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Research Article

Weighted Sum Metrics – Based Load Balancing RPL Objective Function for IoT

Poorana Senthilkumar Subramani[1,*] and Subramani Bojan[2]

[1]Department of Computer Applications, Dr. N.G.P. Arts and Science College, Tamil Nadu, India
pooranasenthilkumar@drngpasc.ac.in
[2]Department of Computer Science, SNMV College of Arts and Science, Tamil Nadu, India
drbsubramani@gmail.com
*Correspondence: pooranasenthilkumar@drngpasc.ac.in

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Abstract: The technological development of Internet of Things (IoT) applications is emerging and attracting the attention of the real world in the automated industry, agriculture, environment, and scientific community. In most scenarios, extending the network lifetime of an IoT network is highly challenging because of constrained nodes. The wireless sensor network (WSN) is the core component of IoT applications. In addition, the WSN nodes are required for the network processes, particularly routing, energy maintenance, load balance, congestion control, packet delivery, quick response, and more. The failure of any of the above network processes will affect the entire network operation. IPv6 Routing Protocol for Low-power and Lossy network (RPL) provides high routing solutions to IoT applications requirements. The load balance, congestion control, traffic load, and bottleneck problems are still open issues in the RPL. To resolve the load balance issue, we propose a weighted sum method objective function (WSM-OF), which provides the ability to select the alternative parent in routing by RPL metrics. WSM-OF adopts congestion control and load balancing to avoid heavy traffic and extend the network's node lifetime. The network parameters of control overhead, jitter, packet delivery ratio, parent switching, energy consumption, latency, and network lifetime are implemented and analyzed through the COOJA simulator. The result shows that the WSM-OF improves the network performance and significantly enhances the network lifetime by up to 7.8%.

Keywords: ***IoT; LLNs; Load Balance; Objective Functions; Routing Metrics; RPL; WSM-OF***

1. Introduction

IoT is the integration of real-world physical objects with the Internet and is used in industry, agriculture, environment, education, and science to improve human life. The Internet protocol version 6 (IPv6), Low-power and Lossy Networks (LLN), is a prominent routing component in IoT applications. It provides a promising opportunity to develop authoritative applications with Internet Protocol (IP) based heterogeneous networks [1]. IoT technology enables billions of smart devices that collect data from the real-world (sensing) and wireless communication connected with computer networks. Moreover, wireless sensor network (WSN) devices are constraints in memory, power, computation, processing, reliability, etc. Several solutions have been proposed to address the constrained network challenges to spring up the IPv6 low-power wireless personal area networks (6LoWPAN). The Internet Engineering Task Force (IETF) has standardized and provided the RPL protocol to communicate effectively on the constrained network and be smoothly connected to the Internet service [2].

RPL is designed to cope with the embedded sensor device resource constraints and support the LLNs/IoT applications. Compared to conventional wired and ad hoc networks, the LLNs have distinct characteristics that necessitate the specification of routing metrics and constraints. The RPL network topology constructs the loop-free Directed Acyclic Graphs (DAG) following the routing metrics and constraints, subject to the different application requirements as on [RFC6551] [3].

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The node selects the parent grounded by Objective Functions (OFs) to accomplish the IoT application requirements and establishes the network topology for routing in the name of Destination Oriented DAG (DODAG). The OFs are individual elements from the RPL specification, which defines the routing policy and strategies according to the metrics defined in OF. IETF has standardized the two types of OFs in RPL that select the optimized parents/roots from the DAG tree. Moreover, the implemented OFs contributing only a single metric for the routing process and the network performance of LLNs in highly dense or dynamic traffic are defective. Moreover, it is worth noting that the implemented OFs contribute only one metric to the operations of LLNs, which is highly defective in routing and load balancing performance on highly dense or dynamic traffic network instances [4].

The IoT applications are different from the regular network; the environmental monitoring application in emergency instances are not only regular intervals to sense the data from the network region but, in some unusual situations, requires rapid response. The IoT network comprises different components, and RPL is specially designed for LLNs, which is the core of the WSN. Moreover, the RPL is used in high-scale networks, and some nodes will suffer from the unbalanced parent selection. In this smart decade, the IoT network environments dominate all other network operations in that designing a feasible IoT should understand the traffic flow, packet delivery, continuous collecting data by the node and communication conditions. Normally, data is collected based on the sensor nodes' interests; the lost data ratio is highly generated at a specific time interval. Therefore, a high percentage of data loss may occur when the network becomes imbalanced due to parent selection in high-dense, and some nodes will experience congestion. These issues will probably degrade the network performance. Although the RPL has been prominently used for low-density traffic in data sensing regions, this juncture of end-point nodes generates high data transmission, and the root may cause overload. Therefore, high-traffic, overloaded, or unbalanced nodes and the choice of routing metrics and parent selection techniques in RPL alleviate the routing performance [5].

In RPL specification [RPL RFC], there is no specific technique to detect and control the high-traffic and overloading nodes. The standardized RPL OFs select parents, avoiding the long hop count or poor links. The main objective of our WSM-OF proposal is to design a balanced network for extending the IoT applications' lifetime and improving the routing performance [6].

In the rest of this paper, in section 2, we outlined the RPL protocol, the section 3 reviews the existing load balancing and extending the network lifetime works. The proposed methodology of WSM-OF is described with RPL metrics in section 4. Section 5 discusses the performance evaluation and section 6 concludes with future enhancements.

2. RPL

The IoT application requires dynamic topology changes in routing. The router and nodes are needed for the information about the topology to be updated periodically. These requirements are fulfilled in LLNs by the RPL protocol in the method of distance vector routing with 6LoWPAN. It works on the network layer, several link layers, and the IEEE 802.15.4 standard [7].

2.1. Control Message

Internet Control Message Protocol version 6 (ICMPv6) performs the Internet layer functions, and reports errors encountered. The RPL control messages are defined with the following names, and it contains the network information [8]:

- DODAG Information Object (DIO)
- DODAG Information Solicitation (DIS)
- Destination Advertisement Object (DAO)
- Destination Advertisement Object Acknowledgement (DAO-ACK)

In the DAG construction stage, the DODAG root broadcasts the DIO control message to the child nodes; it contains the network information for discovering an RPL instance, configuring parameters, and maintaining the DODAG operation. The DIS control messages are raised to request DIO messages from the other nodes for routing topology formation. This message is normally used to request the DIO message from the neighbouring nodes to join the solid network topology. Each node unicasts the DAO message to disseminate the route information to the direction of the parent node for constructing routes throughout the DAG. The DAO-ACK is sent by the DAO received node for acknowledging status. This unicast message is a reply received by the DAO sender, ensuring the completion of routing and packet transmission will begin after this process. Figure 1 depicted about control message format. The length of a message container head is 32 bits, and the second part of 8 bits carries control message information. The 8 bits of the control message section have been divided into three subfields: 0-2 is the message type, the next single bit is used for security, and the last field of 4-7 bits is reserved. The first three bits contain a unique code for each control message type.

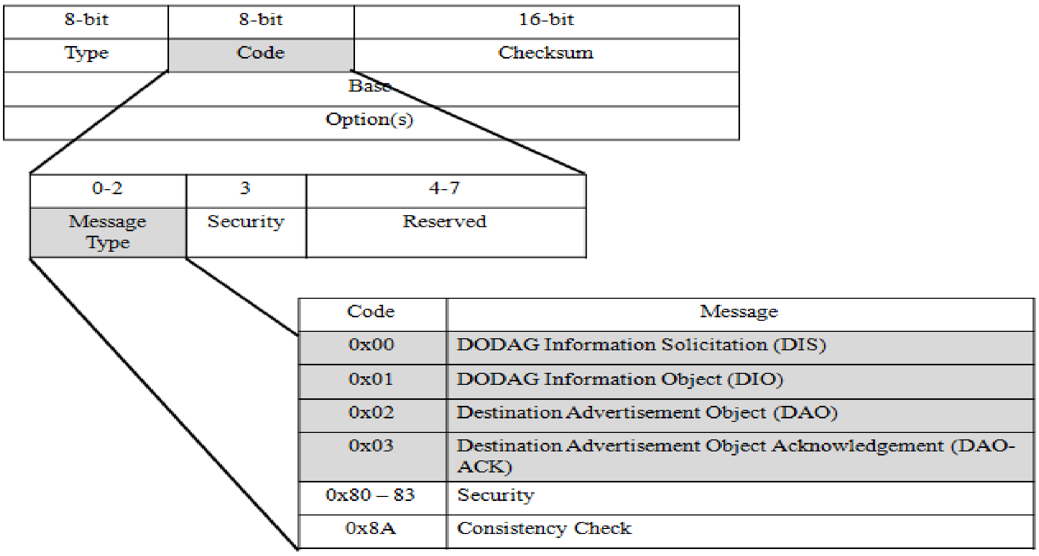

Figure 1. DODAG Control Message format.

2.2. DODAG Formation

The RPL protocol constructs the loop-free tree topology for routing by DODAG; within the network range, neighbouring nodes communicate with each other by the control messages for topology formation. Depending on the receiving message and OFs specifications, the neighbouring nodes decide to join or not in the DODAG. That joining node selects the root node as a parent in the DODAG instance and broadcasts the messages to other child nodes. Each node will take over this process until it forms a loop-free and tree-structured DODAG topology construction. The topology node rank is calculated by the position of the nodes and called scalar values, and the rank values are increased from the DAG root to child nodes. In RPL, exchanging information between nodes and intervals is governed by the trickle algorithm [9]. This algorithm has three parameters for specifying the intervals: minimum interval, maximum interval, and redundancy constant. A node can join the DODAG based on the request, update the seder DIO address information to its parent, and calculate the DAG tree rank.

When a node gets a control message related to the DODAG, it can choose whether to proceed with the respective message to retain or update its rank. Otherwise, the messages may ignore. When a node updates its rank, it must form the new tree topology to reorder all the available list parent nodes whose ranks are lower than the newly calculated node's rank to prevent the routing loop. When a node gets messages from several neighbours' node, it chooses its parent from a list of potential parents according to the OFs specified metrics and constraints. In this situation, if a node does not receive a control message within a specified interval or a new node wishes to be a part of the DODAG network, it will initially request the control message from the neighbouring nodes by sending a solicitation control message for DOADG instance creation.

The RPL protocol consists of three types of units to constitute the DODAG network system:

1. The Low-Power and Lossy Border Router (LBR) node that acts as a gateway for Internet connection establishment builds the DAG and behaves like the root node of DODAG.
2. The sensor node is called a host or leaf of DODAG. It generates data traffic and senses (collecting) the data from the real world. Each node communicates with other nodes for the network transmission operation.

3. The network router is another important unit capable of transmitting and generating traffic flow and configuring, running, and managing different network protocols.

The general scheme of DODAG construction is that the DIO message will be broadcast by the root node, which contains DODAG information. The leaf node receives the DIO from the root node and joins the DODAG. After processing the DAO control message with the leaf node, the leaf node transmits it to the DODAG instance root. The DODAG child node transmits the DIO message to the node directly connected nodes. Now this intermediate node becomes a parent node of the directly connected child nodes in DODAG. The newly joined leaf node will send a DAO message to the intermediate (parent) node [10]. This leaf node has the possibility of receiving the DIS from other non-joined nodes. In this scenario, the leaf node will not respond to the new nodes' DIS until this node joins the DODAG.

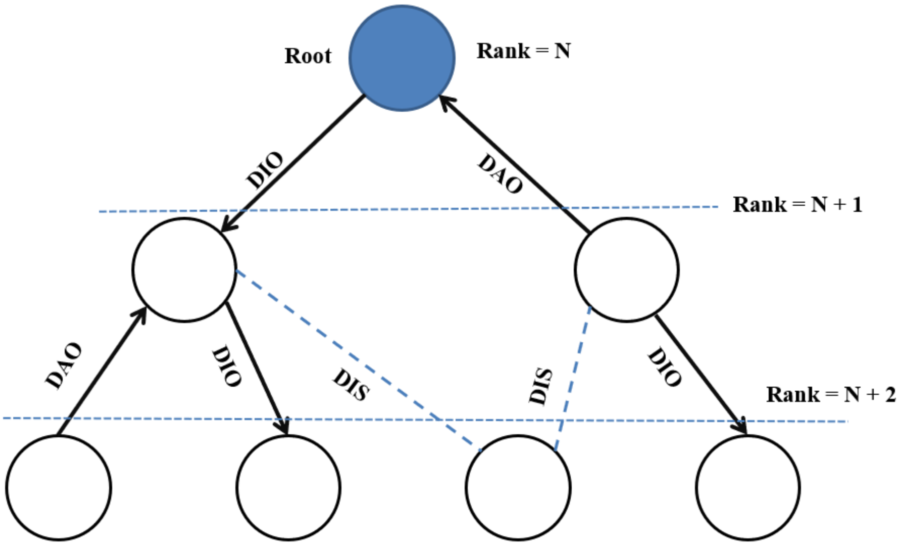

Figure 2. DODAG formation and flow of control messages.

The control message of DIO contains the rank information and other metrics. The DIO received sub-nodes select the minimum rank node as a parent. Then the routers will calculate their rank as stated from defined OF metrics, update the rank in the DIO message, and forward it to their neighbouring nodes to extend the topology. Figure 2 illustrates how the control messages are processed from the DODAG root and constructing the topology by using the control messages in RPL.

2.3. Traffic Flow

IoT applications require many wireless nodes to communicate with each other for data transmissions and route discovery. Moreover, the functionality of applications requires different traffic data flows from one to one, from central point nodes to other nodes, and from many nodes to the receiver node. The RPL fulfils this communication pattern requirement under the names of point-to-point (P2P), single point-to-multipoint (P2MP), and multipoint-to-point (single) (MP2P)[11].

Implement P2P traffic flow to discover routes or form the data flow as a hop-by-hop or from the source node to the destination(s) node with specified constraints. The single-point remote control home appliance requires P2P, for example, the remote control for the smart home lamp. RPL supports the destination advertisement technique in P2MP traffic as the central base node that communicates several nodes, for example, smart emergency alarm applications in industries. The procedure of MP2P communication flow is that all the nodes can communicate with a single node. For example, Smart agriculture applications require this kind of data flow.

2.4. Routing Establishment Mode

A router is a node that forwards data packets between nodes. These nodes are connected to one or more child nodes. When a node receives a data packet, some information is essential for route establishment. In this consideration, the RPL protocol defines and manages downward routes with storing or non-storing modes of operations. In storing mode, each node contains the complete route information of the DODAG.

Each node knows how to reach other nodes directly. Only the border router(s) of the DODAG contains full routing information in non-storing mode, and other instance nodes in the network only keep their immediate parents' list and utilize this list to reach the border router by default [12]. This routing mode is specifically designed for constrained memory utilization in IoT applications.

2.5. Objective Functions (OFs)

The use of OF(s) is for a node to join or establish a DODAG and offers optimized path selection according to a specific metric. Furthermore, the DODAG construction of the OF(s) specifications directs the selection of the parents and computation of the rank. The OFs form the routes and help to select the best path for routing. To generate optimal routing path nodes explicitly using hop count, expected transmission count (ETX), link quality level, node energy, etc., as the metrics and constraints for path calculation. The standardized RPL supports two OFs; an Objective Function Zero (OF0) uses hop count as a metric for routing. In contrast, the Minimum Rank Hysteresis Objective Function (MRHOF) uses the ETX for optimal routing selection. In this instance, IoT networks are operated under an OF0 that only considers hop count as a metric and selects an optimal path with less hop count. Moreover, to minimize the additive metric tabulated in the IETF draft [RFC6551] and to select an optimal and reliable path, the link quality of ETX is the core metric in the designed MRHOF [13]. The noteworthy thing about the existing two OFs is that they only select the optimal path; the network load balancing is unconcerned. In the opinion of researchers, if the load balancing is not addressed properly in these OFs, it can cause excessive churn in the LLNs and rapid energy loss.

3. Related Works

In the recent development of IoT applications, several proposals have improved the performance of the RPL protocol standards and enriched some possible open issues through the metrics [14]. However, the RPL routing method cannot satisfy IoT applications' load balancing, and extending the network lifetime remains an open issue.

The foremost RPL overload and load balancing problem were systematically addressed in Load Balanced OF (LB-OF) [15-16] and extended the nodes' lifetime. The new RPL metric was introduced to balance the unequal traffic and balancing the DODAG. Select the preferred parent node using a regular metric to avoid the child node. The technique is proposed to amend the DIO message by adding the IP address for broadcasting. Moreover, neglects the handshaking and acknowledgement process. In this proposed work, the amended DAG metric container with Child Node Count (CNC) object for the number of child nodes available information from the DIO sender node. This CNC object is used as a metric in the DAG metric container.

The authors [17] combined the ETX and LQL metrics to achieve a reliable route grounded on the aspect of the link, named Link-Quality-Based Objective Function (LQBOF). The LQL values are monitored on an interval basis. Each interval receiver point evaluates the packet reception ratio (PRR), and the obtained PRRs are classified from 0 to 7 in different percentages. The obtained LQL values are updated in the metric container, which should be enabled, and select the new best parent by the threshold value. This work has compared the LQBOF with OF0, MRHOF-ETX, RSSI-Based, and Link Quality Enabled (LQE) in various network sizes (10-150). Convergence times have been evaluated in an ANOVA test with 5 significant levels.

Grid-based load balancing in IoT network nodes has been proposed in [18] Dual Context-based Routing and Load Balancing in RPL-based Networks (DCRL-RPL). Here, the load balance is achieved by dividing the network area into unequal grids, and each grid selects the grid head node using the random walk ranking (RWR). The residual energy (RE), load influence index (LI2), and root distance metrics are used for selecting the grid head. The grid head schedules its sub-nodes using a reputation-based process and avoids congestion during data transmission at the grid level by scheduling method. The adaptive trickle algorithm implements the next load balancing context to minimize the control message transmissions on the network to construct the DODAG instance. The proposed DODAG formation method effectively increases network lifetime (NL) and performs the load-balancing nodes in the grid. The load balancing capability (LBC) is outperformed by up to 36% through the load-related and data transmission metrics.

The authors [19] proposed the ETX and parent count (ETXPC) metric to improve the transmission quality and extend the network's lifetime. The implementation employed in the threshold of ETX and parent count (PC), ETX is greater or equal to PC, then the threshold is ETX - PC, else the threshold is PC - ETX. The RPL load balancing and congestion traffic are tackled to detect the effective path to the parent in the burst traffic load. This proposal was approached and compared with regular and burst traffic by the four packet transmission scenarios in a minute (1, 20, 40, and 60). However, no significant results were identified in the regular traffic and no more good performance in PDR under the regular traffic. Suddenly, they improved the PDR value by 98% in burst traffic. Still, the part of power consumption provides an acceptable level. The result of ETXPC is only good in burst traffic load and compared the proposed method with OF0 and MRHOF.

In [20], an automaton ant colony-based multiple recursive LPL (AMRRPL) avoids unbalancing and congestion issues in IoT networks with heavy and dynamic loads. The node rank is computed in OF using an ant colony according to node context, where a stochastic automata mechanism dynamically selects the new optimal parent. At last, implementation solves the moving node bottlenecks and swarm problems. Load balancing and congestion control are approached by node factor metrics of average link quality indicator (LQI) and signal-to-noise ratio (SNR) for forming a DODAG structure. The simulation results show a network lifetime outperformance of approximately 9.34% in 30 traffic flows and more than 11% in 50 traffic flows. The 14% energy consumption average is noteworthy in up to 30 traffic flows, but in more than 30, it somewhat increases to 12%. The control overhead rate result has improved by 20%. The network energy consumption, PDR with various movement patterns, and control overhead rate tests compared the work in the 30 and 50 AMRRPL implementations.

Without modifying the RPL standard, the network interface average power (NIAP) node-based metric is proposed in [21]. A new cost metric computes the average power consumption of the network interface and contributes to reliable paths, load balancing, and increased network lifetime in WSNs. Total energy E was estimated using software-based online energy computation in sensor nodes[22], and time interval T defines the network monitoring interval. E/T calculates the NIAP metric, and the update algorithm updates the metric in the trickle timer, which reduces the update count before the DIO message is produced. While initially, the nodes have a similar energy NIAP is less than 1%, and a high-scale denser network of slightly more than 1% outperforms in PDR, Latency, and lifetime due to avoiding the high collision probability.

Migrate the oscillations in nodes and frequent parent changes proposed in the [23] stability-aware load balancing method for RPL(SL-RPL). Respectively, they use PTR and ETX metrics. The PTR represents the number of packets a node can transmit in a particular duration. While a node joins the DODAG instance, the estimated PTR metric is updated in the DIO message metric container. In addition, they used the hop count metric as a filter to identify a probable parent set; a node chooses the new best parent with the lowest estimated PTR value and compares it with the previous parent. The SL-RPL reduces the parent changes more than standard OF0, and >80% of nodes' parents changed only less than 3 times, which also significantly improved the result in packet loss ratio compared with other OFs SL-RPL outperforms in energy consumption.

The method with composed metrics of node count of neighbours and node remaining energy to calculate the weight and modified in the standard trickle timer algorithms are proposed in Load Balancing Time Based (LBTB) [24]. It controls the main interval time for message distribution among nodes based on a routing metric. Four cases are used for intervals from 26 to 220 to build a DODAG instance based on the sub-interval values of *lmin* and *lmax* from the trickle timer algorithms of each node; the LBTB shows an average of 68% outperformance in PDR, energy consumption, and delay on three different network densities.

In the last decade, apart from our discussed related work, the number of proposals has been followed, and the work has been performed using other metrics and techniques, then improved and optimized the RPL in more scenarios like improved performance, energy consumption, energy balancing, parent change, good PDR and so on in routing. The cluster-based load balancing is proposed and uses a two ranks method for identifying the cluster head and selecting the parent of the cluster head with several metrics in [25].

Another cluster formation method also proposed in [26] the network has been divided into several clusters. The node priority parameter and residual energy threshold metrics reduce the data flow and make the entire network load-balanced. This cluster head mechanism has two key functionalities: based on the node priority parameter Rn and cluster head rotation depending on the node residual energy Ere. The remaining energy detects the nodes' energy and requests the cluster head rotation. The DIO received from the cluster member nodes sends DIS to the other remaining cluster heads. The DIO received from the cluster head node updates the node attributes in the cluster routing table. The successful competition is over, the current node is selected as the new cluster head, and it permits other nodes to join.

The comparative of the proposed load balancing protocol technique and the summarization of the used metrics and analyzed network parameter performance in existing related work are enlisted in Table 1.

Table 1. Comparative and summarization of related works

Protocol	Proposed Techniques	Performance Metric	Upsides	Downsides
LB-OF [15]	Combined metrics Child Node Count (CNC Object) ETX metric	Packet delivery rate Power consumption Parent selection Child nodes randomly chosen Network lifetime	Optimized solution Randomly balanced network Improved performance than OF0 and MRHOF	The load balance is not evenly distribution Applicable only for the storing mode Poor combination of metrics
LQBOF [17]	LQL metric	Power consumption PDR Control traffic overhead Throughput Convergence time	Achieved better reliability Reducing the packet size	Only used LQL as a metric, does not have any constraints
DCRL-RPL [18]	Rank-based grid head selection process	Network lifetime End-to-end delay Packet loss ratio (PLR) Packet drop ratio Routing overhead Load balancing	Time complexity is good Optimal parent node selection. Effectually reduced the end-to-end delay	Context selection is used in the objective function for sensitive and non-sensitive data. The unequal grids are formed.
ETXPC [19]	Combined metrics ETX and parent count metrics (ETXPC)	PDR Energy consumption	Improved the communication quality and optimize the node lifetime in the heavy traffic	Used only a single gateway in burst traffic
AMRRPL [20]	Ant colony algorithm and multistep recursive model	Network lifetime Remaining Energy Control overhead rate Packet delivery ratio	Balancing model to prevent congestion Network energy consumption Increase lifetime	In three steps, the time complexity is high. The process from the external component More memory
NIAP [21]	Network interface average power metric	Energy efficiency Reliability Network lifetime Packet delivery latency	Reliable paths Energy consumption balancing Alternative to ETX Without modifying the standard RPL	Less than 1% result is a difference Homogeneous hardware topologies
SL-RPL [23]	Combined metrics PTR and ETX	Parent changes Packet loss rate Power consumption	Avoid frequent parent switching Improve the stability Load balancing	The additional part only considered the PTR metric
LBTB [24]	Neighbors' node count Remaining node power metric Modified trickle timer algorithm	PDR Power consumption Delay Convergence time	load balancing Trickle timer algorithm to the constructor the DODAG	Based static interval technique does not support real-time applications

The related work literature review shows that most of the proposal considerations are only the standard performance parameters and do not consider the QoS of the network. At this junction, we considered load balancing with QoS. For this responsibility, we estimate the Jitter, network lifetime, and standard parameters in our proposed work for providing the quality of link service in RPL.

3. Problem Statement

The dealing of non-uniform distribution in LLNs causes the following reasons. Explicitly there is no OFs method or technique to detect and alleviate the load balance and congestion. The root selections method selects the roots with hop count or link-based metric, which affects the maximum utilization of network instance node lifetime.

In the method of rank-based RPL-DODAG's parent selection, the child nodes select the preferred parent node, which leads to overloading issues, bottleneck nodes that may occur, and unbalanced traffic. The preferred parent node may get quick depletion of energy. As a part of the network topology connection, the preferred parent node will be disconnected from the constructed traffic flow. This unbalanced load problem leads the LLNs to the following problems:

- If a node dies early due to energy depletion, the network loss percentage becomes high.
- There is no acknowledgement from the parent node for a certain percentage of the period.
- The fragile parent node energy quickly drains the power of other nodes, and then linked child nodes are decoupled from the existing topology.

3.1. RPL Load Balance

RPL is implemented with several features like delay, avoiding looping, self-repair, rapid configuration, and load maintenance in the network. However, large-scale LLN applications have significant load balance flaws, leading to non-uniform distribution.

The section content represents the topology load balancing issue in RPL; furthermore, this unbalanced overload topology has more unhealthy, harmful churn in parent selection and bottleneck. Figure 3 illustrates the border router (BR) first preference parent nodes A1 and A2, and the node ranks are equal. The node A1 besides more child nodes as it is possible, has 7 nodes (N2, N3, N4, N6, N7, N8, N9); compared to A1, A2 has 5 nodes (N5, N6, N7, N8, N9) in transmission range, A1 has the chances for congestion because of the imbalance load in the current scenario. Furthermore, the 4 nodes (N6, N7, N8, and N9) are available within the shared transmission range of A1 and A2. Table 2 shows the possibility of the preferred parent node A1 or A2 DODAG topology formation and follows Equation (1) to identify the number of nodes for a parent-based count topology.

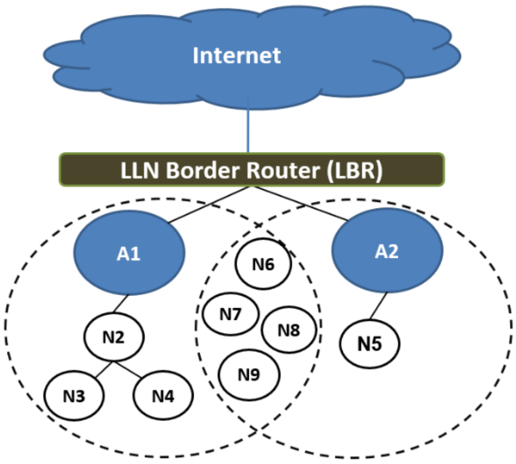

Figure 3. Bottleneck and unbalanced nodes.

Table 2. The possibility of the routing formation

Root nodes	Child nodes	Shared / Intersection nodes	Number of nodes for a parent
A1	N2, N3, N4	N6, N7, N8, N9	7
A2	N5	N6, N7, N8, N9	5

$$\text{Parent\_child\_count} = \sum \text{existing\_Child} + \sum \text{Common\_Trans\_Range\_nodes} \quad (1)$$

In this situation, the connection establishment of the intersection transmission range through the A1 node is overloaded and fragile. If the shared transmission range nodes stick with the A1 as the parent with more children, the result will be an overloaded parent node. This overloaded parent of A1 influences deteriorates, causing high packet loss and no acknowledgement problems for a certain period, and the preferred node quickly loses the energy account of computation. Finally, if the preferred node dies, part of the routing becomes disconnected. To solve this problem without affecting the RPL standard the four metrics are selected, we implement a new novel method that chooses the parent in a load-balancing manner by examining the number of children nodes connected to the preferred parent.

4. Proposed Solution

OFs govern the routing topology and path selection formation in RPL routing metrics. The OFs represent the metrics and constraints for optimizing routing, rank computation, and path selection in a DODAG topology. However, the existing RPL has a great offer to select the OF and routing metrics per application requirements. IETF has the open choice flexibility for LLNs routing method to accomplish the deployment of the different application routing metrics and constraints of RPL OFs. This proposed work section describes and formulates the OFs metrics, and then a novel approach to load balance RPL objective function named WSM-OF is defined. Our intuition indicates that the Multi-Criteria Decision-Making (MCDM) technique is the best technique for solving multiple conflicting decision criteria problems[27]. The Weighted Sum Model (WSM) is the widely used approach that has successfully evaluated the number of alternatives required for decision criteria, and it is the simplest MCDM method. This method is also known as Simple Additive Weighting (SAW) [28]. This alternative selection method combines the value of the metrics with OF and constructs the optimized topology to achieve the load balance in the IoT network.

4.1. RPL Routing Metrics

The metrics are link-based and node-based; the link aspect assesses the speed, QoS, retransmission, time, channel quality, etc. The node-based metrics are measured as physical values like the number of hops, energy, node state, etc. the LLNs routing metrics are listed in Figure 4 by using ETX, residual energy, child count, and link quality level to find the parent and form the routing operations in terms of the balanced network defined as follows:

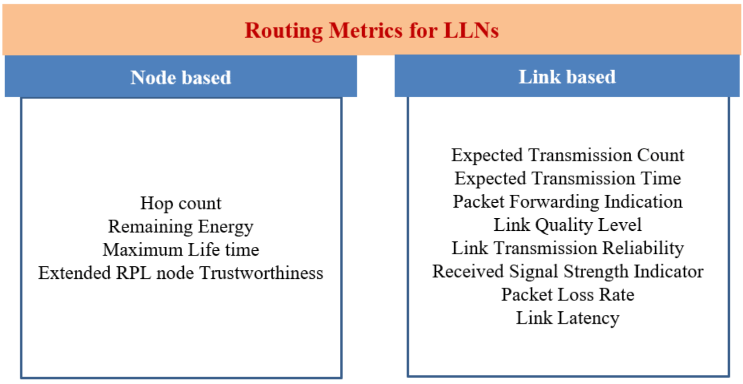

Figure 4. LLNs routing metrics.

4.1.1. ETX

The ETX is identified as a link-based and reliable metric; packet transmissions required expected transmissions count probability for a packet successfully transmitted from the source to the destination node and calculate the ETX value by Equation (2). The highest ETX values indicate the maximum number of transmissions, and the lowest values indicate the minimum number of transmissions for successful Packet delivery for transmitting a packet to the destination with acknowledgement. That means increased ETX values are congested or lossy links.

The ETX calculation follows Equation (2) from the general description of RFC 6551[29].

$$ETX\ (p,c) = 1 / (D_{fd} \times D_{ra}) \qquad (2)$$

Where D_{fd} refers to the probability for the forward delivery rate of the neighbour (e.g., a child node to a parent node), and D_{ra} measures the reversed acknowledgement rate of the neighbour (e.g., a parent node to a child node). ETX estimation measures the link quality between two nodes.

4.1.2. Residual Energy

The Residual Energy (RE) represents the currently available energy for the node. Low RE parent node selection in the routing process should be avoided in the network interface as part of load balancing and to extend the network's lifetime. However, in LLNs, nodes consume energy based on their location in the network and other constraints. The energy availability calculations are shown in the following Equations (3) and (4) are derived from [14]. The spending energy state differs from unit to unit of time. The node energy consumption is calculated in millijoules. This Equation consists of *Energest_Value*, the number of ticks from the running CPU, the current and voltage representing the CPU's energy consumed, and *Rtimer_second*, the fixed number of ticks in the simulation platform.

$$E\_Consumption = \frac{Energest\_Value\ X\ Current\ X\ Voltage}{Rtimer\_Second} \quad (3)$$

$$Remaining\_E(ni) = E(ni) - E\_Consumption(ni) \quad (4)$$

This metric is in our proposed model; the leaf node consideration is high RE root for improving the network lifetime.

4.1.3. Child Count

The child count will be a highly significant node-based metric of DODAG load balance. However, if the parents have a balanced child, it will hypothetically lead to avoiding congestion and unbalanced routing. In the standardized RPL protocol, after the DODAG instance is constructed and the network topology interface is created, the child count is determined using the Child Node Count (CNC) optional(s) field in the DIO message. This method is proposed in [30] to provide the optimization methods for load balance common coverage of child nodes between more than one DAGs. Avoid numerous child nodes connected to dominant parent nodes using other metrics (RANK, ETX, etc.) and alleviate the parent switching. Hence, for the preferred candidate parent set, we use the same CNC metric for the child count metric value in our proposed Equation (5). Sometimes the total number of nodes can be obtained using Equation (7) if needed.

$$Parent\_Child\_Count(i) = MAX\_CNC - CNC\_count \quad (5)$$

$$CNC\_Count = CNC - MAX\_CNC \quad (6)$$

The Equation (6) CNC object field is the number of children, and MAX_CNC is 8 bits, the maximum number of children permitted in the candidate parent nodes. i represent the candidate parent nodes in DODAG. Equation (7) allows finding the total node in the DODAG.

$$total\_node = \sum_{i=1}^{n} Parent\_Child\_Count_i \quad (7)$$

4.1.4. Link Quality Level (LQL)

The LQL metric is not measured directly in MRHOF. If the LQL is well defined, the reliability and PDR would be better in IoT application routing. The LQL estimation mechanism is not mentioned in RFC 6550, but it has represented LQL values from 0 to 7 discrete values. 0 indicates unknown, 1 indicates high, and >= 5 indicates low. There are two open choices for using the LQL, either as a constraint or as a metric. Without any process, the direct actual LQL values are considered a metric, and the indirect (species some condition) LQL values are considered constraints. The single LQL object feature is presented in a DAG metric container. All the nodes can use the LQL value to select the parent node based on IoT routing application requirements. The LQL values are integer number that needs to be lower in providing high point quality, with each node comprising non-monotonic LQL values. The DAG container LQL object metric body is represented in Figure 5. The LQL object has two core fields with 2 bytes of memory. The first 8 bits are reserved fields, and the rest of the 8 bits are divided into 3 bits and 5 bits for maintaining the LQL value (0 to 7) and counter.

16 Bits		
0 1 2 3 4 5 6 7	0 1 2	0 1 2 3 4
(8-Bits) **Reserved**	(3-Bits) **Values**	(5-Bits) **Counter**

Figure 5. LQL object format.

To enable and obtain the DAG LQL object, we proposed the following Equation (8).

Enable_LQL_meritc_object = TRUE;

Parent_node_LQL(i)= node_LQL(i) i.e., for 0,1,2…n; (8)

Where *i* represents a list of available parent node LQL levels.

4.2. WSM Objective Function (WSM-OF) Methodology

The proposed WSM-OF provides a holistic approach for load balancing and congestion aware problems. The previous related work section addressed and proposed the load balancing end enriching the routing problem with single or combined metrics is not enough to achieve a significant routing result. Moreover, the IoT application routing requirements are distinguished from application to application. Hence, the WSM-OF proposes the combined link-based (ETX, LQL) and node-based (RE, Child-count) metrics and addresses the load balancing problem by alternative parent selection and constructs the balanced RPL DODAG, and performs the routing operation. WSM-OF uses MCDM weighted sum model, which selects the optimized alternative parent based on the previous section discussed metrics. Shortly, the metrics values are measured in numerical scaling, assigning the weights to each metric. Then the most preferred alternative parent node would be selected by the highest-scored parent.

Let us consider a DODAG instance with a set of candidate parent $CP = \{cp_i, i=1,..., n\}$ with a set of n number of routing metrics $RM = \{rm_j, j = 1,\dots, m\}$ for a parent. The influence of weight vector $W = \{w_k, k=1,\dots n\}$ is to evaluate the importance of the individual weight of metrics. Then the balanced candidate parent selection decision can be represented in the DM matrix, consisting of *n* alternative parents and *m* is considered routing metrics. This proposal considers four metrics (ETX, LQL, RE, and Child-count) to determine the appropriate parent selection. In this scenario, the metrics (criteria) are defined into two types benefits (positive) and costs (negative), thus defining the importance of metrics. The use of benefits is the high-value preference, whereas the cost value is the opposite for appropriate results. The WSM process is carried out in the following steps:

The decision matrix $DM = n \, X \, m$ is constructed by numerical (metric) values as follows:

$$\begin{array}{ll} \text{Alt.} & \quad \text{rm1} \quad \text{rm21} \dots \ \text{rmN} \end{array}$$

$$\text{DM} = \begin{matrix} \text{cp1} \\ \text{cp2} \\ \vdots \\ \text{cpn} \end{matrix} \begin{bmatrix} \text{x11} & \text{x12} & \cdots & \text{x1m} \\ \text{x21} & \text{x22} & \cdots & \text{x2m} \\ \vdots & \vdots & \cdots & \vdots \\ \text{xn1} & \text{xn2} & \cdots & \text{xnm} \end{bmatrix}$$

Where cp_n are possible alternative parents, among them, the node has to select the desired n metrics represented in r_n to choose alternative criteria. x_{ij} is the value of i^{th} choice with routing metrics for j=1, 2, …, m.

Therefore, in our proposal we have rm = 4 and i.e., rm1 = ETX, rm2 = child_count, rm3=RE, and rm4 = LQL. According to the WSM method proposal, we used Equation (9) for calculating preference parent:

$$\text{wsm}_\text{i} = \sum_{\text{j}=1}^{\text{n}} \text{rm}_\text{i} \ \text{NDM}_\text{ij} \tag{9}$$

Where the x_{ij} values are normalized by the following Equation (10) for without any consideration of benefit or cost metric scale:

$$\text{NDM}_\text{ij} \quad = \frac{\text{rm}_\text{ij}}{\sum_{\text{i}=1}^{\text{n}} \text{rm}_\text{ij}} \tag{10}$$

Determine the maximum comparable scale benefit of RE and LQL metrics values are normalized DM and obtained by Equation (11):

$$\text{NDM}_\text{ij} \quad = \frac{\text{rm}_\text{ij}}{\max(\text{x})_\text{ij}} \tag{11}$$

Determine the minimum comparable scale cost of ETX and child-count metrics values are normalized DM and obtained by Equation (12):

$$\text{NDM}_\text{ij} \quad = \frac{\min(\text{x})_\text{ij}}{\text{rm}_\text{ij}} \tag{12}$$

Then, the highest (max) and lowest (min) values of rm_{ij} equal 1. Then, we assigned equal weights to each metrics. Therefore, the sum of weight w = 1 and average of each metric weight by using Equation (13):

$$\text{rm}_\text{j} = \frac{\text{w}}{\text{rm}_\text{n}} \tag{13}$$

Next is the calculation of potential parent *CP* from the normalized decision matrix (NDM) using Equation (14).

$$\mathrm{CPi} = \left\{ \max\left\{ \sum_{j=1}^{n} \mathrm{rm_i}\ \mathrm{NDM_{ij}} \right\} \right\} \quad (14)$$

The obtained value CPi is ranked from maximum to minimum so that the best parent knows which has the higher value; thus, the successive potential candidate parent is obtained from the gained ranking.

4.3. Parent Selection Method

The proposed WSM result selects the most suitable parent from the candidate parent list based on the defined routing metrics. In the existing DODAG, a node in the position to change the parent due to some of the issues discussed in the problem statement section or a new node that readies to join the DODAG instance utilizes Equation (9). It forms the network instance as a balanced one. Furthermore, to select potential parents from the parent set using the discussed metrics of ETX, LQL, RE, and Child-count.

The presented Algorithm 1 is used for the parent selection method, which uses WSM-OF and metrics to synopsize the proposed parent selection method. The proposed holistic approach, step 8, has selected a preferred parent by WSN computation. These used metrics have the same influence because we assigned an equal weight (w) to each metric. This algorithm ensures whether the candidate parent set (CS) is empty or not in step 2. If the CS is null, there is no network instance. Else, assigning the metrics and DIO to P is performed in step 4. Step 10 counts the parents in the current network instance. If the count is more than one, we move to step 11. Otherwise, it is considered there is only a single parent is available in the network instance.

Algorithm 1. Preferred parent selection method

Input: Candidate_Parent_Set(CS), DIO message
Output: Load balanced preferred parent

```
1:    begin
2:        if (CS ≠ NULL) then
3:            while P ε CS do
      // Node metrics and DIO information of each P
4:                P[i] ← ETX, LQL, CC, RE and DIO;
5:            end While
6:            return P;
7:        while Pp ε P do
      // Compute the proposed method
8:            Pp[i] ← wsmOF(pp[i]);
9:        end while
10:       if(count (PP) > 1) then
      // Select the preferred parent with the top rank from the Pp list
11:           return (max_rank(Pp[i]));
12:       else
13:           return Pp [0];
14:       end if
15:       end if
16:   end
```

5. Performance Evaluation

In this section, the network metric performance of the proposed WSM-OF is evaluated through simulation tests carried out by the Cooja simulator under Contiki operating system. The Cooja simulator provides a flexible, open-source, and easily customizable computing platform to evaluate the RPL protocol implementations [31-32]. The simulation results are analyzed with the existing RPL OFs of OF0, MRHOF, and LB-OF.

5.1. Simulation Configuration

The Cooja simulator is a cross-layer, java-based, and suitable for LLNs and IoT configurations. The Unit Disk Graph Model (UDGM) radio medium is adopted for this work, in this simulation is carried out with different node densities of 10 to 100, and each simulation duration is one hour. During the simulation, the nodes were scattered disorderly in the network transmission range of 100 m x 100 m. Then initially, the node energy is assigned to 10 millijoules (mJ) to obtain the energy utilization average of each density. Each simulation setup runs been performed at different times, and an average of results has been considered and extracted for further discussion. Table 3 presents all other parameters used in this proposal. Figures 6(a) and 6(b) show the node density scenario simulation environment configuration from Table 3.

Table 3. Simulation Setup.

Network Parameters	Value
OS	Contiki 3.0
Simulator	Cooja
Moto type	Tmote sky
Radio model	Unit Disk Graph Model (UDGM)
Routing Protocol	RPL
Objective Function	OF0, MRHOF, LB-OF, and WSM-OF
Media Access Control	IEEE 802.15.4 / 6LowPAN
Nodes Density	10 – 100
Topology Type	Random
Simulation Transmission range	100 m x 100 m
Initial Energy	10 (mJ) milliJoule
Each Simulation duration	60 min
Interference range	75m
TX and RX	100 %
Data Transmission interval	60s

5.2. Result and Discussion

This section discusses the performance of the various routing metrics specifications according to the previous section's simulation configuration. The result analysis is also conducted for each of the different network densities. The result provides useful discernments for attaining the proposed method outcomes.

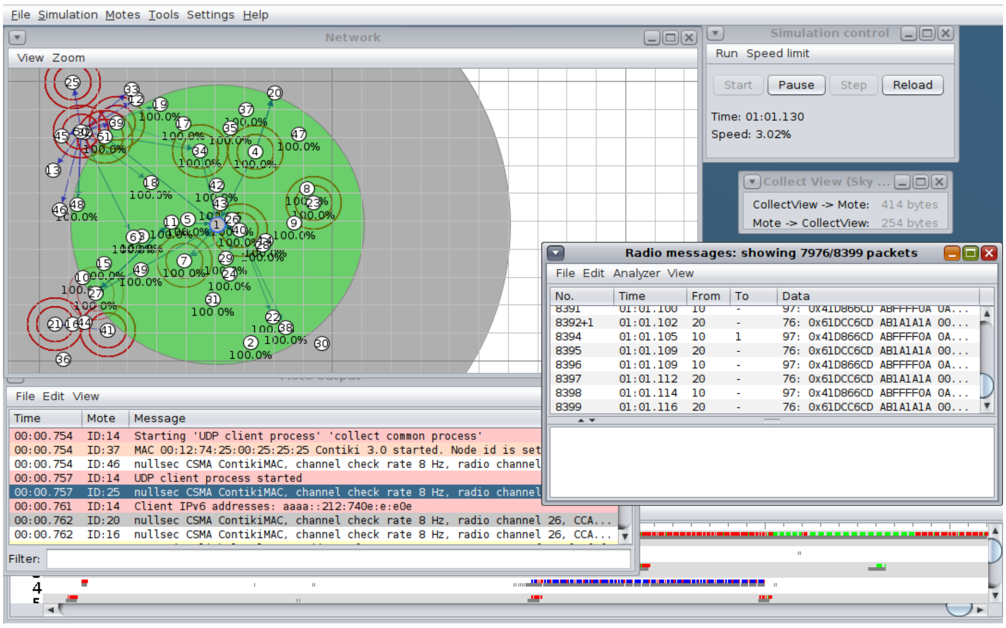

Figure 6 (a). Simulation network setup with 50 nodes random topology.

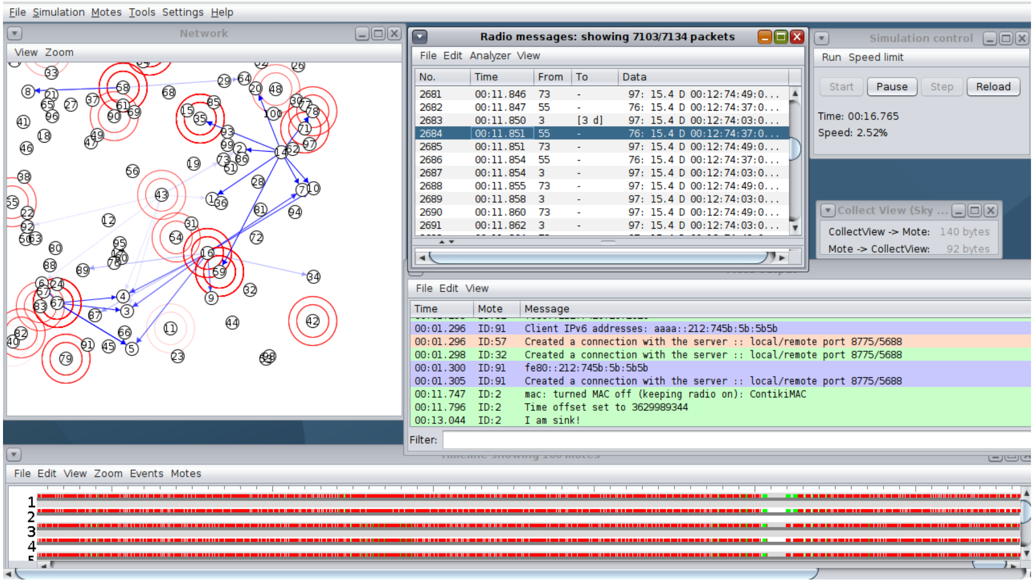

Figure 6 (b). Simulation network setup with 100 nodes random topology.

5.2.1. Control Overhead

The RPL protocol forms DODAG topology by the control messages exchanging technique discussed in the previous section. These control messages are increased or highly generated when the network becomes unstable and affects the network performance. The leaf or source node transmits messages to an unbalanced or overloaded parent then the parent node rejects the packets to the source or leaf node. In this situation, the leaf node increases control messages generated by retransmission. Moreover, the control overhead is also subject to the network performance; in this proposed method, the leaf nodes select the balanced parent and reduce the rejecting ratio. The average control traffic overheads are discovered from a route discovery phase that generates the number of control messages for routing formation. In section 2, we mentioned the control messages for DODAG formation; in this proposal, the default parent switching and bottleneck parent selection are reduced. However, the decrease in control message transmission obtains a good impact result of 5.75%, and the control overhead compared result is presented in Figure 7. The network control overhead between nodes is calculated by Equation (15).

$$\text{Control\_message\_overhead} = \frac{\sum \text{control\_message\_packets}}{\sum \text{data\_packets}} \text{ x } 100 \quad (15)$$

An average control overhead indicates the number of control messages generated during the route discovery phase.

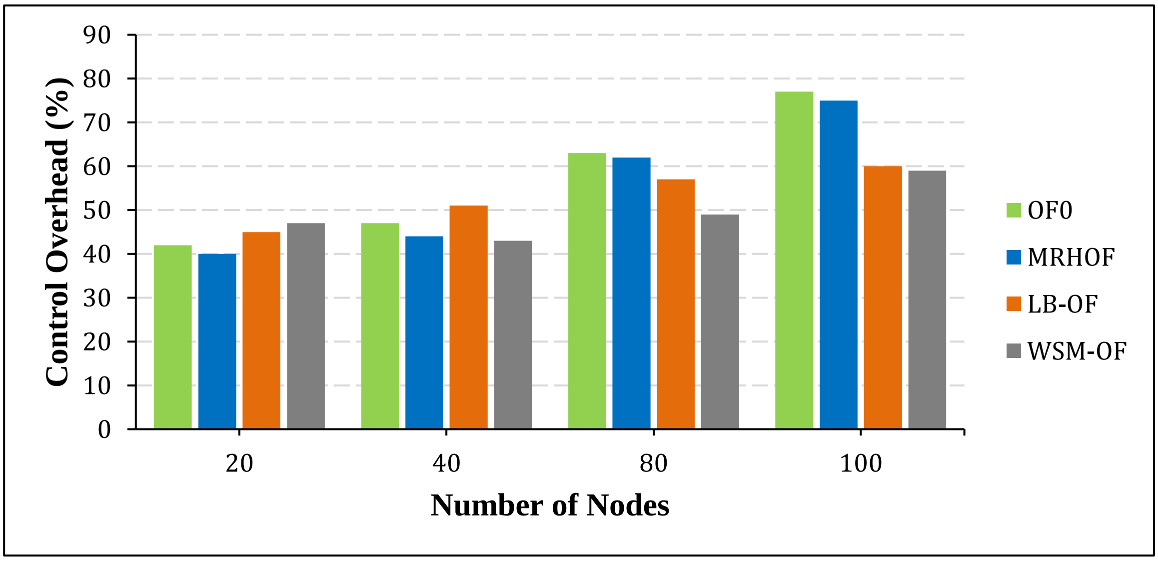

Figure 7. Overheads (%) analyze for 20, 40, 80, and 100 nodes.

5.2.2. Jitter

The Jitter is a QoS performance metric that indicates the packet transmission delay variation over time. The packet transmission randomization time is called a Jitter. Higher end-to-end delays in the existing packet transmission method may increase collisions [23]. Therefore, we considered Jitter as the main QoS parameter in RPL. We attempted to reduce packet retransmission and improve network stability to increase the PDR. The packet delay variation represents the end-to-end delay, and the jitter variation of packet reaching time is calculated as two successful packet transmissions between nodes using Equation (16).

$$\text{Jitter} = \frac{\text{total\_Jitter}}{\text{number of nodes}} \tag{16}$$

The jitter parameter is highly required in real-time applications because the packets should reach their destination node within the constrained delay in IoT applications. In the simulation, the jitter experiments are observed with our WSM-OF on the comparison of the OF0 and MRHOF has more delay due to high overhead in the control message phase itself, and the improper load balancing has more congestion. This case leads to more causes for Jitter. On the other hand, the jitter performance is good at low density in the LB-OF. While the network density increases, the link quality is unstable, and the level of delay is high. Looking at Figure 8 here, OF0 gives a better jitter, but the reality is that when there are more nodes, the node energy drains faster, the number of alive nodes decreases, and the OF0 cannot transmit the packets, which gives the illusion of less Jitter. Also, it is noteworthy that our proposed method has reduced and guarantees low Jitter by up to 7.11 % on average.

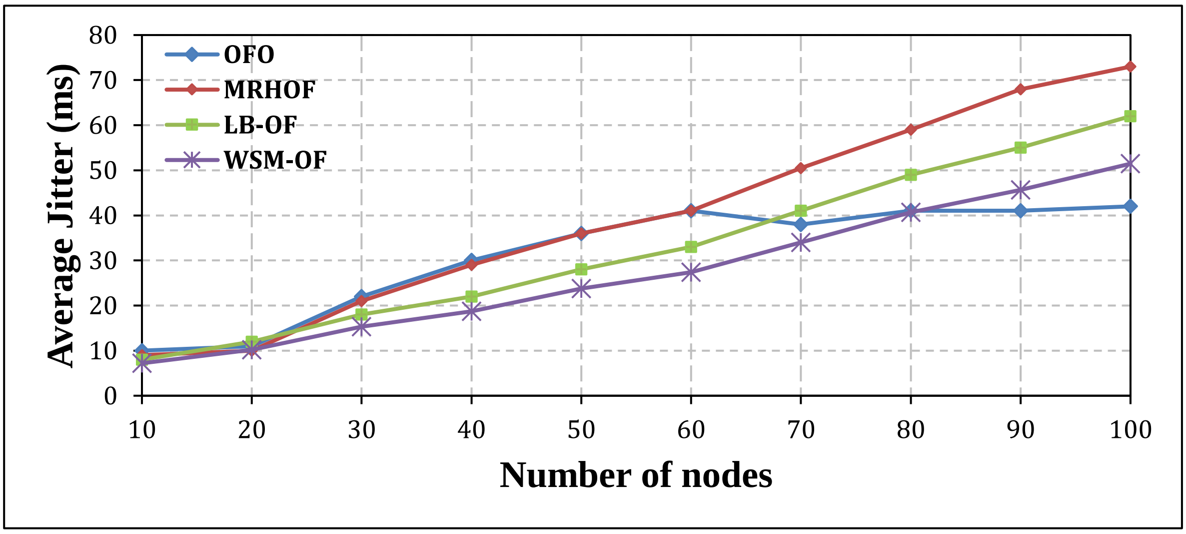

Figure 8. Average jitter performance for the 100 nodes.

5.2.3. Packet Delivery Ratio

The sender node's successful packet delivery ratio will be defined by the default Equation (17), which indicates the sender end's successful delivery ratio. Due to the high packet traffic and unbalanced RPL DODAG instance, reducing the packet drop ratio is challenging. This PDR metric measures the success rate of data transmission from the source to the destination nodes. The packet delivery ratio with diverse node densities is illustrated in Figure 9. To predict the PDR result estimation, we considered four different network density simulations such as 20, 40, 80, and 100 nodes, and analyzed, when compared to other works, the average PDR exhibits up to 94.3% outperformance, resulting in low-density, and when traffic load and network density increase, the result decreases by only 2%.

$$\text{PDR} = \frac{\text{Total\_packets received in sink\_node}}{\text{Total\_Packets send by sender\_nodes}} \text{ X } 100 \tag{17}$$

5.2.4. Parent Switching

In the existing traditional OFs, the node selects the parent randomly due to an improper load-balancing method, and as a result of this scenario, the constructed DODAG is unstable [23]. The root node propagates the DIO message and rank information to its sub-nodes. The DIO message receiving sub-nodes selects the appropriate parent node by minimum rank values. The routers will then calculate their current rank as per OFs. This parent's selection directly influences network balance, and this unbalanced parent selection causes immediate or frequent parent switching.

Moreover, this switching process has a high possibility of delayed transmission, affecting the entire network's stability by default. The preferred parent nodes in our proposed method will be selected based on the metric phenomenon, avoiding reselection and decreasing parent selection, greatly increasing network stability and the possibility of extending network lifetime. By default, the parent selection turns on in OF0, MRHOF, and LB-OF at various time intervals or DIO message, rank update basis, despite our proposed equal weights (w) to selected metrics. Accordingly, at the initial DODAG construction level, the balanced parent selection and reselection will also be reduced. Figure 10 depicts average parent switching among node densities OF0, MRHOF, LB-OF, and WSM-OF, respectively 0.81, 0.73, 0.59, and 0.54 percentages.

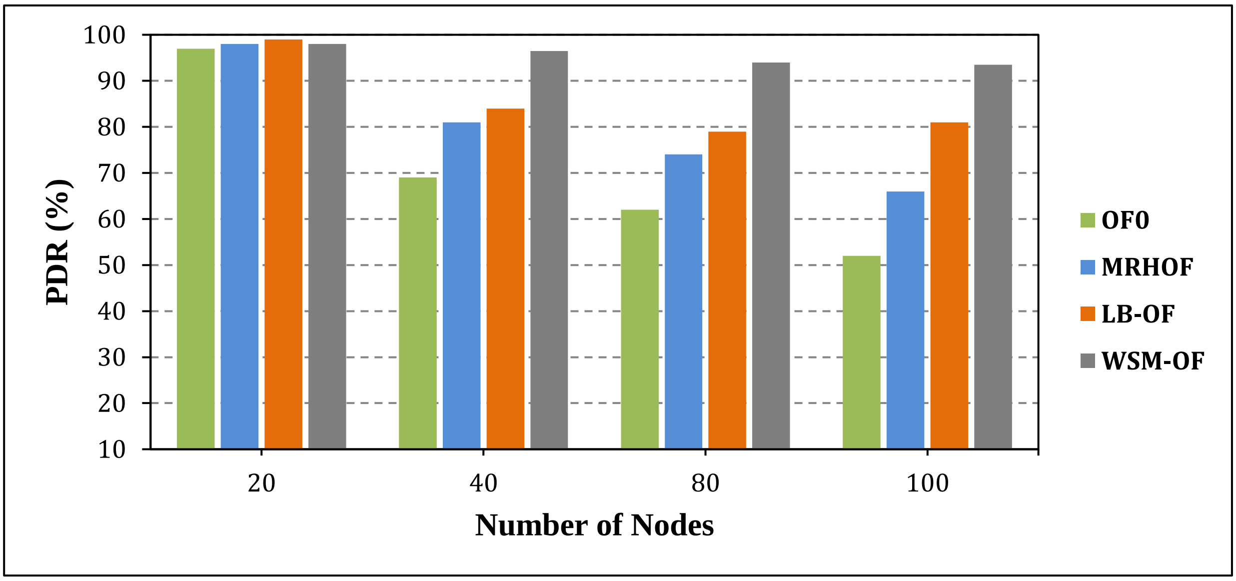

Figure 9. Packet delivery ratio analysis under four scenarios of node density.

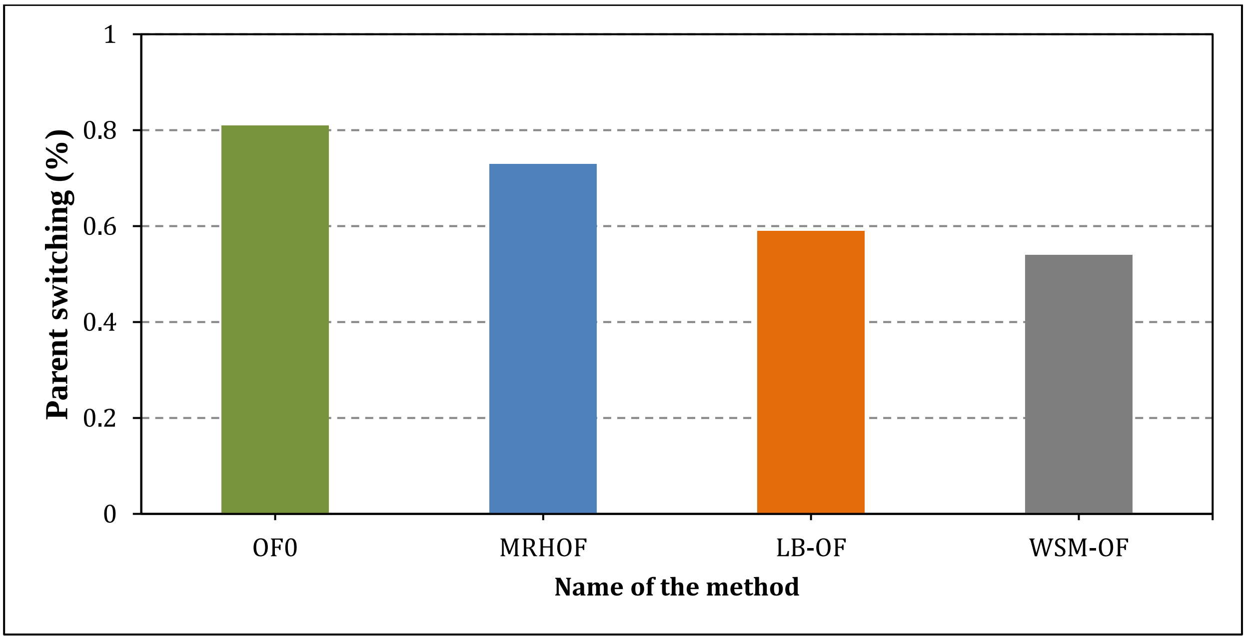

Figure 10. Average parent switching.

5.2.5. Energy Consumption

The utilization of node energy consists of control messages for topology formation, packet transmission between nodes, and sensing. As a result, this energy utilization parameter is noteworthy and highly essential. As a result, poor or high energy consumption directed the nodes to get a quick drain, which caused the issue of quickly down the network instances. The IoT network instance node is fixed in remote locations and physically accessible, and the power battery replacement or recharging of the node is not possible.

The network lifetime depends on this parameter. In our proposed approach simulation setup, the node energy is initially 10 mJ. Equation (21) is used to find the energy consumption of the node and then follows Equations (18) and (19). The following energy components of CPU power indicate (P_{CPU}), transmission power (P_{tx}), packet receiving power (P_{rx}), and idle mode of low power (P_{lpm}) are considered for obtaining the average energy consumption in our proposed result.

$$\text{Pcomp} = P_{tx} + P_{rx} + P_{cpu} + P_{lpm} \quad (18)$$

$$\text{Ncons} = \frac{\sum_{i-n} E_{cons}}{\text{Run\_time}} \quad (19)$$

The obtained comparison result shows the average energy consumption in Figure 11. The proposed work energy consumption is reduced by up to 10.2 % in low density and 7.55 % in high density in a different simulation scenario. Moreover, the main advantage of this proposed work is that load balancing, and the potential parent selection process does not consume additional energy. This default leads to extending the network instance lifetime.

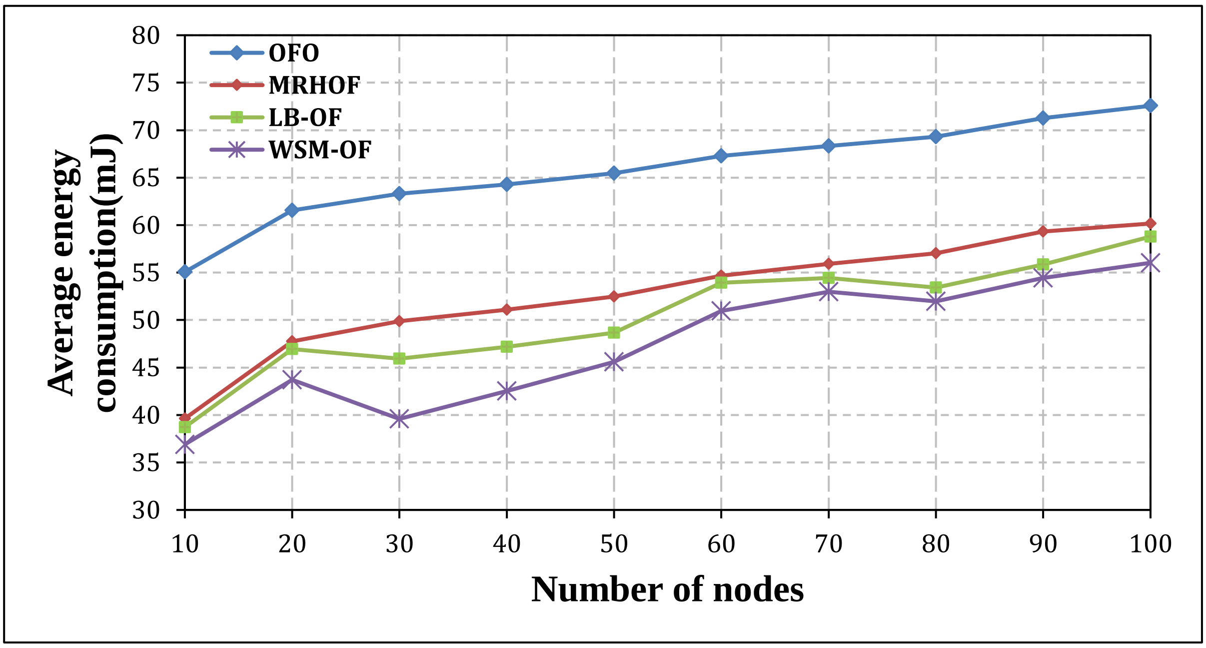

Figure 11. Average energy consumption percentage (mJ).

5.2.6. Latency

Usually, the latency represents time spent on data transmission between nodes; this metric will affect the network performance and decrease the QoS. Moreover, the latency metric is a delay time, or how long a node takes to transmit data between the initiating node and the receiver node. The primary factors affecting transmission time are link quality, buffering delay, path selection, node sensing speed, etc. The following Equation (20) depicts that for calculating the latency, the low latency packet arrival will have a good result in network performance and increase the network lifetime.

$$\text{Latency} = \text{Sink\_Node\_Data\_ Receive\_time} - \text{Data\_send\_Node\_time} \quad (20)$$

Minimizing network latency is another target for this proposed method. In this proposed method, the ETX metrics support the nodes to use the stable paths with minimal latency to arrive at the DAG balanced root because the nodes are balanced and overall traffic flow is lower with the sink node. Figure 12 shows an average latency of up to 6.63 % when the packet transmission interval is short compared to OF0, MRHOF, and LBOF. The latency is notably higher when the network density is high. Unlike regular parent nodes, we balanced the parents based on routing metrics. It has the minimum number of children, and this comparative scheme confirmed that our proposal is improved compared to the existing work.

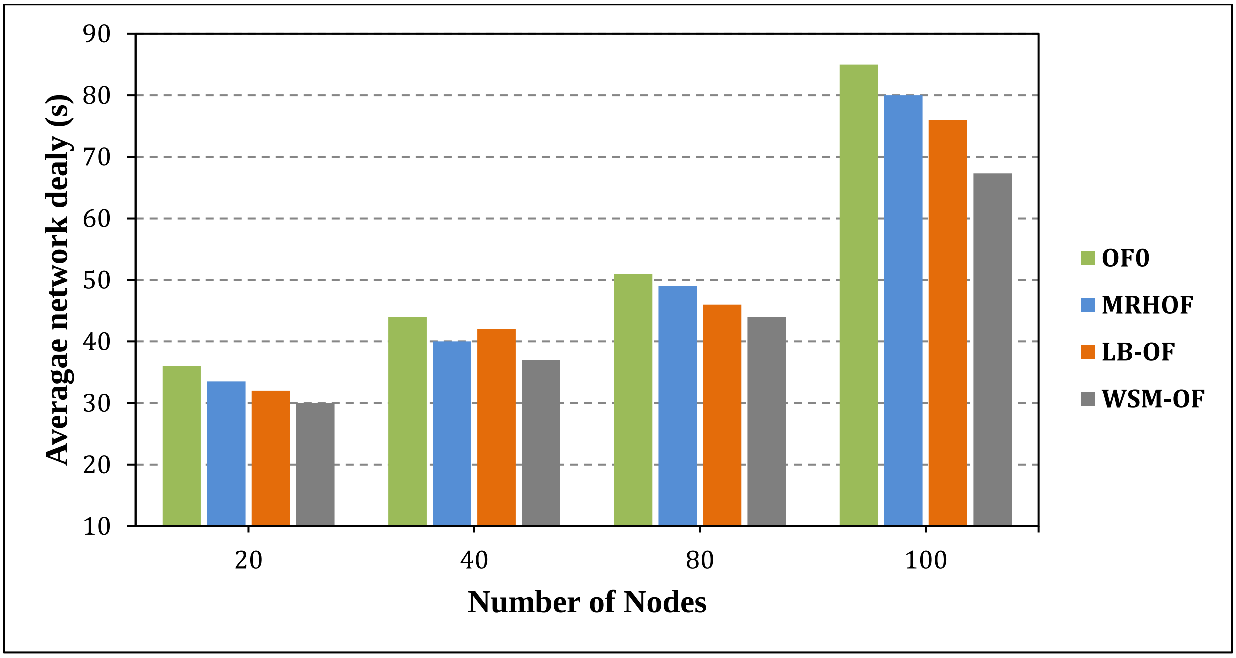

Figure 12. Average network latency of 20, 40, 80, and 100 nodes.

5.2.7. Network Lifetime

The network lifetime is specified by the time duration of a node has expired due to energy depletion. The network lifetime is very low in more packet transmission places, and the energy metric has a high response in the WSN lifetime[33]. The major reasons for quick energy drain are long hop selection for routing, frequent parent switching, a high threshold in the root node, delay in response and reply, misappropriate root selection, etc. Figure 13 assessment shows the node energy is concerning. There is no notable difference in the first 18 minutes, and all the nodes energy varies only from 1% to 2 % in our comparison. All the nodes are in a functional state. On the other hand, the counterparts of OF0, MRHOF, and LBOF observed that energy drains more quickly than in our proposed work. This metric is calculated, and after the simulation, we consider the number of nodes alive. For this finding, the average reaming energy is observed from each node of the entire network. In this scenario, we consider the high-density network instances only. The remaining energy is computed by following Equation (21) from Equation (19) and then counting the number of nodes whose energy is > 1 MJ.

$$Node\_Avial\_Energy(i) = Node\_Initial\_energy(i) - Node(i)_{cons} \quad (21)$$

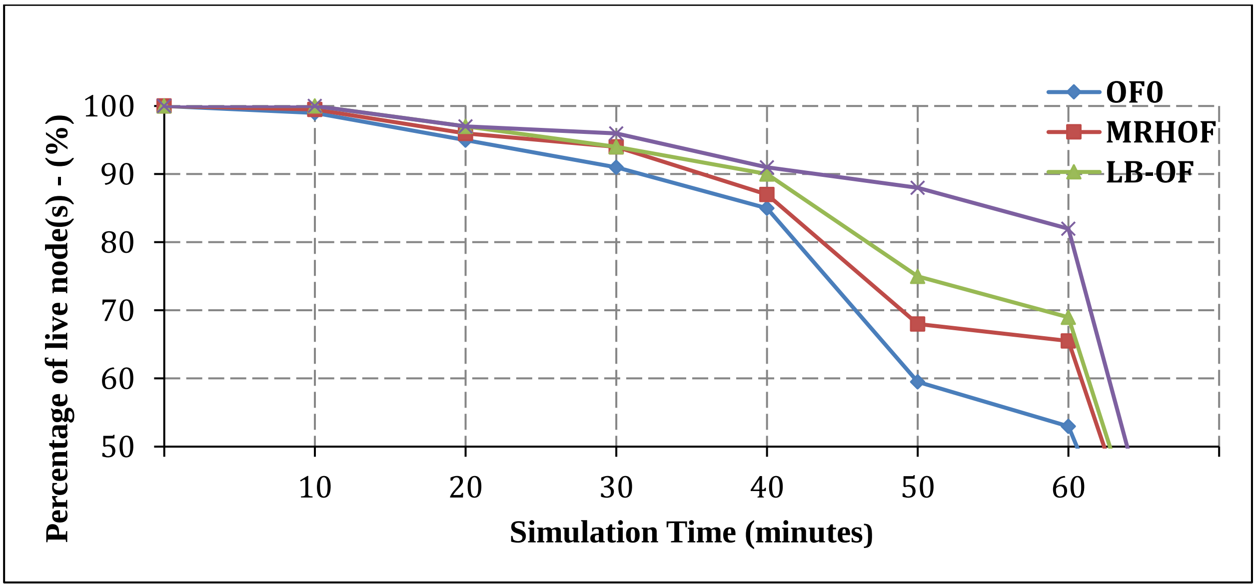

Figure 13. Shows the average of live nodes in 10 minutes intervals.

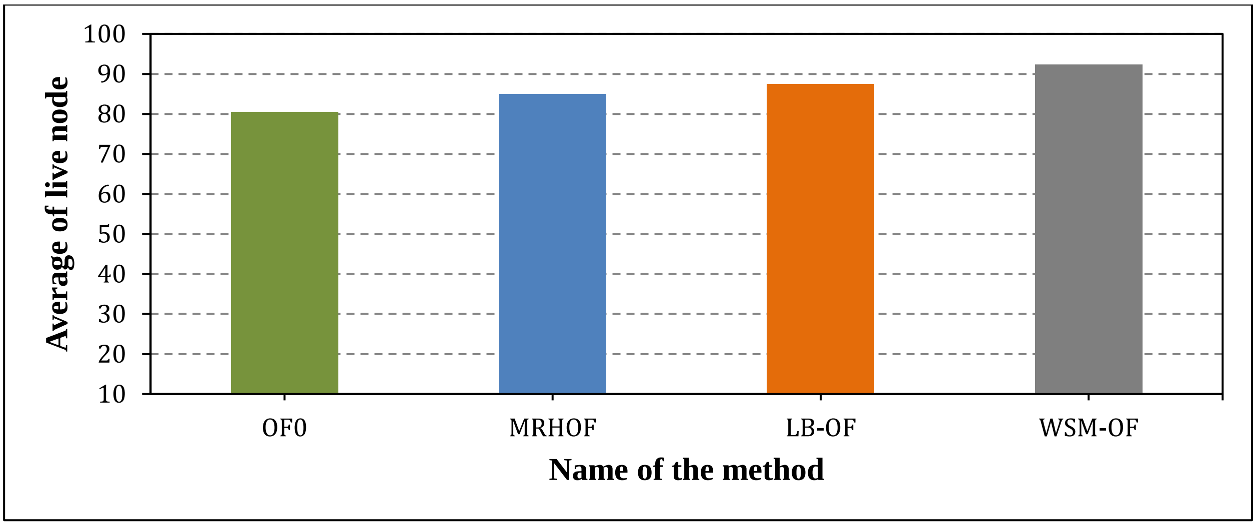

Figure 14. Average of live nodes in 60 minutes simulation.

6. Conclusion

Routing in IoT networks based on RPL has many schemes for network node optimization and extending the network lifetime in terms of energy utilization, improving stability, and handling the load balance from the imbalanced default RPL network topology. In this article, we proposed WSM-OF, which combines link-based and node-based metrics to help alleviate unbalanced routing. The proposed WSM-OF alleviates packet transmission congestion by forming the balanced DODAG topology method. The load balancing method appropriately selects the best parent and constructs the balanced topology for the routing process. We defined the structure as the MCDM problem, which is solved by the WSM approach to solving the parent selection problem in RPL. The WSM-OF balances the topology overload of nodes in the IoT network, achieve a certain load balance level and improves the QoS. The load balancing method ensures that the nodes are protected from unbalanced circumstances while also providing the best preferable parent selection to establish an alternative route to the root to manage and increase the packet delivery ratio.

Additionally, the WSM-OF can extend the network lifetime and improve energy consumption. Extensive simulation experimentations were carried out in the Contiki Cooja simulator to confirm this performance. The simulation result shows that WSM-OF outperforms existing protocols in terms of control message overhead, jitter, PDR, energy usage, parent switching, latency, and network lifetime. Moreover, we propose that the WSM-OF load balancing method utilize link-based and node-based metrics. We suggest that more metrics can be combined to construct a balanced DODAG. Thus, our future flow of this work includes the extension of IoT applications to select the optimized path in the balanced topology. At the same time, the source node has more than one alternative path to the destination node, dynamic metrics selection according to IoT application requirements, interoperating this work into mobile RPL and implementing the same in the test bed to identify the real-time impediments.

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