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Published in:
2018 12th International Conference on Software, Knowledge, Information Management & Applications (SKIMA)

DOI:
10.1109/SKIMA.2018.8631520

Published: 04/02/2019

Document Version
Peer reviewed version

The RPL Load Balancing in IoT Network with Burst Traffic Scenarios

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***Abstract*—In Low Power and Lossy Networks (LLNs) sensor nodes are deployed in various traffic load conditions such as, regular and heavy traffic load. The adoption of Internet-of-Things enabled devices in the form of wearables and ubiquitous sensors and actuators has demanded LLNs to handle burst traffic load, which is an event required by myriad IoT devices in a shared LLN. In the large events, burst traffic load requires a new radical approach of load balancing, this scenario causes congestion increases and packet drops relatively when frequent traffic burst load rises in comparison with regular and heavy loads. In this paper, we introduced a new efficient load balance mechanism for traffic congestion in IPv6 Routing Protocol for Low Power and Lossy Network (RPL). To measure the communication quality and optimize the lifetime of the network, we have chosen packet delivery ratio (PDR) and power consumption (PC) as our metrics. We proposed a traffic-aware metric that utilizes ETX and parent count metrics (ETXPC), where communication quality for LLNs with RPL routing protocol are playing an important role in traffic engineering. In addition, we provided analytical results to quantify the impact of Minimum Rank with Hysteresis Objective on Function (MRHOF) and Objective Function zero (OF0) to the packet delivery, reliability and power consumption in LLNs. The simulation results pragmatically show that the proposed load balancing approach has increased packet delivery ratio with less power consumption.**

***Index Terms*— Internet-of-Things Routing, LLNs, RPL, Objective Function, Load Balancing and Parent Count.**

I. Introduction

In recent years, billion of sensors have been deployed across the world, where our world become a sophisticated network called Internet-of-Things (IoT) network [1]. The network including an important field such as health-care, industry, agriculture and transportation are comprising with IoT network features such as large scale, automated and IP based network, which play an important role to provide a new type of quality of services (QoS) for making environment much smart and flexible [1]. Moreover, the integration of large number of nodes with IoT features has become a very hot topic, regarding these issues the Internet Engineering Task Force (IETF) supports to introduce standard RPL policies, which can specify research areas in ordered to guide the IoT vision [2]. Routing Over Low Power and Lossy Networks (ROLL) is an IETF working group, which mainly focus to organize the routing of Low Power and Lossy Networks (LLN). The main objective of LLN is to keep the routers and its interconnection in a more robust and flexible way. The IETF ROLL working group has worked together, to publish a standard IETF RFC 6550 which called RPL designed for LLNs . However, the RPL is a distance vector routing protocol which is a suitable scheme for the IoT based LLN, the essential aspect of RPL is the Objective Function (OF), which defines the method that is usually used to calculate the nodes rank by utilizing one or more metric and constraint [3]. In the structure of RPL standard, the OF is the core of the RPL mechanisms which is responsible for optimizing the performance of routing in various type of metrics [4]. On the other hand, RPL mainly relies on an OF which is a scalable and flexible algorithm, which manipulates based on the path cost, parent selection and rank calculation. Currently, there are two different OFs introduced for standard RPL. First OF is Minimum Rank with Hysteresis Objective Function (MRHOF). Second OF is Objective Function zero (OF0). MRHOF can compute node rank built on the additive metrics ETX, latency and hop-count. While, OF0 is stated to be a basic OF that does not need any metric to be measured, but it carries a default configuration in order to minimize hop-count [5].

To dominate the IoT environment there is a need to understand the traffic flow to design feasible IoT network. There are three types of traffic presented in the current literature including regular, heavy and burst traffic [6]. In the regular delivery, the data usually collected by the nodes in a continuous bias where less percentage of lost data could be occurred regarding the communication conditions. In the heavy delivery, the data normally collected based on sink or node interests, which mean the sink or nodes ask for specific information then the sender nodes need to send it. Furthermore, the percentage of lost data raised regarding traffic congestion. In the burst traffic, the data collected by powerful sink where a massive data are generated in specific time slots. Therefore, a high percentage of lost data can occur in burst traffic regarding load balancing issues [7]. In event-based delivery, sensor nodes monitor the incidence of events continuously and passively. In this circumstance, the traffic is depending on the distribution of the phenomenon. Burst traffic is one of the IoT application scenarios, where massive data is generated in specific time slots. In certain burst traffic scenarios, the receiving nodes will record a high packet drop probability due to the buffer size limitation problems and congestions. For example, it is common to have a node with relatively higher traffic than neighboring nodes in RPL, due to the missing of load balance feature in RPL [4]. In this case, the parent node can be severely congested and drop many packets due to these limitations. Generally, the burst delivery happens when myriad nodes start sending messages in response to a specific event in relatively smaller duration of time.

For instance, in a network using RPL with MHROF based on ETX metric, nodes will choose the parents with best link quality. Considering a network with non-uniform distribution and uneven data traffic, it may result in significant load imbalance. The sensor nodes that have links with better quality will forward more packet than others. Thereby, their energy depletion will be notably faster than the nodes with light traffic, and thus, gaps and holes in the network will appear, reducing the network lifetime [7]. Followed by IoT literature, the RPL and its OF were primarily targeting only for low power and lossy network, it is found a serious load balancing problem in a network once heavy traffic load applied within RPL. Therefore, more complicated load balancing issues will create alarming situations during event of burst traffic load [6]. As the load balancing become an issue in the RPL, some efforts have been discussed for the load balancing problem using multiple gateways to spread the load of the traffic to more than one sink [9]. On the other hand, there is significant research published regarding the efforts targeting RPL Load Balancing in a single gateway by using either new composed or changed metrics [7], [10], [11], [12], [13] and [14].

However, the load balancing problem has been investigated using multiple gateways in [9]. The author has proposed Multi-gateway Load Balancing Scheme for Equilibrium (MLEQ) and compared its performance to RPL. However, they reduce traffic congestion only by supporting additional gateways and do not address the load balancing problem in LLN with a single gateway. The authors in [14] and [6] have tackled the load balancing problem in a single gateway network. Load balancing of RPL (LB-RPL) is proposed to improve load balancing performance of RPL by considering two optimization points including link-layer communication qualities and workload distribution. While in [6] QU-RPL allows a node to rank its parent candidates depending on their queue utilization (QU), but QU-RPL never consider the parent count number to select the parent set. Moreover, the control overhead needs to be reduced to get a fair average of energy by adjusting the RPL parameters.

In this paper, we mainly focus on two important aspects of IoT networks including packet delivery ratio and network lifetime using a new load balancing mechanism for burst traffic load called Expected Transmission Count and Parent Count (ETXPC-RPL). We also compared the performance of RPL in a LLN with a single gateway using OF0 and MRHOF. The study showed that a serious load balancing problem appears in RPL in terms of routing parent selection and most of the packet losses under burst traffic are due to congestion. We have utilized the MRHOF in order to optimize RPL routing protocol to propose the new mechanism. The main contribution of our proposed mechanism is to improve the packet delivery ratio and lowering the power consumption comparing to the performance of OF0 and MRHOF. Our simulation results show that the ETXPC-RPL algorithm minimizes packet discard counts and the channel collision through parent selection mechanism.

The main contributions of this paper can be summarized as follow:

- **To the best of our knowledge, we are among the first to present performance modeling of RPL with burst delivery mode;**
- **Study the effect of MRHOF and OF0 on the significance performance of RPL routing protocol under burst traffic load;**
- **A novel load balancing routing protocol is proposed on the existing RPL protocol to support RPL routing under burst traffic load called ETXPC-RPL.**

The rest of the paper is organized as, Section 2 mentions the related work. Section 3 defines our proposed ETXPC-RPL protocol. In Section 4, we present performance evolution and enhancement. Section 5 shows analysis the mean packet delay and buffer overflow probability with different burst parameters. Section 6 shows the simulation result with three different case study. In Section 7, we conclude our work.

II. Related Work

A. The Performance evaluation of RPL using single and multiple gateways.

Many performance evaluation studies of RPL have been introduced by the authors in [15] which evaluate the packet loss, packet end-to-end delay and power consumption. However the authors did not explore how the average power transmission affects packet delivery ratio.

The authors in [16] have shown extensive experiments on RPL by analyzing the data collection performance and topology stability of RPL. The study in [10] has been investigated widely where two large wireless sensory network platforms have been covered in terms of packet delivery ratio, packet overhead, and packet dynamicity where node may join or disjoin the network. Through different experimentations, the authors demonstrated failure of few nodes affected the stability of the routing structure.

Author in [11-12] extended the RPL protocol to achieve energy efficiency, reliability and low delay data transfer. The authors highlighted that multi-path routing, load balancing and multiple sinks had a great impact once it is merged with the RPL.

B. RPL with Load balancing.

In RPL load balancing makes the traffic as uniform as possible whilst reducing the power consumption of the nodes [13]. There have been numerous attempts to achieve balance in traffic forwarding in order to decrease congestion and packet drops. In addition, many routing metrics and objective functions have been proposed for the RPL routing protocol in LLNs and 6LoWPAN networks in order to provide a balanced tree in RPL.

- **RPL Load balancing using multiple gateways.**

Increasing the number of gateways allows increasing the lifetime of the network together with load balancing. One of these proposals has been studied in [9]. The authors investigated the load balancing problem with multiple gateways, and proposed the MLEQ to reduce traffic congestion. Their load balancing scheme has been implemented using network simulators-2 (ns-2) simulator, in which it is verified by extensive simulation's comparisons. As the proposed MLEQ performance with RPL, the results showed that network throughput and capacity could increase linearly with the number of gateways. Similarly, in [12] the authors presented SYN-RPL. It extended RPL in order to provide an object with multiple gateway network. A dynamic solution can be employed whenever a gateway fails by finding a new route towards active gateway. Such flows redirection remains transparent to remote peers. The SYN-RPL has been evaluated using several experimentations over a real testbed.

- **RPL Load balancing using single gateway.**

While using single gateway, many routing metrics and objective functions have been proposed to be used within the RPL routing protocol in LLNs and 6LoWPAN networks in order to provide a balanced tree in RPL. The author in [14] proposed a load balanced routing protocol based on the RPL protocol, called LB-RPL. It detects workload imbalance in a distributed and non-intrusive fashion in order to achieve balanced workload distribution in the network. This solution is working via signaling techniques, where nodes with heavy traffic represent their status by delaying the transmission of DODAG Information Object (DIO) messages, then a node will be able to detect the queue utilization information of their neighbors and spread out data among the candidate parents. Load Balancing for RPL (LB-RPL) improves load balancing performance of RPL only be tackling the load balancing problem in a single gateway network. Main problem with this method is that every node has to forward any traffic coming from its sub-tree based on their current topology. In addition, the LB-RPL was only tested on the ns-2 simulator. Some recent works [17] and [18] have optimized the network lifetime by designing new OFs which consider combining two metrics. First metric mentioned choosing links with good quality; whereas, the second metric mentioned another point which is the residual energy concept. Second metric was used by [17] and [18]. The authors in [17] has proposed metric focused on energy consumption of the bottleneck nodes. It also considered parameters such as link data rate, different power transmission, and link qualities. While the authors in [18] have proposed metric as an adaptive parent node selection mechanism where residual energy as well as queue utilization of neighboring nodes have been considered. Recently, Kim et al., [6] proposed Queue Utilization RPL (QU-RPL) for load balancing under heavy traffic. QU-RPL takes the queue utilization of neighboring nodes into consideration when selecting parent nodes. The authors further described the number of packets in the queue divided by total queue size as queue utilization factor (QU). On other hand, in QU-RPL, ETX of nodes are not considered while selecting the preferred parent node.

III. LOAD BALANCING PROBLEM WITH RPL PROTOCOL FOR BURST TRAFFIC

RPL achieves routing in a distributed way, where it can be adopted for LLNs but without load balancing, which means this feature is missing in RPL [6]. A major load imbalance occurs for sensor nodes that have more neighbors than others as irregular data traffics and the non-uniform in large-scale LLNs. This causes missing of the network connectivity in the whole network because the gaps appear during the routing. This is the reason behind running down the energy faster in the heavy workload [7]. A major problem in LLNs is the network connectivity in term of the load balancing, where different parameters influence the routing in LLNs [19], such as, network, node, and link.

RPL traffic depends on the underlying application area for instance, building monitoring, tracking natural disasters, sporting events to name a few. In these application areas traffic patterns can either be regular (normal network traffic) or burst (event triggering the influx of network traffic, recording an infrequent event). The type of routing mechanism is also influenced based on the application area. Distribution of traffic in the network influences the packet delivery ratio and energy consumption involved in forwarding data in the network [20]. Thus, load balancing is a necessary factor that needs to be considered in designing the RPL routing protocol. Most common routing metrics which has been fitted with RPL routing protocol is ETX. It is a communication quality metric in order to provide a useful connection between two nodes. This is why we have selected RPL which clearly relies on an OF. It is a scalable and flexible algorithm that is constructed based on a three main concepts including: the path cost calculation, the Parent selection and the Rank calculation [10]. This flexibility in the OFs keep RPL capable for any application scenarios including burst traffic but OFs need to be adjusted based on the network environment and scenarios, then a new specific OF or metric can be special implemented for burst traffic [5].

IV. ETXPC-RPL PROPOSED PROTOCOL

From the RPL operation, we can recognize that RPL identifies the best paths to route packets through the network according to the OF and a set of metrics as described in the previous section. These metrics can be either node attributes, such as hop-count, remaining node energy; or link attributes, such as link quality, latency, and Expected Transmission Count. A default metric defined MRHOF as standard metric for RPL by IETF RFC 6719, which is used in most of RPL implementations, uses the ETX of links to calculate the path with minimum cost. A Destination Oriented Directed Acyclic Graph(DODAG) created using MHROF with the ETX metric, nodes tend to select parents with best link quality and smallest hop-count to the root node. In addition to this, hop count, energy level are also used metrics/constraints. However, none of the existing OFs has considered ETX and parent account as a metric to support all type of traffic load [7].

In this section, we present the proposed scheme OF RPL load balancing problem which dynamically updates RPL based on packet delivery ratio (PDR) and the power consumption (PC) on MRHOF metric in order to fix the RPL load balancing problem.

The proposed scheme utilizes MRHOF to be used in every packet of RPL traffic during the burst traffic scenarios. Therefore, in order to compute the best path to the root, we have utilized MRHOF by employing both the ETX value and parent count; where, ETX values are considered as the key items in our metric. Similarly, to the MRHOF in RPL [21], we use a hysteresis mechanism to provide stability condition as described in the Equation 1. *ETX (K,pk)* measured by the node *K* which is a link quality indicator between both node *K* and its parent candidate *pk*.

$$ETX(K, PK) = \frac{totaltransmissionsfromKtopk}{successfultransmissionsfromKtopk} \quad (1)$$

In ETXPC-RPL algorithm, we utilized manipulation of ETX with aggregate values of parent count, each node advertises a Parent Set rather than a single parent to the sink. In RPL control message DIO (DODAG Information Object), we have used the MinHopRankIncrease parameter defined in [4] in our algorithm, where the parent count metric is considered only if ETX delta between two candidate parents is smaller than MinHopRankIncrease value. We achieve a load balancing under burst traffic by utilizing more nodes as preferred parent. We compare the number of parent counts via selecting the one with minimum parent count as preferred parent. After doing this, more nodes will have chance to be selected as a preferred parent even their ETX values are not the best.

We propose a new a load balancing mechanism for RPL protocol that has multi-hop data collection applications, such as environmental monitoring in critical event (sport, disaster, festivals). Our scheme is starting with a traffic manager to update the traffic route analyzing the traffic and discover the delivery mode which could be regular or burst, then it will employ threshold of the ETX value and parent count (the number of candidate parents) in order to compute and detect the most efficient path to the sink. Our traffic management offers functionality to avoid the congestions.

Result: Input: ReceivedDIO [Rank, ETX, Parent ID, Parent Count]
M1 =ETX;
M2= Parent Count;
initialization;
while *Current Node Recived DIO;* **do**
    Calculate the Rank based on the ETX (*M1*);
    Calculate the Rank based on the number of (*M2*);
    if *(M1* $\geq M2$) **then**
        use the threshold A = M1-M2;
        if *(A ¡= MinHopRankIncrease Value)* **then**
            use the Values of M1 and M2 if both equal; return M2; .... Selected Parent for node n
        else
    else
        if *(M1* $\geq M2$) **then**
            use the threshold A = M2-M1;
        else
        end
        (A ¡= MinHopRankIncrease Value) use the Values of M1 and M2 if both equal; return M1; .... Selected Parent for node n
    end
end

Algorithm 1: The proposed load balance algorithm.

V. Performance Evolution and Enhancement

In this paper, we tackled the load balancing problem of RPL. We have provided an experimental measurement analysis of RPL in high traffic scenario using Cooja simulator environment within LLN. As a result, we identify that most of packet losses under burst traffic are due to congestion, and that there exists a serious load balancing problem in RPL in terms of routing parent selection via burst scenarios. To solve this problem, we introduce an enhancement to improve the performance of RPL that significantly improves the packet delivery ratio performance with less power consumption by balancing the traffic load within a routing tree considering parent count number.

A. Simulation and Network Setup

Cooja simulator has been selected for use as it is a tool for software development in WSN, and provides a useful method to set the best environment needs[15]. In our study, we have simulated a network with scenario where only a single sink node located at the middle top. Also, random topology has been chosen in order to spread the nodes in a squared area within 1000 meters. In Table 1, we have designed an RPL network using OF0, MRHOF and ETXPC-RPL by setting the network with 30 nodes. The experiments have been conducted under different traffic load networks containing (1, 20, 40 and 60 pps/node) which include regular traffic and burst traffic with random middle topology. Also, we have investigated the RPL performance in terms of two measurements including packet delivery ratio and and power consumption, as shown in Fig.1.

B. Experiment results

The experiment results have been collected considering various traffic load networks (1, 20, 40, and 60 pps/node) within

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Objective Function (OF)	OF0, MRHOF, ETXPC
Traffic Load (PPS)	1, 20, 40, 60
Density Network	30 Motes
Sink Location	Middle Top
TX Ratio	100%
TX Range	100 m
Mote Start up Delays	1.000
Topologies	Random with middle top sink
Simulation Time	900 seconds
Mote Type	Sky Mote

random middle topologies, and we observed the performance of RPL for different metrics MRHOF, OF0 and ETXPC. We set the sink in the middle top and study the RPL behaviour in terms of PDR and PC.

Fig. 1. The network window (Sink located in the middle top).

- **Traffic load RPL Performance within MRHOF.**

Fig. 2.a, shows that the PDR value roughly reached 1.0 when traffic load was less than or equal to 40 PPS. This means that the performance of RPL is good for PDR more than 0.98 whenever the traffic load (1 to 40 PPS). The PDR value decreases once the traffic load under burst traffic (60 or more). Fig. 2.b shows the behavior of the power consumption for the same traffic load. It can bee seen that the power consumption value increases in a linear fashion as the traffic load values increase. The average power consumption value is good (approximately 1.19 kilobyte) when traffic load is less than or equal to 40%. While, the power consumption is very high for RPL performance within MRHOF under burst Traffic (60 pps or more). It is consuming about 4.8 kb energy, which is too high power consumption comparing to the regular traffic (less than 40 PPS).

- **The RPL Performance within OF0.**

Fig. 3.a shows that RPL with OF0 has PDR average similar to the one for MRHOF. The PDR value decreases as traffic load value increases. PDR value under regular traffic which is

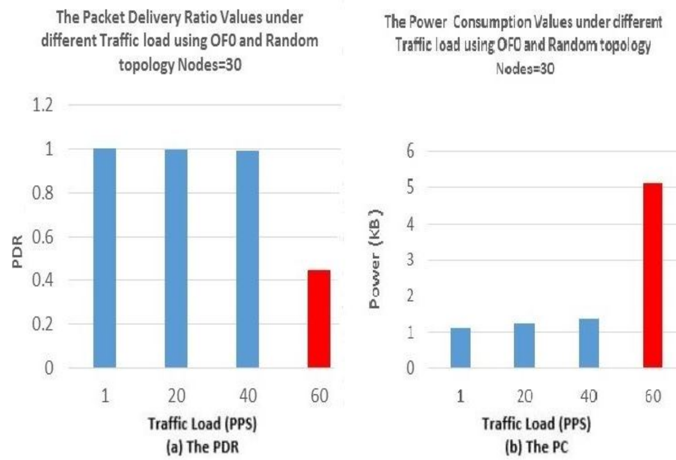

Fig. 2. The PDR and PC values for MRHOF in 30 nodes using random topology.

more than 0.98 whenever the traffic load is between 1 to 40 PPS, while under the burst traffic it is around 0.45 when Traffic Load is equal 60 or more. Fig. 4.b presents the behavior of the power consumption for the same traffic load. It is quite similar to the power consumption values when MRHOF used. Where the power consumption value increases steadily as the traffic load value increases during regular Traffic Load with a good average (approximately 1.3 kilobyte). In addition, we observed that the average power consumption is high (approximately 5.1 kilobyte) when burst traffic load is applied. It is too high power consumption value comparing to its value in the burst traffic with MRHOF.

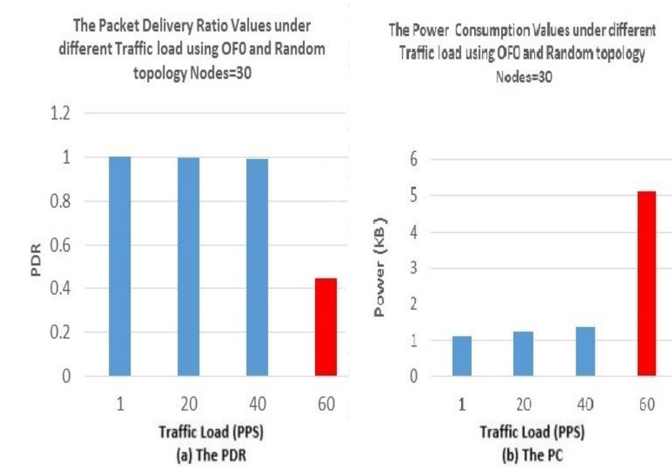

Fig. 3. The PDR and PC values for OF0 in 30 nodes using random topology.

- **Enhancement RPL within ETX and Parent Count (ETXPC).**

In Fig. 4.a an ETXPC has been used and found that the average PDR of RPL performance is around 0.99. Also, the PDR of ETXPC is almost use for both type of traffic load including regular and burst traffic load with values more than 0.98. In Fig.4.b we used ETXPC to signify the average power consumption. Indeed, the results are showing a fair power consumtion especially for the burst Traffic Load with a value about 4 kilobyte. Also, average packet deliver ratio is fair too with ETXPC. The result shows that the performance of RPL using our ETXPC provides an improved behaviour where a load balancing feature applied under critical conditions such as burst traffic.

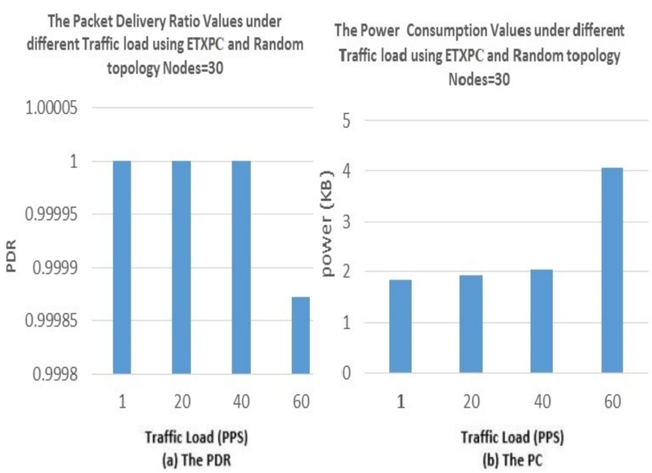

Fig. 4. The PDR and PC values for ETXPC in 30 nodes using random topologyR.

VI. RESULTS DISCUSSION

A. The impact of the objective function metrics OF0, MRHOF and ETXPC.

Form the presented results, we can see that without the load balancing features in the RPL routing. The value of traffic load is very volatile above 60. RPL with MRHOF and OF0 has poor performance while delivering the burst Traffic messages of the LLN. The results in Fig. 5 and Fig. 6 have shown that the performance of RPL is very similar for MRHOF, OF0 and ETXPC under regular traffic which is given a good PDR around 0.98, while ETXPC outperforms both OF0 and MRHOF under burst traffic Load with 1, 0.996793 and 0.980636 respectively. Also, the results show that ETXPC consuming less power compared to OF0 and MRHOF with values 4, 5.1 and 4.8 kb respectively. We observe from the simulation results that the ETXPC enhances the RPL routing protocol in terms of PDR and power consumption using a load balance mechanism in order to support the RPL performance under burst traffic load.

B. Burst Load Balancing Analysis

We gathered our simulations results using various data generation rate including burst traffic load

1) 1 packet per 1 minute scenario.
2) 20 packet per 1 minute scenario.
3) 40 packet per 1 minute scenario.

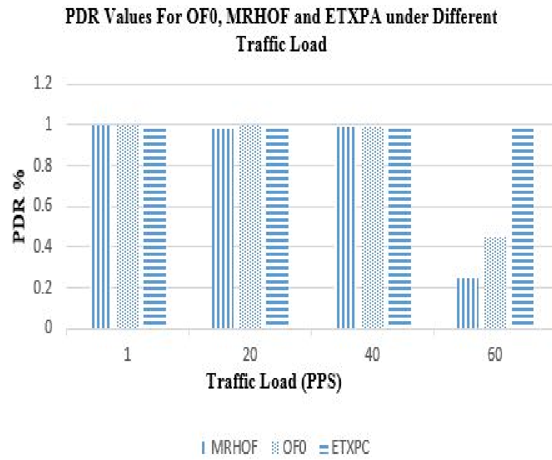

Fig. 5. PDR Values for MRHOF, OF0 and ETXPC under different Traffic Load.

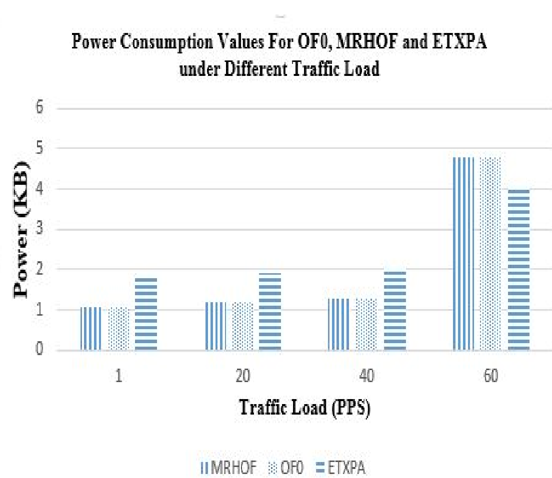

Fig. 6. PC Values for MRHOF, OF0 and ETXPC under different Traffic Load.

4) 60 packet per 1 minute scenario (burst traffic).

To explore the burst delivery in the simulated network, we design the workload into a total number of forwarded packets from each sensor node. Fig. 5 and Fig. 6 show the impact average of PDR and power consumption values for MRHOF, OF0 and ETXPC using different scenarios. Fig 5 shows that a good PDR average is achieved with three scenarios 1, 2 and 3 for MRHOF, OF0 and ETXPC. While in scenario 4 (burst traffic) the PDR value has decreased rapidly when we used MRHOF or OF0 which means both algorithms are not performing well for burst traffic scenarios, while ETXPC offering a good PDR value with the same scenario. This means that new proposed mechanism has worked with burst Traffic where number of parent count has been considered during the load balancing process.

Fig.6 presentes the average of the power consumption value for MRHOF, OF0 and ETXPC using different scenarios. An accepted power consumption average has been achieved with three scenarios 1, 2 and 3 for MRHOF, OF0 and ETXPC. However, ETXPC uses the highest power consumption value among these scenarios. While in scenario 4 (burst traffic) the PC value increases suddenly when we use MRHOF, OF0 or ETXPC for burst Traffic scenarios.

VII. CONCLUSION

In this paper, we address load balancing problem of RPL routing protocol under burst traffic using a single gateway. With simulation experiments, we empirically identified that standard RPL is not able to hold the burst traffic load. To address this issue, we propose a new load balancing protocol, called ETXPC-RPL, which consist of ETX metric and the number of parent nodes for selecting the best parent. With this two-metric combinations, the load in balanced in the network under burst traffic load. We considered different traffic scenarios, the located sink, and single gateway. We prevent the problem of RPL when burst traffic load occurs in the IoT network causing the network with high packet losses and stability problem. The performance of our protocol is evaluated in Cooja under various scenarios demonstrating that ETXPC-RPL outperforms the standard RPL with MRHOF and OF0 in terms of PDR and PC. Based on our results, we conclude that the proposed algorithm is useful for RPL to hold the burst traffic scenarios. We will extend our contribution to improve our algorithim, considering more metrics and more parameters including transmission range and density network using extensive simulations.

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