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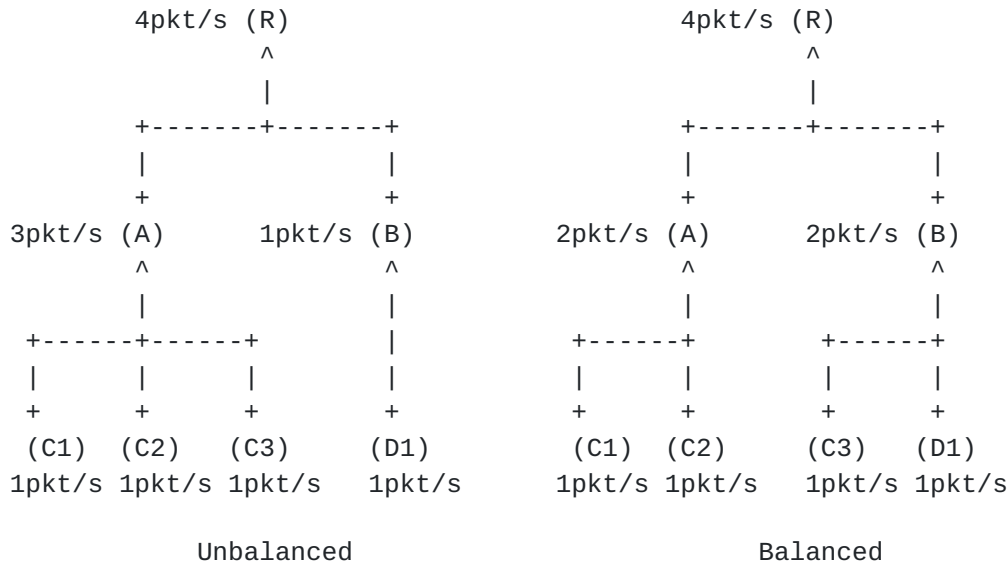
Figure 1: Packet Transmission Rates of nodes with the same
requirements

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
```
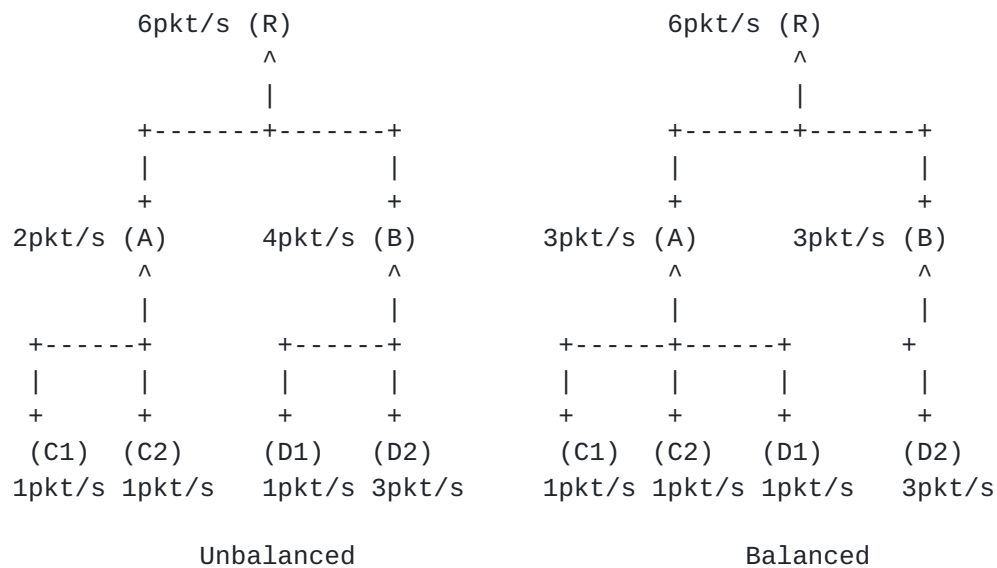
Figure 2: Packet Transmission Rates of nodes with different
requirements

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 (PC)| DAGMC Length | Packet Transmission Rate (PTR)|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

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

   An example DIO Message containing the proposed DAG Metric Container
   type is shown in Figure 4. The explicit definition of the fields is:

   DAGMC type: The type of the proposed DAGMC extension. To be
        assigned by IANA.

   DAGMC Length: The total length of the proposed DAGMC extension in
        bytes. MUST be 2.

   Packet Transmission Rate (PTR): The DAG Metric Container data,
        containing 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 for the metric
   type "PTR" in the Routing Metric/Constraint Type in the DAG MC from
   IANA.

9. **Informative references**

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