Parent-Aware Routing for IoT Networks

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Abstract. The deployment of wireless sensor networks (WSNs) accessible through the Internet has caused a growing trend for IoT (Internet of Things). RPL (IPv6 Routing Protocol for Low-Power and Lossy Networks) is proposed by IETF (Internet Engineering Task Force) for IPv6 (Internet Protocol Version 6) constrained IoT networks as the routing protocol. Here, Objective Function (OF) determines how RPL nodes translate metrics into ranks and select routes in a network. This paper introduces a solution to have a load balanced network based on Parent-Aware Objective Function (PAOF). PAOF uses both ETX (Expected Transmission Count) and parent count metrics to compute the best path for routing. This paper evaluates the proposed solution by implementing in Contiki OS (Operating System) with Cooja simulation. MRHOF (Minimum Rank with Hysteresis Objective Function) is used for comparison. Simulation results verify that PAOF gives better parent load density, delay and parent diversity.

Keywords: IoT · Wireless sensor network · RPL · Objective function · Load balancing

1 Introduction

A Wireless Sensor Network is a distributed, self- organized network of small, energy-constrained nodes that collect and generate data [1]. With the rising of IoT platforms [2], wireless sensors are employed for various fields like transport, manufacturing, building, agriculture, biomedical etc. [3]

6LoWPAN (IPv6 over Low power Wireless Personal Area Networks) [4] is one of the most popular technology standard used in WSNs employing IoT platforms. In 6LoWPAN, the routing protocol is very important to have a connection especially with outside networks, Internet cloud. Here, RPL [5] is the mostly preferred routing protocol. RPL determines the routes using objective functions (called the OF methodology) [6]. The mostly used objective function is MRHOF [7] which decides to select paths based on the ETX [8] value. More detail about RPL will be given in the next section.

Increasing in the number of sensor nodes in a wireless sensor network makes it difficult to utilize all the nodes effectively [9]. In this work we introduce a

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load balancing technique to be used with RPL in order to enhance the load distribution of the network along the network lifetime [10].

In order to achieve load balancing, we propose a new method called PAOF to be used in RPL. The performance of PAOF is studied under various network topologies and compared with that of MRHOF. It is observed that PAOF generates a better load balanced network, diversity of parent selection and reduced end-to-end delay.

The remainder of the paper is organized as follows: Section 2 describes the routing in IoT networks by giving details of RPL. In Section 3, we present the proposed approach for optimization in RPL. The simulation environment, the scenarios employed in simulations and the results obtained for PAOF and MRHOF are presented in Section 4. Finally, Section 5 concludes the paper by giving future directions.

2 Routing in IoT Networks

Routing is considered as one of the critical items in 6LoWPAN networks. In the past, there have been several routing protocols for 6LoWPAN-compliant LLNs (Low Power and Lossy Networks), such as Hydro [11], Hilow [12], and Dymolow [13]. Unfortunately, these solutions are not able to fulfill all the requirements expected from IoT networks.

In order to address most of the requirements and open issues [14], the IETF ROLL (Routing Over Low Power and Lossy Networks) working group [15] has proposed a routing protocol called RPL. RPL is designed for networks with lossy links, which are those exposed to high Packet Error Rate (PER) [16] and link outages.

RPL is a distance vector and a source routing protocol. operates on top of several link layer mechanisms including IEEE 802.15.4 [17] PHY (Physical) and MAC (Media Access Control) layers.

RPL is based on the topological concept of Directed Acyclic Graphs (DAGs). The DAG defines a tree based structure that identifies the routes between nodes in the network. However, a DAG structure is more than a classical tree in the sense that a node might associate with multiple parent nodes in the DAG, in contrast to basic trees where only one parent is allowed. More specifically, RPL organizes nodes as Destination-Oriented DAGs (DODAGs), where most popular destination nodes (i.e. sinks) or those providing a default route to the Internet (i.e. gateways) act as the roots of the DAGs. In Figure 1, a DODAG structure generated using RPL can be seen.

When forming paths to route packets, each node identifies a stable set of parents on a path toward the DODAG root/sink node, and associates itself with a preferred parent, which is selected based on OF. OF defines how RPL nodes map metric(s) into ranks, and how to select and optimize routes in a DODAG. It is responsible for rank computation based on specific routing metrics (e.g. delay, link quality, connectivity, etc.) and also specify routing constraints and optimization objectives.

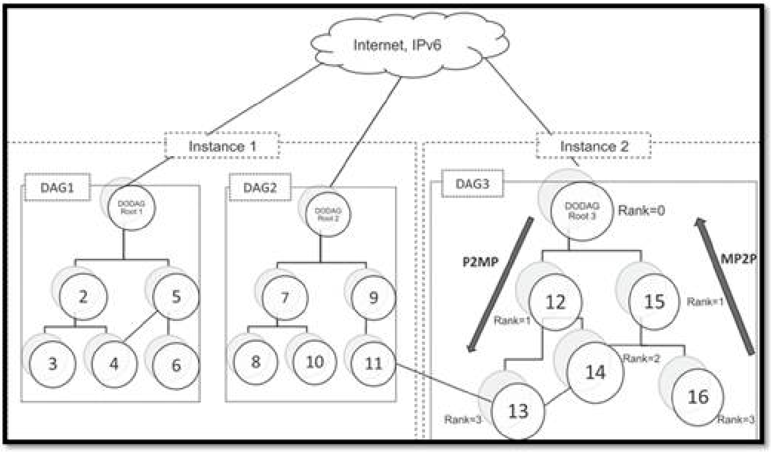


Fig. 1. RPL with DODAG [6]

A couple of designed OF implementation are the Objective Function Zero (OF0) which uses a hop count-based metric [18]; the MRHOF also known as OF1 which selects the path with the smallest ETX value; the Energy-Aware OF (EAOF) which uses energy level of the nodes and ETX value [19].

3 Proposed Routing Technique

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 ETX.

Among these metrics, ETX is widely used to design reliable routing protocols for WSNs since it reflects the quality of the paths employed. In addition to this, hop count, energy level are also used metrics/constraints. However, none of the existing OFs do not consider parent count as a metric.

The proposed technique PAOF employs both the ETX value and parent count (the number of candidate parents) in order to compute the most efficient path to the sink. Here, the ETX values are still the key items being considered. We use the MinHopRankIncrease parameter defined in RPL Control message DIO (DODAG Information Object) [20] as a reference point. PAOF algorithm interests in the parent count metric only if ETX delta between two candidate parents is smaller than MinHopRankIncrease value. If so, the algorithm compares the number of parent counts and selects the minimum one as preferred parent. Within this, more nodes will have chance to be selected although their ETX values are not best. Hence, we are able to utilize more nodes as preferred parent. The details about the algorithm are given in Figure 2.

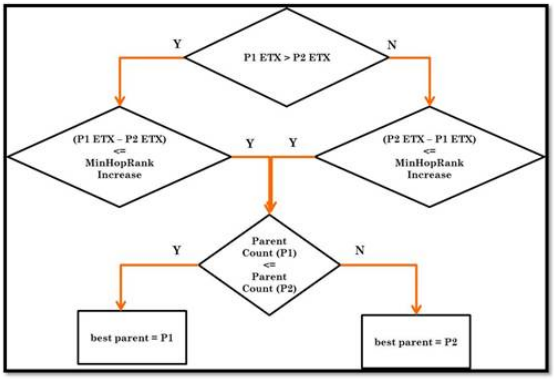


Fig. 2. Algorithm of PAOF

4 Performance Results

Many network simulators are used to measure and compare the performance of routing protocols for WSNs [21]. In this work, we decided to use Cooja [22]. Cooja is a flexible WSNs simulator designed for simulating networks running Contiki OS [23].

In order to show the performance of PAOF, this section provides several simulation scenarios and the corresponding results. We implemented PAOF on top of ContikiRPL in Contiki OS. We compare the results obtained using PAOF with those of MRHOF using the ETX metric which is also known default OF in ContikiRPL.

In the figures comparing the results, OF1 represents MRHOF, and OF2 represents PAOF.

4.1 Performance Metrics

When comparing the results obtained using MRHOF and PAOF, the following metrics were employed:

Average Parent Load Density: Here, the aim is to compute the average load density [24] on all selected preferred parents. This value is computed as

$$(NumberofDeliveredSuccessfulPackets)/(NumberofPreferredParents) \tag{1}$$

Average Packet Delay: To measure the end-to-end delay between time the packet generated and reached to the sink node.

$$((PacketArrivalTime)-(PacketGenerationTime))/(NumberofTotalPackets) \tag{2}$$

Number of DIO Messages: DIO message is used by the nodes to send their rank information to siblings during DODAG construction. As PAOF interacts on directly DIO message generation, this metric will be useful to have an idea from the point of introducing overhead.

Number of DAO (Destination Advertisement Object) Messages: DAO message is used by the nodes to send routing tables to their preferred parent nodes during DODAG construction. As PAOF aims to increase the number of preferred parents, this metric will show us if there is an overhead in the total messaging.

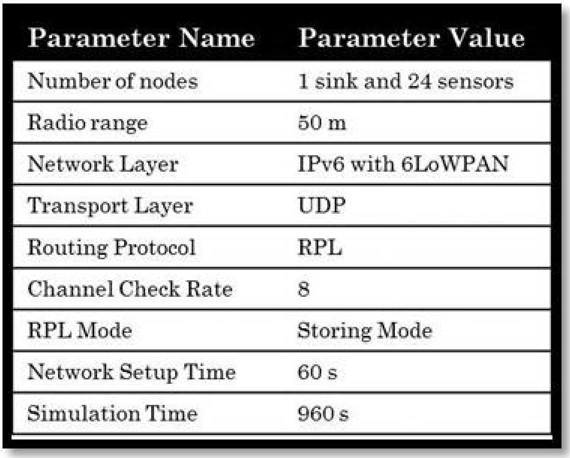
Parent Diversity: This metric shows us how many different nodes [25] can be selected as preferred parent in a network topology. This value is computed as

$$(NumberofPreferredParents)/(NumberofTotalNodes) \quad (3)$$

4.2 Simulation Setup

Figure 3 gives the details about the parameter values employed in the Cooja and Contiki based simulation environment.

In this work, we employed three network topologies, which are given in Figures 4, 5 and 6, in order to study the performance of the method proposed. In all of these three topologies, there exist one sink node and 24 sensor nodes. Sink node, which is colored green, is placed at the center in the first topology, while it is located in the middle top position in the other two topologies as shown in the figures.



Parameter Name	Parameter Value
Number of nodes	1 sink and 24 sensors
Radio range	50 m
Network Layer	IPv6 with 6LoWPAN
Transport Layer	UDP
Routing Protocol	RPL
Channel Check Rate	8
RPL Mode	Storing Mode
Network Setup Time	60 s
Simulation Time	960 s

Fig. 3. Simulation network parameters in Cooja

In the simulations, each node generated a payload data of length 30 bytes at the time intervals determined by the negative exponential [26] function with lambda value 0.2.

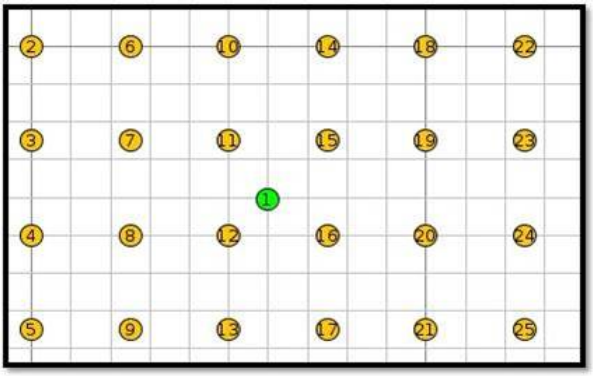


Fig. 4. Topology 1

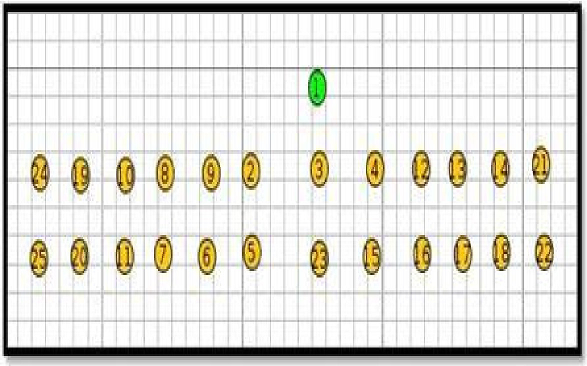


Fig. 5. Topology 2

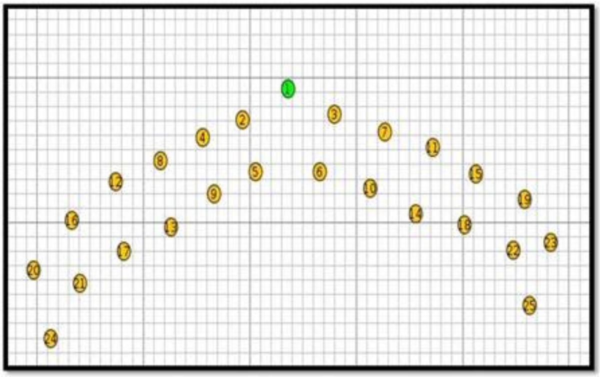


Fig. 6. Topology 3

The traffic started out after 60 seconds. The first minute is left for the RPL control messages DIO, DAO and DIS (DODAG Information Solicitation) traffic in order to setup a stable DODAG graph. After than each node generated 20 packets for each traffic scenario.

Simulation were run three times for each topology and the results show the average values with 95% Confidence Interval.

4.3 Simulation Results

The results by employing PAOF show significant improvements considering the average parent load density and parent diversity. We achieved lower parent load density and higher parent diversity because we increased the possibility of some intermediate nodes to be selected as the preferred parent with the proposed PAOF approach. Hence, more nodes are tagged as the preferred parent in the network where all of them are used to transmit packets toward the sink node.

We have some promising results for average packet delay as the number of preferred parents is increased in the network leading to less collisions.

However, in the proposed PAOF approach the number of DIO and DAO messages increases because we give chance to more nodes to be considered as the preferred parents when the nodes have similar ETX values.

The charts summarizing the simulation results can be found in Figure 7-11.

In Fig. 7, we can see that average parent load density is lower in OF 2 than OF 1 for all of the topologies.

In Fig. 8 we can also observe that average packet delay is better in OF 2 for Topology 1 and 2.

In Fig. 11, OF 2 ensures that number of selected preferred parents is higher than OF 1.

The main drawback of the proposed PAOF routing technique is that it leads more DIO and DAO message generation as shown in Fig. 9 and 10. However, as DIO transmission is governed by Trickle Timer [27], we can evaluate that

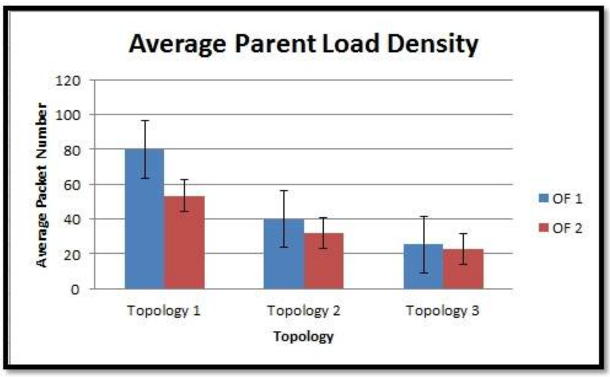


Fig. 7. Average Parent Load Density

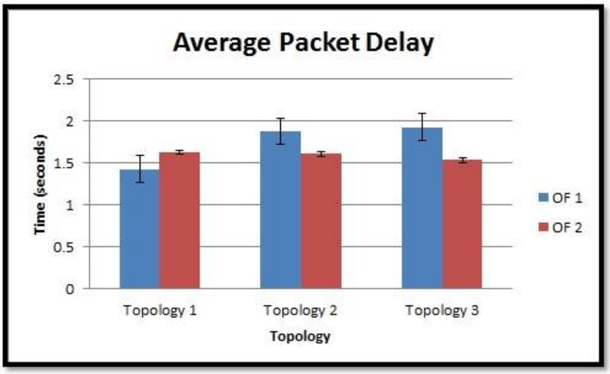


Fig. 8. Average Packet Delay

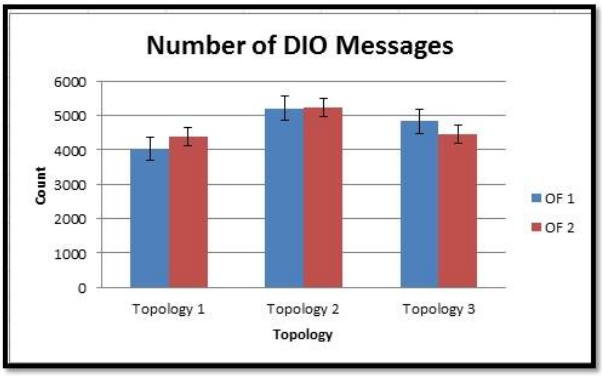


Fig. 9. Number of DIO Messages

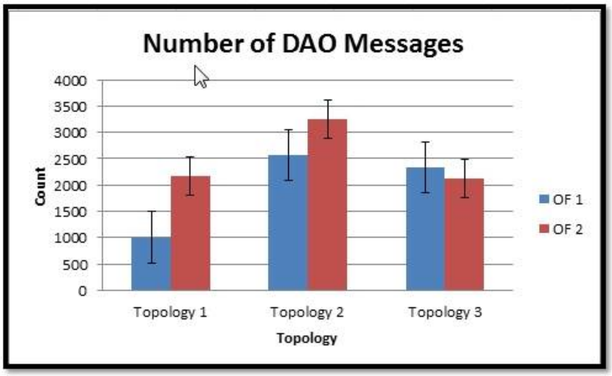


Fig. 10. Number of DAO Messages

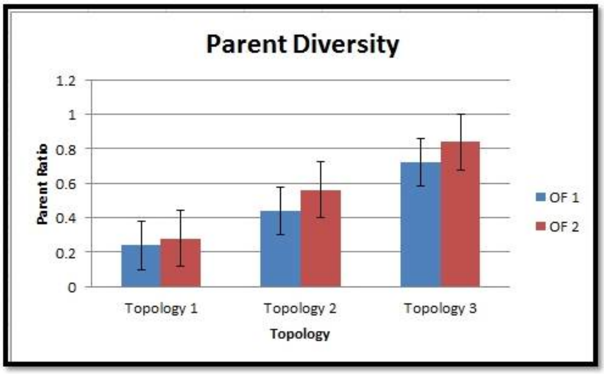


Fig. 11. Parent Density

DIO/DAO message generation will be still under control and stable considering the network lifetime.

5 Conclusion

In this paper, we introduced a new OF approach for RPL to be used in IoT networks, called PAOF. We compared the performance of this new technique with MRHOF employing the Cooja simulation tool with Contiki OS.

From the simulation results, we could conclude that the proposed routing technique PAOF performs better where the topology is mid-level sparse and the sink node is not located in the center.

The obtained results show that PAOF makes significant improvements in parent load density and diversity as compared to MRHOF employing ETX. PAOF ensures that the network will become load balanced, hence, have longer network lifetime and behave tolerantly in case of congestion.

The future work on the proposed technique will be to investigate the effectiveness of the proposed technique employing various IoT applications generating periodic, self-similar, hybrid traffic. Moreover, parent count in this work is considered as a metric with deriving from Layer 3. Similarly, child count can be considered as a new candidate node metric with deriving from Layer 2. This may also pioneer to a cross layer algorithm utilizing both Layer 2 and 3.

In future, PAOF algorithm can also be combined with MRHOF so an Adaptive OF can be introduced into literature where OF is selected dynamically based on node metrics and constraints.

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