Ranking based RPL for Multipoint-to-Point Multi-modal Data Communication in IoT Network.

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Abstract IPv6 Routing Protocol for low power and lossy networks (RPL) is a standardized and default routing protocol for low power lossy networks. However, this is basically designed for sensor networks with scalar data and not optimised for the networks with multi-modal sensors. The data rate of each multi-modal sensor varies based on various applications. RPL suffers from packet drops and re-transmissions which results in packet loss and energy consumption in case of multi-modal data transmission. Hence, the routing strategy implemented in RPL needs better scheduling strategy at parent node for forwarding packets based on various parameters. In this paper, relevant Objective Functions for multi-modal sensor data communication is proposed based on various parameters identified and a weighted ranking based scheduling strategy is proposed for multi-modal data communication called R-RPL. The goal of proposed ranking based RPL (R-RPL) is to increase the throughput and reduce the loss in terms of energy and delay based on proposed scheduling strategy for parent selection. The performance of the proposed R-RPL is evaluated in the contiki based Cooja simulator and compared with RPL protocol. The analysis shows that the R-RPL performs better compared to RPL with respect to packet delivery ratio and energy consumption.

Keywords RPL. Multipoint to Point Communication, Multimodal Routing, IoT, Contiki Cooja.

1 Introduction

The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers and the ability to transfer data over a network without

Address(es) of author(s) should be given

requiring human-to-human or human-to-computer interaction. IoT applications are getting popular in industrial monitoring, building automation, connected homes, healthcare, environmental monitoring, urban sensor networks, asset tracking etc. Along with these applications IoT is also extending with multimedia sensors in the area of road management, traffic management, Habitat monitoring, smart industry, smart city etc.

IPv6 Routing Protocol for Low power and lossy network (RPL) is a popular routing protocol designed and standardized by IETF to support routing in an IoT environment. It is a distance-vector routing protocol based on the construction of RPL graphs. RPL graphs are Directed Acyclic Graphs. Routing occurs in the upward direction (from any node to a root), downward direction (from the root to any node), and any to any (Point-to-point). In RPL, the routing begins after the construction of the Destination Oriented Directed Acyclic Graph (DODAG). DODAG is based on rank value. The rank value is used to identify the position of the node. The rank value of nodes The rank value of the node increases in the topology towards the downward direction and decreases in the upward direction. The rank value is estimated using the OF (Objective function). RPL uses two types of objective functions, namely, HOP and Expected Transmission Count.

Most of the RPL applications concentrate on low data rates for scalar sensor data. Recent analysis and improvement depend on multimedia-based assistance and utilization. This kind of application has different requirements in terms of bandwidth, latency, storage, and so on. Fast growth in the connected devices to the Internet during the last decade and sudden demand for multimedia traffic has given rise to the emergence of the Multimedia Internet of Things(M-IoT).

In [7] M-IoT smart objects are usually resource-constrained, in terms of energy, memory storage, and processing power. To make the devices smaller, cost-effective, and energy-efficient, sensors are usually designed to be battery operated or solar powered with only a few kilobytes of memory, and limited processing power in megahertz.

The traditional multimedia application involves the data transmission of point-to-point, point to multipoint, or multipoint to multipoint. On the contrary, M-IoT applications require immense data transmission during multipoint-to-point communication (e.g., the surveillance system of the entire smart city). The architecture of the M-IoT is shown in figure 1. The sensor nodes which are capable of sensing environment through scalar data and multimedia data are considered in physical layer. The nodes can prefer IEEE 802.11 or IEEE 802.15.4 standard along with IPv6 standard for routing and communication network and data link layer. Edge nodes are sensor nodes which collect sensor data. Fog nodes are intermediate nodes which performs the partial processing of data, or processing data and performing decision making during critical situations. The Cloud layer collects all sensor data for further data analysis. The architecture of M-IoT phases challenge in each layer. This work basically addresses the issues in communication layer.

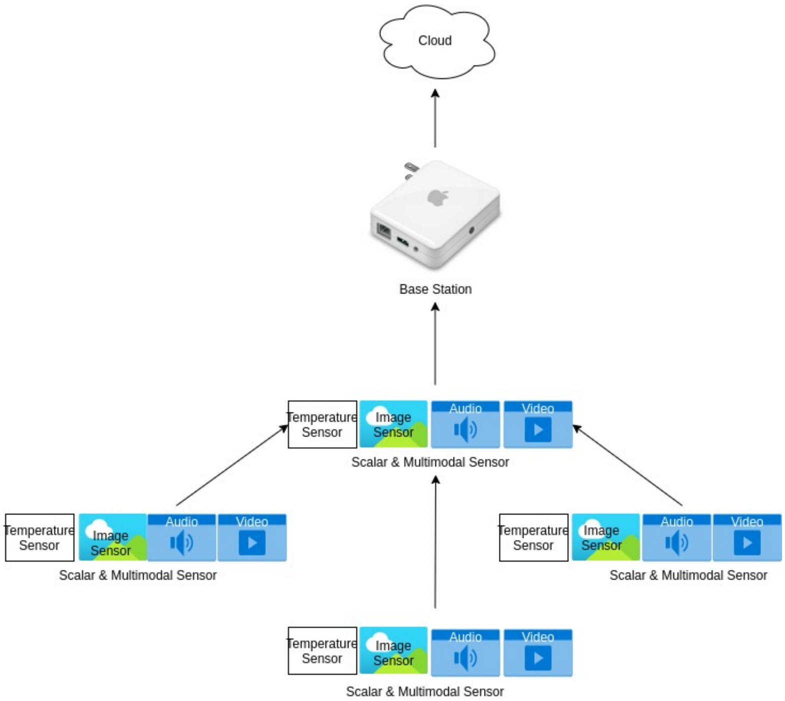


Fig. 1: M-IoT Architecture

Dynamic network, heterogeneous data, higher throughput, QoS, and delay sensitivity over such resource-constrained M-IoT smart objects escalates the challenges for M-IoT. Multimedia data i.e., audio, image, and video is set of unstructured features. Transmission of such bulky and unstructured data over bandwidth and computationally scarce network requires efficient and intelligent network topology. The addition of multimedia data acquisition and communication requires revision and amplification of the traditional IoT system, which we refer to as M-IoT. The revision of IoT for multimedia communication requires efficient feature extraction, event processing, encoding/decoding, energy-aware computation, lightweight and priority-based routing, QoS and QoE maintaining performance metrics, effective channel access, and fair-MAC protocols.

The major aspect in Multimedia IoT is handling Data rate. The data rate varies based on application, event or resource constraints. As a result, in network processing techniques for data aggregation, data transmission and data dissemination is required. Handling data transmission in resource constraint network is one of the great challenge. Hence, there is a need for efficient routing protocol to provide efficient data transmission in the M-IoT. RPL is designed and standardised as routing protocol for IoT network. However, the protocol needs better strategy for multimedia data transmission. Hence, this paper proposes Ranking based RPL called R-RPL. The major contribution of the works are as follows:

1. Proposed a suitable Objective Function for Multimedia IoT called DEE-OF.
2. Proposed a Ranking based scheduling technique for RPL to handle heterogeneous data rate called R-RPL.

The proposed Objective Function DEE-OF considers data rate, energy and ETX as parameters for parent selection and routing. The nodes estimates the rank based on proposed Objective Function, and performs scheduling of data traffic based on obtained rank for each flow in the network. The simulation results shows that the proposed R-RPL performs better compared to RPL for high data rate applications.

1.1 Motivation

The applications of IoT may contain sensor nodes which sense the environment with only scalar data type sensors or it can also include multimedia sensors such as camera, audio recorder etc. The data transmission to sink or gateway may be periodic or event based. The nodes in the networks with resource constraint need energy efficient strategy to increase the life time of the network. Handling heterogeneous multi-modal data in the network with in-network processing is very essential.

The motivation for our work is to define a routing metric that allows RPL to find the best path in terms of energy, data rate, and ETX despite changes in link quality over time. Hence, the proposed framework helps in developing an efficient IPv6-based routing protocol in Low Power Lossy Networks for homogeneous or heterogeneous based multi-modal sensor networks.

1.2 Objective

To design and develop energy efficient multipoint to point routing protocol for IoT network with multi-modal sensors.

2 Literature Survey

In case of M-IoT, some of the major challenges are with respect to selection of Objective Function, performing load balancing in routing protocol and considering energy efficiency for increasing network lifetime. Hence, the literature survey is carried out with respect to these challenging issues.

Table 1: Literature Survey - Objective Function

Author	**Methodology**	**Merits and Demerits**	**Observed work**
Sharwari S. Solapure, Harish H. Kenchannavar[8]	Proposed OFs designs using various routing metrics used to improve the performance of the IoT applications.	1.The composite metric (Energy + ETX = EE) provides good results for extended time. 2.Overload of control messages along with triggering function need to be analyzed.	The cross layer communication between MAC and Network layer design need to be considered to increase the RPL performance.
Hanane Lamaazi, Nabil Benamar [5]	Objective function based combined metric using fuzzy logic method	1.OF combination (ETX,HC,EC) allows equalizing the distribution of energy consumption of all nodes. 2.OF_FUZZY provided low PDR compared to other OFs.	More routing metrics need to be considered to give the best routing decision to choose the optimal path.
Bouzebiba, Lehsaini [1]	Design of new QoS aware objective function based on free bandwidth in an enhanced version of RPL protocol called FreeBW-RPL	1. Reduces the congestion problem by switching to a less congested path. 2. Addressing the application of FreeBW-OF in heterogeneous networks	Improve proposed OF by taking into consideration the hop account.

2.1 Review on Objective Function

In the paper [8] author has mentioned the proposed Objective Functions mapped using various routing metrics used to improve the performance of the IoT applications. Default OFs such as MRHOF and ETX will not fulfill the need for smart applications. For this purpose, the author has combined three metrics ETX, Energy, and Content, single and combination with each other to improve the design of the objective function of RPL for IoT applications. This technique will eliminate the cumulative effect of the short-listen problem of the default trickle timer. Short-listen problem arise when running

Trickle in asynchronous networks. The short-listen problem may turn down the suppression mechanism of Trickle resulting unimportant repetitive transmissions and, thus restricting the algorithm scalability. Energy merged with Content (EC) including aggregation with Enhanced timer (EC En Timer) design gives good results for Latency Delay (LD) and Packet Delivery Ratio (PDR)as compared to default OF design. Residual Energy (RE) joined with ETX (EE) besides combination with Enhanced timer (EE En Timer) design works great for energy consumption. Overhead is extremely low in RE and ETX design. Conversion time is decreased by nearly 50% in an En Timer design. Higher PDR and fewer delay values of EC and EC En Timer design encourage its use in health monitoring applications where reliability is essential. Low energy consumption results of RE, EE, and EE En Timer designs are comfortable for forest monitoring applications, as energy is a crucial aspect. This corresponding result issue will help to meet the IoT application requirements. Overload of control messages onward with triggering function wants to be analyzed further together with its role in IoT applications.

In paper [5] the author has suggested that OF can work to a collection of metrics and restrictions used in a single or combined way. The use of a single metric in the OF can enhance routing performances while diminishes others. To overcome these barriers, the author introduces a new approach to enhance the RPL routing protocol. The proposed OF-EC (objective function-based combined metric using the fuzzy logic method), a novel objective function that recognizes both link and node metrics, namely ETX (expected transmission count), HC (hop count), and EC (energy consumption) based on fuzzy logic concepts. The results show that the new OF-EC within the association to the OF-based ETX and OF-based energy consumption only and OF FUZZY allows improving RPL appearances in terms of PDR and overhead. Also, this novel metric provides balancing the energy consumption of nodes throughout the network. OF_FUZZY provided low packet delivery ratio compared to the other OFs. Since Fuzzy methods are heavy on network, simple energy efficient techniques are required.

In paper [1], author proposed an enhanced version of RPL for M-IoT called free bandwidth (FreeBW)-RPL in which the sensed data is needed by multimedia devices. FreeBW-RPL protocol suggests a novel objective function called FreeBW that holds the FreeBW calculation in the network layer. The setting of QoS routing challenges is the volume of the bandwidth while choosing the routing path to include the maximum FreeBW to deliver better performance of the multimedia applications. Simulations have been managed over the COOJA simulator. The results shown in [1] mastered the basic ones in phases of end-to-end delay, throughput, packet delivery ratio, and energy consumption and delivered better performance than other protocols. Further work on FreeBW-OF in heterogeneous networks and multimodal sensor is required to cover wide range of applications.

Most of the authors have used one or two metrics for better results and have applied Fuzzy methods which are heavy on networks. Most of the work concentrated on homogeneous network for analysis of their proposed methods.

There is need for considering combined metric to reduce loss percentage, energy consumption of each node and latency in the heterogeneous network with respect to sensor data.

Table 1 summarises the pros and cons of various Objective Functions for M-IoT in literature.

2.2 Review on Parent Selection / Load balancing

Load balancing is a major problem in RPL. Rather than concentrating only on energy consumption it is better to concentrate on uniform energy consumption among the nodes to improve the life time of the network. Imbalanced energy consumption in the network may disrupt the network by making the bottleneck nodes die as fast as possible. Hence, handling load balancing during parent selection helps to perform uniform energy consumption in all the child nodes. . In literature, authors have used various methods to overcome the issue of unbalanced networking in a large area.

In [6] highlighted the different traffic patterns in the network and also the problem of uneven distribution of sensor nodes in large areas. Some sensor nodes as compared to remaining nodes, may have heavier workload due to unbalanced workload distribution, network lifetime of the sensor node will be reduced. In order to achieve equal distribution of load in the network, author proposed a load balanced routing protocol based on RPL. LB-RPL considers workload differences and spread out the data traffic among the parent nodes instead of selecting single parent node as a primary parent which is based on pairwise link condition indicators. Results and analysis shows the higher peak workload in network when data collector is placed at the centre of the network. Nodes with heaviest workload using LB-RPL have much smaller number of forwarded packets than that of the nodes using RPL. Nodes that are at same distance from the data collector, has similar workload when using LB-RPL than that of RPL. LB-RPL also achieves 100% PDR which is much better than the performance of basic RPL under same configuration. Future analysis must consider nodes near sink having more load compared to other levels, the network lifetime decreases very fast as the energy of the nodes near sink decreases. As a result, the nodes in the network are not able to communicate with sink node, even though the nodes contain higher energy.

In [4] studied that packet loss under heavy traffic is due to congestion and load balancing problem. To overcome this problem author introduced queue utilization based RPL (QU-RPL) to achieve load balancing and end-to-end packet delivery performance compared to standard RPL. To check end -to-end packet reception ratio of RPL queue loss is the main reason. It is natural that nodes closer to sink experience more relay burden and experience high queue loss in high traffic scenarios. But, queue loss ratio of each node is based on its hop count from the LBR for both high and heavy loads. In routing, the QU-RPL lowers the probability that a node having a congested parent is selected as a parent node. In packet delivery performance, QU-RPL reduces

Table 2: Literature Survey - Load Balancing in RPL

Author	**Methodology**	**Merits and Demerits**	**Observed work**
Hyung-Sin Kim et.al [4]	Tested on real test bed of a multi-hop LLN over IEEE 802.15.4.	1.Overcome packet loss due to congestion and load balancing problem in Routing parent selection and introduced QU-RPL. 2. Not suitable for large-scale networks.	Testbed needs to be compared with ContikiRPL and find the difference between TinyRPL and ContikiRPL.
J. Tripathi and J. C. de Oliveira [9]	Applied Load imbalance metric on tree/hierarchy based data collection or data dissemination in highly varying link condition.	1.Low imbalance help to improve the network lifetime and achieve greater improvement when network is larger than the smaller one. 2.Imbalance metric needs to consider for small networks.	Required to provide similar load balance to the entire network instead of considering particular level or rank.
Xinxin Liu et.al [6]	Validated with workload imbalance detection and signalling and load balancing on data forwarding.	1.Proposed LB-RPL protocol where workload distribution and communication conditions are jointly considered to select optimal data forwarding paths. 2.Routing table of each node receives multiple copies of same DIO messages and provide slow recovery.	Consider nodes near sink having more load compared to other levels, the network lifetime decreases very fast as the energy of the nodes near sink decreases.

the queue loss ratio significantly, especially at bottleneck nodes. In balanced tree-topology of QU-RPL has critical impact on congestion mitigation and thus enables QU-RPL to achieve lower and fairer queue loss compared to RPL.

QU-RPL reduces the data transmission burden on most congested nodes, while only slightly increasing on some other nodes.Test bed needs to be compared with ContikiRPL and find the difference between TinyRPL and ContikiRPL with respect to performance.

In [9] defined a load imbalance metric which is applicable to any tree/hierarchy based data collection which can be applied to large scale LLN's and IoT. It requires only partial topology knowledge and works with RPL without adding extra control overhead and can also work in highly varying link condition. To minimize the variance, mean square error of load estimates the load imbalance, where higher the number of nodes in a particular rank or level of the tree, lesser will be the effect of imbalance traffic that is distributed amongst more forwarders. The simulation results achieves less variance in data traffic, low imbalance and help improve the network lifetime by considerable amount. Analysis is required to provide similar load balance to the entire network instead of considering particular level or rank, because more number of nodes in a particular level will lead to load imbalance in the network.

Table 2 summarises the pros and cons of various load balancing techniques for M-IoT in literature.

2.3 Review on Energy efficiency

In [11] defined traditional routing protocols that propagate through entire network to introduce reliable P2P route, which requires large amount of energy consumption. So author proposed energy - efficient region based routing protocol (ER-RPL) which achieves energy- efficient data delivery without compromising reliability. (i) PDR performance drops as the traffic flow increases. In RPL, root becomes the bottleneck when traffic is heavy and performance goes down. But ER-RPL still achieves an optimal value. (ii) Average hop count - in ER-RPL is 40% less than that of RPL. (iii) Routing overhead increases as the traffic flow increases. ER-RPL achieves 59% less control overhead than P2P-RPL with symmetric and asymmetric links. (iv)Energy consumption increases with the increase of P2P traffic flows. ER-RPL achieves great energy conversation compared to RPL and P2P-RPL. (v) End-to-End delay increases as the traffic flow increases. RPL suffer from longer delay than ER-RPL and P2P-RPL. Analysis can be extended from static networks to mobile networks in future.

In [2] studied that each node should spend the same quantity of energy to increase the network lifetime. Expected lifetime routing metric has been initiated the time unto the node will run out of energy. The author also identifies energy bottleneck nodes and expand the traffic load uniformly between them using DAG structure of RPL. In expected lifetime[ELT] bottleneck node will be the first node to die. So the new node has to calculate its own traffic on the bottleneck's lifetime. Node needs to know the information about bottleneck in order to estimate ELT, which is sent along the path in a compact DIO's. Every time DIO is received, ELT of a node is repeated. Therefore each node main-

Table 3: Literature Survey - Energy Efficient in RPL

Author	**Methodology**	**Merits and Demerits**	**Observed work**
Ming Zhao et.al [11]	Makes use of region information of networks using hybrid of proactive and reactive routing protocol.	1.Introduced ER-RPL which requires a subset of nodes to do the job. 2.As traffic flow increases in a large network, energy consumption will be more and lead to load imbalance network.	Analysis can be extended from static networks to mobile networks in future.
Patrick Olivier Kamgueu et.al [3]	Highlighted energy based objective function.	1.Focus on node remaining energy for next hop select is the ratio of the number of packets obtained successfully and the total number of packets transmitted and increases the network lifetime and distributes energy evenly among nodes 2.Has low packet delivery ratio.	Energy aware scheme and ETX has their own limitations, so needs to aim by combining both routing metric in future.
Oana Iova et.al [2]	Introduced proposed algorithm using preferred parent and load balancing.	1.New routing metric ELT has been proposed and focus on each node that should consume the same quantity of energy to improve network lifetime. 2.Testing each parent node for energy balancing would be time consuming.	Searching a bottleneck node itself is time consuming and network lifetime needs to be considered even after detecting the bottleneck nodes.

tains up to date information. In multipath Construction - assume that a node will transfer all its traffic to individual single parent during preferred parent selection. Author prefer the worst case to balance more efficiently the energy consumption. Once after preferred parent selection, node has to compute its relative distance from the border router i.e Rank. But expected lifetime represents minimum metric along a path, so value cannot be used to compute the rank. Author proposed a constant step value to the rank of its prepared parent. Author also mentioned about load balancing where traffic is spread to all the bottlenecks. Searching a bottleneck node itself is time consuming and network lifetime needs to be considered even after detecting the bottleneck nodes.

RPL provides various metrics to guide the routing metric, one such is expected transmission count which focus on link reliability. So [3] implements the use of nodes remaining energy for next hop selection and compare the result against ETX scheme. The proposed implementation increases the network lifetime and distributes energy evenly among nodes. But in accuracy of routing to collect the application data ETX promotes higher packet delivery ratio than proposed one. Energy and ETX has their own limitations, so needs to aim by combining both routing metric in future.

Table 3 summarises the pros and cons of various energy efficiency for M-IoT in literature.

2.4 Research Gaps

The following are the research gaps related to literature survey in subsections 2.1 to 2.3.

1. Most of the works concentrated on one or two metric to define objective function. Further study on identifying various Objective Function is essential with respect to Multimodal sensor data.
2. In Load Balancing, various works have been achieved with respect to improving network lifetime, energy efficiency, maximizing the packet delivery ratio and different load balancing techniques. The energy efficient load balancing is based on various Objective Functions and types of sensor data.
3. In Energy Efficiency, literature shows the work with respect to improve network lifetime as well as routing reliability. Further work on energy efficiency with respect to multimodal sensor data is essential.

3 Weighted Rank based Packet Forwarding

Many research papers shows the performance of RPL with respect to scalar sensor data. The future IoT requires the multi modal data transmission as the resource constraint devices can also be connected with low and medium resolution cameras and audio devices along with sensors like temperature, humidity sensors. In such applications, RPL needs certain improvement to adopt for heterogeneous sensor data transmissions. In this work, we propose a Rank based RPL for the same.

3.1 Weighted Ranks for Neighbors

In a typical low power lossy network, a given node that is part of the DODAG has one or more neighbors. The neighbors may send or receive packets via the node based on the routing entries. In Contiki, at any given point, a node can have an outstanding connection with up to 2 neighbors. i.e., it can queue packets for up to 2 different destinations before it starts dropping packets for others. All the neighbors are treated equally. Packets coming from different sources are treated the same. While this works reasonably well in a less congested network, in a more congested network, packets from sources with lower energy could get dropped in favor of a higher energy node. These drops could lead to re-transmissions from a lower energy node causing it to use more of its energy and in turn decreasing the lifetime of the node and potentially the entire network.

Similarly, fragmented packets from a higher throughput node (ex: nodes transmitting multimedia data) can be dropped in favor of a low priority packet from a sensor node and thus increasing jitter. To tackle this, we propose a technique where each neighbor is assigned a rank based on the various metrics that govern the network quality and lifetime and use the ranks associated with neighbors to determine priority for packets sourced from each of these neighbors. The process of Rank based priority selection consists of following phases: Metric advertisement and weighted rank calculation.

3.1.1 Metric Advertisement

The rank of each node must be decided on various metrics. As a result, to rank neighbors based on metrics, initially the neighbors must be able to share the metric values associated with various aspects. For example, to decide on parent selection at later stages, a neighbor must be able to communicate the details of remaining energy with its peer nodes. This process is called "Metric Advertisement".

To share the metric information, DIO message is considered and proposed certain changes for original DIO message format as shown in Fig 3. A new sub-option field is added and all other fields of DIO message is considered as represented in [10]. An RPL node will include this sub-option in all its DIO messages. Since it is part of a DIO message Fig 2, all the neighbors in the range of the node receive this information.

Each metric is defined as a TLV (Type, Length, and Value). Type identifies the metric, the length indicates the size of the value associated with the metric and the value is the data associated with the metric. In the proposed work, the 3 metrics are considered as shown in Table 4.

1. Energy - Indicates the percentage of energy left in the node.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| RPLInstanceID |Version Number |             Rank              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|G|0| MOP | Prf |     DTSN      |     Flags     |   Reserved    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                            DODAGID                            +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Option(s)...
+-+-+-+-+-+-+-+-+
```

Fig. 2: DIO - Message format [10]

```
                        Option length
|<------------------------------------------------------------>|
0       1          2        n      n+1        n+2      n+m      len
+-------+----------+--------+------+----------+--------+-------+
| Type | Len (n) | Value | Type | Len (m) | Value | ....  |
+-------+----------+--------+------+----------+--------+-------+
```

Fig. 3: Sub-option - Metric Advertisement message format

Table 4: Metrics

Metric	Type	Length
Energy	1	1
Data-Rate	2	2
ETX	3	2

2. Data-Rate - Indicates the rate (in pps) at which the node is sending data (self generated + routed).
3. ETX - Indicates the quality of the link between the node and the neighbor.

3.2 Weighted Rank Calculation

An RPL node in the network receives DIOs periodically from all the neighbors in its range. The node will parse the DIO and look for the Metric Advertisement sub-option. When it finds the sub-option, it stores the data associated with all the metrics shared in the sub-option in its cache. This cache is updated every time a new DIO is received from the neighbor.

The node runs a fixed interval timer to walk the list of all the current neighbors assigning rank to each based on the metrics advertised. This fixed interval timer is termed 'Metric Advertisement Timer' and set at 3 seconds in the proposed work. Thus, the ranks associated with each neighbor is refreshed every 3 seconds. The node then runs through all the it's current neighbors periodically in Algorithm 1, we call it "Metric Advertisement Timer" and assigns ranks for each of the neighbor based on the values of the metrics advertised. In the proposed work, the periodicity is set to 3 seconds.

Algorithm 1 RunMetricAdvertisementTimer

Energy(Max) = Data-Rate(Max) = ETX(Max) = 0
for each neighbor N in the neighbor table **do**
    if Energy(N) > Energy(Max) **then**
        Energy(Max) = Energy(N)
    end if
    if Data-Rate(N) > Data-Rate(Max) **then**
        Data-Rate(Max) = Data-Rate(N)
    end if
    ETX(N) = Calculate ETX for neighbor
    if ETX(N) > ETX(Max) **then**
        ETX(Max) = ETX(N)
    end if
end for
$W_{Rank}(Max) = 0$
for each neighbor N in the neighbor table **do**
    R_{Energy} = Rank based on Energy(N)
    $R_{Data-Rate}$ = Rank based on Data-Rate(N)
    R_{ETX} = Rank based on ETX(N)
    $W_{Rank}(N) = (W_{Energy} * R_{Energy}) + (W_{Data-Rate} * R_{Data-Rate}) + (W_{ETX} * R_{ETX})$
    if $W_{Rank}(N) > W_{Rank}(Max)$ **then**
        $W_{Rank}(Max) = W_{Rank}$(N)
    end if
end for

3.3 Ranking Method for Child Nodes

The Ranking method is popular because it is relatively simple to implement, and it only requires knowing the marginal proportions for each variable used in weighting. This method has been chosen to sort the child nodes based on energy, data rate, and ETX. The characteristics of the parameters considered are as follows:

1. Lower the energy value the node must get a higher rank.
2. A higher data rate must get a higher rank.
3. Lower ETX must get a higher rank.

From the above characteristics, higher Rank number gets higher priority. The rank based on each metric is calculated separately and finally priority is assigned based on combined metric rank calculation.
The rank is calculated based on energy as follows:

$$R_{Energy} = [10 - N_{Energy} * 10/MAX\_ENERGY] \tag{1}$$

$$N_{Energy} = \frac{(TotalBatteryEnergy - EnergyConsumed) * 100}{TotalbatteryEnergy} \tag{2}$$

The rank is calculated based on datarate as follows:

$$R_{DataRate} = [10 - N_{DataRate} * 10/MAX\_DATA\_RATE] \tag{3}$$

Similarly, The rank is calculated based on ETX as follows:

$$R_{ETX} = [10 - ETX * 10/MAX\_ETX] \tag{4}$$

The combined weighted Rank determined for child nodes is considered as follows:

$$WeightedRank = W_1 * R_{Energy} + W_2 * R_{Datarate} + W_3 * R_{ETX} \tag{5}$$

where W_1+W_2+W_3 $= 1$

In each parent node the priority of child node is assigned based on weighted Rank.

3.3.1 Rank based on Energy

For calculating rank based on energy, the battery capacity of the mote is necessary to consider. For simulation purposes, a Zolertia Z1 mote with a 2xAA battery has been used. Based on the capacity of the Z1 battery, the battery capacity of each node is calculated. Based on the value of estimated energy, assigning of rank has been performed.

3.3.2 Rank based on Data rate

The data rate is a term to indicate the transmission speed, or the number of packets per second transferred. The leaf nodes of the topology have been given different data rates, to check the packet drop of the node. The leaf node with less data rate is considered with x packet/sec and leaf nodes with a high data rate have y packet/sec. Based on the Ranking method, the Rank data rate is calculated.

3.3.3 Rank based on ETX

ETX optimize or constrain a routing metric on the paths. Since ETX is linked specifically, it is not advertised as part of a DIO message since a DIO can be a multicast message destined to all the neighbors in the node's radio range. Instead, the rank based on ETX is calculated as part of the metric advertisement timer. When the timer expires, the ETX for each link is fetched and the rank is assigned based on that.

3.4 Priority based Packet Forwarding using Weighted Rank

Here weighted rank is assigned to each neighbor in the range and use this for determining the priority of the packets being transmitted over a given link. The first step is to determine the priority of the packet at the TCP/IP layer based on the source and destination addresses. Now that we have a weighted rank assigned to each neighbor in the range, we use this for determining the priority of the packets being transmitted over a given link. The first step is to determine the priority of the packet at the TCP/IP layer based on the source and destination addresses.

3.4.1 TCP/IP Layer

The node first determines if the packet being forwarded is destined to the root of the DODAG as in Fig 4. If the packet is destined to the root, the priority for the packet is assigned based on the previous hop for the packet. i.e., assign the priority based on the weighted rank associated with the node from which the packet was received. If the packet is self-generated (generated on this node), assign an arbitrary priority to it. In the proposed work, it is assigned with the highest priority in the priority range. Once the priority is determined, the priority is pushed in the metadata of the packet and forwarded to the MAC layer.

3.4.2 MAC layer

When the packet reaches the MAC layer as shown in Fig 5 , the priority of the packet is looked up from the metadata. At the MAC layer, the neighbor queue for the current destination is looked up and the packet is queued for transmission if -

1. The neighbor queue exists and both the neighbor queue and the packet queue is not full.
2. The neighbor queue does not exist and the current number of neighbor queues is less than the limit and the packet queue is not full.

   In all other cases, the packet is dropped.

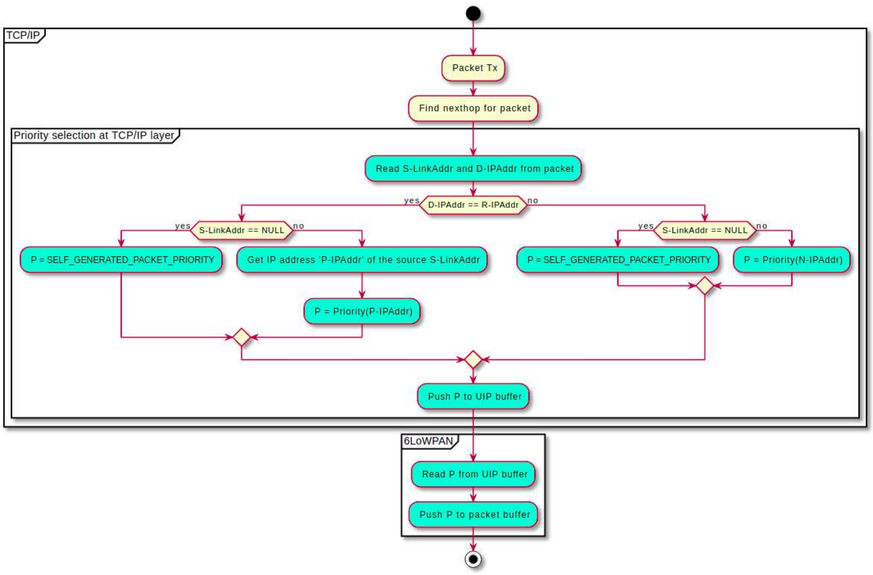


Fig. 4: Data-Plane Packet Prioritization With RPL Metric Advertisement

In this work, additional checks are performed based on the priority of the packet before determining if the packet must be dropped.

1. If the neighbor queue exists but is full, find a packet with a priority less than the priority of the current packet. If a packet is found, drop the packet and queue the current packet for transmission. If not, drop the current packet.
2. If the neighbor queue does not exist and the current number of neighbor queues is at the limit, find the highest priority associated with a packet in each of the neighbor queues. Find the lowest priority amongst all the highest priorities of each queue. If the priority is lower than the priority of the current packet, delete the neighbor dropping all the packets in its queue. Create the neighbor queue for the current destination and queue the current packet for transmission. If the priority is equal to or greater than the current packet, drop the current packet.

This aids in reducing the chances of higher priority packets from being dropped in favor of lower priority packets.

4 Results and Analysis

The experiment included 2 types of Z1 motes. Type 1 with a total energy of 100000mJ and data rate of 1pps and Type 2 with a total energy of 180000mJ and data rate of 5pps. Different weights has been considered for different metrics. The weights used in the experiment are $W_{Energy} = 5$, $W_{Datarate} = 3$ and

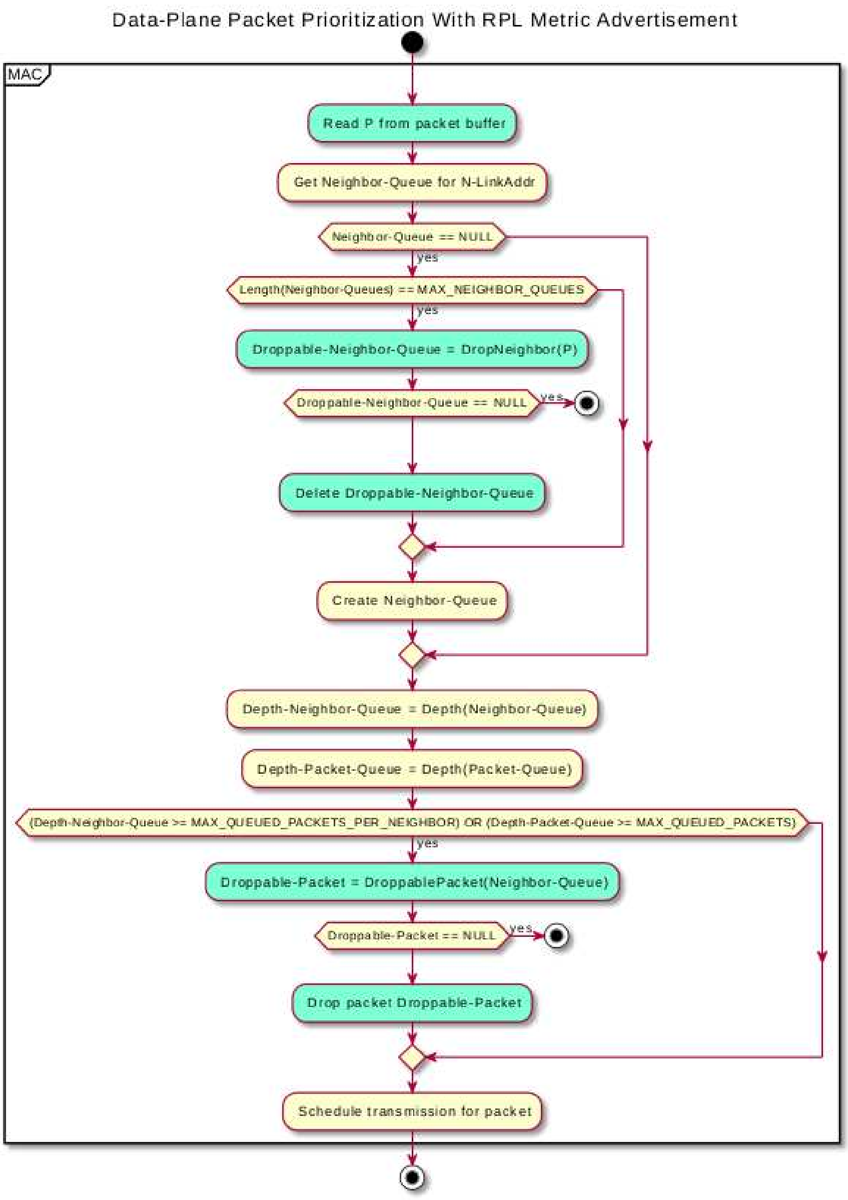


Fig. 5: MAC Layer

$W_{ETX} = 2$. The proposed technique has considered three performance metrics and compared the result with RPL. Fig 6 shows the test topology considered to experiment with the performance metrics. The leaf node with less data rate is considered with 1 packet/sec and leaf nodes with a high data rate have 5 packet/sec based on limitations with the simulator. Table 5 summarizes the simulation settings.

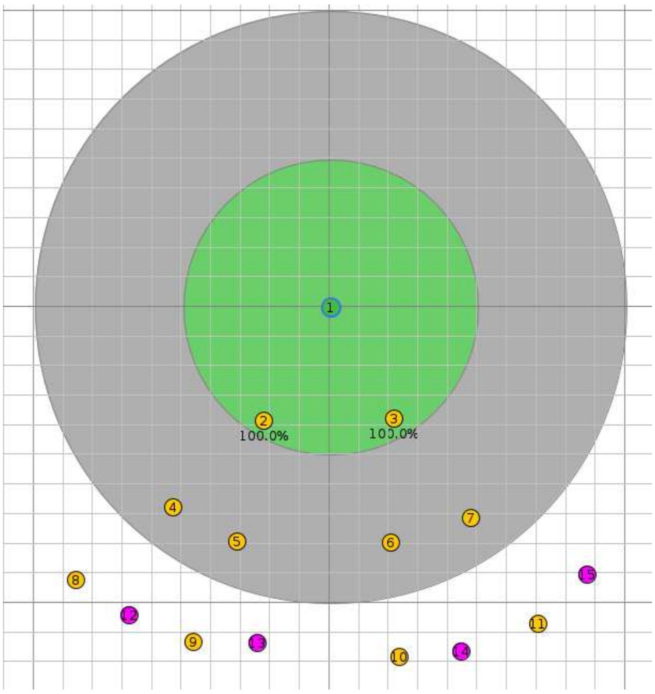


Fig. 6: Deployment of nodes

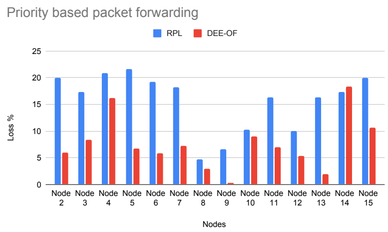
Table 5: Simulation Parameter.

Simulation Parameter	**Values**
OS	ContikiOS-ng
Radio model	Unit disk graph model
Mote type	Z1 Mote
Network size	100 m x 100 m
Application Program	Examples/rpl-udp
Simulation time	15mins

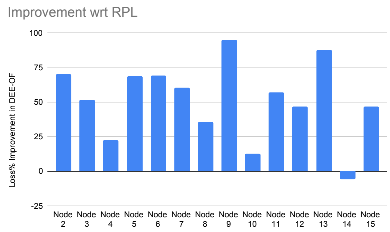
1. Loss Percentage: The reliability of a communication network path is expressed by the packet loss rate. Packet loss occurs when one or more packets within a transmission are successfully sent, but fail to arrive at the destination. Packet loss can be caused by a variety of factors including network

congestion, faulty network components such as hardware or drivers, or corrupted packets within the transmission.

$$Loss\% = \frac{(ReceivedPacket - SentPacket)}{SentPacket} \tag{6}$$



(a) Loss percentage



(b) Loss percentage improvement

Fig. 7: Performance Metrics of Loss% in PPF

From the above results, Fig 7a mention the comparison between RPL and DDE-OF in priority based packet forwarding. Fig 7b says the percentage improvement of each node with respect to RPL. The node 14th provides more loss compared to RPL. But overall, PPF method gives better results than the RPL. The 7b mention the improvement graph with respect to RPL, where the percentage of improvement equals 51.55%.

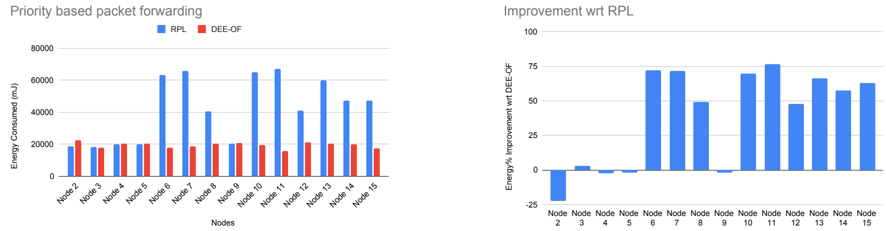
2. Energy Consumed: The calculation is carried out using a powertrace tool available in ContikiOS. It is the energy of nodes spent during the exchange of information in the network. During During transmission, the energy spent by the node is called "all transmit" while in the reception it is called "all listen". With extension, other parameters are analyzed for energy estimation is CPU that outlines the power consumption during the full power mode and LPM mention the power consumption during the low power mode. V corresponds to the battery voltage. Rtimer represents the number of ticks per second (=32768 ticks/s).

$$\begin{aligned} Energy(mJ) &= (Transmit * 17.4mA + Listen * 18.8mA + CPU\_time * 0.33mA \\ &= +LPM * 0.011mA) * 3V/(32768) \end{aligned} \tag{7}$$

From Fig 8a and Fig 8b, percentage of energy consumed in the bottleneck node 2 is more comparatively with the RPL. The percentage improvement with respect to RPL in energy consumption is 54.02%.

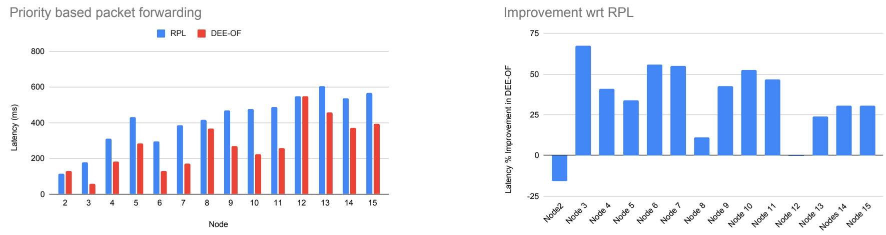
3. Latency: Latency is a measure of delay. In a network, latency measures the time it takes for some data to get to its destination across the network.

$$Latency(ms) = (Senttime - Receivedtime) \tag{8}$$



(a) Energy Consumed (b) Energy Consumed improvement

Fig. 8: Performance Metrics of Energy consumed in PPF



(a) Latency (b) Latency

Fig. 9: Performance Metrics of Latency in PPF

Fig 9a and Fig 9b mention that delay is more in node 2 when compared to other nodes. Overall result of the network says that DEE-OF in priority based packet forwarding method outperforms better compared to the RPL. The 9b describes the improvement with respect to RPL, where percentage equals to 33.72.

5 Parent Selection

5.1 Weighted Rank Based Objective Function

In RPL, an objective function is responsible for determining the best parent for a given node at a given point amongst multiple potential parents. The path cost calculation for a neighbor is what drives the decision on which neighbor is chosen has the parent. Each objective function varies on how it determines the path cost that in turn driving how a parent is chosen. In addition to path cost, the objective function is also responsible for determining the rank to be assigned for a node based on the parent node selected.

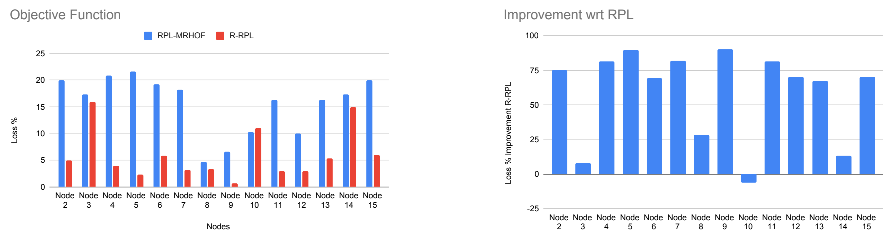
In the proposed objective function, the weighted rank based model is used to determine the path cost and rank for a neighbor.Since the criteria for choosing a parent is different to prioritizing a child, the weights chosen for the metrics is different when calculating the weighted rank for a neighbor as a potential neighbor.

$$PathCost(N) = ((10 - WRank(N)) * (Min\_HopRank\_Inc/10)) + Min\_HopRank\_Inc \tag{9}$$

where 10 is the maximum value of weighted rank that can be associated with any neighbor.

The path cost associated with a neighbor will be lower if it has a higher weighted rank. The path cost for neighbors are distributed between Min_HopRank_Inc and $(2 * Min\_HopRank\_Inc)$.
i.e., $Min\_HopRank\_Inc \leq PathCost(N) \leq (2 * Min\_HopRank\_Inc)$

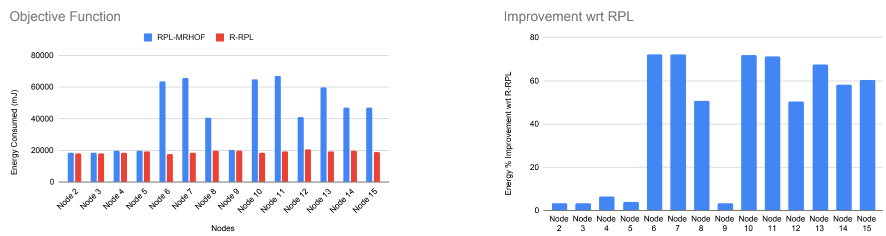
$$Rank = MAX((Rank(N) + Min\_HopRank\_Inc), PathCost(N)) \tag{10}$$



(a) Loss percentage (b) Loss percentage improvement

Fig. 10: Performance Metrics of Loss% in R-RPL

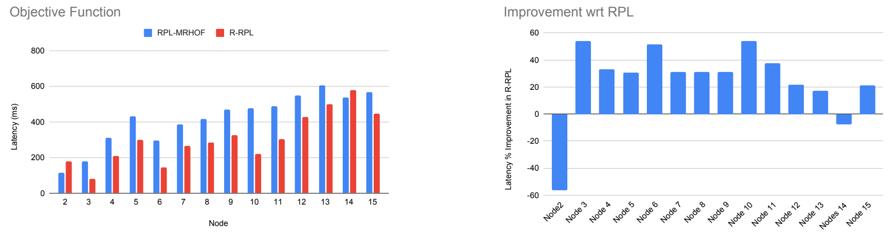
From Fig 10a and Fig 10b one particular node gives more loss, but overall results outperforms better compared to RPL. The graph 10b says the improvement of Loss percentage is 61.8 with respect to RPL.



(a) Energy Consumed (b) Energy Consumed improvement

Fig. 11: Performance Metrics of Energy consumed in R-RPL

Fig 11a and Fig 11b mention about energy consumption of each node in RPL and R-RPL. Bottleneck nodes such as node 2 and node 3 consumes less energy compared to other nodes in the network. Every node gives better results from R-RPL compared to RPL. The percentage improvement of energy consumption with respect to RPL is 55.41.



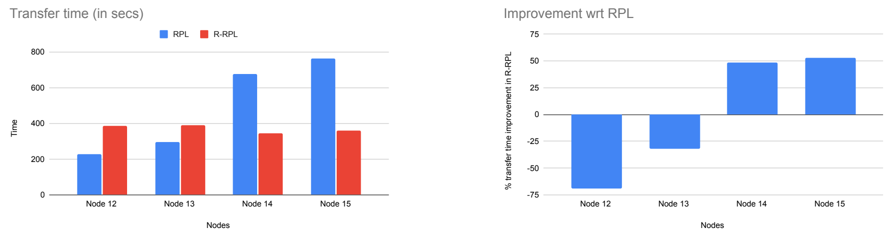
(a) Latency (b) Latency improvement

Fig. 12: Performance Metrics of Latency in R-RPL

Fig 12a and Fig 12b mention the comparison and percentage improvement of latency with respect to RPL and R-RPL. Proposed method gives more delay in the bottleneck node as compared to RPL. Considering overall network, proposed method is better compared to RPL. The graph 12b is the improvement graph, where the percentage equals to 26.78.

5.2 Image Transmission Time

For the same Fig 6, the following graph 13a shows the time taken to transfer image of size 100KB from the multimodal sensor nodes to the root. 13b mention that the percentage improvement with respect to RPL is 24.46.



(a) Transfer Time (b) Latency improvement

Fig. 13: Performance of Image transmission time

6 Conclusion and Future work

Instead of dropping a packet destined to a node arbitrarily, check if it can be forwarded instead of an existing queued packet with lower priority. Instead of calculating path cost using a single metric, use multiple metric with weights assigned to each to determine the path cost. Using the current technique, it needs more computation which in it needs more energy and needs more memory space.

With the introduction of R-RPL, there is a significant improvement in the areas of energy consumption, latency and throughput.

Based on particular weight, developer can check what weight needs to be used based on the application. Further improvement can apply different weights for each metric and with different weighted rank to priority mapping tables and analyze the results. Further improvement can be done on path cost calculation using different weights for each metric.

Declarations

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Conflict of Interest

Author Archana Bhat has received research scholarship (2016-2021) and author Geetha V has received Young Faculty Research Award (YFRF 2019-2021) from grants from the Visvesvaraya PhD Scheme of Ministry of Electronics & Information Technology, Government of India, being implemented by Digital India Corporation (formerly Media Lab Asia),

Data Availability

The authors confirm that the data supporting the finding of this study are available within the article. Raw data that support the findings of this study are available from the authors, upon reasonable request.

Code Availability

The Simulation is carried out using Contiki Cooja Simulator. The implemented modules are available from the authors, upon reasonable request.

Author's Contributions

Both authors contributed equally to this work.

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