International Journal of Computer Science Trends and Technology (IJCST) – Volume 12 Issue 3, May - Jun 2024

RESEARCH ARTICLE OPEN ACCESS

Fault-tolerant Gateway Connectivity Using Honey Badger Optimization Algorithm in LoRaWAN

Mr.A.Ramesh [1] Dr.K.Kamali [2]

[1] Assistant Professor, Dept. of CSE, Annamalai university, Annamalainagar, Tamilnadu

[2] Assistant Professor. Dept. of CSE, Annamalai university, Annamalainagar, Tamilnadu

ABSTRACT

Long Range Wide Area Network (LoRaWAN) stands out for its less energy consumption and cost-effectiveness. Existing studies have largely ignored the fault tolerance of LoRa networks in the event of failures. Addressing the problems of fault tolerance and reliability in LoRa networks is vital for the large-scale deployment of LoRa applications. In this paper, we propose to design a fault-tolerant gateway connectivity using Honey badger optimization algorithm (FTGC-HBO) in LoRaWAN. In this technique, backup gateways are deployed during gateway failures and interference, using HBO algorithm based on Received Signal Strength (RSS), data transfer time and load level metrics. By simulation results, it has been shown that FTGC-HBO technique achieves maximum energy efficiency and packet success rate with reduced packet loss rate.

Keywords:Long Range Wide Area Network (LoRaWAN), Marine Predator Optimization (MPO), Fault-tolerant, Gateway deployment, connectivity

1. INTRODUCTION

One of the common Internet of Things (IoT) communication standards is Low-Power Wide Area Networks (LPWAN) [1]. LPWAN acts as low-power alternatives to cellular networks. LPWANs provide essential features such as low energy consumption, extensive coverage, and low implementation costs. Amongst LPWAN technologies, LoRaWAN stands out for its less energy consumption and cost-effectiveness. Long Range (LoRa) is the physical layer of LoRaWAN that is registered by Semtech. It uses Chirp Spread Spectrum (CSS) modulation for robust transmissions. A LoRa radio is characterized by transmission parameters like coding rate, spreading factor, and bandwidth [2]. LoRaWAN is gaining attention in the Industrial Internet of Things (IIoT) because of its low data transfer volume, wide spatial range, and relatively low energy consumption when compared with other technologies [3].

In spite of these capabilities, several challenges obstruct the broader implementation of LoRa and LoRaWAN, predominantly related to scalability and reliability. Existing studies have largely ignored the fault tolerance of LoRa networks in the face of failures. The sparse distribution of gateways and long communication links make LoRa networks susceptible to gateway interference and failures. In contrast to traditional wireless networks, LoRa uses a single-hop broadcast and the Aloha MAC protocol, making conventional reliability-aware or fault-tolerant approaches through alternative path routing and scheduling inappropriate. Addressing the problems of fault tolerance and reliability in LoRa networks is vital for the large-scale deployment of LoRa applications [4][5].

Fault-tolerant communications encounter several challenges, including the requirement for efficient fault detection and diagnosis mechanisms that operate in real-time without considerably increasing energy consumption, which is vital given the inadequate battery life of IoT devices [6].

2. RELATED WORKS

Bundle Protocol over LoRa (BPoL) has been presented by Schmidt et al. [7] as a workable LoRa-DTN overlay network that supports duty-cycle restrictions. This is extensible for various scenarios and standard routing algorithms, and integrates with an established implementation of the Bundle Protocol (BP) as defined in RFC 9171. An overlay network protocol is developed based on Protocol Buffers (protobufs) for controlling BPoL nodes, including bundle distribution, discovery, and network diagnostics, along with offering a novel convergence layer for BP-over-LoRa. Moreover, a wide range of LoRa transceivers is easily supported by expanding upon the rf95modem4 firmware.

Ribeiro et al. [8] concentrated on important management concerns within LoRaWAN. To improve security and availability in LoRaWAN environments, a secure key management architecture is built on private blockchain and smart contracts. Using open-source tools and commodity hardware, a functioning prototype was created to demonstrate the viability of the suggested architecture.

The core of IoT works and design problems, a discussion of its guiding principles, and IoT development concepts are offered by Dymora et al. [9]. A thorough description of Wireless Sensor Network (WSN) as a crucial part of IoT infrastructure was provided. Fault-tolerance (FT) has emerged as a critical concern for IoT systems, as evidenced by the multiple failures that can occur at all levels of the IoT architecture, including sensor nodes, actuators, network linkages, as well as processor and storage components. When a routing algorithm is implemented correctly, it directly affects the power consumption of sensors, which in severe situations causes nodes to shut down because of battery degeneration. In order to investigate the resilience of IoT infrastructure, a ZigBee network topology was established and multiple node failure scenarios were replicated. Additionally, based on the link between throughput and the quantity of rejected packets, as well as the proportionality between the value of management traffic and other factors, such as the ratio of rejected packets, the results demonstrated the significance and influence of selecting the appropriate routing scheme.

LoRaWAN's low energy and implementation costs are offset by its packet delivery rate and latency, which are insufficient for the IIoT's real-time and dependability needs. According to Rezazadeh et al. [10], LoRaWAN fault tolerance can be achieved by foreseeing packet collisions. A unique technique to prevent packet loss is given by anticipating the occurrence of collisions. By enhancing packet delivery rate and reducing message retransmission, this reduction in packet loss enhances LoRaWAN reliability and efficiency in energy use. The evaluation findings demonstrate that the suggested method's PDR has converged to 88% and that there is an average 21% improvement in latency when compared to regular LoRaWAN.

3. PROPOSED METHODOLOGY

In this paper, we propose to design fault-tolerant gateway connectivity for deploying gateways in LoRa network. In this technique, backup gateways are deployed during gateway failure by applying the HBO algorithm.

3.1 Gateway Connectivity Constraints

Given a set of end devices' locations, how to place gateway and allocate transmission parameters at each end device to satisfy the following constraints:

(i) $RSS_{ij} > PDR_{req}$
(ii) $D_T < D_T^{min}$
(iii) $LL < L_{max}$

In constraint (i), RSS is the Received Signal Strength and PDRreq is the required Packet Delivery Ratio at the device i.

RSS computes the received signal strength from device i at the gateway j with transmit power (TxP) and path loss (PL) ,which is given by

$$RSS_{ij} = TxP_i + G^{tx} + G^{rx} - PL_{ij} \qquad (1)$$

where G^{tx} and G^{rx} are the antenna gains at transmitter and receiver, respectively.

PL_{ij} is the path loss from the end device i to the gateway j, which is computed as

$$PL_{ij}(d) = \overline{PL(d_0)} + 10\gamma\log_{10}\left(\frac{d}{d_0}\right) + N_\sigma \qquad (2)$$

Where d is the distance between LoRa node and gateway, $PL(d_0)$ is the mean path loss at reference distance d_0, γ is the path loss exponent, N_σ is a zero-mean Gaussian variable with std. deviation σ.

In constraint (ii), DT is the data transfer time and D_T^{min} is the minimum threshold of D_T. Data transfer time is the time taken for transmitting data between two nodes. It includes the processing delay (P_D) and network delay (N_D).

$$D_T = P_D + N_D \qquad (3)$$

P_D can be computed as

$$P_D = (S^j_T - A^j_T) + IC_T \qquad (4)$$

Where S^j_T and A^j_T are the service time and arrival time of packet j and IC_T is the inter processor communication time.

N_D is computed as

$$N_D = Rx_T - Tx_T \qquad (5)$$

where Rx_T and Tx_T denote the time of packet receiving and packet sent, respectively.

In constraint (iii), LL is the load level of a node and LL_{max} is the maximum limit of the lode.

LL of a functional node n_i is defined as

$$LL_i = \frac{S_i}{C_i} \qquad (6)$$

Where S_i is the data size and C_i is the capacity of the node.

In order to meet constraints, we will apply the Honey Badger Optimization (HBO) algorithm [13].

3.2 HBO Algorithm

The fitness function derived in terms of the constraints defined in Eq.(7)

$$Fit_{ij}() = f_1.(RSS_{ij} > PDR_{req}) + f_2(D_T < D_T^{min}) + f_3(LL < L_{max}) \quad (7)$$

The HBO algorithm selects the device and gateway such that the fitness meets all the 3 constraints. (ie) with RSS greater than the required PDR, data transfer time less than the minimum threshold and load level less than the maximum.

The metaheuristic algorithm HBO [11] is used for finding the optimal solution. There are three stages are involved in the HBO; they are initializing the population, evaluating the fitness function and when the best solution is obtained the process ends.

HBO influences the foraging characteristics of an Honey Nadger (HB). To identify food sources, the HB smells and follows honey guiding bird. There are two stages like digging and honey stages. In the digging stage, the HB utilizes its smell capacity to show the prey location. When the location is reached, the HB moves over the prey for selecting the proper area to dig and catch the prey. In the honey stage, HB considers the suggestion of honey guiding bird for locating beehive.

Following section briefly the digging and honey stages. HBO has the exploration and exploitation stages and it is the global optimal model. The candidate solution population of HBO is given as:

$$Y = \begin{bmatrix} Y_{1,1} & Y_{1,2} \cdots & Z_{1,Dim} \\ Y_{2,1} & Y_{2,2} \cdots & Z_{2,Dim} \\ \cdots & \cdots \quad \cdots & \cdots \\ Y_{m,1} & Y_{m,2} \cdots & Z_{m,Dim} \end{bmatrix} \quad (8)$$

where the dimension of solution is Dim, and current candidate's solution is Z .

Initialization: The population of HB is randomly produced as:

$$Y_j = r \times (ub_j - lb_j) + lb_j \quad (9)$$

where r is the random number, ub_j and ub_j are, upper and lower bounds.

Describing Intensity: The prey strength and distance among them and the j^{th} HB is called as Intensity. Prey's small intensity is I_j. The movement is fast when the smell is large and the movement is slow when the smell is less.

$$I_j = r_1 \times \frac{S}{4\pi \times dis_j^2} \quad (10)$$

where r_1 is the random number, S is strength, dis_j is the distance of prey and j^{th} HB

Updating density β***:*** The term β manages time varying randomization for ensuring better changing from exploration to exploitation. This β is given as:

$$\beta = K \times \exp\left(\frac{-t}{\max\_iter}\right) \quad (11)$$

where $\max\_iter$ and K are the maximum iterations and constant number.

Digging stage: In this stage, the HB carries out the action in Cardioid shape and it is given as:

$$Y_{new} = Y_{prey} + F \times \alpha \times I \times Y_{prey} + F \times r_2 \times \beta \times dis_j \quad (12)$$

where Y_{new} is the new position, Y_{prey} is the prey position, α is the search factor, r_2 is the random number and F is the Flag that changes the search position.

Honey stage: In this stage, the HB follows honey guiding bird for reaching hive and it is expressed as:

$$Y_{new} = Y_{prey} + F \times r_3 \times \beta \times dis_j \quad (13)$$

For finding the best optimal parameter, the above stages are repeated till the termination strategy is obtained. Algorithm 2 shows the pseudocode of the parameter optimization using the HBO.

Algorithm 1: Pseudocode of HBO

```
Input: Initialize the parameters
Output: Solution best fitness value
Define the fitness of every position of HB using the Equation (7) and assign to $Y_j$
Record $Y_{prey}$ and fitness assigned to $f_{prey}$
while $t \le \max\_iter$ do
    Updating density $\beta$ using the Equation (11)
    for $j = 1$ to $N$ do
        Describing Intensity using the Equation (10)
        when $r < 0.5$ then
            Update the $Y_{new}$ position using the Equation (12)
        Else
```

```
            Update the $Y_{new}$ position using the Equation (13)
        end if
        Develop new positions and provided to the $f_{new}$
        when $f_{new} \le Y_j$ then
            Fix $Y_j = Y_{new}$ $Y_j = f_{new}$
       end if
        when $f_{new} \le f_{prey}$ then
            Fix $Y_{prey} = Y_{new}$ $f_{prey} = f_{new}$
       end if
     end for
end while ending criteria met
Return $Y_{prey}$ (Best fitness value)
```

4. EXPERIMENTAL RESULTS

4.1 Simulation Settings

The proposed FTGC-HBO technique has been implemented in the LoRaWAN cross-layer simulation framework. The performance is compared with the existing energy efficiency-driven heuristic LoRa (EE-LoRa) defined in [12]. The performance metrics packet success rate, packet loss rate, average residual energy and throughput are measured, by varying the nodes.

TABLE 1 shows the simulation settings.

Number of Devices	20 to 100
Size of the topology	150m X 150m
Propagation Model	Two Ray Ground
Antenna Model	OmniAntenna
MAC protocol	IEEE 802.15.4
Traffic Source	CBR
Packet size	512 bytes
Traffic Rate	50Kb
Initial Energy	18 Joules
Transmit power	0.3 watts
Receiving power	0.3 watts
Simulation time	100 seconds
Transmission range	30m

TABLE 1 Simulation Settings

4.2 Results & Analysis

The performances of the techniques are evaluated by varying the number of devices from 20 to 100.

Devices	FTGC-HBO	EE-LoRa
20	0.9762	0.9461
40	0.9735	0.9413
60	0.9681	0.9365
80	0.9646	0.9328
100	0.9573	0.926

TABLE 2 Results for Packet delivery ratio

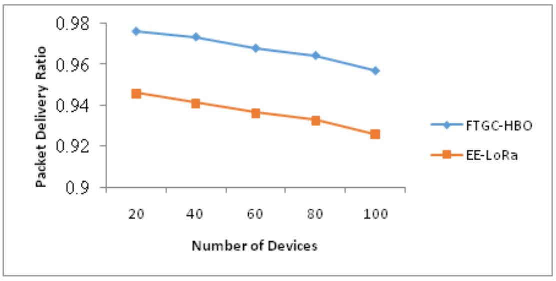

FIGURE 2 Results of Packet success rate

The packet delivery ratios of all the protocols are shown in Table 2 and Figure 2. From the figure, it can be seen that FTGC-HBO has 4% higher success rate than EE-LoRa.

Devices	FTGC-HBO	EE-LoRa
20	915	1108
40	1044	1165
60	1128	1254
80	1173	1287
100	1248	1419

TABLE 3 Results for Packet loss

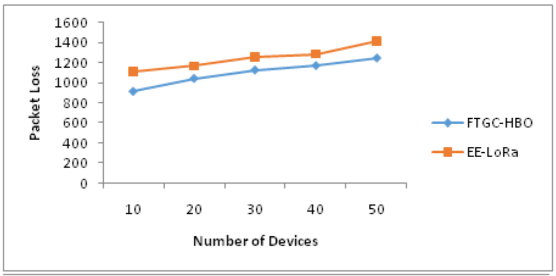

FIGURE 3 Results of Packet loss rate

The average packet loss rates of all the protocols are shown in Table 3 and Figure 3. From the figure, it can be seen that packet loss rate of FTGC-HBO is 12% lesser than EE-LoRa, for varying the devices.

Devices	**FTGC-HBO**	**EE-LoRa**
20	15.16	13.82
40	14.65	13.56
60	14.33	13.15
80	13.05	12.74
100	13.44	12.27

TABLE 4 Results for Residual energy

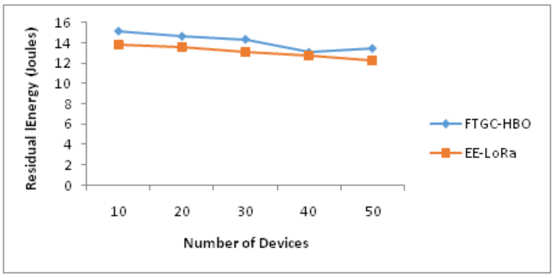

FIGURE 4 Results of average Residual Energy

The average residual energies of all the protocols are shown in Table 4 and Figure 4. From the figure, it can be seen that residual energy of FTGC-HBO is 7% higher than EE-LoRa, for varying the devices.

Devices	**FTGC-HBO**	**EE-LoRa**
20	0.823	0.754
40	0.832	0.772
60	0.848	0.784
80	0.89	0.812
100	0.926	0.825

TABLE 5 Results for Throughput

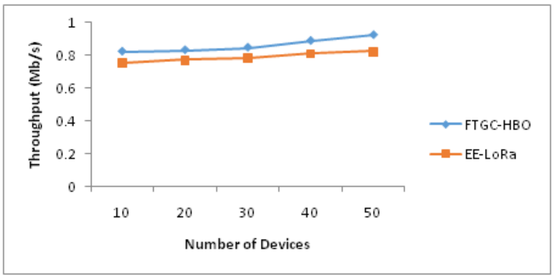

FIGURE 5 Results of Throughput

The throughput measured for all the protocols are shown in Table 5 and Figure 5. From the figure, it can be seen that throughput of FTGC-HBO is 8% higher than EE-LoRa, for varying the devices.

5. CONCLUSION

In this paper, we propose to design a fault-tolerant gateway connectivity using HBO algorithm in LoRaWAN.. In this technique, backup gateways are deployed during gateway failures and interference, using HBO algorithm based on RSS, data transfer time and load level metrics. The proposed FTGC-HBO technique has been implemented in the LoRaWAN cross-layer simulation framework. The performance is compared with the existing EE-LoRa model. By simulation results, it has been shown that FTGC-HBO technique achieves maximum energy efficiency and packet success rate with reduced packet loss rate.

REFERENCES

1. Muhammad Naim Bin, Che Kamarudin, Afida Binti Ayob, and Aini Hussain, “Review of LoRaWAN: Performance, Key Issues and Future Perspectives,” Jurnal Kejuruteraan 36(2), 2024.

2. Ruben M. Sandoval, Antonio-Javier Garcia-Sanchez and Joan Garcia-Haro, “Performance optimization of LoRa nodes for the future smart city/industry,” EURASIP Journal on Wireless Communications and Networking (2019) 2019:200

3. Yifei Zou, Li Yang, Guanlin Jing, Ruirui Zhang, Zhenzhen Xie, Huiqun Li, Dongxiao Yu, “A survey of fault tolerant consensus in wireless networks,” High-Confidence Computing, 4, 2024.

4. Franz Kuntke, Lars Baumgartner, Christian Reuter, “Rural Communication in Outage Scenarios: Disruption-Tolerant Networking via LoRaWAN Setups,” Proceedings of the 20th ISCRAM Conference – Omaha, Nebraska, USA.

5. Gloire Rubambiza, Mueed Rehman, Sachille Atapattu, José F. Martínez, Hakim Weatherspoon, “Comosum: An Extensible, Reconfigurable, and Fault-Tolerant IoT Platform for Digital Agriculture,” USENIX ATC, 2023.

6. Safi, A.; Ahmad, Z.; Jehangiri, A.I.; Latip, R.; Zaman, S.K.u.; Khan, M.A.; Ghoniem, R.M. A Fault Tolerant Surveillance System for Fire Detection and Prevention Using LoRaWAN in Smart Buildings. Sensors 2022, 22, 8411. https://doi.org/10.3390/s22218411

7. Daniel Schmidt, Franz Kuntke, Maximilian Bauer, Lars Baumgartner, “BPoL: A Disruption-Tolerant LoRa Network for Disaster Communication,” 2023 IEEE Global Humanitarian Technology Conference (GHTC), 2023.

8. Victor Ribeiro, Raimir Holanda Filho, Alex Ramos, “A Secure and Fault-Tolerant Architecture

for LoRaWAN Based on Blockchain,” 2019 3rd Cyber Security in Networking Conference (CSNet).

9. Dymora, P.; Mazurek, M.; Smalara, K. Modeling and Fault Tolerance Analysis of ZigBee Protocol in IoT Networks. Energies 2021, 14, 8264. https://doi.org/10.3390/ en14248264

10. Reza Rezazadeh, Yasser Sedaghat, Ismail Ghodsollahee, Farzad Azizi, “Improving Fault Tolerance of LoRaWAN with Predicting Packet Collision,” 2023 28th International Computer Conference, Computer Society of Iran (CSICC), 2023.

11. Hashim, Fatma A., Essam H. Houssein, Kashif Hussain, Mai S. Mabrouk, and Walid Al-Atabany. "Honey Badger Algorithm: New metaheuristic algorithm for solving optimization problems." Mathematics and Computers in Simulation 192 (2022): 84-110.

12.B. Ousat and M. Ghaderi, “Lora network planning: Gateway placement and device configuration,” in IEEE International Congress on Internet of Things (ICIOT). IEEE, 2019, pp. 25–32.