit/s, and then we can experiment with transmitting data using a formula using SF parameters, bit-rate, and LoRa bandwidth.

If the horse is in position A, then moves to position B, which is further away from the gateway, then the thing that needs to be taken into account is the delay time so it doesn't send GPS data every second. Still, there needs to be a time setting, as in Figure 7, in 60 minutes, the horse's position, although at any point, will send data alternately based on the Spreading Factor. For example, in a herd of horses with an area of 300 meters2, its position will be known using GPS in real time using LoRaWAN, with data retrieval for 1 hour, it can be calculated the quality of data that has been successfully sent (throughput) in a free position, meaning that the node is always changing its position [6,9,25,31].

TABLE II.Blind ADR Setting

Coverage Quality	Data Rate on the SF	Battery Capacity
Deep Indoor	SF12	1092 mAH
Indoor	SF11	800 mAH
Indoor_type 2	SF10	392 mAH
Indoor_type 3	SF9	240 mAH
Indoor_type 4	SF8	189 mAH
Outdoor	SF7	136 mAH

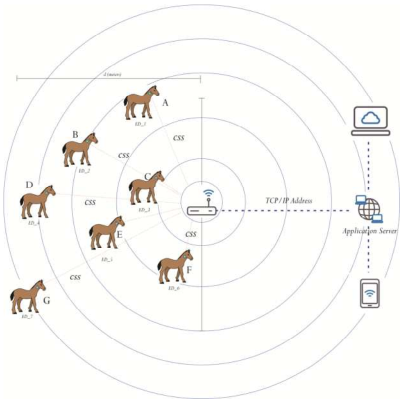

Fig. 4. Blind ADR for Tracking Horse

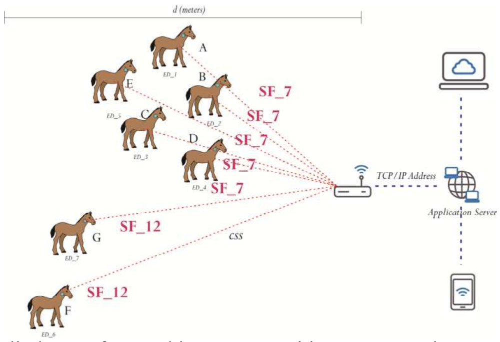

Fig. 5. Blind ADR for Tracking Horse position one scenario

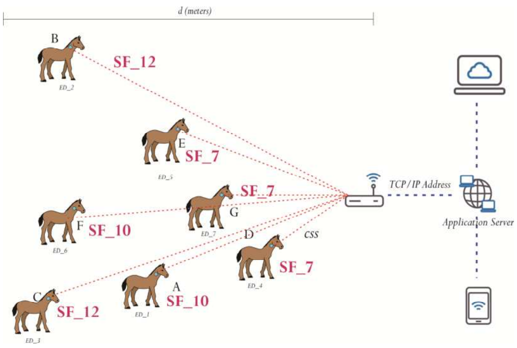

Fig. 6. Blind ADR for Tracking Horse position two scenario

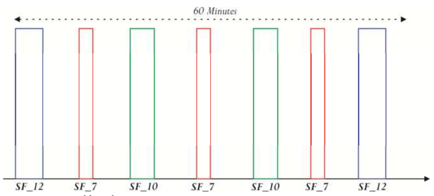

Fig. 7. Delay SF on Blind ADR

Moreover, we use the example of 7 horses that constantly change their position, and when taken for 3 hours, then we get three different places from the 7-horse herd. In this study, the best estimate of the data rate generated using this Blind ADR will be calculated. Data collection is from the first hour, second hour, and third hour. They are broadly described in Fig.5, Fig.6, and Fig.8.

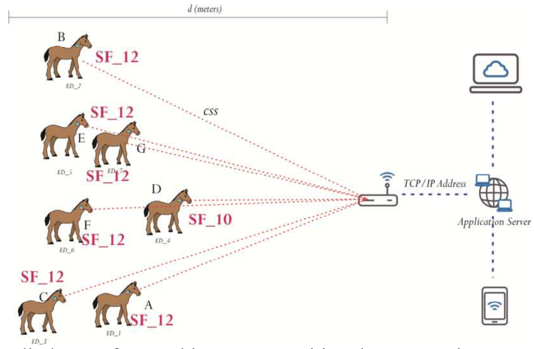

Fig. 8. Blind ADR for Tracking Horse position three scenario

IV. Result and Discussion

A. LoRa Bit-Rate

LoRa type used is ES920LR 920 MHz, with a bandwidth of 125 kHz. CR 1-4 can provide a result of a bit-rate approach in blind ADR. With the process that each data is sent alternately, assuming one horse or each sensor node sends data for 8.5 minutes, 8.5x7 is 59.5 minutes. So data retrieval for 1 hour obtained different bit-rate values at each horse position according to SF and BW LoRa.

In general, the bit-rate shown in figure 9, Figure 9 is LoRa ES920LR 125 kHz bandwidth with SF 7-12 Comparison. SF 7 produced 3418 bps, SF 8 built 1953 bps, SF 9 had 1099 bps, SF 10 produced 610 bps, SF 11 produced 336, and SF 12 produced 183 bps. Moreover, Figure 10 compares the three positions in the previous scenario where the magenta color line is position 1, the blue line is position 2, and the green line is position 3.

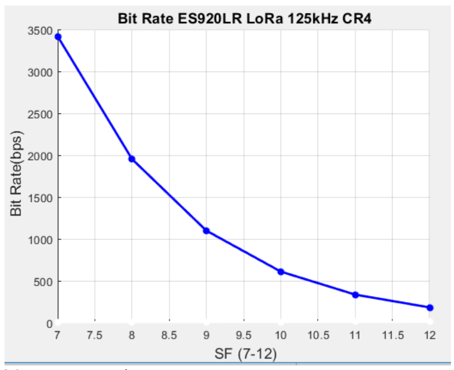

Fig. 9. ES920LR LoRa Bit Rate

B. Bit-rate LoRaWAN calculation positions 1, 2, and 3

Figure 10 shows that SF affects the Bit Rate (bps) generated. The greater the SF, the smaller the Bit Rate, and vice versa. Moreover, Figure 12 shows the best position and the resulting bit-rate, with position 1 yielding 109,100 kbps, position 2 delivering 74,005 kbps, and position 3 yielding 10,681 kbps in more detail is shown in table 3 and table 4. While Figure 11 estimates battery usage (mAH), the average battery used in position 1 is 409 mAH, position 2 is 482 mAH, and position 3 is 992 mAH.

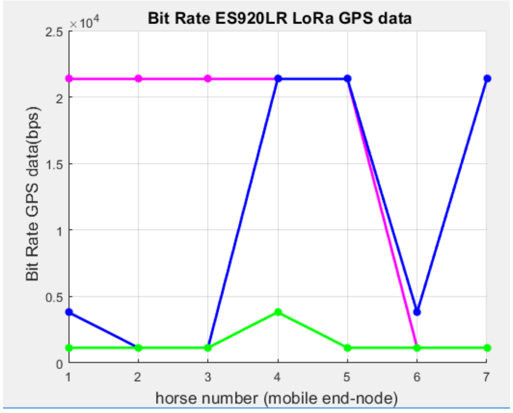

Fig. 10. Bit Rate result from Mobile Node 3 position

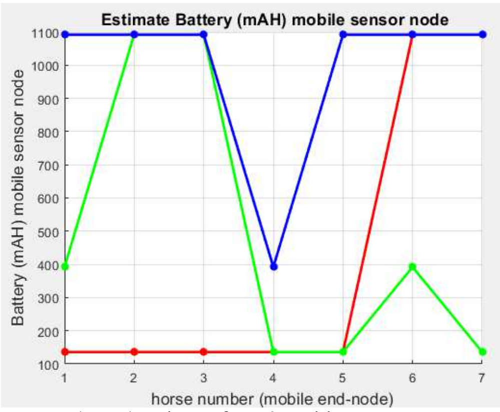

Fig. 11. Battery (mAH) estimate from 3 position

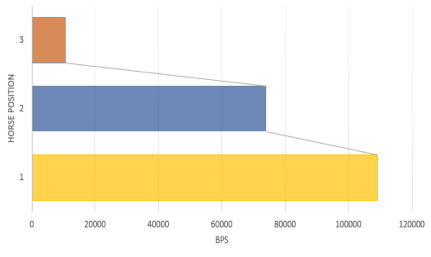

Fig. 12. Bit Rate result from Mobile Node 3 position

TABLE III.Bit Rate (bps) per position

No.or name	Position1 (bps)	Position2 (bps)	Position3 (bps)
1/A	21362	3814	1144
2/B	1144	1144	1144
3/C	21362	1144	1144
4/D	21362	21362	3814
5/E	21362	21362	1144
6/F	1144	3814	1144
7/G	1144	21362	1144

TABLE IV. Battery usage (mAH) per positions

No.or name	Position1 (mAH)	Position2 (mAH)	Position3 (mAH)
1/A	136	392	1092
2/B	136	1092	1092
3/C	136	1092	1092
4/D	136	136	392
5/E	136	136	1092
6/F	1092	392	1092
7/G	1092	136	1092

V. Conclusion

Blind ADR causes the data rate to vary according to the position of the mobile node, whether it is on SF7, SF10, or SF 12. from horse monitoring based on LoRaWAN, it has essential parameters, i.e., Bit Rate or Data Rate (bps), Power consumption or Battery consumption (mAH), and is supported by the position of the mobile node, if SF12 requires a more significant battery consumption, while for the bit rate produce it small. The total of the three experiments at position 1 is 109,100 kbps, in the second position is 74,005 kbps, while at position three, it is 10,681 kbps using GPS data. And ADR is one of the appropriate mechanisms for the static position, and if it is a mobile position of a sensor node, then Blind ADR is used. And the point is that SF7 will produce more data than SF12, and power consumption, SF12 is greater than SF7, as shown in the figure or analysis graph. From the experimental results of the estimation of battery usage (mAH), the average battery used in position 1 is 409 mAH, position 2 is 482 mAH, and position 3 is 992 mAH. This shows that the larger the SF, the greater the energy required.

Acknowledgment

Thank you to the work team who worked hard to help the primary author complete research on LoRaWAN analysis and development methods for efficiency and the performance of the LoRaWAN Network.

References

[1] L. Yang, H. Cui, M. Zhang, Y. Wang, R. Wang and Y. Wu, “Research of ADR mechanism in low mobility scenario,” 2022 IEEE 5th International Conference on Electronic Information and Communication Technology (ICEICT), 2022, pp. 460-463, doi: 10.1109/ICEICT55736.2022.9908849.

[2] P.D.P Adi, Akio Kitagawa, A Review of the Blockly Programming on M5Stack Board and MQTT Based for Programming Education, IEEE 11th International Conference on Engineering Education (ICEED), DOI: 10.1109/ICEED47294.2019.8994922, 2019.

[3] C. Jiang, Y. Yang, X. Chen, J. Liao, W. Song and X. Zhang, “A New-Dynamic Adaptive Data Rate Algorithm of LoRaWAN in Harsh Environment,” in IEEE Internet of Things Journal, vol. 9, no. 11, pp. 8989-9001, 1 June1, 2022, doi: 10.1109/JIOT.2021.3118051.

[4] A. Ilarizky, A. Kurniawan, E. P. Subagyo, R. Harwahyu and R. F. Sari, “Performance Analysis of Adaptive Data Rate Scheme at Network-Server Side in LoRaWAN Network,” 2021 2nd International

Conference on ICT for Rural Development (IC-ICTRuDev), 2021, pp. 1-5, doi: 10.1109/IC-ICTRuDev50538.2021.9656523.

[5] P.D.P Adi, Akio Kitagawa, Performance Evaluation of LoRa ES920LR 920 MHz on the Development Board, International Journal of Advanced Computer Science and Applications (IJACSA), 11(6). http://dx.doi.org/10.14569/IJACSA.2020.0110602, 2020.

[6] N. BENKAHLA, H. TOUNSI, Y. -Q. SONG and M. FRIKHA, “Enhanced ADR for LoRaWAN networks with mobility,” 2019 15th International Wireless Communications & Mobile Computing Conference (IWCMC), 2019, pp. 1-6, doi: 10.1109/IWCMC.2019.8766738.

[7] A. Farhad, D. -H. Kim, J. -S. Yoon and J. -Y. Pyun, “Feasibility Study of the LoRaWAN blind Adaptive Data Rate,” 2021 Twelfth International Conference on Ubiquitous and Future Networks (ICUFN), 2021, pp. 67-69, doi: 10.1109/ICUFN49451.2021.9528716.

[8] P.D.P Adi, Akio Kitagawa; Junichi Akita, Finger Robotic control use M5Stack board and MQTT Protocol-based, 7th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), DOI: 10.1109/ICITACEE50144.2020.9239170, 2020.

[9] N. Benkahla, H. Tounsi, Y. -Q. Song and M. Frikha, “VHMM-based E-ADR for LoRaWAN networks with unknown mobility patterns,” 2021 International Wireless Communications and Mobile Computing (IWCMC), 2021, pp. 86-91, doi: 10.1109/IWCMC51323.2021.9498709.

[10] P.D.P Adi, Akio Kitagawa, Quality of Service and Power Consumption Optimization on the IEEE 802.15.4 Pulse Sensor Node based on Internet of Things, International Journal of Advanced Computer Science and Applications 10(5), DOI: 10.14569/IJACSA.2019.0100518, January 2019.

[11] A. Farhad, D. -H. Kim, D. Kwon and J. -Y. Pyun, “An Improved Adaptive Data Rate for LoRaWAN Networks,” 2020 IEEE International Conference on Consumer Electronics - Asia (ICCE-Asia), 2020, pp. 1-4, doi: 10.1109/ICCE-Asia49877.2020.9276973.

[12] J. Park, K. Park, H. Bae and C. -K. Kim, “EARN: Enhanced ADR With Coding Rate Adaptation in LoRaWAN,” in IEEE Internet of Things Journal, vol. 7, no. 12, pp. 11873-11883, Dec. 2020, doi: 10.1109/JIOT.2020.3005881.

[13] P.D.P Adi, Akio Kitagawa, ZigBee Radio Frequency (R.F.) Performance on Raspberry Pi 3 for Internet of Things (IoT) based Blood Pressure Sensors Monitoring, International Journal of Advanced Computer Science and Applications 10(5), DOI: 10.14569/IJACSA.2019.0100504, January 2019.

[14] A. Farhad, D. -H. Kim and J. -Y. Pyun, “R-ARM: Retransmission-Assisted Resource Management in LoRaWAN for the Internet of Things,” in IEEE Internet of Things Journal, vol. 9, no. 10, pp. 7347-7361, 15 May15, 2022, doi: 10.1109/JIOT.2021.3111167.

[15] Fransiska Sisilia Mukti, Puput Dani Prasetyo Adi, Dwi Arman Prasetya, Volvo Sihombing, Nicodemus Rahanra, Kristia Yuliawan, and Julianto Simatupang, "Integrating Cost-231 Multiwall Propagation and Adaptive Data Rate Method for Access Point Placement Recommendation" International Journal of Advanced Computer Science and Applications(IJACSA), 12(4), 2021, DOI: 10.14569/IJACSA.2021.0120494

[16] A. R. R. Bessa et al., "Design. Implementation and Evaluation of a Private LoRaWan Network for Industrial Internet of Things (IIoT) Applications,” 2022 IEEE International Conference on Consumer Electronics - Taiwan, 2022, pp. 513-514, doi: 10.1109/ICCE-Taiwan55306.2022.9869158.

[17] R. Carvalho, F. Al-Tam and N. Correia, “Q-Learning ADR Agent for LoRaWAN Optimization,” 2021 IEEE International Conference on Industry 4.0, Artificial Intelligence, and Communications Technology (IAICT), 2021, pp. 104-108, doi: 10.1109/IAICT52856.2021.9532518.

[18] P. D. P. Adi and A. Kitagawa, “Performance Evaluation of Low Power Wide Area (LPWA) LoRa 920 MHz Sensor Node to Medical Monitoring IoT Based,” 2020 10th Electrical Power, Electronics, Communications, Controls, and Informatics Seminar (EECCIS), 2020, pp. 278-283, DOI: 10.1109/EECCIS49483.2020.9263418.

[19] M. Niswar et al., “Performance evaluation of ZigBee-based wireless sensor network for monitoring patients’ pulse status,” 2013 International Conference on Information Technology and Electrical Engineering (ICITEE), 2013, pp. 291-294, doi: 10.1109/ICITEED.2013.6676255.

[20] Y. A. Liani et al., “The Broiler Chicken Coop Temperature Monitoring Use Fuzzy Logic and LoRAWAN,” 2021 3rd International Conference on Electronics Representation and Algorithm (ICERA), 2021, pp. 161-166, doi: 10.1109/ICERA53111.2021.9538771.

[21] P. D. P. Adi, A. Kitagawa, D. A. Prasetya and A. B. Setiawan, “A Performance of ES920LR LoRa for the Internet of Things: A Technology Review,” 2021 3rd East Indonesia Conference on Computer and Information Technology (EIConCIT), 2021, pp. 1-7, DOI: 10.1109/EIConCIT50028.2021.9431912.

[22] R. Marini, W. Cerroni and C. Buratti, “A Novel Collision-Aware Adaptive Data Rate Algorithm for LoRaWAN Networks,” in IEEE Internet of Things Journal, vol. 8, no. 4, pp. 2670-2680, 15 Feb.15, 2021, doi: 10.1109/JIOT.2020.3020189.

[23] J. Finnegan, R. Farrell and S. Brown, “Analysis and Enhancement of the LoRaWAN Adaptive Data Rate Scheme,” in IEEE Internet of Things Journal, vol. 7, no. 8, pp. 7171-7180, Aug. 2020, doi: 10.1109/JIOT.2020.2982745.

[24] P. D. Prasetyo Adi, Y. Wahyu and A. Kitagawa, “Analyzes of Chirps Spread Spectrum of ES920LR LoRa 920 MHz,” 2022 11th Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS), 2022, pp. 139-144, doi: 10.1109/EECCIS54468.2022.9902922.

[25] L. Charles, B. Isong, F. Lugayizi and A. M. Abu-Mahfouz, “Empirical Analysis of LoRaWAN-based Adaptive Data Rate Algorithms,” IECON 2021 – 47th Annual Conference of the IEEE Industrial Electronics Society, 2021, pp. 1-7, doi: 10.1109/IECON48115.2021.9589038.

[26] G. G. M. de Jesus, R. D. Souza, C. Montez and A. Hoeller, “LoRaWAN Adaptive Data Rate With Flexible Link Margin,” in IEEE Internet of Things Journal, vol. 8, no. 7, pp. 6053-6061, 1 April1, 2021, doi: 10.1109/JIOT.2020.3033797.

[27] P.D.P. Adi, A.Kitagawa, D.A. Prasetya, R.Arifuddin, S.Yoseph, LoRaWAN Technology in Irrigation Channels in Batu Indonesia, Jurnal Ilmiah Teknik Elektro Komputer dan Informatika, Vol. 7, No. 3, December 2021, pp. 522-538, ISSN: 2338-3070, DOI: 10.26555/jiteki.v7i3.22258, doi:10.26555/jiteki.v7i3.22258

[28] A. Tellache, A. Mekrache, A. Bradai, R. Boussaha and Y. Pousset, “Deep Reinforcement Learning based Resource Allocation in Dense Sliced LoRaWAN Networks,” 2022 IEEE International Conference on Consumer Electronics (ICCE), 2022, pp. 1-6, doi: 10.1109/ICCE53296.2022.9730234.

[29] P.D.P.Adi, et.al., “Low-Power and Lossy Networks of Wireless Sensor Networks with Protocols Algorithm Comparison”, JEEMECS (Journal of Electrical Engineering, Mechatronic and Computer Science), ISSN 2614-4859, Vol. 3, No. 1, February 2020, pp. 11-24, https://doi.org/10.26905/jeemecs.v3i1.3876

[30] Y. A. Al-Gumaei, N. Aslam, X. Chen, M. Raza and R. I. Ansari, “Optimizing Power Allocation in LoRaWAN IoT Applications,” in IEEE Internet of Things Journal, vol. 9, no. 5, pp. 3429-3442, 1 March1, 2022, doi: 10.1109/JIOT.2021.3098477.

[31] F. Ndimumahoro, M. S. Stepanov, A. R. Muzata, D. Tammam and V. G. Popov, “Using the Principles of Mobile Systems Modeling for LoRaWAN Characteristics Estimation,” 2022 Systems of Signals Generating and Processing in the Field of on Board Communications, 2022, pp. 1-8, doi: 10.1109/IEEECONF53456.2022.9744363.

[32] C. Lehong, B. Isong, F. Lugayizi and A. M. Abu-Mahfouz, “A Survey of LoRaWAN Adaptive Data Rate Algorithms for Possible Optimization,” 2020 2nd International Multidisciplinary Information Technology and Engineering Conference (IMITEC), 2020, pp. 1-9, doi: 10.1109/IMITEC50163.2020.9334144.

[33] F. Cuomo et al., “Towards traffic-oriented spreading factor allocations in LoRaWAN systems,” 2018 17th Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net), 2018, pp. 1-8, doi: 10.23919/MedHocNet.2018.8407091.

[34] J. M. Marais, R. Malekian and A. M. Abu-Mahfouz, “Evaluating the LoRaWAN Protocol Using a Permanent Outdoor Testbed,” in IEEE Sensors Journal, vol. 19, no. 12, pp. 4726-4733, 15 June15, 2019, doi: 10.1109/JSEN.2019.2900735.

[35] A. Hoeller, R. D. Souza, S. Montejo-Sánchez and H. Alves, “Performance Analysis of Single-Cell Adaptive Data Rate-Enabled LoRaWAN,” in IEEE Wireless Communications Letters, vol. 9, no. 6, pp. 911-914, June 2020, doi: 10.1109/LWC.2020.2975604.

[36] J. Babaki, M. Rasti and S. K. Taskou, “Improved Configuration of transmission variables for LoRaWAN in High-Noise Channels,” 2020 28th Iranian Conference on Electrical Engineering (ICEE), 2020, pp. 1-6, doi: 10.1109/ICEE50131.2020.9260713.

[37] T. Iggena, A. Bin Muslim, M. Fischer and R. Toenjes, “Quality of Information aware LoRaWAN for mobile Nodes,” Mobile Communication - Technologies and Applications; 25th ITG-Symposium, 2021, pp. 1-6.

[38] U. Coutaud, M. Heusse and B. Tourancheau, “Adaptive Data Rate for Multiple Gateways LoRaWAN Networks,” 2020 16th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), 2020, pp. 1-6, doi: 10.1109/WiMob50308.2020.9253425.