FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 7 No. 3, June, 2023, pp 1 - 6
DOI: https://doi.org/10.33003/fjs-2023-0703-1765

HEURISTIC GATEWAY PLACEMENT FOR MINIMAL TRANSMISSION POWER & COLLISION PROBABILITY IN AN INTERNET OF THINGS LOW POWER WIDE AREA NETWORK (HGPMTPIoT-LPWAN)

***1Aminu Haruna Rawayau, 1Muhammad Dikko Amadi, 2Mubarak Kabir Kankara, 1Mahmud Muhammad Yahaya, 1Samaila Bello**

1Department of Computer Science, Isa Kaita College of Education Dutsin-Ma, P.M.B 5007, Dutsin-Ma, Katsina State
2Department of Computer Engineering, Aboubacar Ibrahim International University, Maradi, Niger Republic

*Corresponding authors' email: mni707@yahoo.com

ABSTRACT

A variety of long-range (LoRa), low-power, and low bit-rate wireless network technologies have been made possible by the Internet of Things' (IoT) rapid growth. As a radio technology for the implementation of numerous Internet of Things applications, the LoRa low-power wide area network (LPWAN) has gained prominence. LoRa is frequently used in conjunction with the Long-Range Wide Area Network Media Access Control (LoRaWAN MAC) protocol and functions in the Industrial, Scientific, and Medical (ISM) bands, which are unlicensed. As a result of receiving a wide variety of different message sizes from diverse applications, LoRa networks experience scalability issues when the number of end nodes connected to one network is more than the shared number of channels. This results in collisions and packet loss. In this paper, heuristic gateway placement for minimal transmission power & collision probability in an internet of things low power wide area network (HGPMTPIOT-LPWAN) is proposed to increase network efficiency, and improve overall performance by measuring collision probability, which in turn can help to reduce the need for retransmissions and packet drop rate. The things network simulator is used to measure the collisions and packet drop rate. An improved performance for HGPMTPIOT as against the efficient graph-based gateway placement (EGBGP) for large-scale LoRaWAN deployments is achieved for packet drop rate by 6%. Likewise, the simulation results show improvements in terms of decreasing the collision probability for 20 to 60 nodes by 20%.

Keywords: Heuristic, Gateway, Collision, LoRa, LoRaWAN, LPWAN

INTRODUCTION

The Internet of Things (IoT) is the network of physical devices (Things) embedded with sensors, software, and connectivity which enable them to exchange data over the Internet to enhance human quality of life. The objects connected can be from household appliances and wearable devices to industrial machinery and vehicles spread into many aspects of life, including smart homes, cities, manufacturing, schools, and workplaces. The IoT ecosystem comprises items such as lights, locks, and industrial machinery that redefined the management of critical and non-critical systems to make lives safer, effective, and pleasant. The IoT technology has affected human lives positively (Ande, Bamidele, Mohammad & Jibran, 2020).

Low-Power Wide-Area Networks (LPWANs) are a type of wireless network technology that are designed to provide long-range, low-power connectivity for IoT devices. LPWANs are optimized for applications that require low data rates, long battery life, and low-cost connectivity. LPWANs use unlicensed radio frequencies to communicate with devices, which allow them to cover large areas without requiring a lot of infrastructure. It can operate on a single frequency band, which reduces the complexity of the network and allows for low-cost devices to be used. There are several different LPWAN technologies available, such as; the Long-Range Wide Area Network (LoRaWAN**)**, which is a low-power wireless network technology that is based on the LoRa modulation scheme. It can operate over distances of several kilometers and is suitable for applications that require low data rates and long battery life (De-Souza, Hoeller, Souza, Montejo-Sanchez, Alves, & De-Noronha, 2020). ***Sigfox*** is another LPWAN technology that operates on ultra-narrowband frequencies. It is optimized for applications that require low data rates and long battery life, and can operate over distances of several kilometers. The next technology is the *Narrowband Internet of Things* (NB-IoT), which is a cellular LPWAN technology that operates on licensed cellular frequencies. NB-IoT is designed to be compatible with existing cellular networks and can provide low-cost connectivity for IoT devices (Tongyang & Izzat, 2020). The Long-Term Evolution for Machines (LTE-M**)**, is another cellular LPWAN technology that operates on licensed cellular frequencies. Its major strength is that it is designed to provide higher data rates and lower latency than NB-IoT, making it suitable for applications that require more bandwidth and real-time connectivity (Sorensen et al., 2022). In general, LPWANs are ideal for IoT applications that require low data rates, long battery life, and long-range connectivity. They are being used in a wide range of applications, including smart cities, asset tracking, environmental monitoring, and agriculture.

In LPWANs, gateways play a critical role in facilitating communication between IoT devices and the wider network. Gateways act as access points for IoT devices to connect to the network, and they also relay data from the devices to the cloud or data center. Optimizing the placement of gateways in an LPWAN is essential for ensuring that the network operates efficiently and effectively. In summary, optimizing gateway placement in LPWANs is crucial for maximizing network coverage, minimizing transmission power, reducing collision probability, and enhancing network scalability. By achieving these goals, LPWANs can provide efficient and cost-effective connectivity for a wide range of IoT applications (Mendes et al., 2022). The IoT devices have the ability of exchanging data with other connected devices and applications in real time, which can be directly or indirectly.

IoT-based device has an input and output sensors interface for connecting sensors to the internet, memory/storage, and for Audio/ Video (Boursianis et al, 2020). The researchers are determined to improve the efficiency of the LPWAN ecosystem and the communication capabilities of LPWANs, making LPWAN deployments for securing the LPWAN clients from malicious adversaries (Gadre, 2020).

Related Work

The rapid growth in the number of connected users and devices in the IoT, along with the need for reliable connectivity considering factors like coverage, battery life, and deployment cost, has led to the evolution of communication requirements for effective device-to-device communication. One promising solution for IoT applications is LPWAN technologies, which offer several advantages such as long communication range spanning several kilometers, simple star network topology, and low power consumption (Dhaval, 2018).

The major challenge of IoT is the provision of connectivity to the devices. Cellular-based technologies provide too much bandwidth for many IoT applications connectivity and the associated power consumption was too high on the other hand. Due to the need for 'clunky' form factors or repetitive recharging for tracking solutions, the growth of tracking use cases was constrained. As a result, the IoT devices need new networking technologies in order to function. Many of the difficulties mentioned are addressed by LoRa. They are currently regarded as one of the "hottest innovation areas in telecoms" for good reason. These technologies have minimal energy consumption, a high degree of indoor penetration, and low cost at slow data rates. They may open up a fresh field of play for creatives whose use cases have yet to be developed. Because of this, LPWAN technologies have the potential for exponential expansion. They may also enable use cases that have a favorable impact on their business case and also open new possibilities which are unlocked by its unique characteristics (Weber et al., 2019).

It was noted that there had not previously been a thorough examination of the design goals and the choices chosen. Eight LPWAN technologies' design decisions, ranging from technical factors to business models, were discovered in the analysis of six (6) significant design goals. They described the system architecture and requirements for these LPWANs solutions and evaluated how well they met each design goal. Therefore, seventeen use cases across twelve domains were identified, with the importance of each design goal to those applications being ranked as low, moderate, or high (Ben et al, 2020). Replication of messages has been found as one method to improve LoRaWAN reliability. They put forth a brand-new hybrid system for coded message replication that combines both straightforward repetition and coded replication techniques. Compared to rival replication strategies, they demonstrate that it improves network performance without using more transmits power (De-Souza et al, 2020). The development of city-scale, low-power internet-of-things IoT is anticipated to connect common objects to the cloud. Therefore, a wireless technology with a large communication range and long battery life is needed to connect things of that size. However, due to interference, greater multipath, and vulnerability to security risks, LPWAN clients perform best in rural areas and significantly worse in urban ones. Therefore, suggest enhancing the LPWAN clients' security, sensing capacity, and connectivity inside the urban environment. Received signal power fluctuates drastically with a low-power transmitter's frequency in multipath-rich metropolitan areas, affecting transmission time, data rate, and battery life. (Gadre, et al, 2020). Besides 5G wireless systems, it was found that LPWANs play an important role in the cellular IoT infrastructure by supporting enormous Machine-Type Communications. Additionally, they provided a throughput and coverage analysis of contemporary LPWAN systems, specifically LoRaWAN (Hoeller, Sant'Ana, Markkula, Mikhaylov, Souza & Alves, 2020). It has been considered to address the scalability of LoRa networks when the number of end nodes linked to one network is greater than the number of shared channels, which results in a collision and packet loss through receiving a wide range of different message sizes from diverse applications. They provided details of an accurate and effective method for simulating the possibility of collision rate and packet loss in LPWANs under various conditions (Rajab, Tibor & Taoufik, 2020).

The article presented by Grochla & Polys (2020) proposes a heuristic algorithm for selecting gateway locations in large-scale LoRa networks. The algorithm considers the distribution of nodes, traffic volume, and radio transmission range to optimize gateway placement for maximizing network coverage and minimizing the number of gateways required. The authors conducted experiments using a realistic simulation model and compared the performance of the proposed algorithm with that of other existing methods. The results showed that the proposed algorithm was effective in reducing the number of gateways required while maintaining a high level of network coverage and minimizing the communication delay. The article concludes that the proposed algorithm can be used in real-world deployments to optimize gateway placement in large-scale LoRa networks.

Through the use of an enhanced LoRa gateway algorithm for a long-range transmission technology and the Framework for LoRa (FLoRa), a simulation framework for running end-to-end simulations for LoRa networks, Mnguni et al. (2021) present a methodology to assess the performance of the LoRa network. To be more precise, this study implements the gateway placement method optimization and analyzes and presents the data obtained from the FLoRa simulator. The packet delivery ratio (PDR) for each LoRa node in the network has been determined in order to describe the coverage of each node. A 10 km radius may be covered by just two gateways put in the network, according to the thorough results acquired.

The article proposed by Loh et al., (2022) designed a graph-based gateway placement algorithm to optimize the performance of LoRaWAN deployments by determining the optimal location of gateways. The algorithm aims to minimize the number of gateways required while ensuring that all end devices are covered with minimal interference and signal loss. The authors evaluate the performance of the proposed algorithm using simulation experiments, and the results show that it outperforms other gateway placement algorithms in terms of coverage, network lifetime, and energy efficiency. The article also discusses the impact of different parameters, such as gateway placement density, on the performance of the algorithm. Overall, the graph-based gateway placement algorithm can significantly improve the performance and efficiency of LoRaWAN deployments, leading to more reliable and effective IoT applications.

The same authors, Loh et al., (2023) extended their work by designing an efficient graph-based gateway placement algorithm for large-scale LoRaWAN deployments. The algorithm takes into account the location and coverage of existing gateways, as well as the distribution of LoRa nodes in the network, to determine the optimal placement of new gateways. The authors evaluate the performance of the proposed algorithm using a simulation-based approach and compare it with other existing algorithms. The results show that the proposed algorithm outperforms the other algorithms in terms of network coverage, PDR, and number of gateways required to achieve a certain level of coverage. The authors also demonstrate the scalability of the algorithm by applying it to a large-scale network with thousands of LoRa nodes. Overall, the article provides a useful contribution to the field of LoRaWAN deployment by proposing an efficient graph-based gateway placement algorithm that can optimize network performance and reduce deployment costs.

From the above literature review, it can be deduced that the placement of gateways is critical in determining the coverage and performance of the network. One approach to gateway placement is graph-based optimization, which involves modeling the network topology as a graph and placing the gateways to maximize network coverage and minimize interference. Graph-based gateway placement algorithms aim to find an optimal set of gateway locations that cover all end devices while minimizing the number of gateways required. The key advantage of graph-based gateway placement is that it enables the placement of gateways based on the physical location of end devices and the network topology. This approach ensures that the network is optimized for performance and coverage, reducing the likelihood of interference and signal loss. Overall, graph-based gateway placement can significantly improve the performance and efficiency of LoRaWAN deployments, leading to more reliable and effective IoT applications.

METHODOLOGY

The methodology adopted in the benchmark paper "Efficient graph-based gateway placement for large-scale LoRaWAN deployments" involves the use of a graph-based heuristic algorithm to determine the optimal placement of gateways in a LoRaWAN network. The algorithm takes into account various factors such as the network topology, signal propagation, and gateway density to determine the optimal placement of gateways. The algorithm works by first constructing a graph of the network topology, with the nodes representing the LoRaWAN nodes and the edges representing the possible connections between them. The algorithm then uses a weighted clustering coefficient metric to determine the optimal placement of gateways. Finally, the algorithm assigns gateways to the nodes with the highest weighted clustering coefficient, taking into account the maximum transmission range of each gateway. The performance of the algorithm is evaluated using simulations, and the results show that the graph-based heuristic algorithm is more efficient and effective than other existing methods for gateway placement in large-scale LoRaWAN deployments. However, the authors only considered the coverage area of gateways when determining their optimal placement. Moreover, there may be other factors that could impact gateway performance, such as interference from other wireless networks, the presence of obstacles (e.g. buildings or trees), and the density of LoRaWAN devices in the area. By incorporating these factors into the optimization algorithm, the resulting gateway placement may be even more efficient. Therefore, to solve the above mentioned problems, the proposed algorithm incorporated an interference detection and mitigation technique that can detect sources and patterns of interference and adjust the transmission parameters of LoRaWAN devices to avoid interference with other wireless networks.

The channel hopping in LoRaWAN is also incorporated, it will modify the firmware of the LoRaWAN devices to switch between different channels within the frequency band used by the LoRaWAN network of the proposed work. LoRaWAN gateways must be configured to listen on all channels within the frequency band.

Here are the general steps to implement channel hopping in LoRaWAN:

i. Determine the frequency band and channel plan for the LoRaWAN network.
ii. Modify the firmware of the LoRaWAN devices to implement channel hopping. This may involve creating a table of available channels and implementing a mechanism to switch between channels periodically. The timing and frequency of channel hopping can be determined based on the specific needs of the LoRaWAN network.
iii. Configure the LoRaWAN gateways to listen on all channels within the frequency band. This can typically be done using the gateway's configuration tool or web interface.
iv. Test the channel hopping implementation to ensure that it is working as expected. The timing and frequency of channel hopping based on the results of the testing should be adjusted.

It's important to note that LoRaWAN networks are typically managed by a network server, which handles tasks such as device authentication, encryption, and message routing. The LoRaWAN network server may also need to be configured to support channel hopping.

The LoRaWAN devices will also use adaptive data rate (ADR) to adjust their transmission power and data rate based on the signal strength and quality of the wireless channel. Moreover, by increasing the density of gateways in the LoRaWAN deployment, distance between devices and gateways can be reduced, and increase the likelihood of successful transmissions with a little tradeoff to cost. However, it can help greatly in mitigating the impact of interference from other wireless networks, as devices may be able to connect to a gateway with a stronger signal and avoid interference from other networks.

Performance Evaluation

The performance metrics used in measuring the efficacy of the proposed work are:

Collision probability: This is a key performance metric for measuring the efficiency of an IoT-LPWAN. The collision probability can be calculated using the following equation:

$$Pc = 1 - (1 - p)^N \qquad (1)$$

Where Pc is the collision probability

p Is the probability of a node transmitting a packet in a time slot

N Is the number of nodes that are actively transmitting packets in the same time slot

To accurately measure collision probability, there is need for the deployment of nodes throughout the network and collect data on the number of collisions that occur during the measurement period. The data can be used to calculate the collision probability using the above equation 1.

The following factors are considered to ensure accurate measurement of collision probability:

i. Node placement: Nodes should be placed in locations that are representative of the typical deployment environment, and they should be spaced out to ensure adequate coverage of the network.
ii. Packet size: The size of the packets used to measure collision probability should be representative of the typical packet size used in the network.

iii. Packet Delivery rate: The rate at which packets are transmitted should be representative of the typical traffic load in the network.

iv. Gateway placement: The placement of the gateway should be optimized to minimize collision probability.

By accurately measuring collision probability, a researcher can identify areas where collisions are most likely to occur and optimize the network to minimize collision probability. This can help to reduce the need for retransmissions, increase network efficiency, and improve overall network performance.

PDR is a performance metric that measures the percentage of packets that are successfully delivered from the nodes to the gateway. It is calculated as follows:

$$PDR = \frac{Np}{Npt} * 100 \qquad (2)$$

Where PDR is the number of packets received by the gateway.

Np is the number of packets received by the gateway.

Npt Is the total number of packets transmitted by the nodes.

To measure PDR, nodes should be deployed throughout the network and collect data on the number of packets transmitted and received by the gateway. You can then calculate PDR using the equation above.

To ensure accurate measurement of PDR, you should consider the following factors:

Node placement: Nodes should be placed in locations that are representative of the typical deployment environment, and they should be spaced out to ensure adequate coverage of the network.

Packet size: The size of the packets used to measure PDR should be representative of the typical packet size used in the network.

Packet rate: The rate at which packets are transmitted should be representative of the typical traffic load in the network.

Gateway placement: The placement of the gateway should be optimized to minimize transmission power and collisions, as this can affect the PDR.

Measurement duration: The duration of the measurement period should be long enough to capture sufficient data, but not so long that it becomes impractical to collect and analyze the data.

By considering these factors and accurately measuring PDR, you can gain insights into the performance of the network and identify areas for improvement.

RESULT AND DISCUSSION

Collision is caused by a number of factors, including arrival time overlap, spreading factor overlap, and coding rate collision, among others. Several factors determine whether the receiver is able to decode one, two, or no packets at all.

The choice of LoRa settings used for packet transmission affects the likelihood of a collision. In this paper, we emphasize two double alternative strategies for handling interference. When the end nodes are transmitting the packets simultaneously in the first scenario, the packets are deemed lost. "Time Collision" will be the name given to this. In the second scenario, packets become corrupted when end nodes simultaneously broadcast packets using the same spreading factor. "Spreading Factor Collision" will be the name given to this. The next section examines the collision probability model. Both strategies strive to increase throughput, reduce packet loss, and reduce collision probability.

The network's end nodes are distributed geographically. The Things Network Simulator performs simulations utilizing various numbers of end nodes (20,25,30,35,40,45,50,55,60,65) for each scenario. In the first scenario, the simulation was done with a slightly increased number of end nodes. The evaluation of the Time Scheduling algorithm was shown in Figure 1. Thus, the assumed number of collided packets is 2 when we applied it for five end nodes. After using the time scheduling algorithm, the simulation results show improvements in terms of decreasing the probability of collision by more than 20%. To be able to evaluate the proposed solution under various conditions, Fig. 1 presents the collision parameters when the number of end nodes increases from 20 to 25 up to 60. The results showed that increasing number of nodes may create a likelihood for the increase in collision probability.

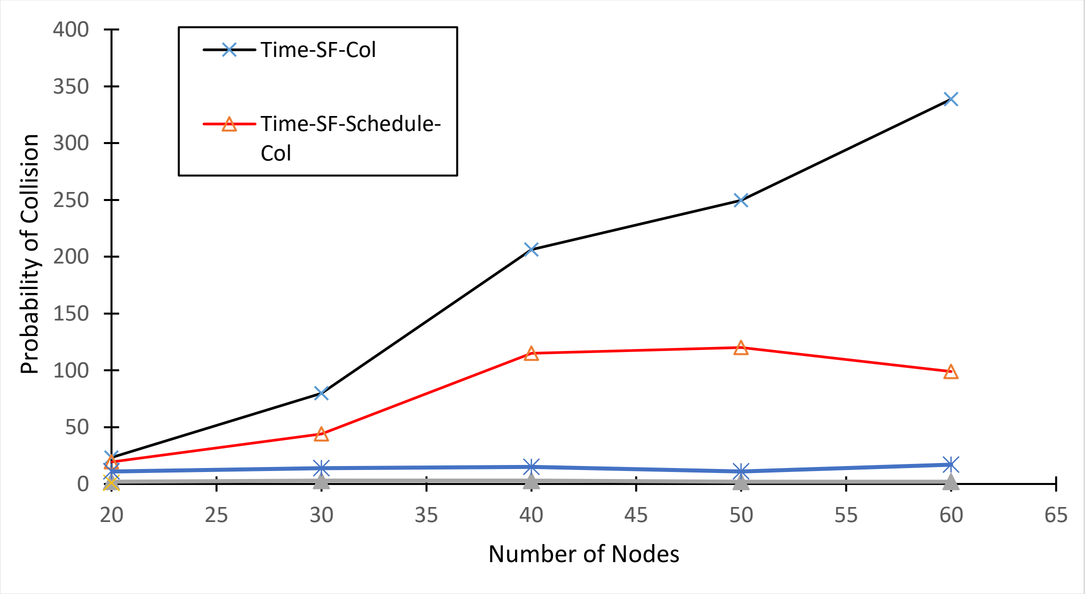

Figure 1: Probability of at least one Collision for 20 to 60 Nodes

The packet drop rate performance measurement was evaluated for the (EGBGP) for large-scale LoRaWAN and proposed work. It was seen that there was a reduction in packet dropping rate for HGPMTPIoT as against the EGBGP.

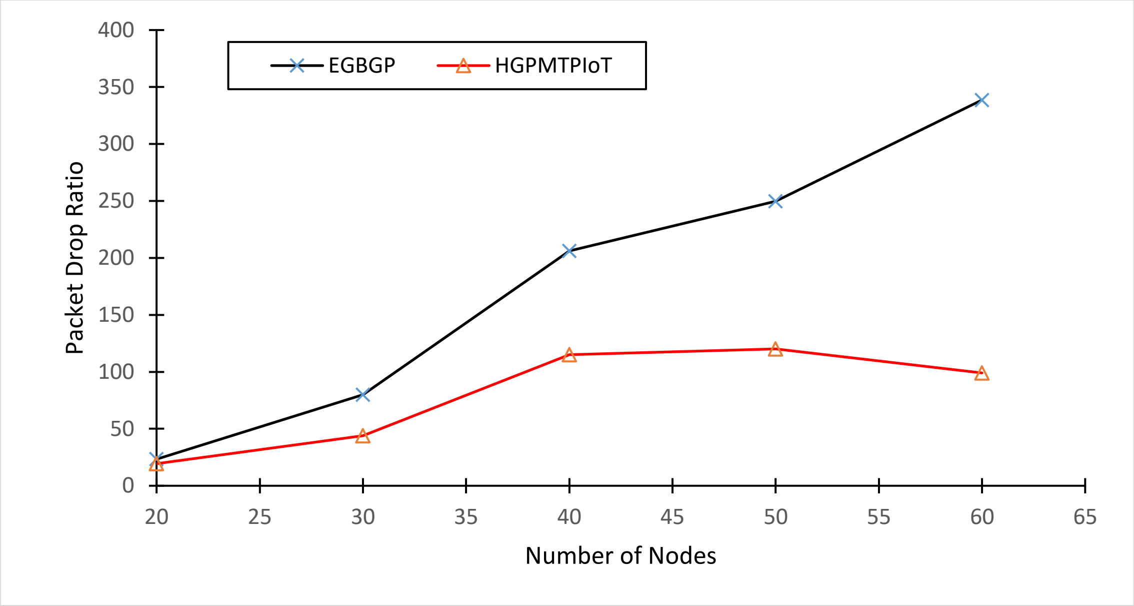

Figure 2: Packet Drop Rate for 20 to 60 Nodes

CONCLUSION

Collision and packet drop rate are the main factors that negatively impact the LoRaWAN throughput. In this paper, a HGPMTPIOT-LPWAN is proposed to increase network efficiency, and improve overall performance by measuring collision probability, which in turn can help to reduce the need for retransmissions and packet drop rate. The things network simulator is used to measure the collisions and packet drop rate. An improved performance for HGPMTPIOT as against the benchmark is obtained as represented on the graph for packet drop rate. Likewise, the collision probability for 20 to 60 nodes is also represented on figure 2.

FUTURE WORK

The researchers in future will consider using other optimization algorithms such as genetic algorithms or particle swarm optimization to enable researchers determine and identify more efficient and effective ways to place gateways in large-scale LoRaWAN deployments.

ACKNOWLEDGMENTS

This work was supported by Isa Kaita College of Education Katsina, through the TETFund intervention program on Institution Based Research (IBR).

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