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Traffic-aware Objective Function
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Abstract

This document proposes a packet transmission rate metric for parent selection. This metric represents the amount of traffic that the node is transmitting to the current parent node. This document also proposes an Objective Function (OF) using the packet transmission rate metric for parent selection in order to balance the amount of traffic between nodes.

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1. Introduction

RPL [RFC6550] is an IPv6 Routing protocol for LLNs. It uses Objective Functions (OF) to construct the Destination Oriented Directed Acyclic Graph (DODAG) containing the nodes of the network. The existing OFs defined are OF Zero (OF0) [RFC6552] and Minimum Rank with Hysteresis OF (MRHOF) [RFC6719]. These OFs specify how nodes in a DODAG select their preferred parent using different metrics.

The metrics can be separated into two different types, link metrics (e.g. ETX) and node metrics (e.g. energy). Experimental results [I-D.qasem-roll-rpl-load-balancing] conclude that using the current OFs leads to an unbalanced network within which some of the nodes are overloaded. In this case, a node is overloaded in the sense that it forwards much more packets than it otherwise would if the network were balanced. This problem has consequences for the lifetime of the network because overloaded nodes tend to drain quicker than others, a problem which becomes even more significant when the overloaded nodes are near the DODAG root [I-D.qasem-roll-rpl-load-balancing].

This problem is still an open issue and this draft proposes a new way of parent selection as an attempt towards a solution. This draft proposes a new OF that considers the packet transmission rate as a representation of traffic each node faces and use this information to balance the amount of traffic between nodes.

In brief, each node tracks its packet transmission rate and appends this information to DIO messages it sends as a DAG Metric Container

option. When the DIO message is received by child nodes or potential child nodes, the packet transmission rate information is stored and used to influence the result when RPL parent selection is performed.

2. 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 [RFC2119].

3. DODAG construction in RPL

RPL uses OFs to construct a DODAG. OFs define the way the nodes select their preferred parent and how they compute the new rank. A node's rank is always larger than its parent's rank because the calculation of rank is based on an increment to the parent's rank. This increment differs for each OF but all include the MinHopRankIncrease which is the minimum increase in rank between a node and a node's parent and a step. Different OFs use different metrics or constraints to select the preferred parent and to define the step, depending on application requirements. Nodes obtain these values from DODAG Information Object (DIO) control messages sent by their neighbor nodes.

The construction of a DODAG starts when the root node sends DIO messages to its neighbors. After receiving the DIO, these neighbor nodes select the root as their preferred parent if they wish to join the DODAG. In order to announce that they joined the DODAG as its child node, they send a Destination Advertisement Object (DAO) to their preferred parent - the DODAG root. After joining the DODAG, these nodes send their own DIO messages with the new computed rank to their neighbors. This procedure repeats for every node which joins the DODAG.

4. Load distribution problem in RPL

Numerous experiments using existing OFs have been conducted and according to results, RPL faces a load distribution problem in large LLNs. With RPL using existing OFs, such as MRHOF, an unbalanced network is formed with some of the nodes overloaded and other nodes at rest. This problem is severe for network performance because overloaded nodes will use up their available energy faster than other nodes. This is exacerbated for nodes near the root (within 1 hop distance) or nodes which are the only parent candidate for some other nodes. Additionally, when the overloaded node shuts down, a big part of the network will become disconnected and will have to be transferred to another parent. There is a high probability that the children nodes will also select the same new node as their parent,

leading to another overloaded node. Also, when a node has selected its parent, it will change only when the parent node is not reachable (due to battery depletion or packet losses).

The existing OFs usually use a single metric to compare parent candidates, for example, as described in [RFC6719] the default metric used in MRHOF is ETX [RFC6551], which represents the number of transmissions a node expects to make to a destination in order to successfully deliver one packet. The result from using a single metric is that nodes prefer to select the same node as their parent, which according to [I-D.qasem-roll-rpl-load-balancing] leads to an unbalanced network with overloaded nodes (node load is indicated by a node's child count). But the child count does not accurately indicate the load because among these child nodes, some of them may have higher traffic load and others may have lower.

The network traffic can be quantified by tracking the packets a node generates/sends/receives and the amount of energy it consumes. Energy consumption is strongly correlated to the amount of network traffic handled by a node since the energy consumption for the operation of the radio is the primary energy consumer in typical nodes. However, directly measuring the packet transmission rate is both more accurate and also works when nodes have atypical energy consumption profiles (e.g. increased node processing or high energy consumption sensors).

```
        4pkt/s (R)                         4pkt/s (R)
                ^                                  ^
                |                                  |
        +-------+-------+                  +-------+-------+
        |               |                  |               |
        +               +                  +               +
3pkt/s (A)      1pkt/s (B)         2pkt/s (A)      2pkt/s (B)
        ^               ^                  ^               ^
        |               |                  |               |
 +------+------+        |           +------+        +------+
 |      |      |        |           |      |        |      |
 +      +      +        +           +      +        +      +
 (C1)  (C2)   (C3)     (D1)         (C1)  (C2)     (C3)   (D1)
1pkt/s 1pkt/s 1pkt/s   1pkt/s      1pkt/s 1pkt/s   1pkt/s 1pkt/s

            Unbalanced                          Balanced
```

Figure 1: Packet Transmission Rates of nodes with the same requirements

As a first simple example, an unbalanced network with nodes which all have the same packet transmission rates is shown in Figure 1. Its

transformation into a balanced equivalent network is shown on the right.

```
            6pkt/s (R)                        6pkt/s (R)
                    ^                                 ^
                    |                                 |
            +-------+-------+                 +-------+-------+
            |               |                 |               |
            +               +                 +               +
    2pkt/s (A)      4pkt/s (B)        3pkt/s (A)      3pkt/s (B)
            ^               ^                 ^               ^
            |               |                 |               |
     +------+        +------+          +------+------+        +
     |      |        |      |          |      |      |        |
     +      +        +      +          +      +      +        +
     (C1)  (C2)     (D1)   (D2)        (C1)  (C2)   (D1)     (D2)
    1pkt/s 1pkt/s   1pkt/s 3pkt/s     1pkt/s 1pkt/s 1pkt/s   3pkt/s

                Unbalanced                         Balanced
```

Figure 2: Packet Transmission Rates of nodes with different requirements

As a second simple example, an unbalanced network with nodes which have different packet transmission rates is shown in Figure 2. Its transformation into a balanced equivalent network is shown on the right.

5. TAOF description

In this specification, a metric is proposed to be used in the parent selection mechanism, the Packet Transmission Rate (PTR) which represents the number of packets each node transmitted (sent or forwarded) during a certain time period. As mentioned below, the number of transmitted packets can directly show the amount of traffic each node is facing. This information is added in DIO messages and is broadcast to every neighbor.

At first, each node MUST identify from their neighbor set which nodes are acceptable to be selected as a parent. For this purpose, the metric ETX is used as a filter to filter out parent candidates with low link quality with a preference for nodes with link quality below a given threshold. The ETX threshold SHOULD be different depending on application requirements. The suggested value for the relevant threshold MAX_PATH_COST from MRHOF [RFC6719] is 32768, which means the specific path has expected transmission counts greater than 256.

For the packet transmission rate, each node maintains in a variable a counter which will increment by 1 every time a data packet is transmitted by the node. When the ETX value is used as a filter, nodes with bad link quality will not be included in the parent set. This ensures that undue retransmissions caused by bad link will be avoided. In any case, the node chooses the parent candidate with the least packet transmission rate.

This proposal is expected to increase the frequency of parent change because the packet transmission rate is more likely to be different between DIO messages, even for DIO messages from the same node. There are multiple ways to minimize the frequency of unnecessary parent changes:

a. Use the packet transmission rate in combination with another metric (e.g. child count, hop counts).

b. Use a threshold when comparing the packet transmission rate, similar to the approach in MRHOF [RFC6719]. Switch parents when the difference of packet transmission rate between the original parent and the alternative parent is above a threshold. This threshold depends on different factors (e.g. network size, average traffic load) and SHOULD be defined differently for each use case.

6. DIO Metric Container Type extension

```
 0                   1
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 | Packet Transmission Rate (PTR)|
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: DAG metric container type format.

A DIO message carries fields as described in RFC6550 [RFC6550] and the available options for the DAG metric container are described in RFC6551 [RFC6551]. In this specification, a metric container option is proposed and the detailed format is shown in Figure 3. The information carried is the PTR, represented as a 2 byte unsigned integer.

```
 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                            +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| DAGMC Type (2)| DAGMC Length  |                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+                               |
|                                                               |
//                   DAG Metric Container data                 //
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4: Example DIO Message with a DAG Metric Container option

The structure of the DIO Control Message when a DAG Metric Container option is included is shown in Figure 4. The DAG Metric Container option type (DAGMC Type in Figure 4) has the value 0x02 as per the IANA registry for the RPL Control Message Options, and is defined in [RFC6550]. The DAG Metric Container option length (DAGMC Length in Figure 4) expresses the the DAG Metric Container length in bytes. DAG Metric Container data holds the actual data and is shown further expanded in Figure 5.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Routing-MC-Type|Res Flags|P|C|O|R| A   |  Prec | Length (bytes)|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Packet Transmission Rate (PTR)|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5: DAG Metric Container (MC) data with Packet Transmission Rate (PTR) object body

An example DAG Metric Container containing the proposed Metric Container object is shown in Figure 5. The explicit definition of the fields is:

Routing-MC-Type: TBD1. The type of the proposed DAGMC extension. To be assigned by IANA.

Packet Transmission Rate (PTR): The packet transmission rate, represented as a 2 byte unsigned integer.

7. Security Considerations

The structure of the DIO control message is extended, within the predefined DIO options. Therefore, the security mechanisms defined in RPL [RFC6550] apply to this proposed extension.

8. IANA Considerations

This proposal requests the allocation of a new value TBD1 for the metric type "PTR" in the Routing-MC-Type field in the DAG MC from IANA.

9. Informative references

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