Taking into Account Children Accurate Weights during Parent Selection Process in RPL to Extend WSN Lifetime

Doda Afoussatou Rollande Sanou
Lab. of Algebra, Discrete Math. and Computer Science
University Nazi BONI
Bobo-Dioulasso, Burkina Faso
E-mail: sanourollande@gmail.com

Tiguiane Yélémou
Lab. of Algebra, Discrete Math. and Computer Science
University Nazi BONI
Bobo-Dioulasso, Burkina Faso
E-mail: tyelemou@gmail.com

Hamadoun Tall
Lab. of Algebra, Discrete Math. and Computer Science
University Nazi BONI
Bobo-Dioulasso, Burkina Faso
E-mail: hamadoun.tall@gmail.com

Mahamadi Boulou
Lab. of Algebra, Discrete Math. and Computer Science
University Nazi BONI
Bobo-Dioulasso, Burkina Faso
E-mail: mamadiboulou@gmail.com

***Abstract*—Wireless sensor networks (WSNs) are composed of several sensors nodes with limited resources. Nodes can collect data in their deployed area and forward them to the sink using multi-hop communication. WSNs have limited energy and are generally deployed in harsh areas. So, it is not easy for humans to access and replace batteries. Thus, the lifetime of the network must be extended to allow data collection for a long time. To optimize energy consumption in low-power and lossy networks, the Routing Protocol for Low-Power and Lossy Networks (RPL) has been proposed. However, the energy consumption in RPL protocol is not fairly distributed. Some nodes are more solicited to forward data toward the sink node. As a result, the most solicited nodes deplete more quickly their energy, that lead to the network partitioning, data packets lost and more re-transmissions.**

In the literature, most of the proposed optimization techniques are not able to balance both routing load and power consumption. To address this challenge, in this paper, we present a routing technique based on children weights to fairly distribute children nodes among candidate parent nodes. Doing so helps all forwarding nodes in the network to have nearly the same traffic load. That permits to balance routing load and power consumption in the network. Analytical results show that our proposal is better compared to other improved RPL protocols using the Expected Transmission Count (ETX) and number of children metrics.

***Keywords*—Wireless Sensor Network; RPL; load balancing; energy consumption**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are collections of sensor nodes able to collect data from their deployment environment and transmit them through a multi-hops routing toward the sink.

The miniaturization and low costs of sensor devices have led to the vulgarization of their usage. They have various fields of application, such as monitoring of harmful chemicals, precision agriculture and monitoring of hostile environments. In most cases, sensor nodes operate with batteries that are generally difficult to recharge or replace. These batteries commonly have a limited lifetime. In addition, human intervention ends after the deployment of the sensor network. Most of the time, we would like to be able to collect data over a long period of time. Source nodes need to collect data from their environments, treat and transmit them to the sink. But, due to the short communication range, many of them are out of the communication range of the sink and multi-hop transmissions must be used to forward the collected data. In turn, that may result to a concentration of traffic on nodes closer to the sink and may induce an imbalance load and power consumption. As direct consequence, this may induce a negative impact on the end-to-end delay and increase the packet loss rate due to congestion, affecting the network lifetime.

To optimize the use of these sensors limited resources, Routing Over Low power and Lossy networks (ROLL), an Internet Engineering Task Force (IETF) working group, has developed a Routing Protocol for low-power and Lossy networks (RPL) [1]. The real problem with RPL is the lack of a mechanism to ensure fair balance of traffic among the nodes in the network. Consequently, as the size of the network increases, techniques for optimizing parent selection do not perform well [2].

In a large size network, energy wastage, non-optimal parent selection, slow recovery time after the death of a preferred parent node and imbalanced load are the main factors leading to low performance in WSNs [2]. In this paper, we focus on the problem of traffic load balancing in WSNs. Our contributions are:

1) a critical analysis of existing methods and techniques for traffic load balancing and lifetime optimization of WSNs;
2) a method for balancing traffic load and energy con-

sumption taking into account the number of intermediate nodes during the parent selection phase;
3) an evaluation of this new approach by comparing its performances with those in the literature.

The remainder of the paper is organized as follows. Section II the briefly presents RPL protocol. Section III is dedicated to related work. In Section IV, we present our new parent selection approach and Section V shows an analytical study of the performance of the contribution. Section VI concludes the paper.

II. Brief overview of RPL

RPL is a reactive distance vector routing protocol developed by the Internet Engineering Task Force (IETF) to overcome the problems of Low-power and Lossy Networks (LLNs). It is primarily designed for static lossy networks. It operates on the principle of Destination Oriented Cyclic Graph (DODAG). To form the network topology, a DODAG root broadcasts a first DODAG Information Object (DIO) message to non-root nodes. Thus, when a non-root node wants to join a DODAG, it sends a first DIO message including its rank, identifier and version number of the requested DODAG. On the way to the requested DODAG, each traversed intermediate node updates its view of the topology. This DODAG version number allows the DODAG roots to reset the routing information and starts the DODAG creation process from scratch. Also, each time a non-root node receives a DIO message with a different version number than the previous one, it resets all information and restarts the process of selecting the preferred parent [2].

The process of sending DIO messages is periodic and regulated by the trickle timer algorithm [3]. This algorithm is integrated in RPL to control the DIO messages sending rate in order to minimize the network routing load and thus save energy. However, it has been found that variations in link quality can lead to a long convergence period or sub-optimal routes. Indeed, if after a certain time, the node has received enough coherent DIO messages from its neighbors, it can increase exponentially the DIO message sending period until it reaches a maximum value called *Imax*. Otherwise, it reduces to a minimum value called *Imin* in order to encourage the dissemination of new information.

It is important to notice that DIO messages are not the only control messages. There is also DODAG Information Solicitation (DIS), which is used by nodes that wishe to have information on available routes. We also have DODAG Advertisement Object (DAO) that child nodes send to a parent node as a membership request and when the parent accepts the request, it sends the DAO-Acknowledgement (DAO-ACK) to the child. However, these messages alone do not allow the election of the preferred parent. Thus, the designers of the RPL protocol have implemented two objective functions. They define the routing metrics and the way they is applied to compute the rank and the selection of the preferred parents. The first one is the objective function 0 (OF0) [4], which allows the selection of the path with the lowest rank toward the route. The second is the Minimum Rank Hysteresis Objective Function (MRHOF) [5] the used to select best path according to the number of re-transmissions or the number of hops and energy.

III. Related Work

In this section, we present and discuss existing techniques for traffic load balancing and energy consumption optimization in WSNs.

In [6], Farshid H et al. present an algorithm to identify the quality of all the shortest paths toward the sink using spatio-temporal correlations and constraints-based programming techniques. These allowed to fairly distribute the energy consumption for all nodes in the same rank. However, given the complexity of the exploited spatio-temporal correlation, it could lead to an additional energy consumption.

Ghaleb et al. [7] have designed an objective function to optimize routing load by taking into account the number of children of potential parent nodes. They extended the DIO message with a field, namely, the number of children nodes. Thus, when receiving DIOs, a child compares the number of children of each parent and chooses as parent the one with the lowest number of children. Their proposed approach is not always efficient. The number of one-hop children does not always reflect the data load to be passed to the parent. It is better to take into account the traffic load to the leaf nodes.

In order to increase the stability of the network and extend its lifetime, Iova et al. in [8] have improved the standard Expected Lifetime (ELT) [9] metric to detect bottleneck nodes. The authors estimate the amount of traffic that each node could carry for an fair distribution of the traffic load. However, the proposal is only compared to single and multiple path ETX metric and ELT standards. To further optimize energy consumption, the authors should determine the possible paths towards the sink as a function of the node's traffic load.

Lamaazi et al. [10] have addressed shortcomings associated with the exploitation of singular metrics and proposed a new objective function exploiting a composite metric (ETX, energy consumption and transmission delay). The evaluation and determination of each parameter is quite delicate and may lead to an additional energy consumption cost.

Nassiri et al. [11] proposed a composite metric to efficiently select preferred parents. This proposal consists in forming DoDAGs using the Received Signal Strength Indicator (RSSI) and the metric in DIO messages. To select links with lowest traffic load and lowest latency, they exploit the upstream load estimate and superframe distance. However, the exploitation of DIO and beacon-enabled message at the same time could induce a significant additional routing overhead.

Pereira et al. [12] first proposed a new objective function that helps to discover all potential paths and then selects the preferred parent based on energy. The proposed approach consists in estimating the energy consumed by a node during the transmission and packet re-transmission phase. Then, on the Network Interface Average Power (NIAP), they determined the rank of the potential parent. To optimize the energy consumption, the authors opted to update that metric before

 ISBN: 978-1-61208-878-5

updating the tickle timer. However, the estimation made by NIAP is not adaptive because, in some cases, it can not support all the load.

Authors in [13] present a new way to elect cluster heads. Their technique allows to select among several candidate nodes, the one with the smallest distance from the sink and in case of same distances, the one with the highest residual energy. Then by exploiting the Voronoi diagram [14] and the probabilistic perception model, nodes are distributed among clusters. Finally, these nodes will coordinate data sending according to the members of each cluster via Time Division Multiple Access (TDMA). However, nothing has been said about time slot allocation according to the amount of data per cluster and its effect on the network performance.

Sampayo et al. [15] have proposed a technique of duty cycling to optimize energy consumption in the network. When an application wants to send packets, it broadcasts control messages with an unique identifier. Then, upon receipt the message, it compares its rank with the previous one. a node wakes up if the rank of the received message is higher than the previous one. A few moments after sending the control message, the source node broadcasts its data packets. Then, it goes into standby mode and starts a timer to wake up and receive the acknowledgment message. The drawback here is that un-synchronized sleep and wake-up of nodes can cause packet loss leading to re-transmissions.

In [16], Shah et al. proposed a scheduling algorithm for connectivity and node coverage. Then, they balanced the power consumption of the WSNs nodes using the duty cycle technique. To ensure continuous operating of the network, the authors divided the network life into cycles. At the end of each cycle, nodes are allowed to send data with statistics on the different operations to the receiving node. The performance evaluation with ns-2.34 simulator show that the approach outperforms some existing works in terms of energy efficiency. However, their metrics are unrealistic. Since, allowing each node to consume the same amount of energy or imposing an energy threshold is almost impossible. Because, there are nodes that are only within the coverage range of a specific node.

To fairly distribute traffic load and reduce frequency of parents switching, Wang et al. [17] proposed a QoS based method. As QoS metric, they combined the ETX and Packet Transmission Rate (PTR) parameters. Thus, for a node to change its parent, the difference in metrics between it and its current parents must be greater than a defined hysteresis threshold. However, the need to calculate and compare metrics each time a node wishes to change parent shows that the solution will incur an additional energy cost.

The authors in [18] designed a new load balancing routing based on objective function that works as follows. First, this function, exploit the ETX metrics to select best parent node. Then, they used the Packet Re-transmission Rate (PTR) metric to select among these parent nodes the one with the lowest PTR value. However, the PTR creates fluctuations. Also, flow metric is more complex and does not reflect the total number of flows in a node. It does not take into account the numbers of sub-children of a child node in the choice of the parent.

The related work shows that several approaches are proposed in the literature to optimize energy consumption in LLNs networks. The main drawback of these proposed approaches are that, they does not take into account all upstream children when selecting the preferred parent. Also, these proposed approaches lack of method to fairly distribution the traffic load amount parent nodes.

Load balancing techniques based on selecting the preferred parent with the fewest children does not take into account all upstream children when selecting the preferred parent. Indeed, when selecting parent, it is better to choose a parent that has less children and its children also have less children.

IV. Our proposal

A. *Number of children based algorithm*

The proposed load balancing routing protocol is based on a composite metrics that combines the ETX metric and the number of children. The protocol has two phases: (i) the network construction and the metric designs phase and (ii) the network optimization phase. In this section, we describe in details these two phases.

1) The network construction and the metric design phase: This phase allows the RPL DODAGs construction and the initialization of the routing metric values. The different steps are presented as follows:

1) At the starting of the network, nodes exploit the ETX metric to form DODAGs;
2) Each node periodically broadcasts DIO messages.
3) Nodes receiving the DIO messages may select the transmitting one as its parent toward the sink;
4) Each node evaluates the value of its metric by summing the child metric (the metric, which counts the weight of all upstream nodes from it) communicated by its children. This information is carried by the DIO message and helps parent nodes to have an updated state of its children including the number of children of each child.

Unlike most RPL improvements that take into account the number of children, our approach allows to consider the actual weight of a each child. Indeed, instead of counting a child as weight 1, we take into account its children and grandchildren (more than one hop children of the parent). Therefore, for a given parent node, the children will not have the same weight.

2) The network optimization phase: This phase will permit to fairly distribute the traffic load of each intermediate node toward the sink and works as follows:

1) if a child node receives DIOs messages from multiple parents, it compares the received values of the metric (that has defined early) and selects the parent with the lowest metric value;
2) then, for each node, a DAO message including its weight (its number of children) is transmitted for the selected parent;

 ISBN: 978-1-61208-878-5

3) to avoid fluctuations, a child node can only move to a new parent if the metric value of this parent have two (02) units greater than the old parent;
4) upon receipt of DAO message, the parent node sends a DAO-Ack message to the child node if its membership request is accepted.Then, the parent node increments the number of its children by the weight of this accepted child. The weight of a node is the number of children using it as an intermediary to reach the sink;
5) To have an updated number of children of each parent, a timer is defined. All children that have not transmitted data to the parent node will be removed after the expiration of the timer. So the parent node decrement its weight by the weight of disconnected node;
6) Each time a node receives a DIO message then restart the process from step 1.

B. Analytical study of the performance of our proposal compared to the ETX metric and to the number of children metric

In our evaluated scenarios, nodes have the same packet generation rate of 5 packets each 10 minutes per nodes. Figure 1 represents a network scenario where 6 children nodes (4, 5, 6, 7, 8 and 9) have possibility to choose a parent node among the three nodes that are (1, 2, 3) as the next hop toward the sink. In this scenario, the selection of parent node is based on the link quality metric. Thus, upon receipt of the DIOs, nodes (6, 7, 8 and 9) select node 2 as the preferred parent because it is the best according to the ETX metric. This will create unbalance load because the number of children of node 2 is 7 when nodes 1 and 3 have 3 and 2 respectively. As a consequence, node 2 will run out of energy more quickly than the others.

we supposed that the only obstacle for the communication is the distance. Node 2 is the nearest parent. In the second scenario, Figure 2, parent node selection is based on the number of children. Here, upon receiving the DIOs including the number of children and after comparing its DIOs, nodes 4 and 5 select node 1 as their parent, node 6 and 7 select node 2 as their parent, and nodes 8 and 9 select node 3 as their parent toward the sink. If we evaluate the load on the basis of the number of children metrics only, we notice a fair distribution of the routing load. Because each of parent nodes 1, 2 and 3 have 2 children. Respectively node 4 and 5 for parent 1, nodes 6 and 7 for parent 2 and nodes 8 and 9 for parent 3.

However, the application of this metric results in load unbalance because, in the Figure 2, node 2 support 5 children when nodes 1 and 3 have 4 and 3 children respectively. Doing so, the parent node with the lowest number of children will be more selected by children that increased its number of children (including grandchildren). As its number of children increased it may be overloaded and can quickly run out of energy.

In the third scenario, Figure 3, we have exploited the number of children of the child metric during the preferred parent selection phase. The results show that the data traffic is fairly distributed between the three intermediate nodes 1, 2 and 3. This result is due to the fact that parent nodes (1, 2 and 3) have exactly the same number of one hop children (02) parent nodes that are one hop away from the sink and the same number of two hop children (04) nodes that are upstream of the parent node. In this scenario, all nodes will have to transmit the same number of packets. As a result, all parent nodes will consume the same amount of energy and the network lifetime will be extended.

The results of the analytical evaluations show that the data traffic of scenario 3 is fairly distributed among the three parent nodes. As the parent nodes have the same traffic load, their energy depletion will be similar and the network lifetime can be extended. So the proposed approach optimize the energy consumption compared to the approach based on ETX metric [19] and the number of children metric [20].

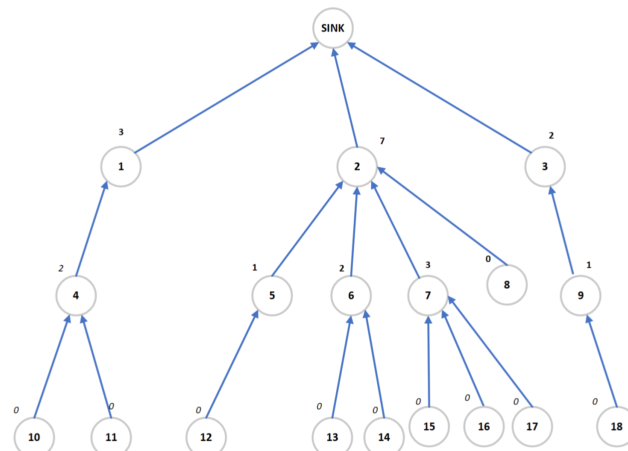

Fig. 1: Network exploiting the ETX metric.

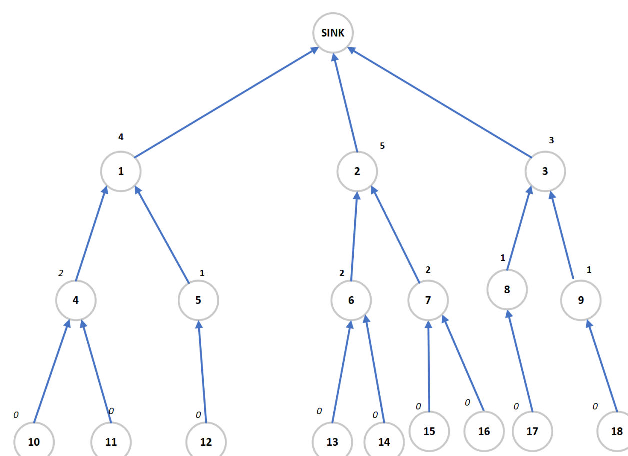

Fig. 2: Network exploiting the number of children metric

TABLE I: LOAD OF DIFFERENT NODES ACCORDING TO ROUTING APPROCH

Nodes/Protocols	ETX	Number of children	Node Weight
1	4 α	6 α	6 α
2	11 α	7 α	6 α
3	3 α	5 α	6 α

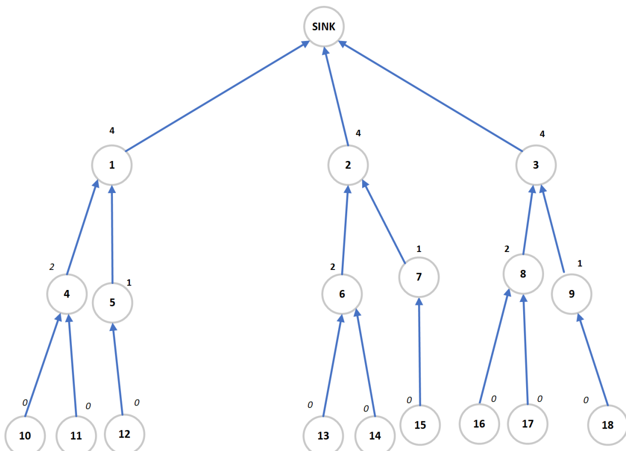

Fig. 3: Network exploiting the number of children of child metric

For simplicity and ease of understanding, we assume in our scenario that each node periodically sends 5 packets each 10 minutes during 30 days. Also, in the current scenario, packets are not treated by intermediate nodes, they are directly forwarded to the sink node. During the evaluation period, each node generates 21600 packets ((5 packets$*$ 30 days$*$ 24 hours$*$ 60 minutes)/ 10 minutes = 21600 packets) that we call α. The Table 1 presents analytical result according to the presented packet generation rate. According to the results presented in Table 1, we notice that with ETX metric node 1 has receive 4α packets while node 3 has 3α and node 2 has 11α. So, node 2 need to transmit three times more than node 1 and 3, thus it will run out of energy more quickly than the two other. This will create the network partitioning. If we consider the number of children protocol we find a slight improvement compared to the ETX metric. Node 1 has to transmit 6α data packet, node 2 has 7α data packet to transmit and node 3 has 5α data packet. However, with our approach, nodes 1, 2, 3 transmit approximately the same amount of data packet, which is 6α. As the energy consumption is proportional to the number of data transmitted. Our proposal is better because in the same time period the nodes consumed the same amount of energy.of the network.

V. CONCLUSION

WSNs are increasingly being used in everyday life and are proving to be an effective solution for data collection. But, the fact that sensors nodes are powered by low capacity batteries limits network lifetime. Also, for the reason that these nodes communicate with the sink on multiple hops, lead to an inequitable energy consumption. Nodes near the sink wastage their energy faster.

Effective energy consumption optimization solution constitute a real challenge for the efficiency of these networks.

In this paper, we first highlighted the shortcomings of works on traffic load optimization in WSNs. Then, we proposed a new approach for parent selection mechanism. In our approach, a node takes into account all other nodes soliciting intermediate services from the target parent in its next-hop selection process. Finally, we performed an analytical evaluation on a given scenario. The results show that our approach improves load balancing in these networks.

In future work, we will carry out an exhaustive evaluation with several parameters and embedded tests in various scenarios to confirm these trends and the impact on performance parameters such as PDR, end-to-end delay.

REFERENCES

[1] T. Winter et al., “RPL:IPv6 Routing Protocol for Low-Power and Lossy Networks,” rfc 6550, 2012, pp.1-157.
[2] N. Guan et al., “Delay compensated asynchronous adam algorithm for deep neural networks,” 2017 IEEE International Symposium on Parallel and Distributed Processing with Applications and 2017 IEEE International Conference on Ubiquitous Computing and Communications (ISPA/IUCC), IEEE, 2017, pp. 852-859,.
[3] P. Levis et al., “The trickle algorithm,” Internet Engineering Task Force, RFC6206, 2011.
[4] Thubert and Pascal, “Objective function zero for the routing protocol for low-power and lossy networks (RPL),” pp. 1-14, 2012.
[5] O. Gnawali et al., “The minimum rank with hysteresis objective function,” RFC 6719, 2012, pp. 13.
[6] F. H. Bijarbooneh et al., “Energy-efficient sensor selection for data quality and load balancing in wireless sensor networks,” 22nd International Symposium of Quality of Service (IWQoS), IEEE, 2014, pp. 338-343.
[7] B. Ghaleb et al., “Load Balancing Objective Function in RPL draft-qasem-roll-rpl-load-balancing-00,” 2017, pp.16.
[8] O. Iova et al., “Exploiting multiple parents in RPL to improve both the network lifetime and its stability,” International Conference on Communications (ICC), IEEE, 2015, pp. 610-616.
[9] O. Iova et al., “Improving the network lifetime with energy-balancing routing: Application to RPL,” 7th IFIP Wireless and Mobile Networking Conference (WMNC), IEEE, 2014, pp. 1-8.
[10] H. Lamaazi et al., “A comprehensive survey on enhancements and limitations of the RPL protocol: A focus on the objective function,” Ad Hoc Networks 96, 2020, pp. 102001.
[11] E. M. Ahrar et al., “RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks,” rfc, 6550,2012, pp.1-15.
[12] H. Pereira et al., “Increased Network Lifetime and Load Balancing Based on Network Interface Average Power Metric for RPL,” IEEE Access 8, 2020, pp.48686-48696.
[13] S. R. Samal et al., “An Energy Efficient Head Node Selection For Load Balancing In A Heterogeneous Wireless Sensor Network,” 52nd Asilomar Conference on Signals, Systems, and Computers. IEEE, 2018, pp. 1428-1433.
[14] K. Hoff et al., “Interactive motion planning using hardware-accelerated computation of generalized Voronoi diagrams,” Proceedings 2000 ICRA, Millennium Conference, IEEE International Conference on Robotics and Automation, Symposia Proceedings (Cat. No. 00CH37065), Vol. 3. IEEE, 2000, pp. 2931-2937.
[15] Sampayo, L. Sebastian , Julien Montavont, and Thomas Noël, “LoBaPS: load balancing parent selection for RPL using wake-up radios,” 2019 IEEE Symposium on Computers and Communications (ISCC), IEEE, 2019, pp. 1-6.
[16] B. Shah et al., “Guaranteed lifetime protocol for IoT based wireless sensor networks with multiple constraints,” Ad Hoc Networks, Vol.104, 2020, pp. 102158.
[17] F. Wang et al., “SL-RPL: Stability-aware load balancing for RPL,” Trans. Mach. Learn, Data Min, 2020, Vol.13, pp.27-39.
[18] C. Ji et al., “TAOF: Traffic aware objective function for RPL-based networks,” 2018 Global Information Infrastructure and Networking Symposium (GIIS), IEEE, 2018, pp. 1-5.
[19] D.S.J. De Couto et al., “High-throughput routing for multi-hop wireless networks, Diss,” Massachusetts Institute of Technology, 2004.
[20] B. Ghaleb et al., “A new load-balancing aware objective function for RPL’s IoT networks,” 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), IEEE, 2018, pp. 909-914.