

# Comparative Analysis of Objective Functions in Routing Protocol for Low Power and Lossy Networks

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**Abstract**—Internet-of-Things (IoT), a new paradigm, has led to the extensive increase in communication among the tiny and embedded network devices. Majority of those devices are power, memory, and energy constrained and are made to work in lossy environments, thus forming an important part of Low Power and Lossy Networks (LLNs). Routing Protocol for Low Power and Lossy Networks (RPL) designed by Internet Engineering Task Force (IETF) is proved to be an effective candidate for routing in such networks. RPL defines the Objective Functions (OFs) in which a set of routing metrics (like hop count, ETX and so on) are used either in an individual or combined manner for optimal path selection between the nodes of the network in terms of various performance factors like power consumed, Packet Delivery Ratio (PDR), reliability and so on. There are two standard Objective Functions- Objective function Zero (OF0) and Minimum Rank Hysteresis Objective Function (MRHOF). The former uses the hop count and the latter uses the Expected Transmission Count (ETX) as the default routing metrics to select the optimal paths. But both of them are single metric Objective Functions (OFs) and have to face various issues regarding the energy consumed, network lifetime and so on. So a number of RPL optimizations incorporating the different routing metrics in a combined way have been proposed to enhance the performance in all respects. This paper gives the comparative analysis of existing Objective Functions that are based on different routing metrics and concludes that the use of a combination of multiple metrics will further improve the RPL performance in future.

**Keywords**-RPL; Objective Function (OF); routing metric; Low Power and Lossy Networks (LLNs).

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## I. INTRODUCTION

In today's era, Internet-of-Things (IoT) has been a new area of research which is based on new information and communication technology. It allows the physical objects to interact with one another and exchange information in order to take an intelligent human like decisions. That's why its applications can be found in diversified fields, from smart wearable devices to the health monitoring machines, transportation, smart cities etc [1]. The tiny intelligent devices used in numerous applications form a crucial part of Wireless Sensor Networks (WSNs) [2]. But these devices have certain resource constraint challenges i.e. they have limited processing power, energy, storage capacities, link failures, and high latencies. These networks are categorized into a special type called as Low Power and Lossy Networks (LLNs). But Routing has become the major issue where the billions of resource-constrained devices are becoming a part of the IoT networks.

To tackle the above issues, Internet Engineering Task Force (IETF) ROLL (Routing over Low Power and Lossy Networks) group has specifically designed an effective routing protocol for LLNs defined as IPV6 Routing Protocol for Low Power and Lossy Networks, commonly named as RPL. It is IPV6 based distance vector proactive routing protocol that has gained a lot of popularity due to its flexibility to work in lossy and dynamic environments consisting of scarce resource devices and thus making the protocol the best candidate to fulfill several IoT application requirements [3]. No topology has been defined for LLNs. But RPL with its auto-configuration feature organizes the scattered nodes into a tree structure named as DODAG (Destination Oriented Directed Acyclic Graph) with the sink node located at the root position [4]. The DODAG is constructed on the basis of Objective Functions (OFs) which

define a set of rules for optimal path selection between the nodes of the network [5]. A number of node and link metrics such as Latency, Hop count, Node energy, Packet Delivery Ratio (PDR) and ETX (Expected Transmission Count) have been defined under the different types of OFs for best route discovery. RPL imposes no restriction on the OFs for the use of particular routing metrics. The different constraints can be used in an individual or combined manner to satisfy the different application requirements. Single metric based OFs do not give the best performance in all terms. So the authors have proposed various OFs combining the different routing metrics in a hybrid way to optimize the various performance factors at the same time.

The remainder of this paper is sorted as follows. Section II gives the overview of RPL, Section III gives the comparative analysis of existing Objective Functions and the conclusion and future scope is given in Section IV.

## II. OVERVIEW OF RPL

RPL is a standard protocol that was given by IETF ROLL working group with the aim of solving the routing issues specifically in LLNs. In March 2012, RPL was released in RFC6550 [6]. RPL provides the optimal paths through the DODAG construction that involves an exchange of ICMPV6 control messages [7] for the flow of data traffic among the low constrained nodes.

### A. Types of Control Messages

- **DODAG Information Object (DIO)**

These are initially broadcast by the root node and are retransmitted further by the neighbors. It contains the information required for the DODAG development and maintenance.

- **DODAG Information Solicitation (DIS)**  
If the nodes do not get DIO packets from their neighbors within a particular time period, the nodes send DIS messages to their neighbors to become a part of the DODAG.
- **Destination Advertisement Object (DAO)**  
This packet is sent by the nodes in the upward directions to inform their respective parents that they have chosen them to reach the sink node.
- **Destination Advertisement Object Acknowledgment (DAO ACK)**  
This control packet is sent by the receiver in response to the DAO message.

### B. Rank

Each node is having a unique position in the DODAG with respect to the root defined as the Rank of the node. It is a scalar quantity that represents the node's position or distance relative to the root. It is calculated using the OF during the process of DODAG construction. It increases downwards when we go away from the root and decreases in the upward direction, as shown in Figure 1 [9]. The rank of the node  $R(N)$  varies according to (1) [7], where  $R(P)$  is the rank of the parent node P and  $RankIncrease$  is a variable that defines an increase in rank while going from parent P to node N,

$$R(N) = R(P) + RankIncrease \quad (1)$$

In Figure 1, Rank is simply shown to be increasing by some fixed integer value, however it varies depending upon the choice of OF.

### C. DODAG Construction

Initially, the root of the DODAG broadcasts the DIO messages to all of its neighbors in the downward routes [10]. Those messages enclose the information regarding the rank of the node and the type of OF chosen by RPL. If the node is receiving DIO message for the first time and is willing to join the DODAG, then i) firstly, it adds the address of the sender of the DIO packet to its parent list, ii) then calculates its rank and, iii) further advertises the DIO packets with the updated information of its rank to its neighbors. And if the node is getting the DIO message from more than one parent, then it performs the following actions:-

- It can discard that packet if it does not satisfy all the conditions. Like, loop avoidance criteria are applied to check whether the incoming DIO packets should be discarded or not.
- Otherwise, it will process that DIO packet and calculates its own rank value on the basis of new DIO. If the calculated value will be more than the previous rank value, then it will maintain the previous location otherwise updates to the lower rank value by improving its position in the DODAG. It will further send the updated information to its neighbors in the DIO packets.

After the DODAG construction, each node sends the DAO control packet to its preferred parent in the upward direction in order to discover the reverse path for each node to reach the sink node. By this way, the complete path can be traced between the root and each node of the DODAG network. The whole process is shown in Figure 1 [9].

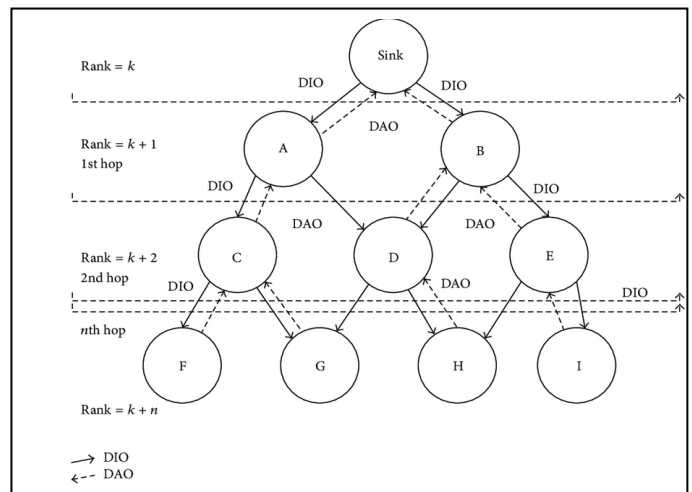


Figure 1. DODAG Construction [9]

### D. Objective Functions (OFs)

A lot of research is going on to develop the optimized versions of RPL using the different OFs. An OF plays a vital role in deciding the DODAG topology. From the parent's list, the best parent is selected on the basis of least rank value which is calculated by OF by using different routing metrics. After selection of preferred parent by each node, the optimal path is tried to be traced out in terms of various performance factors like less energy consumed, best link quality, longer network lifetime, less latency and so on. Two types of metrics are used in RPL [11] (1) *Node metrics*: The metrics (like Hop count, Node energy) that represent the state of the nodes, (2) *Link Metrics*: The metrics (like ETX, Link Latency) that indicate the quality level of the links.

There are two standard OFs- Objective function Zero (OF0) and Minimum Rank Hysteresis Objective Function (MRHOF). Both of them are based on single metrics. There are various variants of OFs that combine the above metrics (Node and Link) into a single one to form a new optimized version of RPL.

## III. COMPARATIVE ANALYSIS OF RPL OBJECTIVE FUNCTIONS

### A. Two Standard OFs

1) *Objective Function Zero (OF0)*: OF0 is the first standard that was released by IETF in RFC 6552 [7] in March 2012. It uses Hop count as the default routing metric. This tries to construct DODAG in such a way that the nodes find the shortest distance in terms of the number of hops (intermediate nodes) to reach the root node. During the construction mechanism, the rank of the nodes is calculated and the parents are selected by each node on the basis of the minimum value of the metric.

The drawback of OF0 is that RPL is mainly designed to work in low power and lossy environments, but OF0 neither considers the battery levels of the nodes nor the quality of the links [12] [13]. Only those paths are chosen that contain the lesser number of hops, so those paths may contain even those links which are unreliable and lead to a lot of retransmissions and thus the higher packet losses. Secondly, nodes in shorter paths are used again and again leading to the depletion of their battery levels very soon thus poorly affecting the lifetime of the network.

2) *Minimum Rank Hysteresis Objective Function (MRHOF)*: MRHOF is another OF that is standardized by IETF in RFC 6719 [14]. Like other OFs, it also tries to choose the path with an optimized value of some routing metric but it gives an advantage of more network stability by using a new concept of “hysteresis”. While any changes occur to the DODAG, the node updates its parent node only if the difference between the new and the previous metric values is more than some given threshold value. It can use various metrics but two are commonly defined in the literature:

a) *Minimum Rank Hysteresis Objective Function with ETX (ETXOF)*: MRHOF uses Expected Transmission Count (ETX) [15] as the default routing metric for MRHOF. It gives the measure of an average number of transmissions required for the successful transmission of the packet. It is given by (2) [7], as

$$ETX = \frac{1}{Df * Dr} \quad (2)$$

In (2),  $Df$  is the forward delivery ratio defined as the probability for the successful arrival of the packet from source to destination and  $Dr$  is the reverse delivery ratio defined as the probability for the successful arrival of the acknowledgment from destination to source. Higher will be the value of  $Df * Dr$ , more is the probability of a successful transmission of a packet, lesser is the ETX value. Lesser ETX value indicates the good quality of a link in terms of reliability. The ETX of the entire path is calculated by adding the ETX values of the connecting links along the path and the best reliable path is chosen for the data delivery. From the simulations carried out in [12], it is concluded that ETXOF performs well than OF0 in terms of power, PDR, control overhead and ETX. ETXOF is a better option than OF0 for LLNs as it truly focuses on the lossy nature of such networks. But the drawback of ETXOF is that it only focuses on the reliability of the networks ignoring the energy levels of the nodes along the path. If the path with the lesser number of transmissions is taken by the data traffic again and again, the energy of the nodes gets down faster than the others leading to decrease in overall lifetime of the network.

b) *Minimum Rank Hysteresis Objective Function with Energy*: MRHOF can use energy as the metric for best parent selection instead of ETX. It chooses that path from source to destination that involves the nodes which are energy efficient. The energy consumed by each node along the path is summed up and the path with least sum is chosen for the data flow. However in [10], it is shown that MRHOF with energy performs well in terms of average power consumption but at the cost of more packet losses and delays. This is because it ignores the link quality and Hop count metrics to reach the destination so it has to face link breakages leading to more packet losses and delays.

#### B. Other Variants of OFs

1) *Energy Efficient and Path Reliability Aware Objective Function (ERAOF)*: Using ETX alone does not guarantee that the paths that are reliable in nature are also energy efficient. It may contain the nodes that consumes too much energy leading to the failure of the network very fast and thus the whole network needs to be reconstructed again leading to further overhead of control messages. Similarly using Energy as a

metric alone is harmful because it does not consider the link quality leading to a lot of retransmissions and packet losses. In [16], an OF has been proposed combining two routing metrics-Energy (Node metric) and ETX (Link metric), termed as Energy Efficient and Path Reliability Aware Objective Function (ERAOF). It aims at selecting the highly reliable and energy efficient paths. The two metrics can be combined using (3) [16] and (4) [16]. The Quality factor  $Q(r)$  for the route  $r$  is calculated by adding the values for a function  $T(n)$  for  $n$  nodes along the route given by (3) [16]. From source to destination, suppose there are  $j$  nodes along the route  $r$  and  $T(n_i)$  denotes the quality factor for  $i$ th node along that route.  $Q(r)$  is given as,

$$Q(r) = \sum_{i=1}^j T(n_i) \quad (3)$$

Where  $T(n)$  gives the quality factor for each node, given by (4) [16] as,

$$T(n) = F_{EC}(n_i) + F_{ETX}(n_i, n_j) \quad (4)$$

Where  $F_{EC}(n_i)$  gives the energy consumption by  $i$ th node, from the time its operation has been started,  $F_{ETX}(n_i, n_j)$  gives the ETX of the link between the node  $i$  and  $j$  ( $j$ th node is the node which has sent DIO message to node  $i$ ). Thus, for each node,  $T(n)$  value is calculated in terms of ETX and Energy consumed, and added to get  $Q(r)$ . The path with least value of  $Q(r)$  is chosen for data flow as it is the most reliable and energy-efficient path. The Simulation results show ERAOF to be the better option for LLNs than using OF0 and ETXOF as it leads to an excellent increase in PDR along with making an efficient use of energy and less hop count.

2) *PER-HOP ETX*: IoT demands Scalability up to a large extent and the above two standards fail to work in highly dense networks. [17] discusses the problem of Long hop that occurs in large scale networks if those OFs are used alone. ETXOF finds the sum of ETX values along the entire path and usually, the path with less number of hops gives the smaller summation. But this creates the problem if the number of nodes increases. As it is observed that the path with less number of hops and less ETX summation value has low transmission rate. This occurs due to the presence of long single hop with high ETX value that may restrict the entire network. But opposite to it, it happens that path with more number of nodes have ETX summed value higher than the above discussed case but its transmission rate is very high. So if the data traffic starts going through that path, the number of retransmissions would be very less and overall delays and energy wastage would also decrease. This problem has been solved by the OF which combines both ETX and Hop count together and design a metric called as *PER-HOP\_ETX*. It calculates the overall sum of the ETX along the path from a particular node to the root and distributes it among the  $n$  number of hops along with that path, given by (5) [17], where  $ETX_i$  gives the ETX value for the  $i$ th link along the path containing  $n$  nodes. So a path with lesser *PER-HOP\_ETX* value is chosen for the flow of data traffic.

$$PER - HOP - ETX = \frac{\sum_{i=1}^n ETX_i}{n} \quad (5)$$

Simulations show the OF to be very useful for routing in highly dense networks as it gives more optimized paths in terms of PDR, energy, and latency than OF0 and MRHOF (with ETX).

3) *Objective Function based on Residual Energy*: A new OF based on the residual energy of node has been presented in [18]. Instead of choosing the path that consumes the lowest energy (called as the TotalEnergy metric), this new OF focuses on remaining battery levels of the nodes. The reason being, the paths with least energy consumption may contain some nodes which are left with minimal energies, they may get died very soon leading to the disconnection of those paths from the network. So this OF is based on the criteria for selecting those paths where nodes are having the highest Residual Energy levels. Cost of the path from the  $i$ th node to the sink node, denoted by  $Pathcost_i$ , is calculated by (6) [18]. Its value is equal to the minimum residual energy of any node along the path containing the node  $i$ . For  $j$ th node in the neighbor list of  $i$ , there will a different path with each having a different value for the defined metric, denoted by  $Pathcost_j$ . Node  $i$  selects one of its neighbors as the preferred parent which is having the maximum value for the  $Pathcost_j$ , where  $j$  belongs to the neighbor list of  $i$ , i.e.  $N(i)$  and then calculates the updated value for  $Pathcost_i$  which is minimum among the residual energy value of the  $i$ th node, denoted by  $REnergy_i$  and the  $Pathcost_j$  for the preferred parent, as

$$Pathcost_i = \min(\max_{j \in N(i)} \{Pathcost_j\}, REnergy_i) \quad (6)$$

The simulation results of [5] show that using residual energy as a metric gives better performance in terms of PDR and Control overhead as compared to the TotalEnergy metric [5]. But residual energy metric does not take into account the link quality so it has less PDR, more delays and longer network lifetime than the ETXOF [19].

4) *Objective Function based on Energy-Oriented Routing (OF-EOR)*: A problem of blackhole in WSNs has been discussed in [20]. Energy is one of the most important concerns for LLNs. If so many nodes in the network get disabled due to the energy exhaustion and are not able to communicate with one another, then that situation creates the blackhole in the network. ETX provides the best paths with high transmission rates but at the same time overburdens the nodes along those particular paths with an unbalanced load and residual energy distribution. Their battery levels drop down very soon and get disconnected from the other part of the network. The overall network lifetime gets affected as well. To address these issues, an Energy-Oriented Routing Algorithm [20] has been proposed by the authors by combining ETX and Residual energy together into a new score  $R$  to balance the residual energies among all the nodes and thus prolonging the overall network lifetime as well. Equation (7) [20] gives the method for computation of the routing criteria  $R$  for selecting the next hop,

$$R = \alpha \frac{ETX}{Max\_ETX} + (1 - \alpha) \left( 1 - \frac{Rem\_Energy}{Max\_Energy} \right) \quad (7)$$

Where  $\alpha$  varies between the energy consumed and ETX. The first term on right hand side of (7) gives the ratio of ETX value of a single link to the maximum possible value of ETX for all the available links i.e.  $Max\_ETX$ , the second term on

right hand side of (7) gives the ratio of the energy consumed by the node to its maximum possible value. Energy consumed is calculated by subtracting the remaining energy ( $Rem\_Energy$ ) from its maximum energy consumption ( $Max\_Energy$ ).

At the time when the next hop is to be selected, one with the least R score value is selected for the flow of data traffic. The Energy-Oriented Routing scheme is compared with the normal mechanism of RPL and the simulations show that the network lifetime increases by 12% when  $\alpha$  is set to 0.5.

5) *QOS-Aware Fuzzy Logic (OF-FL)*: Some research studies show that even a single metric or a combination of two is not sufficient to provide the best quality routes. For instance, if we combine hop count and delay in order to follow the shortest distance to reach destination with the minimum delays, it leads to the drawback that the nodes in the LLNs have to face the battery level issues and high packet losses. To tackle these issues, an OF called as QOS-Aware Fuzzy Logic (OF-FL) [13] has been proposed by the authors in which more than two routing metrics are combined by using the concept of Fuzzy Logic. It can be explained by the following components:

a) *Input variables*: It defines the four routing metrics (Latency, ETX, Hop count and Battery level) in terms of linguistic variables given as inputs to the fuzzy system.

b) *Set of fuzzy rules*: It defines the rules to fuzzify the different inputs to satisfy the requirements of the desired application.

c) *Output variable*: It indicates the quality of neighbors for selecting the best parent. The output variable is assigned the value BEST if it has LOW latency, LESS hop count, LESS ETX, and MORE remaining battery levels available. The different parameters can be tuned to meet several application requirements using the fuzzy based OF.

Results after simulations show that OF-FL achieves a greater improvement in RPL network in terms of Packet loss, latency and network lifetime when compared to OF0 and MRHOF. But its disadvantage is that it has a complex working. Each time a node has to select or update its parent, it has to check the whole set of rules and conditions which causes too much churn and further leads to the instability of the network.

6) *Load-Balanced Objective Function (LB-OF)*: A new issue of Load Balancing has been detected in [21]. So far, the OFs are selecting their preferred parents using the routing metrics such as ETX, Hop count, Energy, and so on. After recent studies, it has been concluded that these OFs lead to the construction of a DODAG where the nodes suffer from the problem of Unbalanced Load distribution, especially those nodes which are very near to the sink node. The nodes are serving more than one child thus some of them get overburdened due to the presence of a large number of child nodes in their queues. This leads to the depletion of their energy levels at a very fast rate than the others. Those nodes become the bottleneck ones and their lifetimes get reduced leading to the disruption of some part of the network or the whole network, if the bottleneck is the sink node which further involves the overhead to reconstruct the whole DODAG. A new Load Balancing based Objective Function (LB-OF) has been proposed by the authors to address the above issues. It uses Childset as the routing metric for the preferred parent selection. A node selects the preferred parent from its parent list which is having the least number of child nodes, means

servicing the least load traffic. The amendments made in the new OF can be explained in three steps:

a) *Amending the DIO*: A new field, chosen Parent\_Id has been added into the DIO packet format along with the Instance\_Id, Version\_Number, and Rank.

b) *Amending the Utilization Scheme for New DIO*: Normally when the sender sends the DIO message to its Children for the first time, they choose it as their preferred parent and further broadcast the DIO packets to their neighbors including their preferred parents also which ultimately discard them. But there is an amendment in this context, instead of ignoring the DIOs coming from the child nodes, preferred parents use them to calculate the value of Childset. If the new Parent\_Id in an amended DIO matches with the Node\_Id of the receiving parent, it updates the value of Childset, and calculates its rank on the basis of children it is servicing.

c) *Parent Selection by load balancing*: The node will select that parent from its parent list as the preferred one which is having the lowest rank i.e. the node with the least Childset is chosen as the new preferred parent, thus balancing their load and energy with the others.

Thus LB-OF reduces the traffic load of the bottleneck nodes, saves their batteries to get drain at a fast pace and thus prolongs the lifetime of the whole network. Simulations justify that LB-OF performs better than OF0 and MRHOF in terms of PDR, balanced lifetime of the nodes, balanced power consumption, and the value for the Childset.

7) *Objective Function based on Expected Lifetime (ELT)*: In this OF [19], the routing metrics- ETX, Residual energy, and Traffic load have been combined to design a new metric termed as the Expected Lifetime (ELT). Its objective is to first identify and find the lifetime of the bottleneck nodes and then try to minimize their energy consumptions. That objective is called as the min-max objective in literature, as it focuses on reducing the energy consumptions made by the highly constrained nodes. The new scheme is based on three steps:

a) *Computation and Advertisement of ELT*: The ELT is computed for the bottleneck node B and then this information is advertised in DIOs to the other nodes along the path containing B. The new node N computes the updated value of ELT for the bottleneck node B while considering the impact of its own traffic on B by using (8) [19], that involves the three parameters:  $Energy_{avg}$ , defined as the energy required by the bottleneck node so that correct packet can be transferred to the next hop,  $Traffic_{total}(N)$ , defined as the total traffic that is injected by the node N along the path that contains B and  $Traffic_{exist}$  is the traffic that is currently handled by the bottleneck node B.

$$ELT_B = \frac{Energy_{avg}}{Traffic_{Total}(N) + Traffic_{exist}} \quad (8)$$

By using (8), the node N can correctly evaluate its traffic impact on B. A node should improve its ELT value whenever it receives a DIO from its neighbors.

b) *Parent Selection Algorithm*: Normally the sink node is assumed to be the bottleneck one denoted by B. The bottleneck node for each path, which contains the parent of a node N is

identified and ELT is calculated for each of them. While choosing preferred parent  $P_N$  from the parent list of N, node N will:

- Compute the  $ELT_N$  for itself by (8), while selecting  $P_i$  as its Parent, where  $P_i$  is the  $i$ th parent of a node N.
- The value for  $ELT_B(Path_i)$  is calculated for a path that contains the parent  $P_i$ , while Node N is injecting its traffic into previous bottleneck B of that path containing  $P_i$ , which at that time is acting as the bottleneck for  $Path_i$ . This is done by using (8).
- The new updated value for ELT of the  $Path_i$  is saved, given by (9) [19], as

$$ELT_B(Path_i) = Min\{ELT_N, ELT_B(Path_i)\} \quad (9)$$

- That Parent  $P_N$  is selected as the preferred one by the node N from all  $P_i$  given by (10) [19], as

$$P_N = Max\{ELT_B(Path_i)\} \quad (10)$$

c) *Computation of Rank*: Then the node N computes its Rank by adding the rank of the preferred parent  $P_N$  (with maximum ELT) to the increase in rank,  $Rank_{Increase}$  while going from N to  $P_N$ . Node N then advertises the updated information about the new bottleneck to its neighbors.

Simulations show that ELT achieves PDR and delay performance values closer to the ETXOF. It performs best even in the worst case, in terms of delays. At the same time, its objectives of balancing the energy distribution and longer lifetimes while identifying the bottleneck nodes are also fulfilled.

8) *Stability based RPL*: A new issue of Stability has been recently identified in [22]. The Stability of the network depends upon the frequent path changes. The nodes frequently change their parents due to the changing values of the routing metric, thus leading to the whole path change. Then the whole DODAG needs to be reconstructed again, leading to further overhead of control packets and overall more utilization of energy. To bring stability to the network, a combination of Hop count and ETX is used. This new hybrid scheme performs very well than the others in terms of control overhead, energy, and overall parent switching. These factors lead to the improvement in overall lifetime of the network and the stability as well.

Table I gives the comparative analysis of existing Objective Functions in RPL and gives the future scope for each one of them.

TABLE I. COMPARATIVE ANALYSIS OF RPL OBJECTIVE FUNCTIONS

Objective Function	Description		
	Routing Metric	Result	Future Scope
OF0 [7][12][13]	Hop Count	Improves end-to-end delays but degrades others factors like link quality, energy etc.	Can be combined with link quality and energy metrics to provide shortest, energy efficient, and reliable paths.

Objective Function	Description		
	Routing Metric	Result	Future Scope
<b>MRHOF (With ETX)</b> [12][15]	ETX	Very good reliability and PDR	Can be combined with energy aware metrics to improve the energy efficiency
<b>MRHOF (With Energy)</b> [10]	Total Energy Consumed	Average Energy Consumption improved but less PDR, high delays	Can be extended to include reliability metrics
<b>ERAOF</b> [16]	Total Energy Consumed + ETX	Provides good PDR with less hop count and energy	To get Complete performance evaluation in terms of different metrics, traffic frameworks, and topologies
<b>PER-HOP ETX</b> [17]	ETX + Hop count	Good for large scale networks providing better PDR, less delay, and energy efficient	Can be extended to work in dynamic network topology to observe energy or latency changes
<b>OF based on Residual Energy</b> [5][18][19]	Residual Energy	Better PDR and control overhead as compared to Total Energy metric but less PDR, more delay than ETXOF	Can be improved by taking link-quality into consideration
<b>OF-EOR</b> [20]	Remaining Energy + ETX	Network lifetime increases by 12% as compared to simple RPL mechanism	Network lifetime can be further optimized depending upon $\alpha$ .
<b>OF-FL</b> [13]	Hop count, ETX, Battery levels, delay	Fewer packet losses, delays, and longer lifetime but more complex working	Can be deployed in different application scenarios consisting of heterogeneous WSNs
<b>LB-OF</b> [21]	Childset	Better PDR with balanced energy consumption, number of children, and lifetime	Can be deployed in applications involving high traffic overhead to get energy balanced topology
<b>OF based on ELT</b> [19]	Traffic Load+ Residual Energy + ETX	High PDR and low delays with balanced energy distribution and longer lifetime	Can be extended to multipath topology
<b>Stability based OF</b> [22]	ETX + Hop count	Improved overall network lifetime and stability	The issue of stability can be applied in large scale networks

#### IV. CONCLUSION AND FUTURE WORK

LLNs are the most important part of the IoT applications. Efficient Routing enables these networks to work in lossy and dynamic environments with scarce resources. RPL proves to be the best solution for LLNs as it provides the optimized versions of Objective Functions for best parent selection. The Authors have proposed different Objective Functions making use of various routing metrics in an individual or combined manner, thus fulfilling the requirements of applications that demands

high reliability, low latencies, longer network lifetime and low energy consumption.

In future, the authors can raise the routing issues that are still not identified, and by making use of different combinations of routing metrics, more optimized versions of RPL can be developed to increase the application scenarios of IoT.

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