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Load-Balancing in Multi-Sink IoT Networks

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Abstract

Embedded items (things) are items that are connected to the Internet and have access to global services and people. Wireless Sensor Networks (WSNs) are increasingly becoming the Internet of Things' core network. Moreover, WSNs must support numerous applications concurrently and process vast volumes of data as IoT becomes more integrated into daily life. Thus, using the WSN multi-sink is crucial. Wireless Sensor Networks with multiple sinks are prone to congestion in sink nodes, lowering the efficiency of data collection and processing. The majority of Internet of Things (IoT) applications use the RPL routing protocol, which is offered by Internet Engineering Task Force (IETF). RPL considers IoT deployment requirements across many applications to be highly interoperable and versatile. Nonetheless, several issues still need to be resolved, particularly in large-scale networks. Congestion is one of the problems with RPL, which leads to packet losses at the sink, as a result of the memory overflow incident. This paper introduces Multi sink Load-Balancing Algorithm (MSLBA) that proposed to resolve the congestion issue across several sinks. The suggested approach effectively balances load across sinks by dynamically updating RPL in accordance with DAG Size (DS), Hope Count (HC), and Node Rank (NR). As a result, RPL is able to appropriately spread the load among the sinks. In terms of Packet Delivery Ratio (PDR), MSLBA greatly outperformed the standard RPL algorithm. Throughput, and Delay. The PDR was improved by 9%, while the throughput and latency were improved by 8.5% and 68%, respectively.

Keywords- Internet of Things (IoT), Wireless Sensor Network (WSN), Multi-Sink WSN, Load-Balancing.

I. INTRODUCTION

The phrase "Internet of Things," which is also sometimes shortened as "IoT," is a combination of the words "Internet" and "Things." Globally, billions of users connect to the Internet through TCP/IP, a standard suite of protocols used by the Internet [1]. Delivering plug-and-play technology that gives the end user flexibility, remote access control, and simplicity of use is the end objective of the IoT. Significant developments in Wireless Sensor Networks have made it possible for pervasive intelligence, which anticipates the development of the IoT [2]. Defining the IoT as a network of sensors, actuators, and computing devices is useful. These systems have the ability to manage or observe the health and behavior of connected devices and objects. Furthermore, networked sensors can monitor people, pets, and the environment [3]. (WSNs) are made up of sensor nodes (motes), each of which has sensors, memory for storing the data collected, a radio, and a processor for data transmission and reception. The sensor node's main duties include gathering, processing, and communicating data from the environment in which the motes operate. It then sends the information to a base station (sink), where it can be stored for later study or used to initiate another process. Each of these tasks is condensed onto a single microchip in a WSN [4]. However, given resource limitations, interference-coupled links, and the requirement for central coordination, congestion in WSNs is more difficult [5]. In a flexible and dynamic manner, load-balancing is a mechanism that distributes network traffic or loads to sinks with less pressing operating requirements. In order to prevent early battery depletion and unexpected network shutdown, no sink and in-between nodes are overflowed with messages [6]. The network's workload will be optimally spread among sinks when load-balancing is taken into consideration and executed. As a result, the lifetime of the Sink and intermediate nodes will be increased. By dividing network responsibilities among accessible sinks, optimal load-balancing will relieve strain on a single sink [7]. RPL (IPv6 Routing Protocol for LLNs) is a standard adopted by the IETF for efficient routing in LLNs. IoT deployments require effective IPv6 connectivity and it is flexible enough to support a variety of application requirements. But there are still a lot of issues with it, particularly with large-scale deployments. Node unreachability, which is brought on by congestion concerns, is one of the unresolved problems. Message losses in sinks will increase when a node is unavailable [8]. Using distance vector routing on embedded networking devices, RPL [9] provides bi-directional IPv6 communication. Peer-to-peer (P2P), multipoint-to-point (MP2P), and point-to-multipoint (P2MP) transmission are the three types of data transfer that are supported. As RPL's topology is composed of Destination Oriented DAGs (DODAGs) that are rooted at sink nodes, it also uses Directed Acyclic Graphs (DAGs). The DODAGs may be connected to a single RPL instance or several. DODAG routes are built using Objective Functions (OFs), which describe how nodes convert metrics and constraints into rank values. Standard RPL supports only Minimal Rank with

Hysteresis Objective Function (MRHOF) and Objective Function Zero (OF0). In the case where the existing OFs in standard RPL does not meet the application's needs, a new OF can be built. In addition, RPL has the capability to operate in two different modes, storing and non-storing, which allow nodes to either store or not store routing information in their tables[9].
The paper proposes a solution to the problem of congestion in a Wireless Sensor Network with multiple sinks. It suggests using a load-balancing mechanism that divides the traffic among the sinks to ensure that every packet sent by the sensor nodes can reach its destination. The approach relies on a dynamic update of RPL that adapts to the current state of the network and balances the load efficiently across the sinks.
The rest of the paper is structured as follows: Section 2 covers the related work on proposed solutions for the issue at hand. Section 3 outlines the RPL load-balancing problem, while Section 4 provides a detailed explanation of the proposed solution. The performance of the solution is evaluated in section 5. The paper concludes with Section 6, which presents the conclusion and recommendations for future work.

II. RELATED WORK

Many researchers work to enhance RPL fundamental functionalities, by introducing several OF and routing metrics. The node unreachability issue when nodes run out of battery and vanish from the network was addressed by the Multi-Sink Load Balancing Objective Function (MSLBOF) for RPL presented in [8]. By increasing the packet delivery ratio, decreasing packet loss, and managing messages using multiple sink nodes, MSLBOF improved MRHOF. The work in [6] introduces of a Multi Sink Load Balancing Mechanism (MSLBM) for WSN. This method assigns network traffic or loads to sinks with less urgent operational needs in an adaptable and dynamic manner. It focused to prevent sink overloading, which could cause early battery depletion and unintentional early network termination. The work in [10]suggests QU-RPL, a load-balancing technique that prevents queue overflows by adapting the parent selection process to new metrics: queue utilization and hop distance to the sink. The authors have demonstrated the viability of their suggested protocol over RPL by testing it in a genuine testbed. Moreover, the RPL protocol is extended in [11] to lengthen network lifetime and reduce packet loss. The parent selection process in this approach considers not only the Expected Transmission Count (ETX) metric but also the remaining queue and energy level of possible parent nodes. Another related study [12] proposed Quell, which uses a different goal function to select parent nodes by taking into account both the queue length and ETX metrics.
An energy-balanced RPL was also proposed in [12], which supports a multipath structure and evenly distributes the energy usage among all the bottleneck nodes. Improvements to RPL dependability, energy usage, and load distribution were introduced in [13]-[14]. The authors in [13] combined child node count, ETX, and hop count as major metrics in the parent selection algorithm. ETXPC-RPL, which was based on ETX and parent account metrics, was presented in [14].

III. PROBLEM STATEMENT

In event-driven applications, network traffic is often low and only occurs in response to a recognized event. Congestion occurs when a lot of sensor nodes start sending data at a high throughput all at once, or when one node distributes a lot of streams over the network [5]; moreover, fewer sinks raise the possibility of network congestion and the duration of data packet delays [15].
Due to memory constraints in the space between sensor nodes, IoT congestion might cause buffer overflow issues [16]. The performance of networks and applications is negatively impacted by congestion in WSN, which causes significant fidelity degradation, random packet loss, increased packet latency, and lost node energy [17]. However, due to resource limitations, interference-coupled links, and the requirement for central coordination, congestion in WSNs is more difficult to deal with [18]. WSN congestion control must take application needs for information integrity into account in addition to network capacity. In a flexible and dynamic manner, load-balancing is a system that distributes network traffic or loads to sinks with less pressing operating requirements. In order to avoid early battery exhaustion and sudden network shutdown, nodes between the sink and the in-between nodes are overrun with messages [6]. The network's workload will be optimally spread among sinks when load-balancing is taken into consideration and executed. As a result, the lifetime of the sink and intermediate nodes will be increased [7]. By dividing network responsibilities among accessible sinks, optimal load-balancing will relieve strain on a single sink. Therefore, to overcome this problem, a dynamic update on the RPL in accordance with using new routing metrics and using a DODAG selection technique that is effective for large-scale scenarios.

IV. PROPOSED MULTI-SINK LOAD-BALANCING ALGORITHM (MSLBA)

The proposed solution to the congestion issue in networks with multiple sinks is the Multi-Sink Load Balancing Algorithm (MSLBA). In order to enable RPL in distributing the load more evenly among the sinks and preventing unreachability difficulties, MSLBA aims to enhance the basic RPL objective function (MRHOF) with other factors in addition to node rank. The node rank often represents the node's position with regard to other nodes with respect to a DODAG root. Stringent regulations dictate that rank rises in a downward manner and declines in an upward direction. The exact formula utilized to calculate Rank is determined by the DAG's Objective Function (OF). The Rank is capable of calculating in terms of link metrics, tracking simple topological distances analogously, and accounting for extra factors like constraints [19]. The DODAG size, which is the number of connected nodes to the sink (root), and Hop Count, which is the number of forwarding times for each data packet, are the additional factors that the MSLBA adds along with ETX (Expected Transmission Count) in an effort to increase the robustness of RPL. The first statistic helps to balance the load on the sink by taking into consideration The number of nodes assigned to each sink., while the final metric helps to prevent the node from choosing a parent sink that is too far away, which results in resource loss.

- Load-Balancing Information Propagation: Nodes in DODAG get LB information from sinks in MSLBA via DIO messages. Several methods for accomplishing information propagation are provided by standard RPL. You can modify the OF to use the new options for processing DIO messages, or you can use a Metric Container within the message to process DIO messages. Due to its compatibility with standard RPL and its use of already-existing control message types (i.e., DIO messages), the second method is great for building MSLBA. The proposed solution involves adding a new ICMP option called Sink Load-Balancing Option (SLBO) to every DIO control message. When a sink generates a DIO message, the hop count counter is examined and the number of nodes connected to its DODAG has adjusted accordingly (as shown in Figure 1) to incorporate them into the SLBO option. Each DIO message must update and maintain this information so that all nodes can have the most up-to-date data. This eliminates the need for a separate control message for the entire network, which would cause additional overhead. Instead, the 4-byte overhead of the transmitted DIO message is utilized to convey the SLBO option.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Type= 0x10   | Opt Length=2  |   DAG Size    |   Hop Count   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure (1) Sink Load-Balancing Option

- Sink Selection Mechanism: The proposed solution involves adding new metrics to the sink selection process that considers stability and reliability factors, in addition to the best rank parameter. When a node receives a DIO message from a parent in another DAG, the Multi-Sink Load Balancing Algorithm (MSLBA) is activated. To select the best sink, two new metrics are introduced: Dag Size (DS) and Hop Count (HC), which are incorporated into the Rank calculation. The main equations for MSLBA are shown in Equations (1 and 2):

$$P(n,s) = \alpha_a \, rank(n) + \alpha_b \, DS(s) + \alpha_c \, HC \quad (1)$$

Weighting factors in the form of coefficients are introduced to suit the application's needs. Node n selects the optimal sink by combining the rank, DS, and HC through a weighted sum operation.

$$\min \{P(n,s_1), P(n,s_2)\} \quad (2)$$

In contrast to the rank-based selection, the MSLBS technique enables each node to select the sink node with the fewest hop counts and the fewest nodes in its DODAG. The sink-selection procedure is demonstrated by Algorithm (1); when DIO messages come in from several DODAGs, each node executes a distinct instance of the algorithm.

Algorithm1: Sink-Selection Algorithm

Function best sink (s_1, s_2)
Input: (s_1, s_2)
Output: Preferred Sink (PS)
  if s_1 = PS Then
    if $P(n,s_1) \leq P(n,s_2) + \beta$
      return s_1
    else
      return s_2
    end if
  else if s_2 = PS Then
    if $P(n,s_1) \leq P(n,s_2) + \beta$
      return s_2
    else
      return s_1
    end if

end Function

V. Simulation Results and Analysis

To validate and evaluate the proposed algorithm, Cooja simulation was used to run experimental simulations. It is a tool for simulation and emulation that is a part of the Contiki OS, where it enables researchers to make all the required simulation experiments with RPL protocol. All of the experimental configurations used Contiki 3.0. We contrast MSLBA's performance versus MRHOF in Contiki RPL in order to examine it. For experimental purposes, the configuration parameters listed in Tab.1 were taken into consideration.

Table (1) General configurations

Parameters	Configurations
Simulation Area	70x70 m^2
Simulation Duration	2100 sec.
Number of Sinks	2
Number of nodes	20,40
Mote Type	Z1
Node Placement	Randomly
Radio Model	Unit Disk Graph Medium (UDGM)

We take into account a consistent 2D grid within a 70m x 70m area for our physical topology. The topology of the network has two sinks positioned in the top left and top right corners, together with 20 Z1 motes nodes for the first scenario and 40 motes for the second scenario as depicted in figures (2) and (3). A 16 MHz MSP430F2617 microprocessor, 8 Kbytes of RAM, and 92 Kbytes of ROM are all included in the Z1 Zolertia platform.

The sending and receiving node lists are present on each sink. A 127-byte IPv6 data packet is continuously produced by nodes on the sending list. To satisfy P2P communication, the packets are forwarded to the nodes on the receiving list. The simulations were performed in two scenarios to better understand the influence of various sinks and for improved accuracy and comparison with the existing RPL objective function, MRHOF. In Scenario one; 20 sensor nodes and 2 sinks, and in scenario two; 40 sensor nodes and 2 sinks, the simulation results are averaged over 5 simulations and each experiment lasts 2100 seconds.

The evaluation metrics listed below are used to assess the simulation test results:

- The Packet Delivery Ratio (PDR): expressed as a percentage, is the proportion of total data packets received by destination nodes to total data packets transmitted by source nodes.
- Throughput: the amount of data that is actually transmitted from source to destination during a period of time, measured in (bps).
- Delay: which represents the network's typical delay.

The MSLBA and MRHOF in typical RPL according to each evaluation metric are compared as described in table 2.

Table (2) Optimization ratio for each scenario

Evaluation Metric	MSLBA optimization ratio over MRHOF for the 1st scenario	MSLBA optimization ratio over MRHOF for the 2nd scenario
PDR	5%	9%
Throughput	6.4%	8.5%
Delay	75%	68%

Figure (4) demonstrates that the first algorithm enhanced the PDR ratio by around 5% higher than the second. Figure (5) demonstrates a considerable gain in throughput, with MSLBA offering 6.4% more than MRHOF. Figure (6) shows that Delay has significantly improved, with MSLBP offering 75% more than MRHOF. On the other hand, Figures (8,9, and 10) show an improvement in PDR, Throughput, and Delay by 9%, 8.5%, and 68 % respectively.

VI. Conclusion

In Multi-Sink WSNs, especially in large-scale networks, congestion is a typical problem. The most effective way to reduce congestion and improve the performance of the multi-Sink network is to apply load-balancing principles. Using the suggested algorithm, MSLBA, significantly improved network performance in terms of PDR, Throughput, and Delay. The simulation was run in two scenarios, each of which produced a new set of outcomes, and each scenario's results improved as the number of nodes increased. When MSLBA's performance was contrasted with that of the MRHOF standard objective function, it was discovered that there had been a significant advancement. Future work will primarily focus on broadening this study's scope focused on broadening the scope of this study by applying other parent selection processes, adopting a new set of criteria, and increasing the network size.

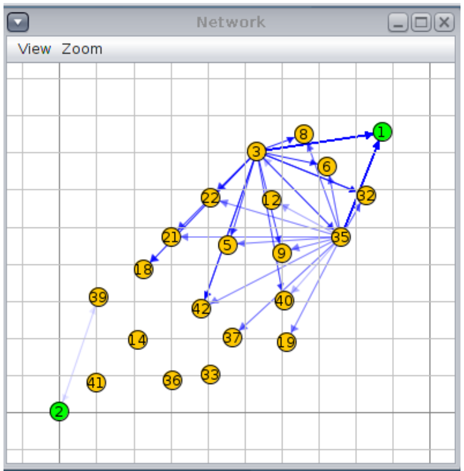

Figure 2: Network topology for 20 nodes in Cooja simulator

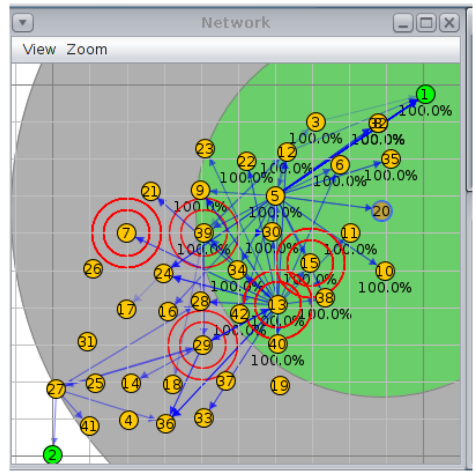

Figure 3: Network topology for 20 nodes in Cooja simulator

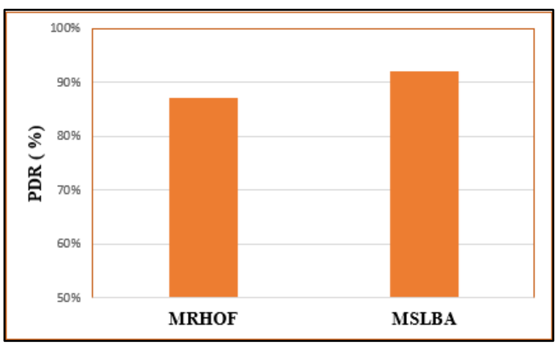

Figure 4: Packet Delivery Ratio / 20 nodes and 2 sinks

Figure 5: Throughput / 20 nodes and 2 sinks

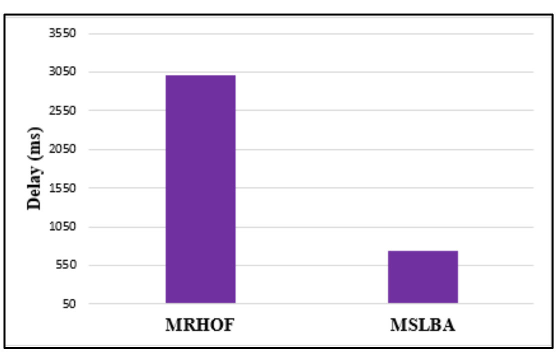

Figure 6: Delay / 20 nodes and 2 sinks

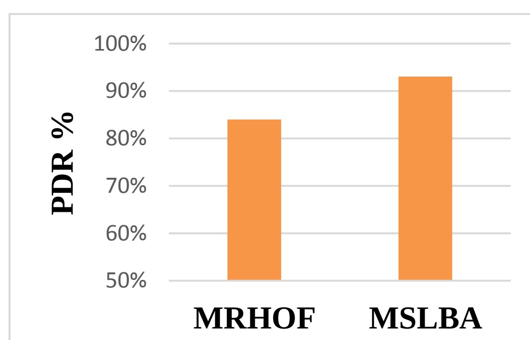

Figure 7: Packet Delivery Ratio / 40 nodes and 2 sinks

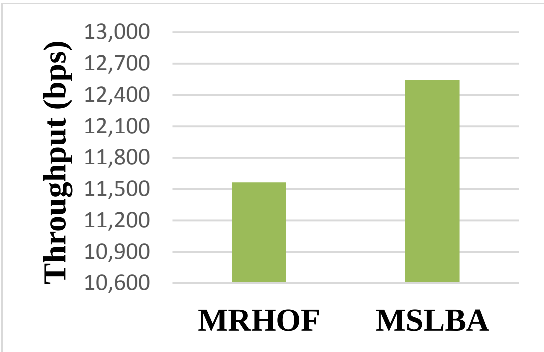

Figure 8: Throughput / 40 nodes and 2 sinks

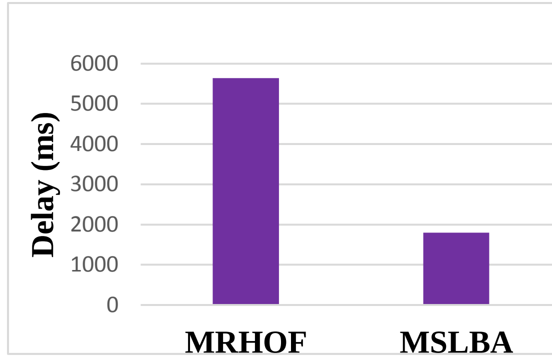

Figure 9: Delay / 40 nodes and 2 sinks

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REFERENCES

[1] S. Madakam, V. Lake, V. Lake, and V. Lake, "Internet of Things (IoT): A literature review," *Journal of Computer and Communications*, vol. 3, no. 05, p. 164, 2015.
[2] K. Govinda and R. A. K. Saravanaguru, "Review on IOT technologies," *International Journal of Applied Engineering Research*, vol. 11, no. 4, pp. 2848–2853, 2016.
[3] K. Shafique, B. A. Khawaja, F. Sabir, S. Qazi, and M. Mustaqim, "Internet of things (IoT) for next-generation smart systems: A review of current challenges, future trends and prospects for emerging 5G-IoT Scenarios," *IEEE Access*, vol. 8. Institute of Electrical and Electronics Engineers Inc., pp. 23022–23040, 2020. doi: 10.1109/ACCESS.2020.2970118.
[4] F. Medjek, D. Tandjaoui, N. Djedjig, and I. Romdhani, "Multicast DIS attack mitigation in RPL-based IoT-LLNs," *Journal of Information Security and Applications*, vol. 61, p. 102939, 2021.
[5] H. A. A. Al-Kashoash, H. Kharrufa, Y. Al-Nidawi, and A. H. Kemp, "Congestion control in wireless sensor and 6LoWPAN networks: toward the Internet of Things," *Wireless Networks*, vol. 25, no. 8, pp. 4493–4522, Nov. 2019, doi: 10.1007/s11276-018-1743-y.
[6] I. U. Onwuegbuzie, S. A. Razak, and A. Al-Dhaqm, "Multi-Sink Load-Balancing Mechanism for Wireless Sensor Networks," in *2021 IEEE International Conference on Computing, ICOCO 2021*, 2021, pp. 140–145. doi: 10.1109/ICOCO53166.2021.9673578.
[7] I. U. Onwuegbuzie, S. A. Razak, and I. F. Isnin, "Control messages overhead impact on destination oriented directed acyclic graph—a wireless sensor networks objective functions performance comparison," *J Comput Theor Nanosci*, vol. 17, no. 2–3, pp. 1227–1235, 2020.
[8] M. Abdullah, I. Alsukayti, and M. Alreshoodi, "On the Need for Efficient Load Balancing in Large-scale RPL Networks with Multi-Sink Topologies," *IJCSNS International Journal of Computer Science and Network Security*, vol. 21, no. 3, p. 212, 2021, doi: 10.22937/IJCSNS.2021.21.3.29.
[9] N. N. Hadaya and S. A. Alabady, "DESIGN AND EVALUATION OF MULTI-SINK RPL ROUTING PROTOCOL FOR LOW POWER ENVIRONMENTS," *Journal of Modern Technology and Engineering*, vol. 7, no. 3, pp. 172–186, 2022.
[10] H. S. Kim, H. Kim, J. Paek, and S. Bahk, "Load Balancing under Heavy Traffic in RPL Routing Protocol for Low Power and Lossy Networks," in *IEEE Transactions on Mobile Computing*, Apr. 2017, vol. 16, no. 4, pp. 964–979. doi: 10.1109/TMC.2016.2585107.
[11] S. Taghizadeh, H. Bobarshad, and H. Elbiaze, "CLRPL: Context-Aware and Load Balancing RPL for Iot Networks under Heavy and Highly Dynamic Load," *IEEE Access*, vol. 6, pp. 23277–23291, Apr. 2018, doi: 10.1109/ACCESS.2018.2817128.
[12] O. Iova, F. Theoleyre, and T. Noel, "Exploiting multiple parents in RPL to improve both the network lifetime and its stability," in *2015 IEEE International Conference on Communications (ICC)*, 2015, pp. 610–616.
[13] B. Ghaleb, A. Al-Dubai, E. Ekonomou, W. Gharib, L. Mackenzi, and M. B. Khala, "A new load-balancing aware objective function for RPL's IoT networks," in *2018 IEEE 20th International Conference on High Performance Computing and Communications; IEEE 16th International Conference on Smart City; IEEE 4th International Conference on Data Science and Systems (HPCC/SmartCity/DSS)*, 2018, pp. 909–914.
[14] H. S. Altwassi, Z. Pervez, K. Dahal, and B. Ghaleb, "The RPL load balancing in IoT network with burst traffic scenarios," in *2018 12th International Conference on Software, Knowledge, Information Management & Applications (SKIMA)*, 2018, pp. 1–7.

[15] W. Wei, Z. Sun, H. Song, H. Wang, X. Fan, and X. Chen, “Energy balance-based steerable arguments coverage method in WSNs,” *IEEE Access*, vol. 6, pp. 33766–33773, 2017.
[16] F. H. El-Fouly, R. A. Ramadan, M. I. Mahmoud, and M. I. Dessouky, “REBTAM: reliable energy balance traffic aware data reporting algorithm for object tracking in multi-sink wireless sensor networks,” *Wireless Networks*, vol. 24, no. 3, pp. 735–753, Apr. 2018, doi: 10.1007/s11276-016-1365-1.
[17] M. Masdari, “Energy Efficient Clustering and Congestion Control in WSNs with Mobile Sinks,” *Wirel Pers Commun*, vol. 111, no. 1, pp. 611–642, Mar. 2020, doi: 10.1007/s11277-019-06876-z.
[18] W. W. Fang, J. M. Chen, L. Shu, T. S. Chu, and D. P. Qian, “Congestion avoidance, detection and alleviation in wireless sensor networks,” *Journal of Zhejiang University: Science C*, vol. 11, no. 1, pp. 63–73, Jan. 2010, doi: 10.1631/jzus.C0910204.
[19] T. Winter *et al.*, “RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks, March 2012,” *IETF, RFC6550*.