



EVALUATING LORAWAN ADAPTIVE DATA RATE EFFECTIVENESS IN HETEROGENOUS SMART FARMING CONDITIONS

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Abstract

The long-range wide area network (LoRaWAN) has become popular in modern environmental sensing applications particularly in areas with limited cellular infrastructure. However, the deployment of this system has been restricted to homogeneous applications largely due to their inherent restrictions like collision and use of unlicensed bands. To mitigate these limitations, LoRaWAN employ the adaptive data rate (ADR) optimization technique to improve the reliability of LoRaWAN deployments. While ADR performance in homogeneous applications and been well study with acceptable results, there has been limited studies aimed at the performance of LoRaWAN in heterogeneous applications. This paper addresses this gap by investigating the effectiveness of ADR for optimizing transmission parameters in heterogeneous environments with varying priority levels under concurrent transmission scenarios. The study evaluated the impact of ADR on key performance metrics such as packet delivery rate (PDR), energy consumption, and network range. The research findings revealed that ADR performs well under high-frequency, mobile conditions as exhibited by livestock trackers. This resulted in significant reductions in transmit power and spreading factor over time. However, static and infrequently transmitting nodes, such as soil moisture and temperature sensors, experienced limited ADR convergence, leading to suboptimal transmission efficiency and increased energy consumption. The findings underscore the limitations of uniform ADR policies and highlight the need for context-aware adaptations in heterogeneous deployments. This work contributes new insights into performance trade-offs in LoRaWAN-based smart farming and lays the groundwork for developing intelligent ADR strategies that consider application-specific dynamics to enhance reliability, energy efficiency, and network scalability.

Keywords: ADR, Heterogeneous, Smart farming, LoRaWAN, Spreading factor.

Introduction

The practice of agriculture has experienced rapid advancement in the last few years due to the evolution of Internet of Things (IoT) technology (Demestichas *et al.*, 2020; Thilakarathne *et al.*, 2025). IoT has helped in the promotion of sustainable agriculture, environmental conservation and food security through various smart farming technologies. According to the study in Brijesh (2023), smart farming techniques have helped farmers improve their productivity by up to 30 percent while cutting cost by as much as 80 percent over the past 10 years. Smart farming technologies help to improve farming conditions by providing real-time information on soil conditions, livestock health, crop environments, irrigation patterns, and machineries (Ayaz *et al.*, 2019). To achieve these

tasks, smart farming relies heavily on wireless sensor networks to transmit information from the farms to the farm owners and managers. Some of these wireless technologies include Wi-Fi, Bluetooth, Narrow band Internet of Things among several others (Chicaiza *et al.*, 2024).

However, one notable technology that has received increased popularity in recent times is the Long-Range Wide Area Network (LoRaWAN) (Gourshettiwar *et al.*, 2024). LoRaWAN has emerged as a leading candidate for agricultural deployments due to its long-range communication capability, minimal energy consumption, low operational cost, and suitability for battery-powered IoT devices in remote rural settings (Adi *et al.*, 2022).

LoRaWAN operates in the unlicensed ISM band and uses Chirp Spread Spectrum (CSS) modulation, which allows end devices to communicate with a central gateway over several kilometres. To maximize energy efficiency and spectrum utilization, LoRaWAN introduces an optional feature known as Adaptive Data Rate (ADR). ADR dynamically adjusts a device's Spreading Factor (SF), transmission power (TP), and other radio parameters based on link quality indicators such as Signal-to-Noise Ratio (SNR) and Received Signal Strength Indicator (RSSI). Authors in (Efrain et al., 2023) and (Wei et al., 2023) have demonstrated that ADR in certain conditions can improve network performance and extend battery life by optimizing transmission parameters without compromising on the network delivery success rates. A similar study by Li *et al.* (2018) however noted that the radio link condition must be right for ADR to make any meaningful improvement in LoRaWAN. Studies by (Triantafyllou et al., 2020) and (Dix-Matthews *et al.*, 2018) concluded that in dynamic conditions, ADR can encourage network link degradation rather than improving it.

While ADR has proven effective in controlled homogeneous environments, its performance in heterogeneous conditions have been largely understudied (Agbolade *et al.*, 2023). Of particular interest in this study is the performance of LoRaWAN in smart farming deployment particularly in real-life applications. Most real-world smart farming deployments are inherently heterogeneous. Devices vary significantly in terms of their roles, locations, mobility patterns, data generation intervals, and hardware capabilities (Agbolade *et al.*, 2022). For example, soil moisture sensors may be buried in static positions and transmit infrequently, while livestock trackers mounted on cattle move across large grazing areas and transmit frequently. Weather stations installations and irrigation system controllers may be subjected to differing radio conditions due to farm specific obstructions like trees or greenhouses structures. Additionally, some units may be powered by small cells, while others are connected to solar power or machinery, giving them broader energy limits. This diversity creates complex states that challenge the assumptions behind traditional ADR rules, which often rely on stable links and uniform device modes. In smart farming implementation, where accuracy, timeliness, and power usage are critical, a poorly adapted ADR choice can lead to increased packet drops, wasted energy due to unnecessary retrials, or suboptimal network throughput (Kufakunesu *et al.*, 2020).

In this paper, we present a comprehensive simulation-based approach to evaluate the

performance of LoRaWAN Adaptive Rates (ADR) in a heterogeneous smart farming setup. We model a network of 100 sensor nodes, comprising 30 high-priority mobile livestock tags, 50 medium-priority static soil moisture probes, and 20 low-priority static farm temperature sensors, all operating under a single LoRaWAN gateway within a 1000 m×1000 m farm space. Our simulation which we developed using SimPy, incorporates a Log-Distance Path Loss model, a fixed noise floor, and a simplified collision logic, alongside detailed implementations of both gateway-side and node-side ADR steps for dynamic parameter tuning. Key performance metrics such as Packet Delivery Ratio (PDR), average Spreading Factor (SF), average Transmit Power (TP), total energy consumption, and cumulative collisions are meticulously noted, processed using Pandas, and visualized with Matplotlib, allowing for a thorough analysis of ADR's adaptive algorithm and the trade-offs inherent in supporting diverse IoT tasks under dynamic link states.

Research Methodology

The entire process of implementing this study is discussed in the section. The section provides details of the network architecture, gateway placement, sensor deployment and data collection. The section also detailed the radio and channel propagation model employed in the study. The simulation environment was developed using SimPy which is a Python-based discrete-event simulation library and ran the entire setup for a duration of 240 simulation hours to provide sufficient timeframe to observe the long-term behaviour and adaptation of the ADR mechanism under varying conditions. The system framework is as shown in Figure 1. The setup consists of a total of 100 nodes of three priority levels. The nodes connect to the network gateway using the LoRaWAN protocol while the LoRa web server provides backend support for the network. It also handles all adaptive data rate request with collision resolution protocols.

Gateway and sensor node Placement

For simplicity and to establish a clear reference point for signal propagation calculations, a single LoRaWAN gateway is deployed centrally within the simulated farm area. The farm itself is modelled as a square geographical region with dimensions of 1000 m×1000 m. Consequently, the gateway's fixed coordinates are (500,500) which corresponds to the centre of the farm.

A total of 100 sensor nodes constitute the end-device population in our simulated network. These nodes are designed to represent the heterogeneous nature of a real-world smart farming deployment and are categorized as high, medium and low priority. The setup includes 30 nodes of high priority livestock

trackers, 50 nodes of medium priority soil moisture trackers and 20 nodes of low priority farm

temperature trackers. The setup configuration for each priority level is as shown in Table 1.

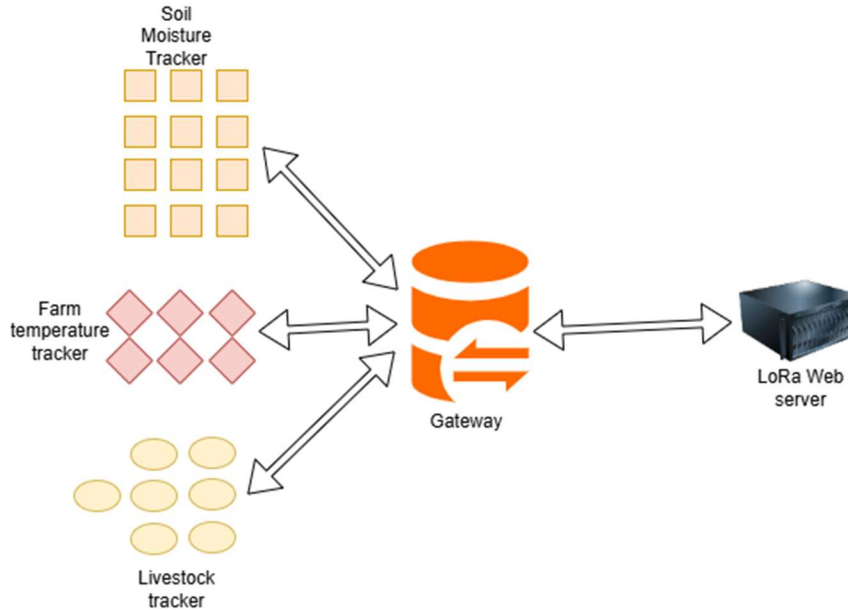


Figure 1: The heterogeneous LoRaWAN experimental framework

Table 1. Characteristics of Deployed Sensor Nodes by Application Priority

Parameter	Livestock Trackers	Soil Moisture Trackers	Farm Temperature Trackers
Application Priority	High	Medium	Low
Number of Nodes	30	50	20
Initial SF	12	10	8
Initial Tx Power (dBm)	14	14	14
Transmission Interval	Every 5 minutes	Every 30 minutes	Every 60 minutes
Payload Size (bytes)	10	5	3
Mobility	Mobile	Static	Static
Energy per Byte (mJ)	0.05	0.03	0.02

Radio Propagation and Channel Model

The attenuation of the radio signal as it propagates from a sensor node to the central gateway is modelled using the **Log-Distance Path Loss Model**. This model is widely adopted for its balance of simplicity and reasonable accuracy in various outdoor environments. The path loss PL(d) in decibels (dB) at a given distance d (in meters) from the transmitter is calculated using Eq. 1.

$$PL(d) = PL(d_0) + 10 \cdot n \cdot \log_{10} \left(\frac{d}{d_0} \right) \text{ (dB)} \quad (1)$$

Where $PL(d_0)$ is the pathloss reference at a reference distance d_0 , n the path loss exponent and d the Euclidean distance between the transmitting node. The Received Signal Strength Indicator (RSSI) at the gateway is then derived by subtracting the calculated path loss from the node's transmit power (TxPower) as calculated in Eq. 2.

$$SNR = RSSI - NF \text{ (DB)} \quad (2)$$

Where NF is the noise floor. For successful demodulation of a LoRa packet, the received signal's RSSI must exceed a minimum sensitivity threshold specific to the Spreading Factor (SF) used. Packets received with an RSSI below this SF-specific sensitivity are deemed lost and are discarded by the gateway.

LoRaWAN Adaptive Data Rate (ADR) Mechanism

ADR in LoRaWAN is a technique that is natively used to dynamically adjust the communication parameters used for uplink transmission. Specifically in this study, ADR was enabled for all the 100 sensor nodes simulated. The SF and TP are controlled by the gateway based on the link margin of individual node. Also, ADR algorithm was implemented both in the gateway and end node side as explained in the next section.

Gateway-Side ADR

The gateway plays a very important role in the ADR implementation. Whenever an uplink packet, the gateway uses the received signal to noise ratio (SNR) to evaluate the link quality. The gateway also keeps historical record of 20 successive uplink and averages and margin. The gateway compares the average of the last 20 uplinks with a network preset requirement of 10 dB. This value is used to adjust the end device transmission parameter. This is done in two ways. First, the gateway reduces each nodes transmit power in discrete steps of 3 dB from around 14 dBm which is the common maximum to a minimum of 2 dBm. If further optimization is possible after reaching the minimum TxPower, or if the link margin remains high, the gateway then commands the node to increase its Data Rate (which corresponds to a decrease in SF). Each increase in Data Rate (from SF8 to SF7) generally provides an approximately 3 dB improvement in link budget.

Conversely, if the link quality is poor (the average SNR falls below the minimum required for the current SF, resulting in a negative link margin), the gateway prioritizes reliability. It first commands the node to decrease its Data Rate (which corresponds to an increase in SF). This makes the transmission more robust and tolerant to noise. If the node is already operating at the lowest Data Rate (highest SF which is the SF12), the gateway then commands an increase in the node's transmit power by 3 dBm steps, up to the maximum allowed of 14 dBm. Once the gateway successfully initiates an ADR adjustment, each node's internal ADR counter is reset to prevent counter looping. This approach helps to simulate a successful delivery of ADR downlink command.

Node-Side ADR

Our implementation of ADR includes an autonomous implementation at the end-devices

level. The approach serves as a fallback scenario in instances where the gateway's ADR commands are not consistently received due to issues such as prolonged poor network link qualities or other gateway related problems. For our simulation, if a node transmits 64 ADR_ACK_LIMIT uplink without receiving and ADR acknowledgement from the gateway, a grace period of 32 ADR_ACK_DELAY additional count. If after this combined period, no ADR acknowledgement is received from the gateway, the node autonomously takes a series of actions to improve its link quality. First, the node increases its spreading factor in step from its current position up to a maximum of SF12. However, if the node is already at the highest possible SF, it increases its transmit power in a step of 2 dBm.

Performance Evaluation Metrics

In order to access the performance of ADR under heterogeneous smart farming condition, this study employed the packet delivery ratio, the average spreading factor and the total energy consumption of the nodes. The PDR was calculated as the ratio of successfully received uplinks to the total uplink attempt while total energy consumption is the addition of energy consumed by all nodes for both uplink and downlink transmissions

Results and Discussion

In this section, we present the results of our performance evaluation of heterogeneous LoRa Network deployed for smart farming applications. We focused this section on the three categories of sensor nodes that were deployed for livestock movement, soil moisture and farm temperature tracking. We analysed three critical metrics which include the packet delivery ratio, the average transmits power and the average spreading factor used by each node in each nodal segment. The focus is to provide insights into the behaviour of ADR in such application specific environment.

Packet Delivery Ratio

The result for the packet delivery rate for each application in the three categories is as shown in Figure 2. The PDR across the simulation time reveals a low delivery across the three classes of nodes with none exceeding 25 percent. Livestock trackers however exhibited the highest PDR all through the simulation. This is closely followed by the farm temperature sensing node while the soil moisture trackers recorded the lowest PDR of the three. This result is an indication of the impact of network load and heterogeneity on transmission success. Livestock trackers which have the highest transmission frequency (every 5 minutes) was due to higher dynamic mobility patterns within a fixed

geographical space thus leading to generation of a higher ADR feedback relative to other node types. This arrangement ensures a more responsive link adaption and consequently, a higher PDR. It is noted that in practice, a higher uplink frequency naturally leads to higher collision rate. However, for the nodes in this category, their better link adaptation helped to offset a likely higher loss rate. In contrast, the relatively lower transmission rate from the soil

moisture nodes (every 30 minutes) and a much lower uplink frequency of once every 60 minutes for the temperature monitoring nodes provided much-limited feedback to the ADR algorithm. This resulted in prolonged use of suboptimal transmission parameters and subsequently, a poorer packet delivery performance.

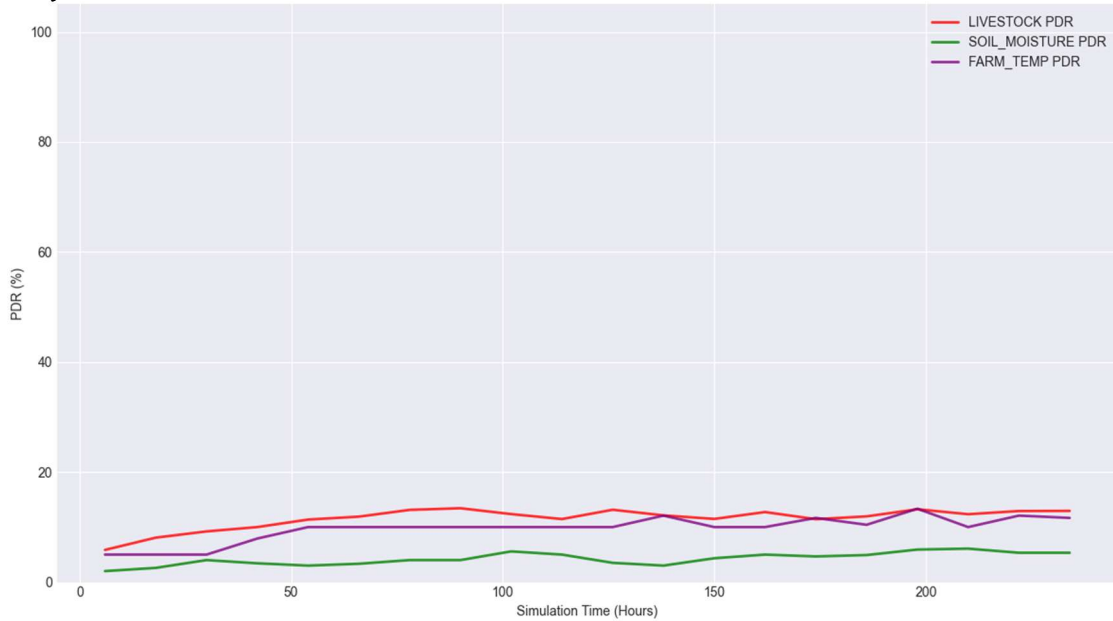


Figure 2: The packet delivery rate for each smart farming applications

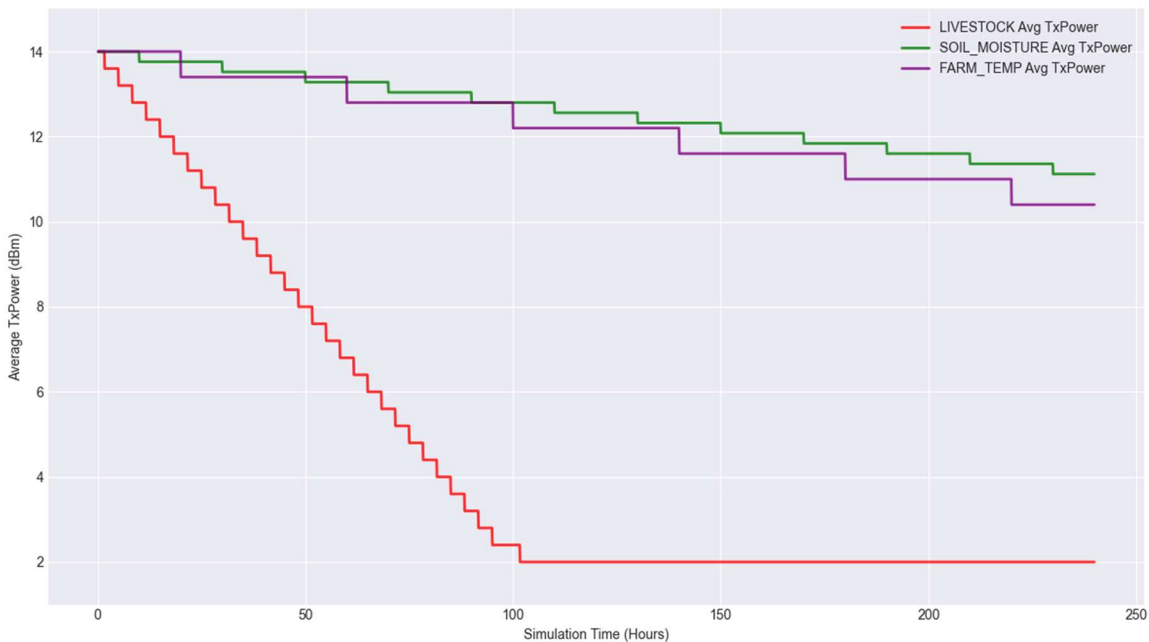


Figure 3: Average transmit power per node type over time

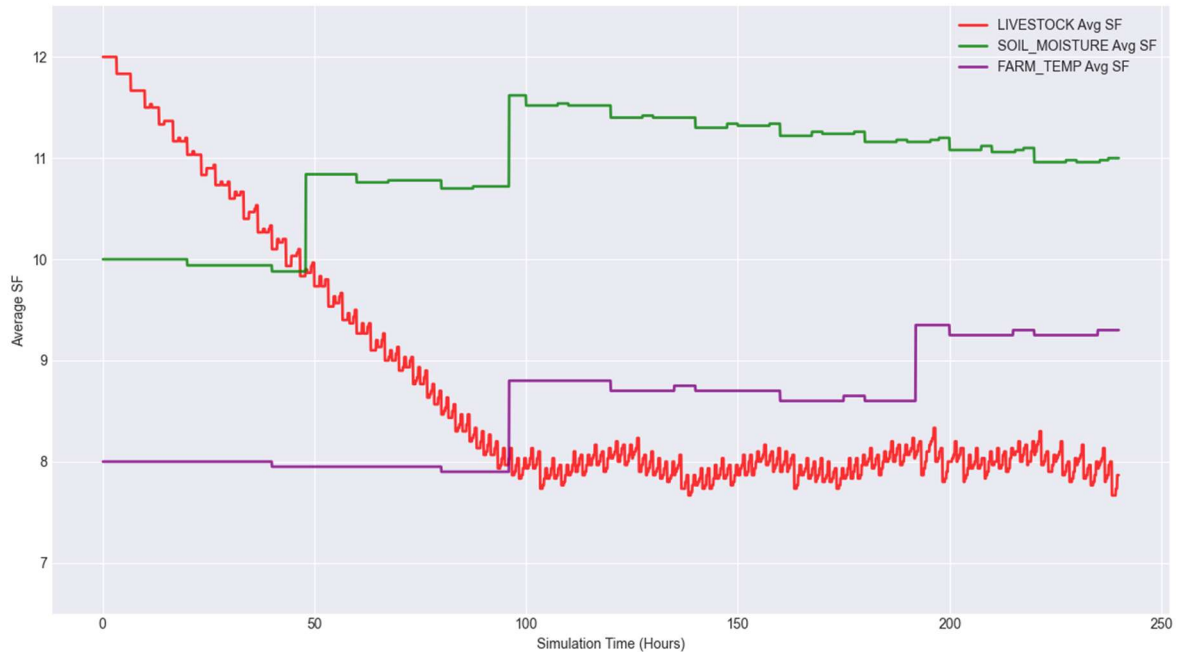


Figure 4: Average spreading factor per node type over time for all applications

Transmit Power Adaptation

The average transmit power across nodes in three categories that were considered is shown in Figure 3. The result further illustrates the impact of the three application dynamics on the ADR algorithm performance. The result shows an aggressive reduction of transmit power from the initial 14 dBm to a stable 2 dBm within the first 100 hours of simulation. This sharp drop emphasizes the aggressive behaviour of ADR particularly during the period of frequent uplink messages by high mobility applications. This results in high mobility induced link variation that provides sufficient context for optimization. Conversely, soil moisture and temperature tracker experienced slower and less significant reduction in their transmit power. This is because of a relatively more stable link condition which necessitates less aggressive ADR optimization. Their static nature and low transmission frequency delay the ADR convergence. Consequently, allocating high transmission power for extended periods for this node class is unnecessary.

Spreading Factor Dynamics in Heterogeneous Network

The results in Figure 4 shows the average spreading factor per node for all node type in the three applications considered for this study. The result showed how well ADR algorithm adapted individual node's spreading factor over the entire simulation time. The result in Figure 4 shows a pattern that is noticeably consistent with ADR activity. The figure shows Livestock trackers

demonstrating a progressive and significant decrease in SF starting from the initial spreading factor 12 (SF12) and stabilizing near spreading factor 8 (SF8). This evolution aligns with improved link quality assessments due to mobility and high-frequency transmissions. This invariably enabled ADR to lower the SF and thus increase data rate while reducing airtime.

In contrast, soil moisture nodes largely maintained a relatively stable spreading factor of 11 with the farm temperature nodes fluctuating between SF9 and SF10. This result again suggests that ADR was less effective for these nodes, primarily due to the lack of frequent updates necessary for timely parameter adjustment. The continual reliance on higher value SF results in longer airtime. Unfortunately, with this high airtime comes increased energy usage and a higher chance of packet collisions. This collision is even expected more frequently as the network continues to scale.

Energy Consumption Analysis

The total energy consumption per each node type is shown in Figure 5. The result reflects the relationship between the spreading factor and energy consumption. Livestock trackers, as expected, consumed significantly more energy compared to other node types, owing to their higher data generation rate. They also benefit from mobility-induced variability, and early operation at maximum SF and transmit power. However, despite extensive optimization by the ADR algorithm, their initial energy overhead was substantial. The soil moisture nodes energy consumption was moderate

owing to limited transmission frequency. This can be attributed to their extensive use of high SF and transmit power. This behaviour is also an indication of the inefficiency of the native ADR in LoRaWAN particularly under low-frequency traffic. Finally, the

result in Figure 5 showed that the farm tracker nodes have the least energy usage. This, from the result is consistent with their minimal data rate and static positioning.

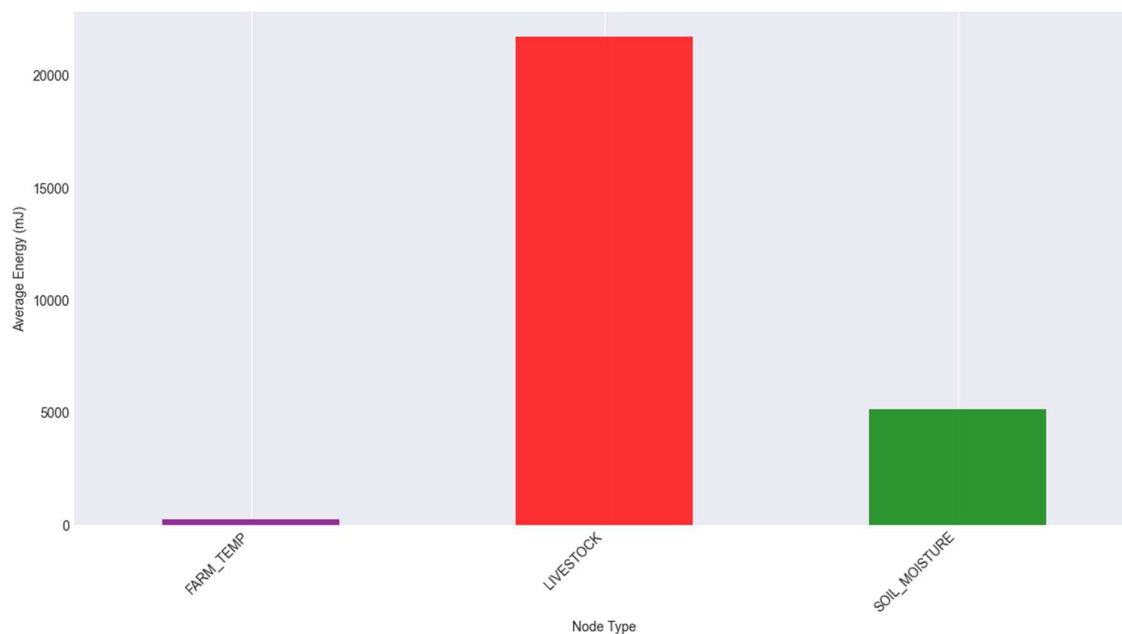


Figure 5: Average total energy consumption per node type for the heterogeneous network applications

Implications of Heterogeneous LoRaWAN on Smart Farming Networks

The results obtained in Figure 2 to 5 collectively highlight the key trade offs in heterogeneous LoRaWAN deployment particularly in a smart farming context. The results showed that high priority applications such as livestock tracking benefit from frequent transmissions and mobility. This enabled the ADR algorithm to optimize link settings more aggressively, thus improving communication efficiency despite higher energy use. Conversely, medium and low-priority applications such as the farm temperature and moisture tracker suffer from limited ADR feedback. This consequently result in more conservative transmission parameters that eventually culminate in rapid network degradation and unnecessarily exaggerated energy costs. These findings reveal that ADR performance is highly dependent on node activity profile. Consequently, an application-aware ADR tuning or hybrid approaches are necessary to maintain overall network efficiency particularly in heterogeneous deployments.

Conclusion

In this study, we presented a comprehensive performance evaluation of a heterogeneous

LoRaWAN deployment tailored specifically for a smart farming application. We simulated three distinct classes of sensor nodes (livestock trackers, soil moisture sensors, and farm temperature monitors). The goal was to investigate the relationship between application-specific requirements of smart farming and the Adaptive Data Rate (ADR) mechanism in LoRaWAN. The results obtained showed that application heterogeneity significantly affects network performance. Nodes with high transmission frequency benefited the most from ADR by achieving more aggressive optimization in transmit power and spreading factor. It was however noted this came at a cost of higher energy consumption.

In contrast, static nodes such as soil moisture and temperature sensors in spite of their lower data rates and energy budgets suffered from suboptimal ADR adaptation which resulted in poorer packet delivery rates and inefficient transmission settings over prolonged periods. Findings from our study underscored the limitations of a one-size-fits-all ADR strategy in heterogeneous networks. They highlight the need for context-aware optimization mechanisms that consider node type, transmission frequency, and mobility patterns in real-life implementations.

Future work on this study can focus on the development and integration of an intelligent ADR scheme that leverages advancement in machine learning and artificial intelligence to produce optimal parameter settings for nodes operating in a heterogeneous network. Further studies can also investigate the suitability of reinforcement learning-based ADR strategies or edge-intelligent gateways capable of dynamically adapting parameters based on both node history and network state. Real-world field trials with actual sensor hardware and varying environmental conditions can also be conducted to validate the simulation findings and improve the robustness of the proposed solutions.

References

- Adi, P. D. P., Kitagawa, A., Prasetya, D. A., Arifuddin, R., & Yoseph, S. (2022). LoRaWAN Technology in Irrigation Channels in Batu Indonesia. *Jurnal Ilmiah Teknik Elektro Komputer Dan Informatika*, 7(3), 522.
- Agbolade, O. A., Dahunsi, F. M., & Oyetunji, S. A. (2022). Heterogeneous LoRaWAN Deployment for Application Dependent IoT Networks. *Journal of Engineering and Technology for Industrial Applications*, 8(34), 4-11.
- Agbolade, O. A., Oyetunji, S. A., & Dahunsi, F. M. (2023). Sustainable Business Model for Long-Range Wireless Wide Area Based Internet of Things Network: The Heterogeneous approach. *2023 International Conference on Science, Engineering and Business for Sustainable Development Goals (SEB-SDG)*, 1, 1-6.
- Ayaz, M., Ammad-Uddin, M., Sharif, Z., Mansour, A., & Aggoune, E. H. M. (2019). Internet-of-Things (IoT)-based smart agriculture: Toward making the fields talk. *IEEE Access*, 7, 129551-129583.
- Chicaiza, K., Paredes, R., Sarzosa, I. M., Yoo, S. G., & Zang, N. (2024). Smart Farming Technologies: A Methodological Overview and Analysis. *IEEE Access*.
- Demestichas, K., Peppes, N., & Alexakis, T. (2020). Survey on security threats in agricultural iot and smart farming. In *Sensors (Switzerland)* (Vol. 20, Issue 22, pp. 1-17). MDPI AG. <https://doi.org/10.3390/s20226458>
- Dix-Matthews, B., Cardell-Oliver, R., & Hübner, C. (2018). Lora parameter choice for minimal energy usage. *RealWSN 2018 - Proceedings of the 7th International Workshop on Real-World Embedded Wireless Systems and Networks, Part of SenSys 2018*, 37-42. <https://doi.org/10.1145/3277883.3277888>
- Efrain, R., Dandachi, G., Hadjadj-Aoul, Y., Maillé, P., & Navas, R. E. (2023). Energy-Aware Spread-ing Factor Selection in LoRaWAN Using Delayed-Feedback Bandits. *IFIP Conference Networking*, 1-9.
- Gourshettiwar, P., Reddy, K. T. V., & Raymond, D. (2024). IoT Agriculture System Based on LoRaWAN. *AIP Conference Proceedings*, 3188(1).
- Kufakunesu, R., Hancke, G. P., & Abu-Mahfouz, A. M. (2020). A Survey on Adaptive Data Rate Optimization in LoRaWAN: Recent Solutions and Major Challenges. *Sensors (Switzerland)*, 20(18), 5044-5068.
- Li, S., Raza, U., & Khan, A. (2018). How Agile is the Adaptive Data Rate Mechanism of LoRaWAN? *2018 IEEE Global Communications Conference, GLOBECOM 2018 - Proceedings*, 206-212.
- Saluja Brijesh. (2023, February 23). *Why Smart Farming is the Future*. Nasscom Community. <https://community.nasscom.in/communities/iot/why-smart-farming-future>
- Thilakarathne, N. N., Abu Bakar, M. S., Abas, P. E., & Yassin, H. (2025). Internet of things enabled smart agriculture: Current status, latest advancements, challenges and countermeasures. *Heliyon*, 11(3), e42136-e42176.
- Triantafyllou, A., Sarigiannidis, P., Lagkas, T., & Sarigiannidis, A. (2020). A Novel LoRaWAN Scheduling Scheme for Improving Reliability and Collision Avoidance. *2020 9th International Conference on Modern Circuits and Systems Technologies, MOCAS 2020*, 1-4.
- Wei, Y., Tsang, K. F., Wang, W., & Zhou, M. M. (2023). Priority-Based Resource Allocation Optimization for Multi-Service LoRaWAN Harmonization in Compliance with IEEE 2668. *Sensors*, 23(5), 1-15.