Energy efficiency based RPL protocol using grasshopper optimization algorithm

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ABSTRACT

The routing protocol for low-power and lossy networks (RPL) is necessary for the internet of things (IoT) because it offers scalable, reliable, and energy-efficient routing capabilities. The trickling algorithm generates a destination-oriented directed acyclic graph (DODAG) with the broadcasting of suppression. However, broadcast suppression is insufficient when addressing network coverage and optimization problems based on uneven node distribution. Network congestion develops in large-scale IoT implementations where many devices are interconnected and congestion causes data transmission delays, decreased overall reliability, and higher latency. In this paper, the grasshopper optimization algorithm with the DODAG (GOA-DODAG) is proposed to determine optimization problems and energy-efficient reliable routing paths which include coverage-based dynamic trickling technique to construct DODAG energy-efficient without affecting the coverage of network and data routing reliability. The GOA-DODAG achieves a 98% packet delivery ratio (PDR) while consuming 0.48 mJ, which is more preferable in comparison to the existing methods like efficient-routing protocol for low-power and lossy networks (E-RPL), reliable and energy-efficient RPL (REFER), elaborated cross-layer RPL objective function to achieve energy efficiency (ELITE).

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1. INTRODUCTION

Routing protocol for low-power and lossy networks (RPL) is a utilized in internet of things (IoT) networks [1], [2]. IoT network comprises many constrained nodes, some of which have energy constraints, rates of low data, low consumption of energy, storage, short communication ranges, frame size restrictions, and dynamic network topology [3], [4]. Systems of IoT are built on low-power and lossy networks (LLNs), and inherit their limited resources, making any routing protocol suitable for the applications of low-resource [5]. RPL developed by the working group of the internet engineering task force (IETF) routing over low-power and lossy networks (ROLL), is regulated as a routing protocol for the IoT while also addressing the needs of LLNs [6], [7]. IPv6 distance vector-based routing protocol is an RPL that starts at the root node and builds a directed acyclic graph (DAG) [8], [9]. Due to this, social and cognitive computing-based routing in the IIOT has the potential to enhance the performance of the network including overhead, end-to-end delay [10], and throughput [11]. In the IoT, trust management (TM) is crucial for trustworthy mining and data fusion, competent services with context-aware intelligence [12], and increased data security [13] and user privacy [14]. Unmannered aerial vehicles (UAVs) is employed across a narrow area that transfers data to a central node through stable topology which helps to support the transmission of data in multi-point-to-point (MP2P) [15]. As a result, to save energy, child nodes avoid selecting an unstable node as a parent [16]. However, broadcast suppression is insufficient when addressing network coverage and optimization problems based on uneven node distribution. Network congestion develops in large-scale IoT implementations where many devices are interconnected. Congestion causes data transmission delays, decreased overall reliability, and higher latency. Preeth *et al.* [17] implemented an energy-efficient routing protocol for low-power and lossy networks (E-RPL) algorithm that combined ACO-based optimization with coverage-based dynamic trickling to construct destination-oriented directed acyclic graph (DODAGs) and maintain the network coverage. The expected transmission count (ETX) and value of rank were categorized by the ACO as the factors of pheromone, whereas the remaining energy was labeled as factors of heuristic. However, ETX causes a lengthy routing path and significant message latency when routing messages.

Lalani *et al.* [18] presented a reliable and energy-efficient RPL (REFER), a mobility-aware version of RPL that enabled stable and communication efficiency among the devices of IoT with the use of a new neighbor policy placement based on a parent's leasing time by incorporating several link/nodes for its selections of the path in mobile situations. REFER increases overhead in terms of computational demands and control messages to achieve dependability and energy efficiency. Safaei *et al.* [19] introduced an ELITE, a sophisticated cross-layer function to achieve energy efficiency in the applications of IoT, and strobe per packet ratio (SPR), a newly developed routing metric used by ELITE was created to function together with the protocols of asynchronous MAC. However, broadcast suppression was insufficient when addressing network coverage and optimization problems based on uneven node distribution. Solapure and Kenchannavar [20] implemented an RPL objective function (OF) that employed different routing metrics energy, and content, ETX, single, and combinations to improve the IoT application performances. However, the addition of different routing metrics raised the routing protocol's processing and communication overhead. Acevedo *et al.* [21] presented a weighted random forward (WRF) RPL that utilized load balancing and distributing messages to prevent congestion in one chosen parent. Here, transmitting a lot of packets resulted in the most undesirable performance in such situations because it required more control messages for operation. The protocol seeked to increase the life of the network. Homaei *et al.* [22] introduced a decision system method based on learning automata in the RPL (DDSLA-RPL) to dynamically evaluate and change the weight of significant routing parameters. But, overhead involved learning and making decisions that affected the network's overall performance and caused inefficiencies or delays. From the overall analysis, it was seen that the existing research had limitations like the addition of different routing metrics that raised the routing protocol's processing and communication overhead in terms of computational demands, data transmission delays, decreased overall reliability, higher latency, and control messages to achieve dependability and energy efficiency. To overcome these issues, grasshopper optimization algorithm with the DODAG (GOA-DODAG) is proposed to solve the optimization and energy efficiency problems.

Further, the primary contributions of this paper are summarized as: i) the main goal of the GOA-DODAG is to determine the optimization problem, high reliability, and energy-efficient optimal selection of parents in IoT context; ii) the parent selection method uses heuristic information to reduce child node association and packet loss, as well as avoid network collision which results in fewer expected packet transmissions; and iii) to maximize energy efficiency and ensure reliable packet delivery, the nodes are characterized by using the remaining energy to produce DODAG information object (DIO) messages. The Cooja simulator is used to assess the proposed method's performance.

The rest of this research is organized as follows. Section 2 discusses the proposed method. Section 3 displays a detailed explanation of a research method, while section 4 describes the results and discussion of the proposed methodology, and section 5 presents the conclusion.

2. PROPOSED METHOD

The energy-efficient routing has the greatest significance in the network of sensors with limited resources. The GOA-DODAG creates an RPL routing protocol to enable energy-efficient IoT routing. There are two key parts to this protocol that are, a coverage-based dynamic trickling method and a GOA which are both used in this section. The overview of the energy efficient RPL network is represented in Figure 1.

2.1. System model

A network of sensors (N), edges (E), graph (G), root node, or node of gateway (R) creates the IoT. $E = \{i, j\} \in N$ denotes the collection of direct connections between the nodes. If positioned within the transmission range (T_r), it is possible for the nodes to communicate directly with one another and initially, the same amount of energy E_N is used to install each node. Two procedures including DODAG construction and GOA are performed by the proposed method. The message of DIO includes the rank value to deliver the node of gateway R, as well as the current value of E_i. The received consistent DIO message is counted by each node and the nodes N list their node of neighbors in two lists. The nodes within the $\frac{T_r}{3}$ range, and those outside the $\frac{T_r}{3}$ range are kept in separate lists. The DIO message rebroadcasting includes the node $\in C1$. Calculating the distance to the C1 boundary, the proposed method gives nodes in $i \in C1$ priority as far as broadcasting of DIO messages is concerned. Convergence time ratio (CTR) is a measure of the amount of time required by the nodes to determine the node of a parent in the T_r, while the coverage of nodes broadcasting DIO messages are the major determinants of the ideal K value. The proposed method provides routing of energy-efficient without affecting the integrity of data transmission by utilizing the dynamic trickle algorithm and GOA.

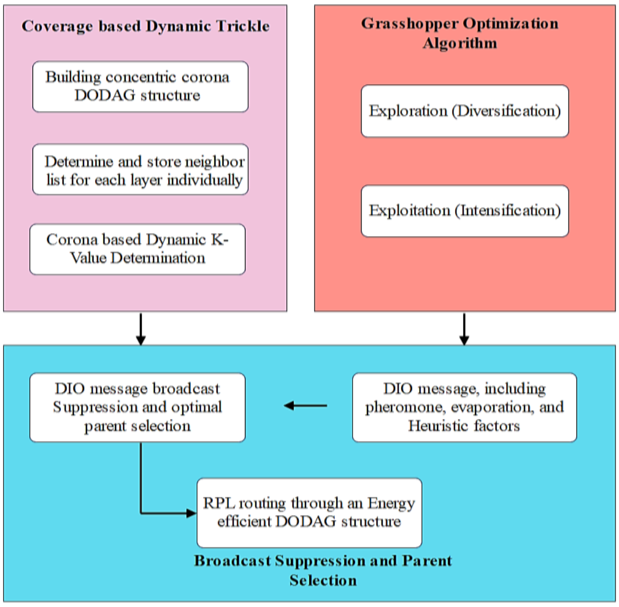

Figure 1. Block diagram for the implemented method

3. GRASSHOPPER OPTIMIZATION ALGORITHM AND COVERAGE-BASED DYNAMIC TRICKLE ALGORITHM

Here, the GOA and coverage-based dynamic trickle algorithm are explained below for energy-efficient-based RPL. GOA provides adaptability and high convergence speed to optimize energy-efficient RPL which increases the overall performance of the network and maximizes the lifespan of constrained devices. Coverage-based dynamic trickle algorithm adjusts the transmission of data rates dynamically depending on network coverage, thereby decreasing energy consumption.

3.1. Grasshopper optimization algorithm

The GOA in energy-efficient RPL optimizes the process of routing by simulating the grasshopper's behavior in optimal search paths. It utilizes a population-based technique to update routes iteratively, decreasing transmisson delays, and balancing energy consumption that results in increased energy efficient in LLN. This method identifies the optimal solution consisting of two primary phases: exploitation (intensification) and exploration (diversification) [23], [24]. Initially, assuming that there is a group of N grasshoppers, the i^{th} grasshopper's position is derived as given in (1):

$$X_i = r_1\, x\, s_i + r_2\, x\, g_i + r_3\, x\, a_i \tag{1}$$

Where r_1, r_2, r_3 refer to the random values in [0,1], s_i is denoted as social communication, g_i refers to grasshopper gravity and a_i specifies the affection of wind. Following is a calculation of social communication in (2) to (4):

$$s_i = \sum_{j=1, j\neq 1}^{N}\left(0.5\, x\, e^{\frac{-d_{ij}}{1.5}} - e^{-d_{ij}}\right) x\, \widehat{d_{\iota,J}} \tag{2}$$

$$\widehat{d_{\iota,J}} = \frac{x_j - x_i}{d_{i,j}} \tag{3}$$

$$d_{i,j} = |x_j - x_i| \quad (4)$$

Where $d_{i,j}$ refers to the distance between the i^{th} and j^{th}grasshopper. In (5) and (6) are used to compute the force of gravity and wind affection:

$$g_i = -g\ x\ \widehat{e_g} \quad (5)$$

$$a_i = u\ x\ \widehat{e_w} \quad (6)$$

$g\ and\ \widehat{e_g}$ denote the gravitational constant (9.8 m⁄s^2) and vector of the unit against the Earth's center. $u\ and\ \widehat{e_w}$ describe the drift constant and unit vector in the wind direction. Since the grasshopper swarm does not provide coverage to a predetermined position, the mathematical model in (1) cannot be employed to solve the optimization issues. To achieve the best result, the equation is modified as given in (7) to (9):

$$x_i = c\ x\ v + Bx \quad (7)$$

$$v = \sum_{j=1, j\neq 1}^{N} c\ x\ \frac{ub-lb}{2}\left(0.5\ x\ e^{\frac{-d_{ij}}{1.5}} - e^{-d_{ij}}\right) x\ \widehat{d_{i,j}} \quad (8)$$

$$c1 - \frac{it}{it_{max}} \quad (9)$$

Where $ub\ and\ lb$ are denoted as upper and lower limits vector, it and it_{max} refer to the current iterations and maximum number of iterations, and Bx specifies the best grasshopper from the previous iteration. The best Pareto front solutions are kept in external records in the multi-objective version. At each iteration of the GOA, this index is determined. In (10) is the mathematical formulation of this stopping condition.

$$B = \begin{cases} 1 & if\ |SI_{it} - SI_{it-a}| < TOL \\ 0 & Otherwise \end{cases} \quad (10)$$

Where B refers to a binary variable employed for the stopping process and TOL indicates the tolerance. After performing GOA, the coverage based dynamic trickle approach is established to construct the DODAG structure.

3.2. Coverage-based dynamic trickle algorithm

It adjusts the trickle timer dynamically depending on the quality of link and network coverage. Using a constrained DIO message broadcasting, nodes construct the structure of DODAG using the trickle method. Dynamic message broadcasting adjustment typically ends in a DODAG structure that uses less energy. The fundamental trickle method's goal is to establish suppression of simple broadcasts to minimize control costs when maintaining the performance of RPL. Using a trickle-based default RPL broadcast suppression model does not interfere with the convergence time or best DODAG creation [25], [26].

3.2.1. Determination of dynamic value by applying concentric corona mechanism

The proposed method makes an effort to establish the best broadcast K with the best DODAG construction time to address this problem. In (11) measures the area coverage of one border nodes, which are positioned above the root node DODAG. This equation indicates if the DIO message node of broadcasting at coronas 1 covers the neighbor of Node i. L is a node list that DIO broadcasts messages in the neighbors' list. The result of (11) for all the broadcasting DIO message nodes L is the common neighbor's ratio.

$$Coverage = \bigcup_{j=1}^{L} \frac{Common\ Neighbors_{ij}}{Total\ neighbors_i} \quad (11)$$

Each node at the coronas center 1 chooses whether to broadcast the message of DIO by applying in (12) to all of the broadcasting DIO node messages. The CTR in (12) is the ratio of the time taken by nodes in the communication range. It is to identify which parent node is the primary node.

$$Rebroadcast\ Probability = \begin{cases} \left({CTR}/{Coverage}\right) & If\ Coverage\ is\ above\ 0.5 \\ 1 - \left({CTR}/{Coverage}\right) & otherwise \end{cases} \quad (12)$$

When the coverage is greater than 0.5, the probability of rebroadcasting is minimal; otherwise, it is high when the CTR is low. When the coverage is less than 0.5, there is a high probability of rebroadcast. The proposed method employs the ideal K value for the suppression of broadcast. When a node's rebroadcast probability is reduced, then the nodes achieve the ideal value K. The DIO message is then transmitted into the network before it finally ceases. Additionally, the coverage ability of DIO broadcasting node messages provides a timely ideal construction of DODAG. It balances the rate of data transmission, and decreases energy consumption by minimizing unwanted communication in low-coverage areas which maximizes the overall efficiency in LLN.

4. EXPERIMENTAL SETUP AND RESULTS

To assess the effectiveness of the GOA, this paper employs the Cooja simulator of the Contiki operating system to configure IoT devices. A system running Ubuntu 14.04 LTS (32 bit) with a RAM of 2 GB, a Processor of 2.5 GHz and above, and a Contiki 2.7 is employed for analysis. Nodes have a starting energy of 1,000J. Every IoT device collects data and periodically sends it to the root node of DODAG. The 100×100 m^2 grid of 30 sensor nodes is used for the experiment. The nodes have a 50 m communication range. UDP is employed to configure the transport layer, with each node transmitting data every 60 seconds, which is 127 bytes in size.

4.1. Evaluation metrics

The expressions for packet delivery ratio (PDR), delay, communication overhead and energy consumption are expressed in (13) to (16).

$$PDR = \frac{Packet_{delivered}}{Packet_{total}} \tag{13}$$

$$Delay = Transmission\ delay * Expected\ (HC)_i + \{Max_{ETX_{j\in i}}\}_{delay} \tag{14}$$

$$Communication\ overhead - \ Nodes\ x\ \left(1 - Min_{Coverage_{i\in N}}\right) x\ Seq\ Time\ Interval \tag{15}$$

$$Energy\ Consumption = Energy_{RPL} + \left(\frac{Min\_HC}{Hop\ Count_{j\in i}}\right) - \ (Overhead\ reduction)_{Energy\ Required} \tag{16}$$

4.2. Experimental results

Contiki is a portable, open-source, and light operating system. It is specialized for WSNs and utilized significantly in networks of IoT. A 50-node network is created and the nodes are distributed in a 100×100 m^2 space using a random topology. These simulation results are obtained after 1,200 seconds within the transmission range fixed at 50 m and the range of interference fixed at 100 m. Table 1 represents the number of nodes vs number of received packets. Figure 2 shows the graphical representation of received packets per node. The number of nodes is varied from 1 to 50 and packets are varied from 0 to 8. According to the routing and forwarding rules, each network node such as switches or routers, receives and processes the packets.

Table 1. Performance analysis of number of nodes vs number of received packets

Number of nodes	Number of received packets
10	6
20	6
30	6
40	1
50	1

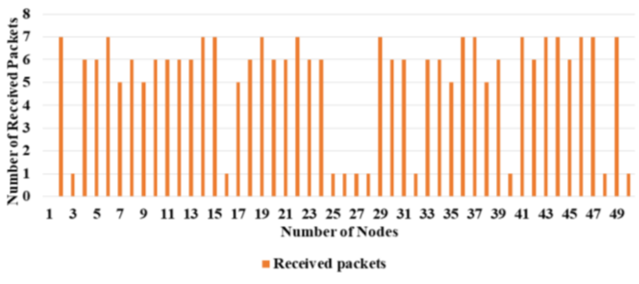

Figure 2. Graphical representation of received packets per node

Table 2 illustrates the performance analysis of number of nodes vs number of hops. The graphical representation of network hops are shown in Figure 3, in that, the network hops are varied from 0 to 3.5.

Network hops are employed to measure the latency of the network or the delay data packets when traveling across a network. Since network devices need time to process and forward the packets, each hop introduces some latency. Thus, reducing the number of hops and enhancing the routing path helps lower latency and enhances the performance of the network.

Table 2. Performance analysis of number of nodes vs number of hops

Number of nodes	Number of received packets
10	2
20	2
30	3
40	2
50	2

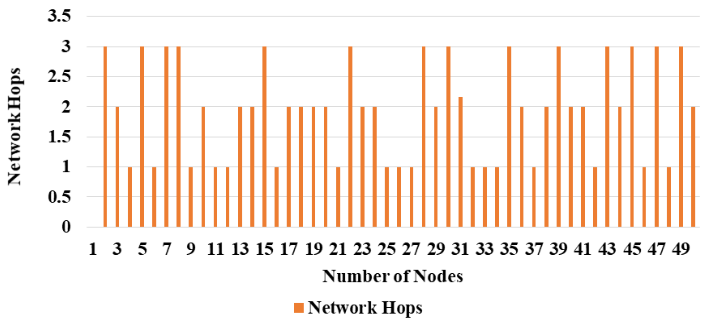

Figure 3. Graphical representation of network hops

Table 3 indicates performance analysis of number of nodes vs power (MW) for instantaneous power consumption. The graphical representation of instantaneous power consumption is shown in Figure 4. The number of nodes is varied from 1 to 50 while the power is varied from 0 to 2.5 to examine the effectiveness of the proposed method. In all simulations, the energy consumption of the OF0 objective function is the highest.

Table 3. Performance analysis of number of nodes vs power (mW) for instantaneous power consumption

Number of nodes	Power (mW)			
	CPU power	LPM power	Radio listen power	Radio transmit power
10	0.4	0.2	0.4	0.1
20	0.5	0.2	0.6	0.21
30	0.4	0.2	0.55	0.3
40	0.7	0.2	1.7	1.6
50	0.55	0.18	1.4	1.57

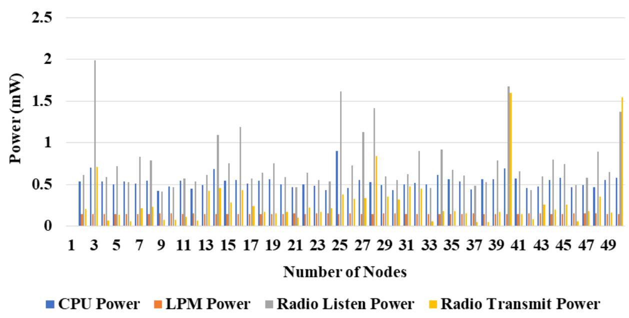

Figure 4. Graphical representation of instantaneous power consumption

Table 4 shows the performance analysis of number of nodes vs power (mW) for average power consumption. The graphical representation of average power consumption is shown in Figure 5. The nodes are varied from 1 to 50 and the power (mW) is varied from 0 to 2.5. For each node, the average consumption of power is monitored in four different ways: LPM, CPU, radio listening, and transmission of radio. This increases the network's efficiency and demonstrates the effectiveness of the objective function.

Table 4. Performance analysis of number of nodes vs power (mW) for average power consumption

Number of nodes	Power (mW)			
	CPU power	LPM power	Radio listen power	Radio transmit power
10	0.45	0.19	0.45	0.05
20	0.49	0.2	0.6	0.21
30	0.45	0.2	0.56	0.35
40	0.71	0.2	1.75	1.7
50	0.6	0.15	1.41	1.52

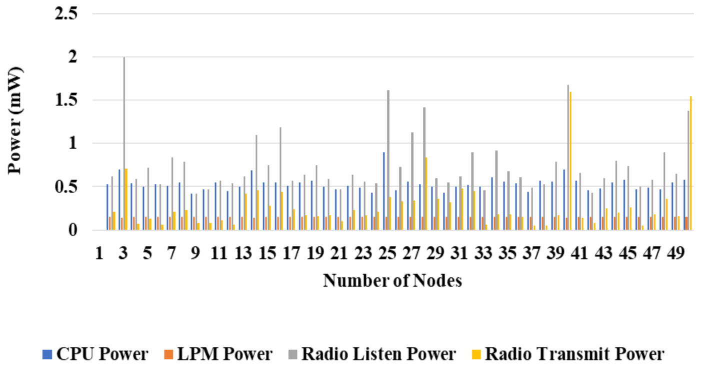

Figure 5. Graphical representation of average power consumption

Table 5 indicates the performance analysis of number of nodes vs duty cycle (%). Figure 6 shows the graphical representation of average radio duty cycle, where the nodes are varied from 1 to 50 and duty cycles are varied from 0 to 3.5. Depending on the applications, the average radio cycle ranges from very low values such as a few percentage points to nearly constant transmission or receival.

Table 5. Performance analysis of number of nodes vs duty cycle (%)

Number of nodes	Duty cycle (%)	
	Radio listen duty cycle	Radio transmit duty cycle
10	0.8	0.2
20	0.9	0.3
30	0.85	0.6
40	2.8	3
50	2.3	2.9

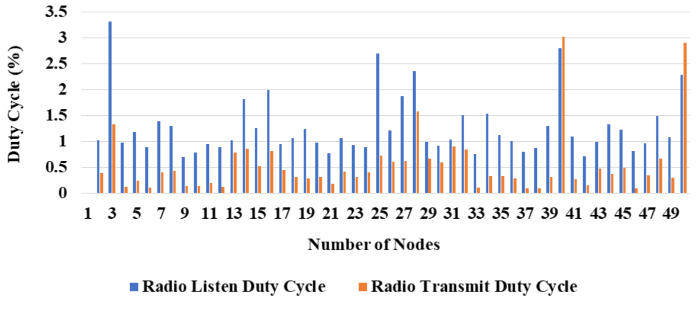

Figure 6. Graphical representation of average radio duty cycle

4.3. Comparative analysis

The comparative analysis includes methods of PDR, delay (mins), communication overhead (packets), and energy consumption (mJ). Table 6 demonstrates the comparative analysis with the existing methods E-RPL [16], REFER [17], ELITE [18]. The existing method E-RPL [16] has a PDR of 90%, 0.4 delays (mins), 150 communication overhead (packets), and 0.532 energy consumption (mJ). REFER [17] has 45% of PDR, 0.5 delay (mins), 145 communication overhead (packets), and 1.25 energy consumption (mJ). ELITE [18] has 95% of PDR, 0.8 delay (mins), 127 communication overhead (packets), and 0.20 energy consumption (mJ). The existing methods when compared with GOA-DODAG, achieves better PDR of 98%, 0.2 delay (mins), 37 communication overhead (packets), and 0.48 energy consumption (mJ).

Table 6. Comparative analysis with existing methods

Authors	Methods	PDR (%)	Delay (mins)	Communication overhead (packets)	Energy consumption (mJ)
Preeth *et al.* [17]	E-RPL	90	0.4	150	0.532
Lalani *et al.* [18]	REFER	45	0.5	145	1.25
Safaei *et al.* [19]	ELITE	95	0.8	127	0.20
Proposed method	GOA-DODAG	98	0.2	37	0.48

4.4. Discussion

The advantage of the GOA-DODAG approach and the limitations of existing techniques are discribed in this section. The limitation of existing techniques like E-RPL [17] has ETX which causes a lengthy routing path and significant message latency when routing messages. REFER [18] increases overhead in terms of computational demands and control messages to achieve dependability and energy efficiency. ELITE's [19] broadcast suppression is insufficient when addressing network coverage and optimization problems based on uneven node distribution. On the contrary, the GOA-DODAG overcomes these existing technique's limitations. GOA provides adaptability and high convergence speed to optimize energy-efficient RPL which increases the overall performance of the network and maximizes the lifespan of constrained devices. Coverage-based dynamic trickle algorithm adjusts the transmission of data rates dynamically depending on network coverage which decreases energy consumption in DODAG. By combining GOA and DODAG, the proposed approach achieves better 98% PDR, delay of 0.2 mins, communication overhead of 37 packets, and 0.48 mJ energy consumption. The limitation of GOA-DODAG is the transmission of many packets resulting in the most undesirable performance, as it requires more control messages for operation.

5. CONCLUSION

In this paper, the GOA-DODAG is proposed to determine optimization problems and energy-efficient reliable routing paths. This approach includes a coverage-based dynamic trickling technique for the construction of DODAG energy-efficient without affecting the coverage of network and data routing reliability. To create the structure of the ideal DODAG, the RPL considers a variety of routing parameters and chooses an effective parent node. Furthermore, the dynamic value as compared to a default trickle algorithm effectively reduces the broadcasting of DIO messages. The GOA-DODAG method achieves 98% PDR, delay of 0.2 mins, communication overhead of 37 packets, and 0.48 mJ energy consumption in contrast to the existing techniques like E-RPL, REFER, and ELITE. In future, energy-efficient routing protocols will be assessed across a range of network sizes to demonstrate the scalability of routing.

REFERENCES

[1] N. N. Hadaya and S. A. Alabady, "Improved RPL protocol for low-power and lossy network for IoT environment," *SN Computer Science*, vol. 2, no. 5, 2021, doi: 10.1007/s42979-021-00742-1.

[2] A. E. Hassani, A. Sahel, A. Badri, and E. M. Ilham, "A hybrid objective function with empirical stability aware to improve RPL for IoT applications," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 3, pp. 2350–2359, 2021, doi: 10.11591/ijece.v11i3.pp2350-2359.

[3] S. Garg, D. Mehrotra, H. M. Pandey, and S. Pandey, "Static to dynamic transition of RPL protocol from IoT to IoV in static and mobile environments," *Cluster Computing*, vol. 26, no. 1, pp. 847–862, 2023, doi: 10.1007/s10586-022-03689-x.

[4] S. A. Fatemifar and R. Javidan, "A new load balancing clustering method for the RPL protocol," *Telecommunication Systems*, vol. 77, no. 2, pp. 297–315, 2021, doi: 10.1007/s11235-021-00760-7.

[5] Z. Royaee, H. Mirvaziri, and A. K. Bardsiri, "Designing a context-aware model for RPL load balancing of low power and lossy networks in the internet of things," *Journal of Ambient Intelligence and Humanized Computing*, vol. 12, no. 2, pp. 2449–2468, 2021, doi: 10.1007/s12652-020-02382-4.

[6] T. L. Jenschke, R. A. Koutsiamanis, G. Z. Papadopoulos, and N. Montavont, "ODeSe: on-demand selection for multi-path RPL networks," *Ad Hoc Networks*, vol. 114, 2021, doi: 10.1016/j.adhoc.2021.102431.

[7] O. A. Khashan, R. Ahmad, and N. M. Khafajah, "An automated lightweight encryption scheme for secure and energy-efficient communication in wireless sensor networks," *Ad Hoc Networks*, vol. 115, 2021, doi: 10.1016/j.adhoc.2021.102448.

[8] P. Deepavathi and C. Mala, "IMDRPL: identifying and eliminating malicious devices using DIO and DAO ICMP control messages in RPL-based protocol," *Peer-to-Peer Networking and Applications*, vol. 16, no. 5, pp. 2380–2398, 2023, doi: 10.1007/s12083-023-01539-0.

[9] S. Sahraoui and N. Henni, "SAMP-RPL: secure and adaptive multipath RPL for enhanced security and reliability in heterogeneous IoT-connected low power and lossy networks," *Journal of Ambient Intelligence and Humanized Computing*, vol. 14, no. 1, pp. 409–429, 2023, doi: 10.1007/s12652-021-03303-9.

[10] M. Mahyoub, A. S. H. Mahmoud, M. Abu-Amara, and T. R. Sheltami, "An efficient RP-based mechanism for node-to-node communications in IoT," *IEEE Internet of Things Journal*, vol. 8, no. 9, pp. 7152–7169, 2021, doi: 10.1109/JIOT.2020.3038696.

[11] K. Prathapchandran and T. Janani, "A trust aware security mechanism to detect sinkhole attack in RPL-based IoT environment using random forest–RFTRUST," *Computer Networks*, vol. 198, 2021, doi: 10.1016/j.comnet.2021.108413.

[12] S. A. Fatemifar and R. Javidan, "A new load balancing clustering method for the RPL protocol," *Telecommunication Systems*, vol. 77, no. 2, pp. 297–315, 2021, doi: 10.1007/s11235-021-00760-7.

[13] A. E. Hassani, A. Sahel, and A. Badri, "IRH-OF: a new objective function for RPL routing protocol in IoT applications," *Wireless Personal Communications*, vol. 119, no. 1, pp. 673–689, 2021, doi: 10.1007/s11277-021-08230-8.

[14] F. Kaviani and M. Soltanaghaei, "CQARPL: congestion and QoS-aware RPL for IoT applications under heavy traffic," *Journal of Supercomputing*, vol. 78, no. 14, pp. 16136–16166, 2022, doi: 10.1007/s11227-022-04488-2.

[15] Z. Yang, H. Liu, Y. Chen, X. Zhu, Y. Ning, and W. Zhu, "UEE-RPL: a UAV-based energy efficient routing for Internet of Things," *IEEE Transactions on Green Communications and Networking*, vol. 5, no. 3, pp. 1333–1344, 2021, doi: 10.1109/TGCN.2021.3085897.

[16] A. Gasouma, K. M. Yusof, A. Mubarakali, and O. E. Tayfour, "Software defined network for energy efficiency in IoT and RPL networks," *Soft Computing*, pp. 1–10, 2023, doi: 10.1007/s00500-023-08608-9.

[17] S. K. S. L. Preeth, R. Dhanalakshmi, R. Kumar, and S. Si, "Efficient parent selection for RPL using ACO and coverage based dynamic trickle techniques," *Journal of Ambient Intelligence and Humanized Computing*, vol. 11, no. 11, pp. 4377–4391, 2020, doi: 10.1007/s12652-019-01181-w.

[18] S. R. Lalani, A. A. M. Salehi, H. Taghizadeh, B. Safaei, A. M. H. Monazzah, and A. Ejlali, "REFER: a reliable and energy-efficient RPL for mobile IoT applications," in *Proceedings of RTEST 2020 - 3rd CSI/CPSSI International Symposium on Real-Time and Embedded Systems and Technologies*, 2020, pp. 1–8, doi: 10.1109/RTEST49666.2020.9140135.

[19] B. Safaei, A. M. H. Monazzah, and A. Ejlali, "ELITE: an elaborated cross-layer RPL objective function to achieve energy efficiency in internet-of-things devices," *IEEE Internet of Things Journal*, vol. 8, no. 2, pp. 1169–1182, 2021, doi: 10.1109/JIOT.2020.3011968.

[20] S. S. Solapure and H. H. Kenchannavar, "Design and analysis of RPL objective functions using variant routing metrics for IoT applications," *Wireless Networks*, vol. 26, no. 6, pp. 4637–4656, 2020, doi: 10.1007/s11276-020-02348-6.

[21] P. D. Acevedo, D. Jabba, P. Sanmartin, S. Valle, and E. D. Nino-Ruiz, "WRF-RPL: weighted random forward RPL for high traffic and energy demanding scenarios," *IEEE Access*, vol. 9, 2021, doi: 10.1109/ACCESS.2021.3074436.

[22] M. H. Homaei, S. S. Band, A. Pescape, and A. Mosavi, "DDSLA-RPL: dynamic decision system based on learning automata in the RPL protocol forachieving QoS," *IEEE Access*, vol. 9, 2021, doi: 10.1109/ACCESS.2021.3075378.

[23] B. Ahmadi, O. Ceylan, and A. Ozdemir, "Distributed energy resource allocation using multi-objective grasshopper optimization algorithm," *Electric Power Systems Research*, vol. 201, 2021, doi: 10.1016/j.epsr.2021.107564.

[24] A. Sherif and H. Haci, "A novel bio-inspired energy optimization for two-tier wireless communication networks: a grasshopper optimization algorithm (GOA)-based approach," *Electronics (Switzerland)*, vol. 12, no. 5, 2023, doi: 10.3390/electronics12051216.

[25] I. S. Alsukayti, "Dynamic-RPL: enhancing RP-based IoT networks with effective support of dynamic topology management," *Electronics (Switzerland)*, vol. 12, no. 18, 2023, doi: 10.3390/electronics12183834.

[26] P. S. Nandhini, S. Kuppuswami, S. Malliga, and R. DeviPriya, "Enhanced rank attack detection algorithm (E-RAD) for securing RPL-based IoT networks by early detection and isolation of rank attackers," *Journal of Supercomputing*, vol. 79, no. 6, pp. 6825-6848, 2023, doi: 10.1007/s11227-022-04921-6.

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