# Improving the Performance of RPL Routing Protocol for Internet of Things

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**Abstract**

The emerging Internet of Things (IoT) connects the physical world to the digital one and composes large networks of smart devices to support various applications. In order to provide a suitable communication in such networks, a reliable routing protocol is needed. In this paper, a modified version of an IPv6 Routing Protocol for Low-Power and Lossy networks (RPL), which has been standardized by IETF is proposed. It is used in Low power and Lossy Networks (LLNs) that consist of lossy links and electronic devices use a set of novel Internet of Things technologies. RPL protocol is based on the constructional concept of Directed Acyclic Graphs (DAGs) that is constructed using a scalar value called rank. The default metric which is commonly used in low power and lossy networks to compute rank of Expected Transmission Count (ETX) based on the number of re-transmission. While the results represent that this method of calculation is not effective enough. Therefore, we introduce a new method of ETX computation which is used to construct the DAGs with better rank computation and selected routes. The simulation results show that our proposed idea has better performance in contrast with the basic RPL and AODV protocols in terms of Packet Delivery Ratio (PDR), number of re-transmission, end to end delay, and throughput.

***Keywords:*** *Internet of Thing (IoT), RPL, Routing Protocol, Low Power and Lossy Networks (LLNs), Link Reliability Metric.*

## 1. Introduction

In recent years, the Internet of Things (IoT) has become the novel research for investigating the impact of technology in human life. It is used to describe smart devices that collect and forward data to the centralized computing resources [1]. The concept of Internet of Things refers to smart objects which are connected to the IP-based Internet. The number of things connected to the Internet has been improved and will grow in near future. In spite of the resource constraints of lossy communication links and connected devices, routing is mentioned as a fundamental and challenging concept in the Internet of Things [2].

In 2012, due to the lack of a suitable routing protocol for low power and lossy networks (LLNs), RPL protocol (RFC 6550) has been standardized for these networks with special features [3]. LLNs include a huge number of embedded devices with power, memory and resource constraints. These devices are connected by various links like IEEE 802.15.4, Bluetooth, Wi-Fi and Power Line Communication (PLC) [4]. The RPL protocol is used in a specific network which collects data and forwards it through a concentrator. Therefore, the RPL protocol is recommended to use in LLNs in order to analyse its behaviour in such networks [5].

The LLNs such as smart grids include thousands of embedded devices with constraint resources such as smart meters, Intelligent Electronic Devices (IEDs), and etc [6]. Therefore, the routing protocol plays a really significant role

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to guarantee reliability and end-to-end delay for delivery of data. RPL is a routing protocol which is designed for low power and lossy networks and it is expected to be the standard routing protocol for low power and lossy networks [7].

On the other hand, studies show that even though RPL protocol has some dominant beneficial to use in LLNs and it is considered the preferred routing protocol in them, it seems inevitable to ignore its disadvantages. Nodes in a network may suffer from unreliability, inconsistency, and low operation [8].

Since there are limited numbers of solutions to improve the performance of RPL routing protocol, our objective in this paper is to enhance RPL to perform better in LLNs. Thus, we propose a new parameter to calculate the Expected Transmission Count (ETX) as the link metric to reduce the unreliability problems by selecting the links with higher qualities and sending the data traffic through those links. So, by using this new parameter, the transmission probability is being calculated in a rather practical scenario. Therefore, the probability of failure in selecting reliable network paths will decrease. We compare the modified RPL protocol with AODV and basic RPL in a defined condition. We show that our proposed RPL protocol improves network reliability. We also believe that the findings of this study may facilitate the design of new methods to improve the reliability of RPL protocol more.

The rest of the paper is organized as follows. After introduction, we provide the recent studies and their achievements on RPL protocol in Section 2. Then in Section 3, we explained the RPL routing protocol and the main features and specification of this standard protocol based on previous literatures. We proposed the modifications on RPL in section 4 and finally, the performance evaluation investigated in Section 5 and concluded in last section.

## 2. Related Work

The results from some of the recent literatures show that most of these studies focus on the modification of the RPL protocol [9-12]. In 2010, a modified RPL protocol was developed for low power and lossy networks and the authors use ETX as the default link metric to measure the expected transmission count [9]. Also in [10], ETX was used as the link metric and the authors propose multipath to forward data traffic through the control center. So, the traffic would be divided between more than one path and it causes an increase of packet delivery ratio. In both paper [9,10], the authors studied the functionality of RPL protocol over sensor networks. In similar work by Clausen et al. [11] a new approach proposed to improve root initiated broadcast mechanisms in networks which were based on RPL protocol. Finally, detecting connectivity and also the procedure of scanning a channel were explored by Kulkarni et al. [12] to provide self-configuration and achieving the probability of using multiple channels in wireless mesh networks based on RPL protocol. In general, these methods make good attempts to improve the effectiveness role of RPL protocol in LLNs in different terms to increase the probability of data delivery. However, several open research problems have not been resolved yet.

## 3. RPL Routing Protocol

RPL is a distance vector routing protocol that can work on different MAC layer mechanisms [13]. RPL protocol is based on the topological concept of Directed Acyclic Destination Advertisement Graph (DODAG). DODAG has a tree-base structure and specifies the default routes in the network. It should be noted that the DODAG is more than a simple tree. It means that in DODAG, each node can have more than one parent, while in a simple tree each node can have only one parent. The RPL protocol organizes its nodes in a DODAG [14]. The structure of DODAG consists of two steps of making Upward and/or Downward routes.

### *3.1. Making Upward Routes*

In order to construct a DODAG, the DODAG's root broadcasts a DODAG Information Object (DIO) message to advertise the Graph ID and its rank and on the other hand let other nodes to find their locations in the network. Once a node receives the DIO message and wants to join the network [13]: First, it will add the address of the DIO sender to its parent list. Second, computes its rank based on the objective function. Finally, updates the DIO message by its rank and broadcasts the packet again. This process will repeat until the whole nodes in the network compute their ranks. Each node must select a node from the parents set as its default parent node in order to forward the data packets through the root. When a joined node receives a DIO message, it could process the message in two or three stages as follow: stage 1. Discard the DIO message based on some criteria in RPL, stage 2. Process the message to maintain its location in the network, or stage 3. Improve its location by achieving a better rank. After these stages, each node will have a default path to the root and could send its packets through it.

### 3.2. Making Downward Routes

If the function type flag does not set to zero in DIO message, all downward routes from the root to nodes have to be supported and maintained. In this case, each node has to send a Destination Advertisement Object (DAO) message to its parent to set the information of reverse path (the downward path). When the packets are forwarded from nodes through the root, the addresses of intermediate nodes will be saved in DAO messages. When these packets receive to the root, the whole path between the root and the nodes will be established. This message can be approved by DAO confirmation message. RPL protocol has two functional models to maintain the downward paths [13]:

Model 1. Storing mode: In this mode, when a node receives a DAO packet, it is able to save the content of DAO message before sending it to its parent. Therefore, a node's parent could save the whole addresses of its children.

Model 2. Non-storing mode: In this mode, the DAO message is sent through the root directly. Hence, the intermediate nodes will not save the DAO message and just save their addresses in the stack of reverse path DAO message and forward it through their default parents. Therefore, parents do not save their children addresses and only root which receives all the DAO messages is able to save and maintain the downward paths.

## 4. Modification for RPL Protocol

In this section, we describe the structure of our proposed method. While we want to keep the DAG, the structure would be the same.

In the beginning, the gateway node sends a DIO message. Here the Expected Transmission Count (ETX) is used as the Objective Function (OF) to calculate the rate of nodes which is commonly used in low power and lossy networks [15]. The ETX metric of a link from node to node is computed as follows:

$$ETX_{a,b} = \frac{1}{p_{a,b}} \quad (1)$$

Where in equation.1, represents the probability of receiving data from node to node. The value of this probability shows the quality of the considered link. Therefore, there are different ways to calculate the probability based on the quality of a link.

One of the methods to obtain the probability of a successful transmission between two nodes is by considering the number of re-transmission in a link between two special nodes [15]. In order to calculate the number of data re-transmission, if the default parent does not receive the packet in a specific time, the packet will be re-transmitted by the child node. In contrast, a threshold is considered for the number of re-transmission. Therefore, if after a specified number of re-transmission the packet did not receive, it can be concluded that the destination node is inaccessible and another node is needed to choose as the default parent. Hence, the value of ETX could be calculated as follows [15]:

$$p_{a,b} = \frac{1}{1 + NumOfRetrans} \quad (2)$$

Where in equation. 2, the value of *Num of Retrans* shows the number of re-transmission between node *a* and node*b*.

Another method proposed in this paper is calculating ETX based on Signal to Noise Ratio (SNR). This metric shows the power of a signal against the noise in the environment. This parameter specifies the quality of a link and it can be used for probability calculation of a successful transmission between a pair of nodes. The SNR formula is represented as follows:

$$SNR = \frac{P_{a,b}}{\eta} \quad (3)$$

Where in equation. 3, $P_{a,b}$shows the power of node *a* sends *a* packet to node *b* and$\eta$represents the noise power. Since the existence of some factors like the effect of signals fading is unavoidable, a Rayleigh fading is considered between an arbitrary pair of nodes in the network. Therefore, the value of SNR due to the considered assumptions in the network will be calculated as follows:

$$SNR = \frac{P_{a,b}\,|h_{a,b}|^2}{\delta^2} \quad (4)$$

Where in equation. 4, the value of $P_{a,b}$ represents the transmission power from node *a* to node$b$,$\delta^2$shows the noise variance which in fact is the noise power, and $h_{a,b}$ shows the channel co-efficient which is obtained from the following formula [16]:

$$h_{a,b} = F_{a,b}\sqrt{\frac{1}{L_{a,b}}} \quad (5)$$

Where in equation. 5, the value of $F_{a,b}$ indicates fading co-efficient and $L_{a,b}$ shows the path loss between node *a* and node *b*. It should be noted that a communication between node $a$ to node $b$ would be successful if the SNR is above a certain threshold. Therefore, the formula of $P_{a,b}$ is given as follows:

$$p_{a,b} = \mathrm{P}\left[SNR \geq \gamma\right] \tag{6}$$

$$p_{a,b} = \mathrm{P}\left[\frac{\left|F_{a,b}\right|^2 \times \dfrac{P_{a,b}}{L_{a,b}}}{\delta^2} \geq \gamma\right] \tag{7}$$

Where in equation. 7, $\left|F_{a,b}\right|^2$ represents the fading attenuation, $\gamma$ shows the threshold of SNR for a successful data transmission, $\delta^2$ shows the variance of noise or the noise power, $L_{a,b}$ indicates the power loss, and finally $P_{a,b}$ expresses the power of node $a$ transmitting a packet through node $b$.

As a result, the value of ETX could be calculated from the final formula of   which is based on SNR and calculated as follows:

$$ETX_{a,b} = \frac{1}{p_{a,b}} = \frac{1}{\mathrm{P}\left[\frac{\left|F_{a,b}\right|^2 \times \dfrac{P_{a,b}}{L_{a,b}}}{\delta^2} \geq \gamma\right]} \tag{8}$$

Since the novel formula uses SNR metric as the link evaluation, if the value of ETX is calculated from this formula, it would be closer to real value and as a result, the calculation will be more accurate.

The ETX metric will be measured and updated continuously while data traffic is transmitted. Then the rank of each node is calculated based on ETX from the following formula:

$$Rank(Node) = Rank(Parent_{Node}) + ETX \tag{9}$$

Where in equation. 9, $Rank\ (Parent_{Node})$ shows the rank value of the parent node, $ETX$ represents the quality of a path from a node through the parent node, and $Rank\ (Node)$ declares the node rank which is calculated by the mentioned formula.

The schematic for method of rank calculation of a joined node to the DAG presents in Figure 1. This figure shows that a node with the least rank will be chosen as the default parent. For instance, in Figure1, the default parent for node 5 is node 2 which has the lower rank in contrast with node 3. After defining the default parent node, node 5 will calculate its rank base on the formula mentioned before.

The forwarding rules for a node joining a DAG by considering the new parameter (SNR) to calculate the rank of nodes in ETX is shown in Figure2. As it was mentioned in section.3, a node which is already a member of DAG receives a DIO message can either discard the DIO or compute its rank again (which is specified as temp rank in Figure 2) to ensure that it is using the lowest rank. In addition, the SNR is used for computing the rank of nodes as a novel parameter in ETX.

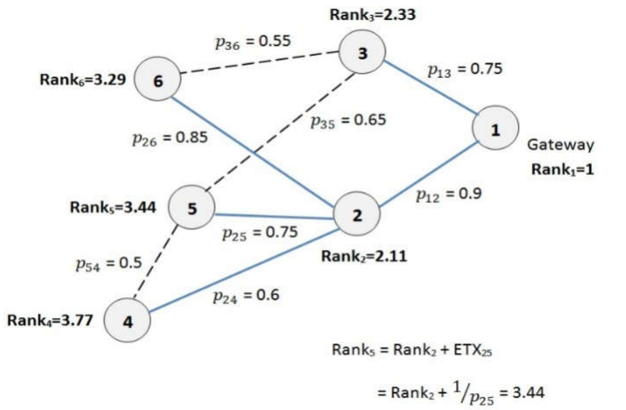


Fig.1. The procedure of the rank calculation in a DAG

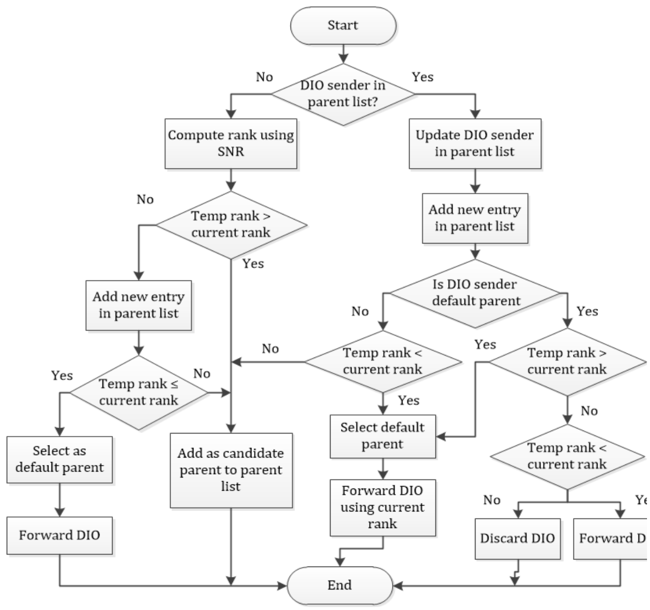


Fig.2. Flowchart to indicate forwarding rules of DIO messages to construct DAGs and compute node rank based on SNR as the new parameter to calculate ETX.

## 5. Performance Evaluation

We evaluate the modified RPL routing protocol in low power and lossy networks via simulation in MATLAB. We consider a network with one gateway node and 1000 smart meters which are distributed randomly over a region of 1000 meters. Since we consider a schematic example of a communication in smart grids as an LLN, the nodes are fixed and have sources of energy supply.

The gateway node is randomly selected among all nodes. Noise power is considered as Additive White Gaussian Noise (AWGN) and the number of packet re-transmission is limited to five times.

In order to evaluate the performance of our method, we consider the following performance metrics: (1) Packet Delivery Ratio (PDR), (2) number of re-transmission, (3) end to end delay, and (4) throughput. We compare our new approach with the standard RPL protocol which uses number of re-transmission in calculating ETX as its default link metric for the rank of nodes. Also it makes comparisons with the performance of the Ad hoc On-Demand Distance Vector (AODV) routing protocol [17].

First, the modified RPL protocol in terms of Packet Delivery Ratio (PDR) against Link Success Rate (LSR) and density evaluated and plotted in Figures 3 and4.

PDR is defined as the ratio of the number of received packets to the number of sent packets and LSR shows the ratio of links with higher SNR than the threshold to the whole links. The result in Figure 3 shows that the PDR when using RPL with SNR as the link parameter to calculate ETX and finding the best paths with higher qualities is higher than PDR with computing ETX based on the number of re-transmission as the link parameter and also has better performance than AODV in terms of PDR. In RPL protocol, PDR is not sensitive to the distance for each meter node. However, it is obvious that in AODV, PDR decreases linearly for each node regarding the distance.

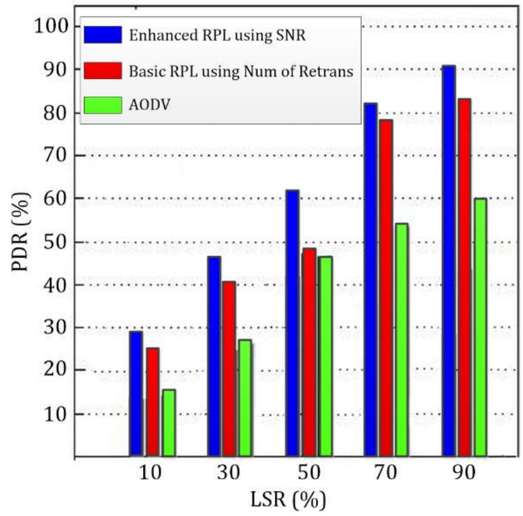


Fig. 3. Comparison of PDR performance vs. LSR in RPL with SNR, RPL with number of re-transmission, and AODV

Fig. 4 shows that by increasing the density of network, due to the growth in the number of meter nodes in the network, the PDR increased. Also, likewise to Fig. 3, the RPL protocol with SNR has the highest value in contrast with both traditional RPL and AODV.

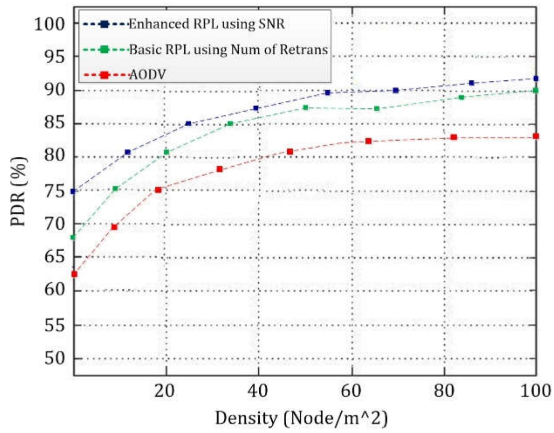


Fig. 4. Comparison of PDR performance vs. Density when using RPL with SNR, RPL with number of re-transmission, and AODV

The results for re-transmission against Link Success Rate (LSR) present in Figure 5. This figure shows that using Signal to Noise Ratio (SNR) to compute ETX in RPL protocol for calculating the rank of nodes and finding the links with better quality dramatically reduces the number of re-transmission in forwarding a packet. Also our proposed method in RPL protocol provide much better performance in terms of number of re-transmission in contrast with AODV protocol, hence it could decrease the number of re-transmission noticeably.

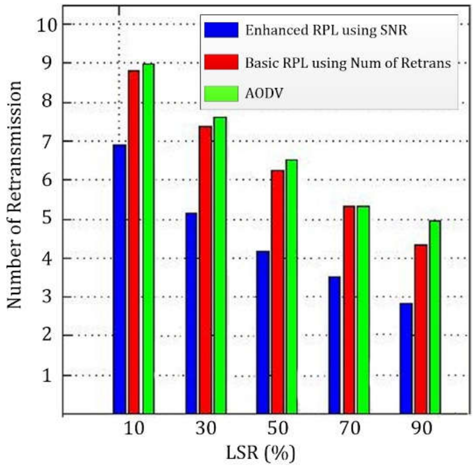


Fig. 5. Comparison of number of re-transmission vs. LSR in RPL with SNR, RPL with number of re-transmission, and AODV

Figure 6 shows the plot of the average end to end delay versus LSR. The end to end delay illustrates the time when a packet has successfully received to a destination. This figure indicates that using SNR as the link parameter to calculate ETX in RPL protocol noticeably decreases the number of re-transmission and therefore, this issue dominantly decreases the average end to end delay in the network. On the other hand, the end to end delay is not sensitive to the distance in RPL protocol, while in AODV the farthest the distance, the increase in end to end delay will be seen.

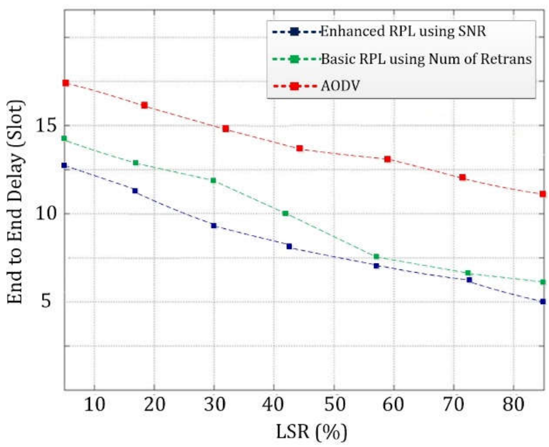


Fig. 6. Comparison of average end to end delay vs. LSR in RPL with SNR, RPL with number of re-transmission, and AODV

Then the modified RPL protocol is evaluated in terms of overall throughput in contrast with the density. The throughput represents the number of received packets to the whole value of time needed to send packets. It is clear that when the number of nodes increases in a network, the number of packets which receives to the destination node will grow noticeably and hence, by improving the density of a network, the overall throughput increases. Figure 7, shows that the overall throughput generated in RPL protocol using SNR is greater than that of RPL using number of re-transmission to compute ETX and also AODV.

The reason for the fact that AODV does not provide a considerable performance in LLNs is that in this protocol each node must create a route request to make a route to the gateway in this protocol. Due to the frequent link failures in such networks, a large number of route request packets needs to be generated in the network. Therefore, for nodes with a long distance to the gateway, the probability of link failure is higher than the nodes near the gateway. In addition, the delay for further nodes from the gateway to create a path through it in AODV is much higher than the closest ones. Under the considered network scenario, it is proved that the modified RPL with SNR to calculate the value of ETX as the defined link parameter produces a satisfactory performance in LLNs.

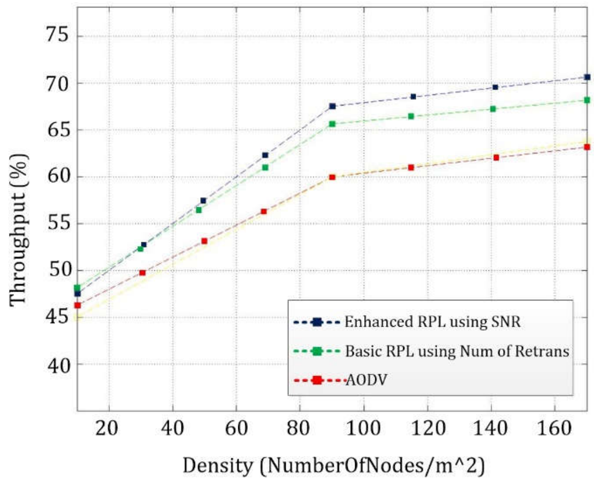


Fig. 7. Comparison of throughput vs. density in RPL with SNR, RPL with number of re-transmission, and AODV

The performance evaluation shows the effectiveness of the modified RPL protocol by 5% and 15% increase in PDR and throughput in contrast with traditional RPL and AODV respectively. Apart from this, results show that the proposed method reduces the number of re-transmission by 5% and 15% and end to end delay by 7% and 23% compared to traditional RPL and AODV respectively.

## 6. Conclusion

In this paper, we have proposed a modified RPL routing protocol for Internet of Things (IoT). RPL protocol may suffer from unreliability problem in some conditions specially because its lack of enough knowledge of the quality of links. Therefore, we have shown via simulation that using a new link parameter instead of number of re-transmission to calculate ETX improves the performance by selecting the links with higher reliability. Hence, our method outperforms not only the traditional RPL protocol, but also AODV protocol. In conclusion, we find that by modifying the calculation of ETX as a typical objective function in RPL protocol, we can improve the performance of a defined network in terms of PDR, number of re-transmission, throughput, and end to end delay. For future work, we will consider node metrics in addition to link metrics as routing metrics for rank computation in RPL protocol in order to achieve the minimum power consumption in a specific situation that nodes have energy constraints.

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