LoRa Optimal Channel Selection using RSSI

Soham Kadtan*, Biraja Nanda Mohanty*, Alekhya Gorrela*, Nikumani Choudhury*
* Dept. of Computer Science & Information Systems, Birla Institute of Technology & Science, Pilani, Hyderabad, India
. Email: {h20231030094, h20231030070, p20220103@hyderabad.bits-pilani.ac.in, nikumani}@hyderabad.bits-pilani.ac.in

***Abstract*—Low-power wide area networks (LPWAN) have greatly improved the Internet of Things (IoT). LoRaWAN is a potential technology for IoT applications because it uses low-power long-distance communication and offers excellent availability with low energy consumption. LoRaWAN power consumption can be reduced by using the pure Aloha protocol at the MAC level. Vertical transmission parameters also reduce packet loss and avoid collisions. Therefore, an important challenge for LoRaWAN is to optimize transmission parameters to improve network performance. To meet the needs of large device-type networks, it provides a lightweight planning framework for LoRaWAN. The methodology avoids the need for long downlink transmission and time between devices and web servers by using the transit time, multi-channel and data rate of LoRaWAN. implemented in LoRaWAN's publicly available ns-3 module. It had a channel selection problem, so here we use a game theory network algorithm to optimize the channel selection.**

***Index Terms*—LoRaWAN, Industrial Internet of Things, Game Theory, Optimal Channel Selection, RSSI.**

I. Introduction

In today's world, the Internet of Things (IoT) is a must, connecting devices through battery-powered sensor networks. Choosing the right communication technology to manage and maintain service quality in the form of IoT is important because of its important features [1]. Low-Power Wide Area Networks (LPWANs) represent a transformative force in the realm of communication technology, offering a compelling solution to the challenges posed by the increasing proliferation of Internet of Things (IoT) devices and applications. The ability of LPWANs to provide extensive radio coverage at minimal data costs has revolutionized the way in which devices are connected and communicate over long distances. This capability is particularly valuable in scenarios where traditional wireless WANs fall short, as LPWANs excel in balancing the need for efficient data transmission with energy conservation.

In the context of smart cities, LPWANs play a pivotal role in enabling a wide range of innovative applications that enhance urban infrastructure and services. From optimizing agricultural practices through precision farming techniques to streamlining traffic flow and parking management with smart solutions, LPWAN technology has become instrumental in driving sustainable urban development. By facilitating real-time monitoring of environmental parameters and enabling seamless communication in home automation systems, LPWANs empower cities to become more efficient, responsive, and environmentally friendly.

The versatility of LPWAN technology is further underscored by the distinct operational modes of LoRaWAN devices across different classes. Class A devices, with their periodic data transmission and short listening windows, are well-suited for applications requiring intermittent communication with minimal power consumption. Class B devices, featuring scheduled receive windows, enhance the efficiency of bidirectional communication, making them ideal for scenarios where timely data exchange is essential. Meanwhile, Class C devices, with their continuous listening windows, offer immediate downlink reception capabilities, catering to applications that demand constant connectivity and responsiveness.

By offering a diverse array of device classes tailored to varying IoT application needs, LPWANs demonstrate their adaptability and scalability in meeting the evolving demands of the digital landscape. As the adoption of IoT devices continues to expand across industries and sectors, the role of LPWANs in providing reliable, cost-effective, and energy-efficient connectivity solutions will only grow in significance. The seamless integration of LPWAN technology into the fabric of modern communication infrastructure is poised to drive innovation, enable new possibilities for smart applications, and pave the way for a more connected and intelligent future.

A. Motivation

In the area of IoT communication, the issue of random channel selection poses a significant challenge such as inefficient use of resources and degraded performance. To address this issue we are using online algorithm based on game theoretical approach which is used to select the optimal channel from the available channels in real time. Before selecting the optimal channel game theory considers some factors such as signal strength, utility of each channel and historical data transmission success rates. By continuously monitoring this algorithm it dynamically selects the channel that maximizes throughput and minimizes packet loss. Once the optimal channel is selected, data packets are routed through this channel, ensuring efficient transmission and reliable communication over the network.

B. Contribution & Organization

In this paper, we propose a novel technique to select optimal channel selection in the LoRa network. This is achieved by using a game theoretic approach which is based on the online algorithms. We also used RSSI to calculate the intensity of each channel incorporating exponential weighting to select the parent node based on the number of packets in the node's queue at a given instance of time. The proposed mechanism identifies and manages congestion in 6TiSCH networks. The contributions of the paper are summarized below.

1) Development of a parent selection and swapping mechanism for congested networks and avoiding unnecessary parent swapping during sporadic traffic data bursts.
2) Development of a new metric for RPL-based routing using the concept of exponential weighting to compute the appropriate parent with the least congested path. This helps in managing congestion in the network.
3) Performance comparison with existing work shows the proposed mechanism improves RPL-based several QoS measurements under heavy and dynamic traffic loads.

The rest of the paper has been divided into the following sections: Section II discusses the related work in the routing domain of 6TiSCH and LLN networks. The network model considered has been discussed in Section III. Section IV describes the proposed work and the algorithms used. Section V discusses in extensive detail the experimentation performed and the performance evaluations. Section VI concludes the paper.

II. Related Work

[1]Scalability Analysis of LoRa Network for SNR-Based SF Allocation Scheme. Primarily, SFs are assigned based on distance from the gateway, using equal-interval-based (EIB) and equal-area-based (EAB) SF allocation schemes. we have proposed an SNR-based SF allocation scheme to improve the scalability of LoRaWAN. [2]Improving LoRaWAN Scalability for IoT Applications using Context Information.The large number of devices that communicate with each other in IoT applications has raised concerns about resources availability and the suitable technologies for managing these resources in LoRaWAN networks. To improve the scalability, we have presented a framework to improve the performance of LoRaWAN network, in which the devices are scheduled according to their QoS requirements, the density of the network, and the context information. [3]Improving Reliability and Scalability of LoRaWANs Through Lightweight Scheduling. LoRa networks face the problem of scalability when they connect thousands of nodes that access the shared channels randomly. In this paper, we propose a new MAC layer—RS-LoRa—to improve reliability and scalability of LoRa wide-area networks (LoRaWANs). [4]Optimal Channel Selection Based on Online Decision and Offline Learning in Multichannel Wireless Sensor Networks. We propose a channel selection strategy with hybrid architecture, which combines the centralized method and the distributed method to alleviate the overhead of access point and at the same time provide more flexibility in network deployment. [5]Collision Resolution Protocol for Delay and Energy Efficient LoRa Networks. In the event of collisions, the perceived rate is further reduced due to packet loss and retransmissions. First, to alleviate the harmful impacts of collisions, we propose a decoding algorithm that enables to resolve several superposed LoRa signals. Secondly, we design a full MAC protocol enabling collision resolution. [6]Leveraging fairness in LoRaWAN: A novel scheduling scheme for collision avoidance. The utilization of low power but long range communication links of the LoRaWAN technology promises low energy consumption, while ensuring sufficient throughput. However, due to LoRa's original scheduling process there is a high chance of packet collisions, compromising the technology's reliability. In this paper, we propose a new Medium Access Control (MAC) protocol, entitled the FCA-LoRa leveraging fairness and improving collision avoidance in LoRa wide-area networks. [7]Lightweight Timeslot Scheduling Through Periodicity Detection for Increased Scalability of LoRaWAN. mMTC (Massive Machine Type Communications) is a wireless paradigm which focuses on traffic that is transmitted by a huge number of low cost, low power, infrequently transmitting devices. LoRaWAN, a Low Power Wide Area Network technology, is particularly suited to contribute to coverage of this form of traffic. In this work, we introduce a novel, lightweight timeslot scheduling scheme that supports the requirements for massive Machine Type Communications on LoRaWAN networks (based on traffic periodicity, and the multiple channels and quasi-orthogonal data rates in LoRaWAN). [8]A Novel LoRaWAN Scheduling Scheme for Improving Reliability and Collision Avoidance. The utilization of low power but long range communication links of the LoRaWAN technology promises low energy consumption, while ensuring sufficient throughput.However, due to LoRa's original scheduling process there is a high chance of packet collisions, compromising the technology's reliability. In this paper, we propose a new Medium Access Control (MAC) protocol, entitled the RCA LoRa towards improving reliability and collision avoidance in LoRa wide-area networks. [9]LIDS: Lightweight Dynamic Scheduling Technique for 6G-enabled Massive LoRa based IoT Systems. The LoRa standard does not define any scheduling mechanism and leaves it to the research community to explore. In this paper, we propose a distributed scheduling mechanism under the supervision of a common LoRa gateway. The proposed mechanism focuses on a Lightweight Dynamic Scheduling (LIDS) scheme to minimize loss in data transmissions through collisions and the proposed mechanism optimizes the power consumption to achieve the desired level of QoS requirements such as throughput and latency. [10]Dynamic multi-frame multi-spreading factor scheduling algorithm for LoRaWAN. The existing synchronization and scheduling algorithms transmit synchronization messages randomly using one super frame with fixed time slots that accommodate devices using different Spreading Factors (SFs). This phenomenon can result in collisions, idle slots, and inefficient energy use, hence limiting the LoRaWAN network scalability. To alleviate the aforementioned problems, this work proposes a dynamic Multi-Frame Multi-Spreading Factor (MFMSF) scheduling algorithm with slotted synchronization approach.

III. Network Model

The network model considered in this paper has been shown in Fig. 1. The image represents a detailed network server system with a gateway and multiple sets of sensor nodes,

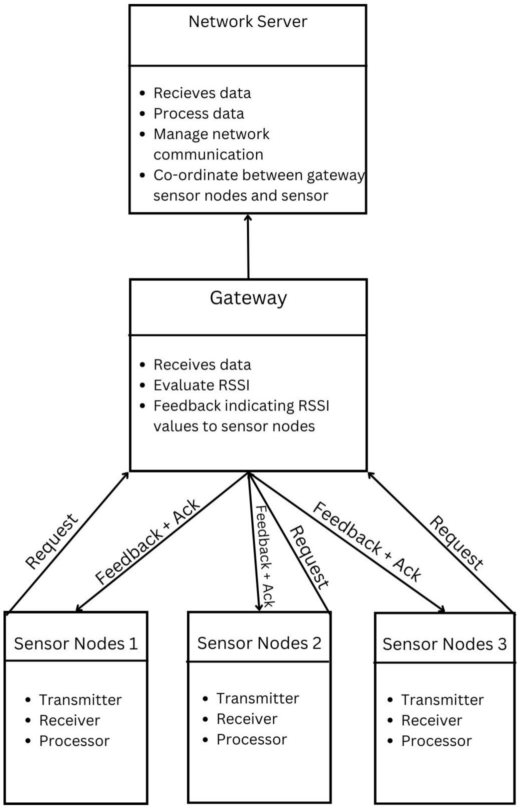


Fig. 1. LoRaWaN Working

each performing specific functions in data transmission and network management. Here is an in-depth breakdown of the components and interactions depicted in the diagram:

1. Network Server:

Positioned at the top of the diagram, the network server serves as the central hub for data processing, network management, and coordination of communication between the gateway and sensor nodes. Functions of the network server: Processes incoming data from the sensor nodes. Manages network communication protocols and data flow. Coordinates interactions between the gateway and sensor nodes for seamless operation.

2. Gateway:

The gateway acts as a bridge between the network server and the sensor nodes, facilitating data exchange and feedback mechanisms. Key functions of the gateway: Receives data packets from the sensor nodes for further analysis and processing. Evaluates the Received Signal Strength Indicator (RSSI) values to assess signal quality and reliability. Provides feedback to the sensor nodes based on the RSSI values, enabling adjustments in transmission parameters for optimal performance.

3. Sensor Nodes:

The diagram showcases three sets of sensor nodes (Sensor Nodes 1, Sensor Nodes 2, Sensor Nodes 3) connected to the gateway, each comprising essential components for data transmission and reception. Functions of the sensor nodes:

TABLE I
SYMBOL TABLE

Symbols	Meaning
LoRaWaN	Low Power Wide Area Network
RSSI	Received Signal Strength Indicator
MAC	Media Access Control
SF	Spreading Factor
MFMSF	Multi-Frame Multi-Spreading Factor
LIDS	Lightweight Dynamic Scheduling
QoS	Quality of Service
mMTC	Massive Machine Type Communication

Transmitter: Sends data packets to the gateway for processing and analysis. Receiver: Receives feedback and acknowledgments from the gateway regarding data transmission and signal quality. Processor: Manages data processing tasks within the sensor nodes, ensuring efficient operation and communication with the gateway.

4. Feedback and Acknowledgment:

The presence of feedback and acknowledgment mechanisms indicates a robust communication protocol within the network, allowing nodes to confirm successful data transmission, receive feedback on signal strength, and adjust their operations accordingly.

5. Request:

The diagram includes request arrows, suggesting a bidirectional communication flow where nodes can request specific actions, data, or responses from other components in the network. In summary, the detailed network server system architecture depicted in the image highlights the collaborative efforts of the network server, gateway, and sensor nodes in ensuring seamless data transmission, signal evaluation, and feedback mechanisms for efficient network operation and communication in IoT or sensor network applications.

IV. PROPOSED WORK

LoRaWaN stands for Long Range Wide Area Network. It is a wireless communication protocol designed for long-range, low power IoT applications. It ranges over approximately 25km-40km. It enables devices to communicate over a long distances while consuming less power, making it suitable for IoT deployments in various industries such as in agriculture, environmental monitoring, smart city solutions, etc. IoT refers to the use of IoT technology in industrial areas to mainly improve efficiency, productivity, and safety. IoT allows industries to collect and analyze data from machines and equipment to optimize operations and make informed decisions. Game theory is a mathematical framework used to analyze strategic interactions between rational decision-makers. In the network algorithms, game theory can be applied to optimize channel selection, resource allocations, and decision-making processes. Optimal channel involves choosing the best communication channel based on factors like signal strength, interference, and data rate. Selecting the optimal channel helps improve network performance, reduce packet loss, and enhance communication reliability. RSSI is a metric that quantifies the strength of the signal received by a receiver from a transmitter. RSSI is used to assess the signal quality, determine link reliability and optimize communication parameters in wireless networks. In a sensor network, multiple sensors are deployed to monitor and gather data from various environments. These sensors often communicate wirelessly with a central gateway or a base station to transmit the collected data. Efficient communication is crucial in such networks to ensure timely and reliable data transmission while conserving energy and bandwidth.

Wireless communication channels can be subject to various factors that affect the quality of transmission, such as signal strength, interference, noise, and environmental conditions. Received Signal Strength Indicator (RSSI) is a commonly used metric to quantify the strength of the signal received by a receiver from a transmitter. It provides valuable information about the quality of communication between nodes in a wireless network.

A. Illustrative Example

Algorithm 1: Non-cooperative Game for Channel Selection

Gateway evaluates the RSSI
Sensor i evaluates the RSSI
for $i = 1$ to n **do**
    Sensor i transmits request to Gateway
end for
Sensors receive RSSI feedback from Gateway
while True **do**
    for $i = 1$ to n **do**
        for $k = 1$ to K **do**
            Calculate utility function $u_{i,k}$ for channel k based on RSSI
        end for
    end for
    Break if no sensor can improve its utility by switching channels
end while
Each sensor selects the channel that maximizes its utility

Detailed Explanation Let's dive deeper into each step of the algorithm:

1. Gateway Evaluation of RSSI

The central gateway serves as a hub for communication in the sensor network. It continuously evaluates the RSSI values received from each sensor. RSSI is a measure of the power level received by the gateway from each sensor. By analyzing these RSSI values, the gateway gains insights into the strength of communication links with individual sensors.

2. Sensor Evaluation of RSSI

Similarly, each sensor evaluates its RSSI, indicating the strength of the signal it receives from the gateway. This evaluation allows sensors to assess the quality of their communication links with the gateway. A sensor with a high RSSI value indicates a strong signal reception, suggesting a robust communication link.

3. Transmission Request to Gateway

In order to initiate communication with the gateway, each sensor transmits a request. This request serves as a notification to the gateway that the sensor intends to transmit data. By sending these requests, sensors signal their readiness to communicate and participate in the channel selection process.

4. RSSI Feedback Reception

After transmitting their requests, sensors receive feedback from the gateway regarding the RSSI values associated with their transmissions. This feedback provides sensors with information about the quality of their communication links. Sensors can use this information to make informed decisions about channel selection and optimize their communication strategies.

5. Channel Selection Loop

The main loop of the algorithm runs indefinitely, continuously optimizing channel selection for each sensor. Within this loop, sensors evaluate the utility of different channels based on RSSI feedback. By iterating over available channels, sensors assess the potential for improving communication quality by switching channels.

6. Utility Function Calculation

For each sensor and each available channel, a utility function is calculated based on RSSI feedback. This utility function represents the quality of communication that can be achieved through each channel. By considering factors such as signal strength and interference, the utility function helps sensors prioritize channels that offer optimal communication performance.

7. Break Condition

The loop continues until no sensor can improve its utility by switching channels. Once all sensors are using the channel that maximizes their utility, the loop breaks, and the algorithm terminates. This break condition ensures that the algorithm converges to a stable channel allocation where further channel switching does not yield significant improvements.

8. Channel Selection Decision

After the loop breaks, each sensor selects the channel that maximizes its utility. This decision is based on the utility function calculated earlier. By choosing the channel with the highest utility, sensors aim to optimize communication quality and maximize data transmission efficiency.

Non-cooperative games that are relevant to the optimal channel selection problem discussed in the paper:

Non-cooperative games model scenarios where players act independently to maximize their own utility or payoff, without cooperating or making binding agreements with other players. In the context of wireless channel selection, each node or sensor can be viewed as a self-interested player trying to choose the best available channel to maximize its performance metrics like throughput or single quality.

Some key aspects of non-cooperative channel selection games include:

1. Utility Function: Each player(node) has a utility function that quantifies the benefit or cost of selecting a particular

TABLE II
NS3 SIMULATION PARAMETERS

Simulation Parameters	Values Considered
Number of end-devices	600
Duty Cycle	0.01
Packet Length	20 bytes
Preamble Length	8 bytes
Frequency	868 MHz
Bandwidth	125 KHz
Number of end devices	60
Coding rate	4/5
Path loss exponent	4
Spreading Factors	{7,8,9,10,11,12}
Transmission Powers	{2,5,8,11,14} dBm

channel based on factors like RSSI, interference, congestion, etc. Nodes aim to maximize their individual utility.
2. Strategy Space: The set of available channels forms the strategy space for each player. Nodes can choose to transmit on any of the available channels.
3. Best Response: Given the current channel of other nodes, each node tries o find its best response - the channel that maximizes its utility against the current strategies of others.
4. Nash Equilibrium: A nash equilibrium is a stable state where no node can further improve its utility by unilaterally deviating from its current channel choice, given the selections of other nodes.
The non-cooperative game algorithm iteratively lets nodes evaluate their utilities across channels and switch to the best response channel, until convergence to a Nash Equilibrium is achieved.

V. EXPERIMENTAL RESULTS

In this section, the performance of the proposed mechanism is evaluated and compared with the other closely related schemes (QOF scheme,...). The performance metrics considered for the evaluation of the proposed scheme are 1) Throughput, 2) Packet Delivery Ratio, 3) Average number of Swaps, and 4) Average Energy Consumption.

A. Simulation Setup

We consider a network topology as shown in Fig. **??**, comprising numerous end devices and gateways. This network occupies a spatial expanse of 1000×1000 m. We introduce additional LoRa end devices or gateways to expand the network's capacity. Simulations are executed on the ns3 network simulator, leveraging the LoRa module. Detailed simulator parameters and configurations can be found in Table II. The simulations are averaged over 30 different runs. This paper considers the following performance metrics: a) Packet Success Rate, b) Energy Consumption, c) Convergence Time, d) Distribution of SFs, e) Latency, and f) Throughput.

B. Throughput

C. Packet Delivery Ratio

D. Average Energy Consumption

VI. CONCLUSION & FUTURE WORK

REFERENCES

[1] D. Saluja, R. Singh, L. K. Baghel, and S. Kumar, "Scalability analysis of lora network for snr-based sf allocation scheme," *IEEE Transactions on Industrial Informatics*, vol. 17, no. 10, pp. 6709–6719, 2020.

[2] H. Mahmoudi and B. S. Ghahfarokhi, "Improving lorawan scalability for iot applications using context information," in *2021 11th International Conference on Computer Engineering and Knowledge (ICCKE)*. IEEE, 2021, pp. 358–362.

[3] B. Reynders, Q. Wang, P. Tuset-Peiro, X. Vilajosana, and S. Pollin, "Improving reliability and scalability of lorawans through lightweight scheduling," *IEEE Internet of Things Journal*, vol. 5, no. 3, pp. 1830–1842, 2018.

[4] M. Qiao, H. Zhao, S. Huang, L. Zhou, S. Wang *et al.*, "Optimal channel selection based on online decision and offline learning in multichannel wireless sensor networks," *Wireless Communications and Mobile Computing*, vol. 2017, 2017.

[5] N. El Rachkidy, A. Guitton, and M. Kaneko, "Collision resolution protocol for delay and energy efficient lora networks," *IEEE Transactions on Green Communications and Networking*, vol. 3, no. 2, pp. 535–551, 2019.

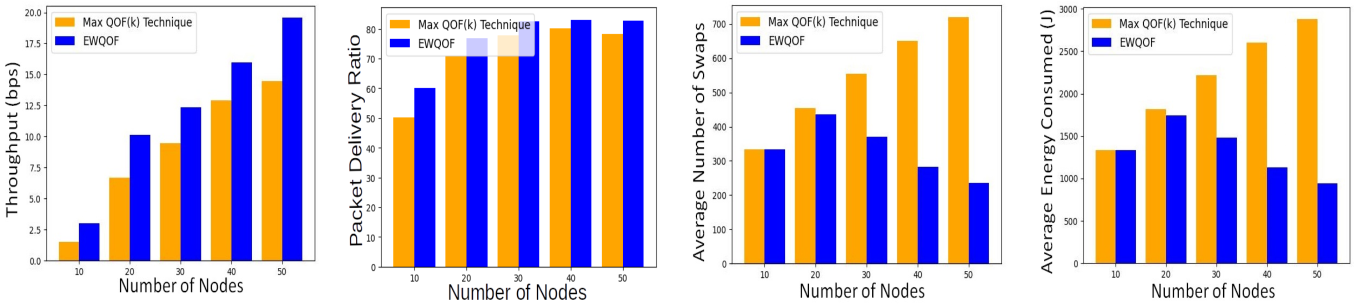
[6] A. Triantafyllou, P. Sarigiannidis, T. Lagkas, I. D. Moscholios, and A. Sarigiannidis, "Leveraging fairness in lorawan: A novel scheduling scheme for collision avoidance," *Computer Networks*, vol. 186, p. 107735, 2021.

[7] J. Finnegan, R. Farrell, and S. Brown, "Lightweight timeslot scheduling through periodicity detection for increased scalability of lorawan," in *2020 IEEE 21st International Symposium on" A World of Wireless, Mobile and Multimedia Networks"(WoWMoM)*. IEEE, 2020, pp. 8–15.

[8] A. Triantafyllou, P. Sarigiannidis, T. Lagkas, and A. Sarigiannidis, "A novel lorawan scheduling scheme for improving reliability and collision avoidance," in *2020 9th International Conference on Modern Circuits and Systems Technologies (MOCAST)*. IEEE, 2020, pp. 1–4.

[9] A. Kumbam, N. Choudhury, and M. M. Nasralla, "LIDS: Lightweight Dynamic Scheduling Technique for 6G-enabled Massive LoRa based IoT Systems," in *2022 IEEE Globecom Workshops (GC Wkshps)*, Dec. 2022, pp. 1622–1627.

[10] E. I. Shayo, A. T. Abdalla, and A. J. Mwambela, "Dynamic multi-frame multi-spreading factor scheduling algorithm for lorawan," *Journal of Electrical Systems and Information Technology*, vol. 10, no. 1, p. 11, 2023.



(a) (b) (c) (d)

Fig. 2. (a) Throughput, (b) Packet Delivery Ratio, (c) Average Number of swaps, (d) Average Energy Consumed.

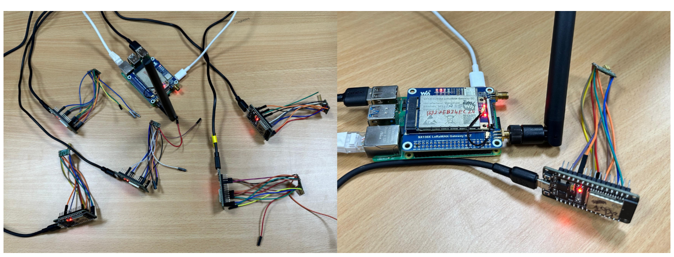


Fig. 3. Testbed Setup