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# AN ENHANCED ANALYTIC HIERARCHY PROCESS OBJECTIVE FUNCTION (EAHP-OF) FOR AN OPTIMIZED PARENT SELECTION IN RPL NETWORKS

**[1]Ramadevi Chappala, [2]Dr. E.Sreenivasa Reddy**
[1]Research Scholar, Department of Computer science and engineering, Acharya Nagarjuna University (ANU), Guntur, Andhra Pradesh, India-522510.
[2]Dean & Professor, Department of Computer Science and Engineering, Acharya Nagarjuna University (ANU), Guntur, Andhra Pradesh, India-522510.

**Abstract**
Lossy and low power networks describe the technology used for the Internet of Things (IoT). In order to efficiently manage and administer high quality of service objectives in such networks, a reliable routing protocol is required. The Objective Function has allowed the IPv6 Routing Protocol for Low Power and Lossy Network (RPL), which prioritizes the Internet of Things, to gain traction. The RPL core uses a single measure as its default Objective Function (OF). As a result, the routing protocol is unable to handle various restrictions and exhibits congestion problems with heavy traffic. For that, we proposed in our paper Enhanced Analytic Hierarchy Process Objective Function (EAHP-OF), which uses novel strategies to combine ETX, child count, queue size and work-metric in OF to calculate rank, for the best parent selection procedure. Using an adaptive threshold, the network stability was also considered because several limitations might result in frequent parent changes. The proposed work was simulated in NS-3 against AHCCP and CBMPLB, and the results were good in terms of Packet Loss Ratio (PLR), throughput, and the number of DIO packets.
**Keywords –** Child Count, Expected Life Time (ETX), Internet of Things, Load Balancing, Objective Function, Queue size, Work Load.

## I. INTRODUCTION

Low-power Lossy Networks (LLNs) are a type of embedded device network that is often used in the IoT. These networks have few routers and connections. The routers only have a little amount of resources, including memory, battery life, bandwidth, and processing power. LLNs made up of hundreds of embedded networking devices can be useful for many applications, such as smart grid automated metering infrastructures (AMIs) [1], industrial monitoring [2], and wireless sensor networks (WSNs) [3]. Nowadays, most LLN implementations connect to the larger Internet via an open, standardized IPv6-based infrastructure. This method improves the versatility, adaptability, and interoperability of LLNs, opening the way for such idea of the IoT. Many standardization efforts by the IEEE, IETF, and Zigbee have helped get the protocols and application profiles of IoT systems ready for large-scale deployments [4]. The 6LoWPAN (IPv6 over Low-power Wireless Personal Area Network) protocol allows devices that can't connect to an IPv6 network to do so. However because the Internet and the Internet of Things are expanding, traditional routing protocols like OSPF, OLSR, AODV, or DSR cannot function with the IoT and cannot get beyond LLN restrictions. For use in 6LoWPAN for LLNs, the IPv6 Routing Protocol for Low power and

Lossy Networks (RPL) was made and defined. RPL supports all types of communication, such as Multipoint-to-Point (MP2P), Point-to-Multipoint (P2MP), and Point-to-Point (P2P). RPL has a number of distinctive characteristics, including as the ability to self-heal, minimal energy usage, simplicity in topology building, and loop-free design. This protocol's inability to conduct load balancing is one of its major weaknesses, which is essential for the fair distribution of traffic throughout the network.

Our method uses an OF to express the routing metrics and constraints that control the network path selection process. Which metric(s) and OF are employed will depend on the network requirements and application demands. Thus, an OF's design is crucial in a large WSN because devices vary in terms of their technological and physical attributes and because a variety of factors might have an impact on how effectively the network functions. The RPL routing protocol lets users create routing methods based on their preferences for network requirements and metrics [5]. The OF concept gives us this ability, and it is also one of the main topics of our study. It is necessary to assess a node's suitability in accordance with OF in order to use it as a tool for achieving the network aim. Nevertheless, RPL and its components were designed particularly for networks with low throughput and dynamicity. The path selection and topology development are governed by the routing metrics and OFs used by RPL. The article shows how to find and optimize routes in a DODAG, as well as how to use connection metrics and limitations for the rank calculation. Nevertheless, the RPL standard does not mandate which OF or routing metric must be used, leaving this open to implementations. It has a lot of flexibility because it needs to meet the many optimization needs of a wide range of deployments, applications, and network architectures. Even though the IETF has given different ideas for how to design OFs [6], it has not said what routing metrics should be used. The precise selection of a parent set is still left to the implementation. RFC 6551 [7] provided a variety of routing metrics and restrictions for use in path calculation in RPL, but the specific option was left up to implementations. In our proposal, we provide the novel notion of a mutual decision process between a parent node and a child node such that a parent node also take part in parent node selection, in contrast to RPL, which only depends on a child node to make decisions. A combination of routing metrics, including ETX, child count, queue size and work metric form the basis of the Enhanced Analytic Hierarchy Process Objective Function (EAHP-OF). Depending on the node's rank, EAHP-OF maintain the network stability by suggesting an adaptive threshold value. To the best of our knowledge, there is no other OF that selects the optimal parents while taking into consideration all of these important factors.

This paper follows the following structure: Part II provides a high-level summary of RPL. The most recent research addresses the various RPL OFs are included in section III. The proposed OF for the best parent selection was discussed in Section IV. Section V, which comes next, shows the results for NS 3. In Section VI, we talk about the conclusions, and in Section VII, we list the sources we used.

## II. BACKGROUND DETAILS OF RPL

In order to overcome the routing issues specific to LLNs, the IETF ROLL working group developed the standard protocol known as RPL. RPL was made available in RFC6550 [8] in March 2012. Low-power embedded devices may connect to the 6LoWPAN edge router using RPL, which operates on top of the 6LoWPAN adaption layer. In order to do this, RPL creates a Destination-Oriented Directed Acyclic Graph (DODAG). RPL employs routing tables as a proactive distance vector protocol to find the shortest path depending on distance. Every device in the network keeps one or more tables with a streamlined representation of the topology. High packet loss rates, quick energy depletion of bottleneck nodes, and load imbalance are performance concerns with RPL networks brought on by large traffic loads. A DAG, often referred to as a loop-free directed acyclic graph (DODAG), was produced by RPL. Its unique origin and destination are identified by its DODAGID. The best routes through RPL are those that use the DODAG design, which needs the exchange of ICMPV6 control messages [9] for data traffic to move between low-restricted nodes. Understanding the following RPL-related topics is necessary:

*A. ICMPv6 Control Messages*

- **DODAG (DIO)**

The root node broadcasts DIO initially, and then the neighbours repeat them. With the upstream route information, a node can use this multicast control message to find an RPL instance and join it. For RPL-based DODAGs to be made and kept up-to-date, they need four basic inputs. Initially, an RPL Instance is formed by a collection of unique or many DODAGs that share the same RPL_InstanceID. Second, a new version of the DODAG can be created using the number known as the DODAG_VersionNo, which is incremented progressively from the root. The tuple (RPL Instance ID, DODAGID, and DODAG VersionNo) is a unique way to find information about the DODAG Version. DODAG root's identification is the DODAGID. Last but not least, Rank is the DODAG node property that describes the node's position in relation to the system's root. Rank rises steadily in the direction of departure from the DODAG root.

- **DODAG Information Solicitation (DIS)**

In order to join the DODAG, the nodes send DIS messages to the nodes next to them if they do not receive DIO packets from them within a predetermined amount of time. When a node enters a network, it sends a multicast message known as the DIS to request a DIO message in order to learn more about the DODAG.

- **Destination Advertisement Object (DAO)**

The nodes travelling upwards send this packet to their respective parents to let them know that they have selected them to travel to the sink node. It is sent to the DODAG root (storing mode) or to the parent that was chosen (non-storing mode). A full path will be built once at the root, and nodes will update their routing table each time a Request is received.

- **DAO Acknowledgment (DAO ACK)**

This control packet contains information such as the DAO Sequence, RPL_Instance ID, and Status that was generated by the recipient in response to the DAO message.

***B. Rank***

The node's specific location or distance from the root is a scalar value derived using the OF during the DODAG creation process. Whenever we move away from the root, it grows downward. $R_{\text{parent}}$ is the rank of the parent node P, and RI is the Rank Increase in a variable that specifies a rise in rank when moving from parent P to node N, and it changes according on the choice of OF. According to (1), the rank of the node $R_{\text{node}}$ changes.

$$R_{\text{node}} = R_{\text{parent}} + RI \qquad \text{---------------} \qquad (1)$$

At first, the DIO signals are sent downward from the DODAG root to all of its neighbours. When a node receives its first DIO message and decides to join the DODAG, it adds the sender's address to its parent list, figures out its rank, and then sends DIO packets to its neighbours with its most recent rank. If the DIO message comes from more than one parent, the node also does the following:

-  In the event that the packet does not meet all the requirements, it may be discarded.
-  If none exist, it will analyse the DIO packet and use the new DIO to establish its own rank value If the calculated value is higher than the previous rank value, the position stays the same. If it isn't, it moves down in the DODAG to the lower rank value. DIO packets with the revised data will then be sent to the neighbouring DIOs. After putting together, the DODAG, each node sends a DAO control packet upstream to its chosen parent to find out the path to the sink node. This makes it easy to see how each step got from the root of the DODAG network to each node. Figure 1 shows the whole thing.

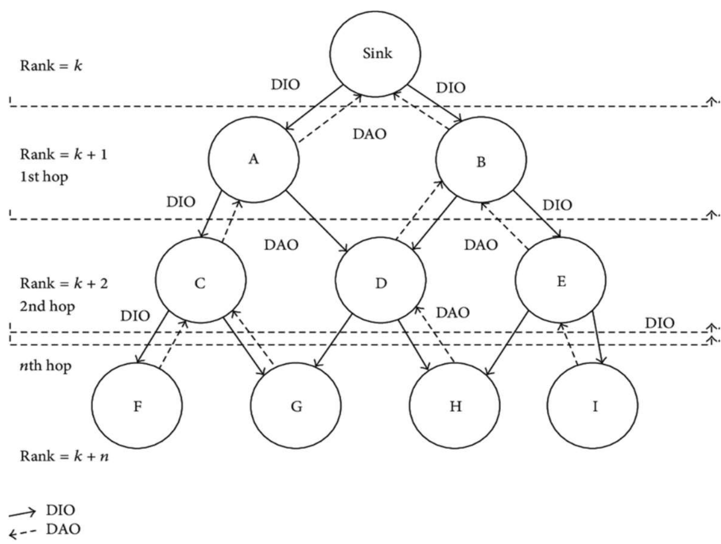


Figure1. Rank Evaluation process

*D. Objective Functions (OFs)*

The OF in RPL supervises the construction of a DODAG in accordance with a set of standards and the rank computation process in RPL using certain metrics. The best RPL versions employing the different OFs are being developed via extensive investigation. From the list of parents, the one with the lowest rank value is chosen. OF uses a number of routing criteria to figure out which parent has the lowest rank value. Each node chooses a preferred parent, and then the best path is found based on a number of performance criteria, such as using the least amount of energy, having the best connection, making the network last longer, reducing latency, and so on. RPL is made up of two different measures. Link measurements like ETX and latency show how good the connections are. Node measurements like hop count and energy show how the nodes are doing [19]. The two varieties of conventional OFs are Minimum Rank Hysteresis Objective Function (MRHOF) [11] and Objective function Zero (OF0)[10]. The combination of the Node and Link metrics into various sorts of OFs results in an improved form of RPL. An important problem with the present OFs is the load distribution problem.

This degrades the DODAG's performance since it is impractical to evaluate all of a good link's characteristics using only one or two measures, especially when the standards occasionally clash. For instance, adopting the Expected Transmission count (ETX) as a single routing metric may result in substantial delay while routing messages as nodes commonly chose the same node as the preferred parent, creating queue overflow. The current OFs construct networks where the load is mostly allocated to some nodes that carry a "favourite" metric value, and these nodes may be forced to handle a traffic load that exceeds their capacity termed load distribution or load balancing problem. This problem has a major influence on network performance and grows worse as the bottleneck node. As a result, a node that is overloaded is more likely to encounter buffer overflow-related packet loss and tends to send packets with greater delays as a result of queuing.

A node receives and forwards more packets than other nodes when it is overloaded. A loaded node uses more power and uses its battery more rapidly than other nodes because an LLN device uses the greatest power when packets are transmitted and received. The burden will be distributed to its neighbours as an overloaded node exits the network owing to battery exhaustion, almost certainly resulting in the emergence of a new overload node. Another impact of a node being overloaded is that more packets will be waiting in the forwarding queue the more packets a node forwards in a given amount of time.

## III. RELATED WORK

Researchers have looked into ways to improve or change the RPL protocol so that it can meet more criteria. Right now, it only uses three metrics: expected transmission count, energy usage, and hop count. In this section, we present other research that supplement our own and improve how well the RPL protocol performs its target tasks across a range of IoT applications.

In LLNs, saving energy is one of the most important goals. The protocol uses ETX as a measure and, by default, puts more emphasis on connection consistency. This shows how the transmission delay and residual energy can be used as a routing measure [12]. The Ant Colony Optimization (ACO) technique is used in selection and rank calculation to calculate route metrics. The findings are encouraging for the field of energy efficiency.

The major focus of the author is on reducing network resource consumption while still effectively managing routing in an LLN. The research presents an innovative OF based on a Non-Linear Length that considers metrics and limits for Quality of Service (QoS) routing (NL-OF) [13]. Path input restrictions are handled by NL-OF for real-time applications. The NL-OF enactment is predicted using the Cooja simulator. For End-to-End (E2E) latency, packet loss, and jitter, NLOF performs better than the three currently used OFs.

Rules and limitations must be established by the OFs in order to choose the optimum pathways based on various routing parameters. In order to facilitate dependable data transmission and energy-efficient communication in IoT systems, article [14] provides an Energy Efficient and Path Reliability Aware Objective Function (ERAOF). As compared to other OFs in the literature, ERAOF has superior network performance. Future IoT applications will support mobility in wireless sensor networks.

As a reaction to the fuzzy model, the author in [15] created an optimised RPL goal function by combining a number of RPL parameters, including as ETX, hops, and Received Signal Strength Indicator (RSSI). All variables are adjusted for simulations, and the results show that the strategy is the best for optimising the objective function.

Both the Link Quality Level Objective Function and OF0 were analyzed in this paper (LLQ OF) [16]. The link quality indicator that LLQ OF is based on is the Received Signal Strength Indicator (RSSI), which changes based on how far apart the communication nodes are. They came to the conclusion that OFs control both the average number of hops and the number of child nodes connected to each router. Both of these things are important to the overall structure of the RPL. In a network that runs on batteries, using OF0, which tries to reduce the number of hops, could cause the nodes closest to the root to lose power quickly.

The FLEA-RPL objective function, which is utilised to calculate the step parameter for rank assignment, was also developed by Sankar et al. in [17]. It is based on residual energy, load, and ETX. The hypothesis predicted that longevity would increase by roughly 10% while PDR would increase by 2% to 5%.

According to Gao et al. suggestion in [18], the ETEN-RPL is a hybrid routing measure that combines residual energy and ETX with additive injection into an objective function. It fixes the issues with imbalanced energy and poor data dependability, enhances network stability, and uses less power overall. The concept, however, is only applicable to performance outcomes at very low concentrations.

In Mishra et al. [19], suggested using lexicographic and additive methods to include ETX, available energy, and hop count routing data in an EHA objective function for rank processing and to choose an ideal preferred parent. When compared to MRHOF-ETX and OF0, the results showed that MRHOF-ETX and OF0 did better in terms of energy use, network latency, and packet delivery ratio.

Abuein et al. [20] looked at how well the OF0 and MRHOF RPL objective functions worked in the random and grid topologies as part of their research. The number of nodes in the network is medium, with 50 to 85 nodes. They found that the network works at its best when the density is between 50 and 65 motes and the RX is 60%.

Adeeb Saaidah et al. suggested an improved Objective function for RPL called OFRRT-FUZZY in their study [21]. It takes into account the throughput, the Received Signal Strength

Indicator (RSSI), and the amount of energy left (RE). They put these metrics together and used a well-known method called "fuzzy logic" to figure out the best route. Simulations run on the COOJA simulator show that OFRRT-FUZZY is better than both OF0 and MRHOF.

Mah Zaib Jamil et al. [22] have shown how the new node metric ELT (Expected Lifetime metric) can be used to build an objective function. ELT is calculated by comparing the amount of energy left over to the amount of energy used. The ELT, HOP, and ETX metrics are used to measure how well RPL is put into place. In order to improve RPL, Hanane et al. [23] made an objective function for RPL called OF-EC that depends on three metrics: ETX, hop count, and energy consumption. With the help of fuzzy logic, they made this Objective Function.

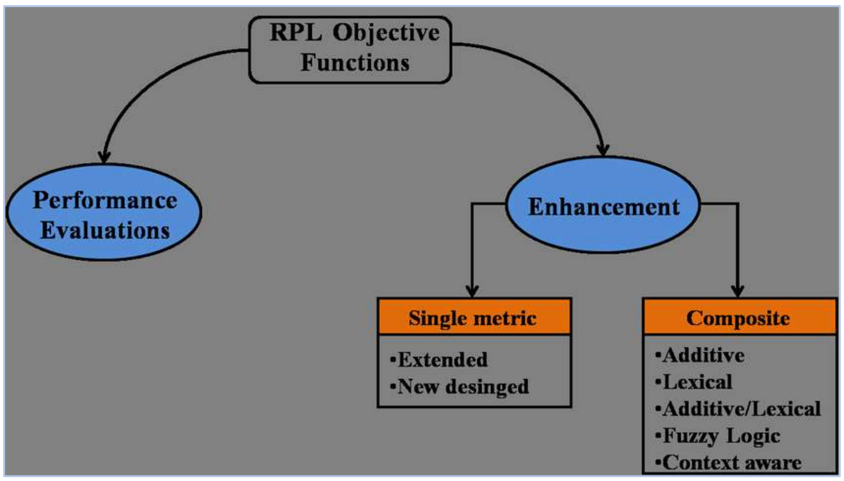


Figure 2: Different researchers related to Objective Functions (OF) with RPL

## IV. PROPOSED METHOD

By design, RPL only considers one routing measure, such ETX, energy utilization, or hop count, when choosing the preferred parents. This causes it to have certain limitations and performs poorly in situations where many restrictions must be taken into consideration. In fact, RPL chooses non-optimized or static routing pathways based on one parameter that the OF has reduced, which has a significant impact on the QoS performance of the network. The frequent preferred parent change phenomenon also rises with network density, which is remarkable and destabilizes the network.

We provide an Enhanced Analytic Hierarchy Process Objective Function (EAHP-OF) based on a linear combination of multiple metrics, including ETX, child count, Queue size, and work metric to deal with various limitations, while an empirical Threshold is introduced to provide improved network stability. Hence, the measure with the highest weight has the most impact on the decision of the node's parent. The monotonicity property described as being loop-free directed to sink must be respected while designing a novel goal function utilising composite routing metrics.

## ENHANCED ANALYTIC HIERARCHY PROCESS OBJECTIVE FUNCTION (EAHP-OF)

The utmost significant factors affecting the QoS of IoT applications are dependability, energy consumption, workload management, and shortest path. Determining how these four characteristics should be integrated in order to create the optimum routing selections is crucial. In this regard, our article suggests an additive combination of four metrics: ETX, work metric, Queue size, and child count. To eliminate routing loops and respect the convergence of the goal function, these metrics should be selected so that they must all be minimized.

**Expected Transmission Count Metric (ETX):** The expected number of transmissions (ETX) needed to send packets from the sender node to the reception node without any problems [21]. It assesses the network's route quality between two nodes and offers high-throughput, dependable pathways. A connection that has a low ETX value is solid. ETX [24] value is computed via (2).

$$ETX_N = \beta.\ ETX_{OLD} + (1 - \beta).\ ETX_{pckt} \qquad \text{---------} \qquad (2)$$

Where $ETX_{pckt} = 1/(P_{frwrd} \text{ X } P_{rvrs})$, where β is the learning ratio and is assigned a value of 0.9 [24] and is the likelihood that the packet is transmitted in the forward direction, arrives at the receiver(PF), and then is acknowledged by the sender in the reverse direction. The ETX measure is used by the OF to determine rank in RPL. While building a DODAG, the node selects the parent node using the rank value with the lowest ETX value after receiving the DIO message. Although while ETX could offer a dependable network, it might not offer the best route given the traffic on the network.

**Queue Size:** Packet loss is caused by both the queue size and the network quality. When the queue is full, the node discards the majority of the packets. Certain nodes in the Internet of Things (IoT) could have high connection quality but a tiny queue capacity, which causes them to lose packets. As a result, while designing metrics, the queue usage statistic should also be taken into account for dependable service. Both ETX and queue usage can be employed in OF for rank computation in order to respond to the dynamic network state. Node N Queue utilization (3) is defined as ratio between sum of packets in queue of N to the total queue size of N.

$$Q\ (N) = S_{pckt}\ /Q_{size} \qquad \text{-------------} \qquad (3)$$

**Child Count Metric:** In RPL networks, the leaf nodes always give preference to the parent node with the most children over the parent node with the fewest children but the highest rank. As a result of attracting more leaf children, a parent node with a lower rank uses up its energy quicker than other nodes, resulting to network failure [20]. In order to optimize node lifespan and relieve the overloading problem, our recommended work employs the child count metric to keep track of the number of offspring nodes for a specific parent node throughout the parent selection phase of DODAG construction in RPL network [20]. In this situation, we think about choosing a parent node that has fewer children than other parent nodes in order to accomplish load balancing.

**Work-metric:** It is the total of the number of DAO control messages and data packets transmitted. The DAO does indeed only broadcast to the parent node from children. Because of this, a node managing more nodes implies getting more DAO. The work-metric, which should be minimizable, then provides a sense of each node's burden. Due to this, we created a measure to distribute the load among all the nodes.

$$W(i) = Sent_{pack} + DAO_{recv} \qquad \text{---------} \qquad (4)$$

It is the total number of DAO control messages and data packets transmitted. The DAO does indeed only broadcast to the parent node from children. Because of this, a node managing more nodes implies getting more DAO. The work-metric, which should be minimizable, then provides a sense of each node's burden. Due to this, we created a measure to distribute the load among all the nodes which counts the quantity of IP-layer packets that have been transmitted. It contains the quantity of DAO control messages and packets containing data transmitted by node i.

Nodes are chosen as parents depending on rankings determined by the goal function. The concerned node selects neighbours of lesser rank as its preferred parents. EAHP-OF employs a combination of measures instead of a single metric like traditional objective functions do for rank processing. In fact, during a DIO receipt from a neighbour, the node I determines the number of children, the work-metric, and the new rank in relation to (6).

$$RI = ETX_N + \alpha^* Q(N) + \beta^* W(i) \qquad \text{-----------} \qquad (5)$$

In addition, the weights of α and β must be complimentary in order for their sum to equal 1. Where and α and β are the weights effect of each metric included between 0 and 1.

$$Rank_{new} = Rank_{parent} + RI \qquad \text{-------------} \qquad (6)$$

Where $Rank_{parent}$ denotes the rank deduced from the potential parent DIO's sender. RI stands for rank improvement and is determined using (5).

If the node does not already have a preferred parent, it picks the newly calculated rank after analysing its susceptible new rank. If not, it is important to compare the vulnerable new rank with the selected parent rank; if it is larger, the prospective parent is rejected. If the rank falls below the selected parent rank by a predetermined threshold for stability awareness, the candidate parent is maintained otherwise. The preferred parent changes must be lowered by the threshold (7).

$$Threshold = ETX_N + (ETX_N)/2 \qquad \text{------------} \qquad (7)$$

At this point, the node updates its metric container, rank in the DIO message, and broadcasts a new one if the preferred parent change condition is satisfied. And finally the algorithm has been given below:

**An Enhanced Analytic Hierarchy Process Objective Function Algorithm:**

Input: CurrentNode ($C_n$), NodeID, ParentNode ($P_n$), ParentID,
NodeList (NL)
Output: parent selection with Load balanced DODAG
Begin
DIO message when received by node i from $P_n$
IF ($P_n$ ! = NULL)
Initial$_{rank}$ = $P_n$.dio.rank;
$ETX_N = ETX_n$
RI = RI = $ETX_N + \alpha * Q(N) + \beta * W(i)$ ;
Threshold = $ETX_n + (ETX_N)/2$;
if ((NodeID == ParentID) then
CC = CC + 1;
end if
//Rank evaluated depending on the ETX, Child Count, work metric and Queue size
//for all CN in NL do

IF ((Initial$_{rank}$ + RI) < Initial$_{rank}$)
return rank$_{\infty}$;
ELSE
IF ((Initial$_{rank}$ + RI)<( $P_n$.rank + Threshold)
Prefer$_{parent}$ = $P_n$;
rank = Initial$_{rank}$ + RI;
ELSE
do not change Preferred parent
exit;
ENDIF
/* new DIO message is created
dio.rank = rank;
a new DIO message is broadcast
ENDIF

## V. SIMULATION RESULTS

NS-3 was utilised as a simulation tool to carry out the tests and create a network model in order to assess the performance of the suggested OF. The ETX and the CBMLB, two additional significant objective functions found in the earlier study, were compared to the proposed EAHP-OF. Regarding the packet loss ratio, number of DIO packets, and throughput for the supplied data packet, the three OFs' performance was assessed. It is assumed that the nodes are stationary wireless sensor nodes that randomly create packets at a rate of one packet every minute on average. We evaluated the RPL protocol's performance for an hour of simulation time, measuring each node's average packet loss ratio, average end-to-end latency, and throughput for several objective functions.

| Parameter | Value |
|---|---|
| Time -Simulation | 70 minutes |
| Number of nodes | 20, 40, 60 |
| Protocol | RPL |
| Area | 300m x 150 m |
| Metrics | ETX, Child count, work metric, Queue size |
| Transfer range | 100 m |
| Packet transfer rate | 25 KB |
| Load size | 512 Bytes |

TABLE I: Parameters Used in Simulation

By contrasting the packet loss ratio (PLR) of EAHP-OF with ETX and CBMLB at various densities, its network reliability is evaluated. The EAHP-OF offer a low PLR, as seen in Figure 3. It could be because multiple routing metrics hybridization increases the number of routing channels, which keeps packet loss from happening at bottlenecks.

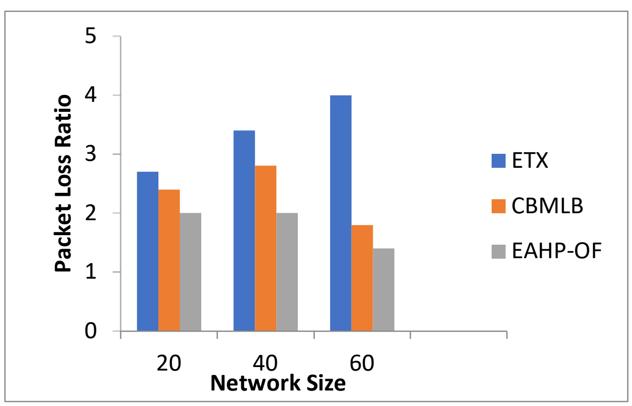


Figure 3: Network size vs. Packet Loss Ratio

When we compare the throughput with the ETX and CBMLB OFs, the throughput of the EAHP_OF is improved by 26%.

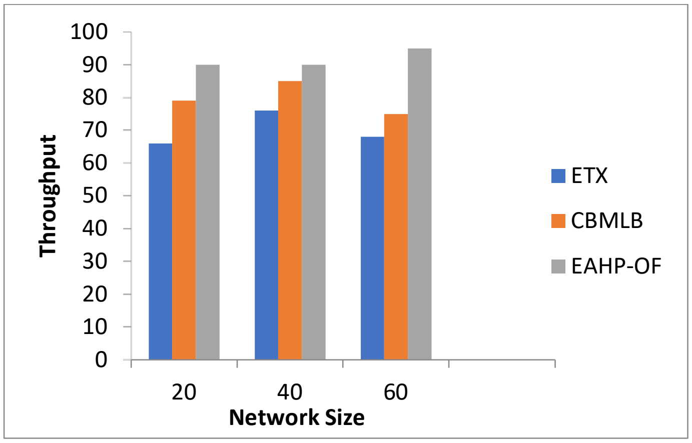


Figure 4: Network size vs. Throughput

The quantity of DIO control packets contributes to network stability. In fact, as seen in Figure 5, our solution can offer less DIO packets than ETX and CBMLB due to the optimal pathways chosen utilising a combination of criteria. With regard to the influence of weight, we can observe that the number of DIO naturally rises due to the instability created when the work metric has a larger weight.

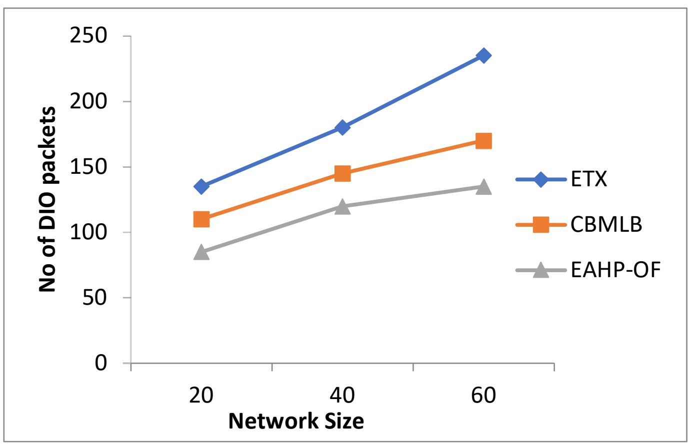


Figure 5: Network size vs. Number of DIO packets

## VI. CONCLUSION

The use of appropriate protocols at various IoT levels is necessary for any IoT application to achieve its goals. We concentrated on the network layer in our article, especially the RPL routing protocol. Some Internet of Things applications need constant high packet throughput, nodes that use little power, and a network with an evenly distributed load. As a result, we have presented EAHP-OF, which considers ETX, Child Count, Queue Size, and work-metric combined additively and resolves multi-constraint metrics. The nodes use an innovative method to process their rankings and choose their preferred parents. In order to reduce the number of parents, an adaptive threshold was implemented, taking network stability into account. Our assessment findings on NS-3, an IoT modelling environment, supported

EAHP-OF outperforms AHCCP and CBMPLB by improving the PDR, throughput in high traffics.

## VII.REFERENCES

[1] Cisco, "Connected Grid Networks for Smart Grid - Field Area Network," http://www.cisco.com/web/strategy/energy/field area network.html.

[2] German Federal Ministry of Education and Research, "Project of the Future: Industry 4.0," http://www.bmbf.de/en/19955.php.

[3] J. Paek, J. Hicks, S. Coe, and R. Govindan, "Image-Based Environmental Monitoring Sensor Application Using an Embedded Wireless Sensor Network," Sensors, vol. 14, no. 9, pp. 15 981–16 002, 2014.

[4] "IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks. Specific requirements – Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low- Rate Wireless Personal Area Networks (LR-WPANs)," Available at http://www.ieee802.org/15/pub/TG4.html, May 2003.

[5] A. Mayzaud, R. Badonnel, and I. Chrisment. "A Distributed Monitoring Strategy for Detecting Version Number Attacks in RPL-Based Networks". In: IEEE Transactions on Network and Service Management 14.2 (June 2017), pp. 472– 486.

[6] "The ETX Objective Function for RPL," draft-gnawali-roll-etxof- 01, May 2010.

[7] J. Vasseur, M. Kim, K. Pister, N. Dejean, and D. Barthel, "Routing Metrics Used for Path Calculation in Low-Power and Lossy Networks," RFC 6551, Mar. 2012.

[8]T.Winter, P. Thubert, "RPL: IPv6 Routing Protocol for Low Power and Lossy Networks", 2011 Available: http://tools.ietf.org/html/draft-ietf-roll-rpl-18

[9] W. Khallef, M. Molnar, A. Benslimane, and S. Durand, "Multiple constrained QoS routing with RPL," *IEEE Int. Conf. Commun.*, 2017.

[10] P. Thubert, "Objective Function Zero for the Routing Protocol for Low-Power and Lossy Networks (RPL). Internet Engineering Task Force(IETF)," RFC 6552, 2012.

[11] O. Gnawali and P. Levis, "The Minimum Rank with Hysteresis Objective Function. Internet Engineering Task Force(IETF)," RFC 6719, 2012.

[12] Lee, S., Shin, D., & Kim, D. (2010). The effect of ETX measurement on routing performance in underwater sensor networks. In Proceedings, international conference on information and communication technology convergence (ICTC), pp. 139–140. IEEE.

[13] Khallef, W., Molnar, M., Benslimane, A., & Durand, S. (2017). Multiple Constrained QoS routing with RPL. In IEEE ICC 2017 ad-hoc and sensor networking symposium, IEEE.

[14] Sousa, N., & et al. (2017). ERAOF: A new RPL protocol objective function for Internet of Things applications. In 2nd international multidisciplinary conference on computer and energy science (SpliTech). IEEE.

[15] Urama, I. H., Fotouhi, H., & Abdellatif, M. M. (2017). Optimizing RPL objective function for mobile low-power wireless networks. In IEEE 41st annual computer software and applications conference.

[16] Agnieszka Brachman. RPL objective function impact on LLNs topology and performance. In Internet Things, Smart Spaces, Next Gener. Netw., volume 8121 LNCS, pages 340–351. Springer-Verlag, 2013.

[17] S. Sankar, and P. Srinivasan, ”Fuzzy logic based energy aware routing protocol for internet of things,” International Journal of Intelligent Systems and Applications, vol. 10, pp. 11-19, 2018.

[18] L. Gao, Zengwei Zheng, and Meimei Huo ”Improvement of RPL protocol algorithm for smart grid,” International Conference on Communication Technology Proceedings, pp. 927-930, 2019.

[19] S. N. Mishra, et al., ”Eha-rpl: A composite routing technique in iot application networks,” Advances in Intelligent Systems and Computing, vol. 1045, pp. 645-657, 2020.

[20] Qusai Q. Abuein, Muneer Bani Yassein, Mohammed Q. Shatnawi, Laith Bani-Yaseen, Omar Al-Omari, Moutaz Mehdawi and Hussien Altawssi, “Performance Evaluation of Routing Protocol (RPL) for Internet of Things”, International Journal of Advanced Computer Science and Applications, Vol. 7, No. 7, 2016, pg 17-20.

[21] Adeeb Saaidah, Omar Almomani, “An Efficient Design of RPL Objective Function for Routing in Internet of Things using Fuzzy Logic”, International Journal of Advanced Computer Science and Applications, Vol. 10, No. 8, 2019, pg 184-190.

[22] Mah Zaib Jamil, Danista Khan, Adeel Saleem, Kashif Mehmood, Atif Iqbal, “Comparative Performance Analysis of RPL for Low Power and Lossy Networks based on Different Objective Functions”, International Journal of Advanced Computer Science and Applications, Vol. 10, No. 5, 2019, pg 183-190.

[23] Hanane Lamaazia, Nabil Benamarb, “OF-EC: A novel energy consumption aware objective function for RPL based on fuzzy logic” Journal of Network and Computer Applications, Elsevier, Sept 2018. https://doi.org/10.1016/j.jnca.2018.05.015.

[24] Sankar, S., and Srinivasan, P, “Energy and load aware routing protocol for internet of things”, International Journal of Advances in Applied Sciences, Vol. 7, No. 3, pp. 255-264, 2018, ISSN: 2252-8814.