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Load Balancing Objective Function in RPL
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Abstract

This document proposes an extended Objective Function (OF) that balances the number of child nodes of the parent nodes to avoid the overloading problem and ensure node lifetime maximization in the IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL). The standard OFs are used to build a Destination Oriented Directed Acyclic Graph (DODAG) where the bottleneck nodes may suffer from unbalanced traffic load. As a result, a part of the network may be disconnected as the energy of the overloaded preferred parent node will drain much faster than other candidate parents. Thus, a new RPL metric has been introduced to balance the traffic load over the network. Finally, the potential extra overhead has been mitigated using a new utilization technique.

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1 Introduction

IPv6 Routing Protocol for LLNs (RPL) [RFC6550] defined two OFs to optimize the path selection towards the root node, namely, the OF zero (OF0) [RFC6552], and the Minimum Rank with Hysteresis OF (MRHOF) [RFC6719]. The Destination Oriented Directed Acyclic Graph (DODAG) construction is built by the RPL OF, that specify how nodes select the preferred parent node by translating one or more metrics into the rank value.

The used OF calculates the rank based on some routing metrics [RFC 6551] such as hop-count, delay, energy, and so forth. The parent node in RPL can serve more than one child if it is chosen by them as preferred parent. Consequently, the overloaded preferred parents will become fragile nodes as their energy risks to drain much quicker than other nodes.

Having conducted simulation experiments and rigours analysis, it is concluded that the current OFs lead to build a topology that suffers from an unbalanced load traffic in bottleneck nodes especially for the first hop nodes (i.e., from the root). Consequently, this problem has a crucial impact on the lifetime of these types of nodes. The battery depletion of that overloaded parent node may affect the network reliability negatively.

This challenging problem is still an open issue. In an attempt to overcome this problem, this draft proposes a new OF to mitigate the overusing of the bottleneck node to prolong its battery lifetime.

This draft proposes an extended Objective Function (OF) that balances the number of children nodes for the overloaded nodes to ensure node lifetime maximization in RPL and can be summarized as follows. First, a new RPL metric has been used to balance the load traffic among the bottleneck nodes. Second, the DODAG Information Object (DIO) message has been amended by injecting the IP address of the chosen parent before broadcasting it. Third, a new utilization technique has been proposed for the amended DIO message to avoid increasing the overhead of the handshaking and acknowledgment processes. Simulation experiments have been conducted to validate the extended OF performance as detailed in Appendix A.

1.1 Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

2 DODAG construction in a nutshell

RPL is a proactive distance vector routing protocol designed for LLNs [RFC6550], it constructs a DODAG using a certain OF that suits the application requirements. Essentially, RPL relies on a DODAG Information Object (DIO) control message to build the DODAG.

Thus, the starting point begins when the root node broadcasts the DIO message to the downstream neighbor nodes. As soon as the closest node receives the message, it can decide whether to join this DODAG or not based on the calculated rank according to the equations (1) and (2) [RFC6719].

$$\text{Rank}(N) = \text{Rank}(PN) + \text{RankIncrease} \quad (1)$$

$$\text{RankIncrease} = \text{Step} * \text{MinHopRankIncrease} \quad (2)$$

Where Step represents a scalar value and MinHopRankIncrease represents the minimum RPL parameter. If the node decides to join, then it adds the DIO sender to the candidate parent list. Next, the preferred parent, i.e. the next hop to the root, will be chosen based on the rank from this list to receive all traffic from the child node. Then, it computes its own rank with a monotonical increase according to the selected OF.

After that, the node propagates its own DIO with all updated information to all its neighbors including the preferred parent. [RFC 6551] defined the number of node metrics/constraints (e.g. hop count and energy) and the link metrics/constraints (e.g. ETX and throughput) that might be used in the OFs [RFC6552][RFC6719].

3 Load balancing in RPL

RPL is designed with several robust features such as exiguous delay, quick configuration, loop-free topology, and self-healing. However, the load imbalance is considered as a significant weakness in this protocol. More specifically, RPL is dealing with non-uniform distribution in large-scale LLNs, which may lead to unequal data traffic distribution. Consequently, the energy of the overloaded nodes will be drained much faster than other nodes. Furthermore, this problem has more harmful impacts if the overloaded node is a bottleneck node (i.e. with the first hop to the root) as shown in Figure 1 for node A and B.

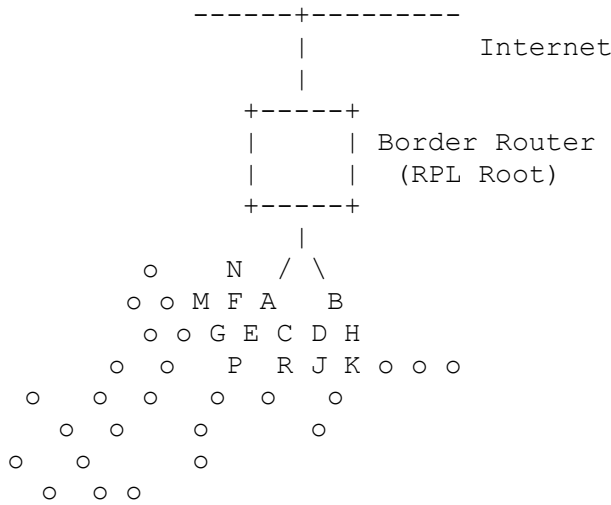


Figure 1: Bottleneck nodes in RPL

Figure 2 depicts the selection of the preferred parent for those nodes are within the first hop from nodes A or B. Clearly, node A has more children as it is surrounded by the nodes (N,M,F,G,E,P). Despite the fact that A has more children, it dominates the shared nodes (C,D,R,J) that are also located within the shared area of node B (i.e., within the transmission range of A and B). That unbalanced parent selection approach in RPL left node B only with two children, while node A has ten children.

Parent nodes	Child nodes	Shared nodes between A and B
A	N, M, F, G, E, P, C, D, R, J	C, D, R, J
B	H, K	C, D, R, J

Figure 2: The selection of the preferred parents

It is notable that the connection of all nodes through A is fragile as it is the only link to the root with an overloaded bottleneck node, thus, disconnecting part of the network if node A dies. In particular, this serious problem occurs in RPL due to omitting the number of children in existing parent selection technique.

To this end, the node sticks with the current preferred parent and influences its rank, even if this parent deteriorates with more load (i.e. being a parent for more children). The only conceivable scenarios to change the current parent to another candidate parent are as follow: first, if the current parent dies due to battery depletion. The second possibility, when the lossy percentage becomes higher than before, so no acknowledgement message can be heard from the preferred parent for a certain period of time.

4 The proposed objective function

The proposed OF leverages the lifetime of the entire network. The load balanced OF (LB-OF) balances the data traffic by taking into account the number of children for each candidate parent.

4.1 Balancing the load traffic

As aforementioned, being a preferred parent for more children means more overhead and unbalanced load, that results in a drain its own energy much faster than other candidate parents. To solve this problem, a new metric has been proposed. The children set created in section 4.2 provides each preferred parent with the number of children it has. Based on that, the number of children in the rank calculation in formula (1) is considered.

Specifically, the parent with the least number of children will be elected as preferred parent. To this end, the balance has been achieved by declining the number of children of the overloaded bottleneck node. As a result, the majority of children (i.e., the shared nodes between A and B) will choose another preferred parent according to the lower rank, and surely has less number of children.

However, it is expected to increase the churn or oscillation as a result of changing the parent. It is a trade-off between unfairness and oscillation, however, this oscillation can be minimized in two techniques to enhance the stability:

a) using the number of children along with another metric(s) (e.g. ETX, number of hops, energy, etc., according to the application requirements).

b) Using the hysteresis threshold for the number of children (in a lexical manner) to switch from parent to another, the selected threshold depends on the application requirements.

4.2 A new utilization technique for DIO message

Generally, in the upward routes the root initiates the DODAG construction by sending the first DIO message. Once other nodes receive this DIO, they select the sender as a preferred parent, and then they start calculating their own ranks based on the assigned OF. After that, each node broadcasts its own DIO message (i.e. the updated DIO that contains the new calculated rank value) to all neighbors including the chosen preferred parent which sent the original DIO message. In the standard OFs, the preferred parent ignores the DIOs that come from its child based on the rank.

In this stage, the aim is to allow each parent to count its number of children to avoid later possible overloading situations. However, that is not possible in the upward routes (i.e., while maintaining the DODAG through DIOs), as the only control message that can be acknowledged by the destination is the Destination Advertisement Object (DAO) message in the downward routes to recognize the number of children for each parent.

Alternatively, setting up an acknowledgement mechanism between parent and children to count the number of children for each parent. However, this acknowledgement also brings an extra overhead for the entire network and subsequently increases the power consumption massively. To overcome this problem, LB-OF using a new technique is proposed as detailed below. In LB-OF algorithm, the received DIO from the child node is counted by the preferred parent node. Each DIO contains the IP address of the chosen preferred parent as detailed in section 4.3. Thus, for each received DIO, the node matches its own IP address with the preferred parent IP address which is inserted in the DIO message, then increments the number of children by ONE for this node if there is a matching.

Hence, this technique evades increasing any extra overhead, additionally, the coming DIOs from the child nodes has been utilized to allow each preferred parent to distinguish the number of its children during the DODAG construction stage to optimize the routing.

4.3 Proposed New Metric for Parent Selection

Typically, the DIO carries the RPL InstanceID, DODAG identifier, version number, Rank and the OF that has been used to calculate the rank, in addition to other identifiers [RFC6550]. This section introduces the number of child nodes as a new metric/constraint in the DAG Metric Container, which includes the selected parent address in the option field within the DIO message. The newly added information is 2 octets named by Child Node Count (CNC) which is per this document defined in the DAG Metric Container.

The Child Node Count (CNC) object is used to provide information related

to the number of child nodes in the DIO source node, and may be used as a metric or as constraint.

The CNC object MAY be present in the DAG Metric Container. There MUST NOT be more than one CNC object as a constraint per DAG Metric Container, and there MUST NOT be more than one CNC object as a metric per DAG Metric Container. The format of the CNC object body is as follows:

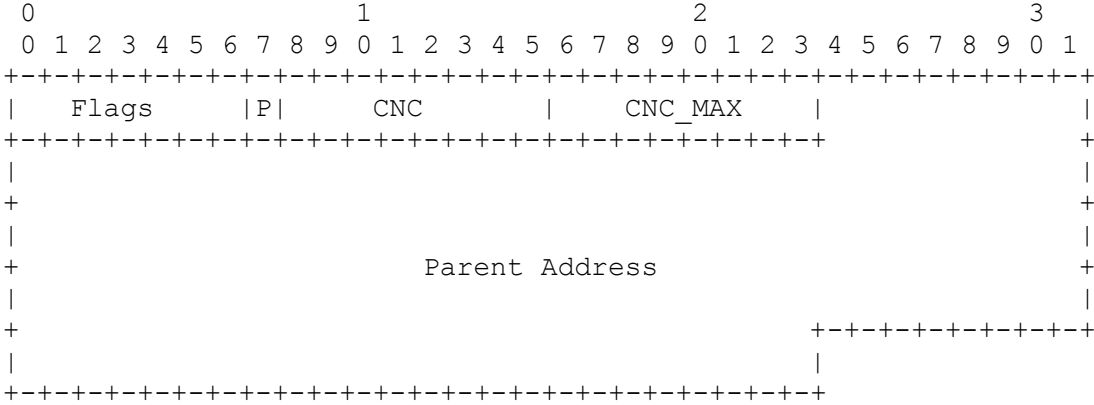


Figure 3: Child Node Count Object Body Format

Flags field (8 bits). The following one bits of the CNC object are currently defined:

'P'flag: Parent Address State. This, if set to 1, indicates there is a parent address field in the CNC object.

CNC: 8-bits. The Child Node Count is encoded in 8 bits in unsigned integer format, expressed in number count, representing the number of child nodes.

MAX_CNC: 8-bits. The Maximum Child Node Count is encoded in 8 bits. The MAX_CNC field indicates the maximum number of children a node can hold. This parameter is set by implementers based on neighbor cache entry or the size limit of routing table. Nodes should not hold child nodes more than MAX_CNC.

Parent Address (optional): 128-bit IPv6 address of parent node. This field is only present when the 'P' flag is set to 1.

In the storing mode, DAO can be used for child nodes registration while No-PathDAO can be used for de-registration, and this gives a way to count the number of child nodes. Thus, to minimize traffic load, the

Parent Address field in the CNC object should not be present in the storing mode.

In the non-storing mode, NS/NA could be an optional way for child node counting. When the 'P' flag is set, the Parent Address in the CNC object should be used for child node counting according to the technique illustrated in section 4.2.

When this CNC metric is used, RANK computing reflects the ability of each node to hold more child nodes. Also, a new way for the RANK computing has been suggested: $RANK = CNC / CNC_MAX * 255$. A node with smaller RANK has high priority to accept new child nodes, a node with $RANK = 255$ should not hold new child nodes any more.

5 Security Considerations

Since the routing metrics/constraints are carried within RPL message, the security routing mechanisms defined in [RFC6550] apply here.

6 IANA Considerations

IANA is requested to allocate a new value for the new metric type "CNC" in the Routing Metric/Constraint Type in the DAG Metric Container.

7 References

7.1 Normative References

- [RFC6550] Winter, T., Ed., Thubert, P., Ed., Brandt, A., Hui, J., Kelsey, R., Levis, P., Pister, K., Struik, R., Vasseur, JP., and R. Alexander, "RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks", RFC 6550, March 2012.
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- [RFC6551] Vasseur, J., Ed., Kim, M., Ed., Pister, K., Dejean, N., and D. Barthel, "Routing Metrics Used for Path Calculation in Low-Power and Lossy Networks", RFC 6551, March 2012.

7.2 Informative References

[RFC5226] Narten, T. and H. Alvestrand, "Guidelines for Writing an IANA Considerations Section in RFCs", BCP 26, RFC 5226, May 2008.

[Contiki] Contik O.S and cooja simulator <http://www.contiki-os.org/>

Appendix A.

The protocol has been simulated with Cooja simulator based on Instant Contiki 2.7 operating system [Contiki]. Collected results corroborate the superiority of our OF over the existing ones in terms of lifetime, power consumption and packet delivery ratio.

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