          The Minimum Rank Objective Function with Hysteresis
               draft-ietf-roll-minrank-hysteresis-of-02

Abstract

   The Routing Protocol for Low Power and Lossy Networks (RPL) uses
   objective functions to construct routes that optimize or constrain
   the routes it selects and uses. This specification describes the
   Minimum Rank Objective Function with Hysteresis (MRHOF), an objective
   function that selects routes that minimize a metric, while using
   hysteresis to reduce churn in response to small metric changes.
   MRHOF works with metrics that are additive along a route, and the
   metric it uses is determined by the metrics RPL Destination
   Information Object (DIO) messages advertise.

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1. Introduction

   An objective function specifies how RPL [I-D.ietf-roll-rpl] selects
   paths. Objective functions can choose paths based on routing metrics
   or constraints. For example, if an RPL instance uses an objective
   function that minimizes hop-count, RPL will select paths with minimum
   hop count.

   The nodes running RPL might use a number of metrics to describe a
   link or a node [I-D.ietf-roll-routing-metrics] and make it available
   for route selection. These metrics are advertised in RPL Destination
   Information Object (DIO) messages using a Metric Container suboption.
   An objective function can use these metrics to choose routes.

   To decouple the details of an individual metric or objective function
   from forwarding and routing, RPL describes routes through a value
   called Rank. Rank, roughly speaking, corresponds to the distance
   associated with a route. An objective function is responsible for
   computing a node's advertised Rank value based on the Rank of its
   potential parents, metrics, and other network properties.

   This specification describes MRHOF, an objective function for RPL.
   MRHOF uses hysteresis while selecting the path with the smallest
   metric value. The metric that MRHOF uses is determined by the
   metrics in the DIO Metric Container. For example, the use of MRHOF
   with the latency metric allows RPL to find stable minimum-latency
   paths from the nodes to a root in the DAG instance. The use of MRHOF
   with the ETX metric allows RPL to find the stable minimum-ETX paths
   from the nodes to a root in the DAG instance.

   MRHOF can only be used with an additive metric that must be minimized
   on the paths selected for routing.

2. Terminology

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

   This terminology used in this document is consistent with the
   terminologies described in [I-D.ietf-roll-terminology],
   [I-D.ietf-roll-rpl], and [I-D.ietf-roll-routing-metrics].

   This document introduces two terms:

Selected metric: The metric chosen by the network operator to use
     for path selection. This metric can be any additive metric
     listed in [I-D.ietf-roll-routing-metrics].

Path cost: Path cost quantifies a property of an end-to-end path.
     Path cost is obtained by summing up the selected metric of the
     links or nodes along the path. Path cost can be used by RPL to
     compare different paths.

Worst parent: The node in the parent set with the largest path cost.

3. The Minimum Rank Objective Function with Hysteresis

   The Minimum Rank Objective Function with Hysteresis, MRHOF, is
   designed to find the paths with the smallest path cost while
   preventing excessive churn in the network. It does so by finding the
   minimum cost path and switching to that path only if it is shorter
   (in terms of path cost) than the current path by at least a given
   threshold. MRHOF may be used with any additive metric listed in
   [I-D.ietf-roll-routing-metrics] as long the routing objective is to
   minimize the given routing metric.

3.1. Computing the Path cost

   Nodes compute the path cost for each candidate neighbor reachable on
   an interface. The Path cost represents the cost of the path, in
   terms of the selected metric, from a node to the root of the DODAG
   through the neighbor.

   Root nodes (Grounded or Floating) set the variable cur_min_path_cost
   to MIN_PATH_COST.

   A non-root node computes the path cost for a path to the root through
   each candidate neighbor by adding these two components:

   1. If the selected metric is a link metric, the selected metric for
       the link to a candidate neighbor. If the selected metric is a
       node metric, the selected metric for the node.

   2. The value of the selected metric in the metric container in the
       DIO sent by that neighbor.

   A node SHOULD compute the path cost for the path through each
   candidate neighbor reachable through an interface. If a node cannot
   compute the path cost for the path through a candidate neighbor, the
   node MUST NOT select the candidate neighbor as its preferred parent,
   with one exception. If the node does not have metrics to compute the

path cost through any of the candidate neighbors, it MUST join one of
the candidate neighbors as a leaf node.

If the selected metric is a link metric and the metric of the link to
a neighbor is not available, the path cost for the path through that
neighbor SHOULD be set to MAX_PATH_COST. This cost value will
prevent this path from being considered for path selection.

If the selected metric is a node metric, and the metric is not
available, the path cost through all the neighbors SHOULD be set to
MAX_PATH_COST.

The path cost corresponding to a neighbor SHOULD be re-computed each
time:

1. The selected metric of the link to the candidate neighbor is
    updated.

2. If the selected metric is a node metric and the metric is
    updated.

3. A node receives a new metric advertisement from the candidate
    neighbor.

This computation MAY also be performed periodically. Too much delay
in updating the path cost after the metric is updated or a new metric
advertisement is received can lead to stale Rank or parent set.

3.2. Parent Selection

After computing the path cost for all the candidate neighbors
reachable through an interface for the current DODAG iteration, a
node selects the preferred parent. This process is called parent
selection. Parent Selection SHOULD be performed each time:

1. The path cost for an existing candidate neighbor, including the
    preferred parent, changes. This condition can be checked
    immediately after the path cost is computed.

2. A new candidate neighbor is inserted into the neighbor table.

The parent selection MAY be deferred until a later time. Deferring
the parent selection can delay the use of better paths available in
the network.

A node MUST select a candidate neighbor as its preferred parent if
the path cost corresponding to that neighbor is smaller than the path
cost corresponding to the rest of the neighbors, except as indicated

below:

1. If the smallest path cost for paths through the candidate
    neighbors is smaller than cur_min_path_cost by less than
    PARENT_SWITCH_THRESHOLD, the node MAY continue to use the current
    preferred parent.

2. If there are multiple paths with the smallest path cost and the
    smallest path cost is smaller than cur_min_path_cost by at least
    PARENT_SWITCH_THRESHOLD, a node MAY use a different objective
    function to select the preferred parent among the candidate
    neighbors on the path with the minimum cost.

3. A node MAY declare itself as a Floating root, and hence no
    preferred parent, depending on the configuration.

4. If the selected metric for a link is greater than
    MAX_LINK_METRIC, the node SHOULD exclude that link from
    consideration for parent selection.

5. If cur_min_path_cost is greater than MAX_PATH_COST, the node MAY
    declare itself as a Floating root.

6. If the configuration disallows a node to be a Floating root and
    no neighbors are discovered, the node does not have a preferred
    parent, and MUST set cur_min_path_cost to MAX_PATH_COST.

Except in the cases above, the candidate neighbor on the path with
the smallest path cost is the preferred parent. A node MAY include a
total of PARENT_SET_SIZE candidate neighbors in the parent set. The
cost of path through the nodes in the parent set is smaller than or
equal to the cost of the paths through any of the nodes that are not
in the parent set. If the cost of the path through the preferred
parent and the worst parent is too large, a node MAY keep a smaller
parent set.

3.3. Computing Rank

The DAG roots set their rank to MIN_PATH_COST for the selected
metric.

Once a non-root node selects its parent set, it can use the following
table to covert the the path cost of the worst parent (written as
Cost in the table) to its rank:

```
+--------------------+------------+
|  Node/link Metric  |    Rank    |
+--------------------+------------+
|     Node Energy    | 255 - Cost |
|     Hop-Count      |    Cost    |
|      Latency       | Cost/65536 |
| Link Quality Level |    Cost    |
|        ETX         |    Cost    |
+--------------------+------------+
```

                  Table 1: Conversion of metric to rank.

   Nodes MUST support at least one of the above metrics. Nodes SHOULD
   support the ETX metric.

   Node rank is undefined for these node/link metrics: Node state and
   attributes, throughput, and link color. If the rank is undefined,
   the node MUST join one of the neighbors as a leaf node.

3.4. Advertising the Path Cost

   Once the preferred parent is selected, the node sets its
   cur_min_path_cost variable to the path cost corresponding to the
   preferred parent. Thus, cur_min_path_cost is the cost of the minimum
   cost path from the node to the root. The value of the
   cur_min_path_cost is carried in the metric container corresponding to
   the selected metric when DIO messages are sent.

3.5. Working Without Metric Containers

   In the absence of metric container, MRHOF uses ETX as its metric. It
   locally computes the ETX of links to its neighbors and adds this
   value to their advertised Rank to compute the associated Rank of
   routes. Once parent selection and rank computation is performed
   using the ETX metric, the node advertises a Rank equal to the ETX
   cost and SHOULD NOT include a metric container in its DIO messages.

4. Using MRHOF for Metric Maximization

   MRHOF cannot be directly used for parent selection using metrics
   which require finding paths with maximum value of the selected
   metric, such as path reliability. It is possible to convert such a
   metric maximization problem to a metric minimization problem and use
   MRHOF provided:

There is a fixed and well-known maximum metric value corresponding
to the best path. This is the path cost for the DAG root.
Example, the best link reliability has a value of 1.

Metrics are all positive. Example, link reliability is always
positive.

For metrics meeting the above conditions, the problem of maximizing
the metric value is equivalent to minimizing the negative of the
metric value. MRHOF is not required to work with these metrics.

5. Settings of RPL parameters

The MinHopRankIncrease parameter MUST be set to 1.

6. MRHOF Variables and Parameters

MRHOF uses the following variable:

cur_min_path_cost: The cost of the path from a node through its
preferred parent to the root computed at the last parent
selection.

MRHOF uses the following parameters:

MAX_LINK_METRIC: Maximum allowed value for the selected link
metric for each link on the path.

MAX_PATH_COST: Maximum allowed value for the path metric of a
selected path.

MIN_PATH_COST: The minimum allowed value for the path metric of
the selected path.

PARENT_SWITCH_THRESHOLD: The difference between metric of the path
through the preferred parent and the minimum-metric path in order
to trigger the selection of a new preferred parent.

PARENT_SET_SIZE: The number of candidate parents, including the
preferred parent, in the parent set.

The parameter values are assigned depending on the selected metric.
The best values for these parameters should be experimentally
determined. The working group has long experience routing with the
ETX metric. Based on those experiences, these ETX parameters are
known to work in many settings:

MAX_LINK_METRIC: 10. Disallow links with greater than 10 expected transmission count on the selected path.

MAX_PATH_COST: 100. Disallow paths with greater than 100 expected transmission count.

MIN_PATH_COST: 0. At root, the expected transmission count is 0.

PARENT_SWITCH_THRESHOLD: 1.5. Switch to a new path only if it is expected to require at least 1.5 fewer transmission than the current path.

PARENT_SET_SIZE: 3. If the preferred parent is not available, two candidate parents are still available without triggering a new round of route discovery.

7. Acknowledgements

   Thanks to Antonio Grilo, Nicolas Tsiftes, Matteo Paris, JP Vasseur, and Phoebus Chen for their comments.

8. IANA Considerations

   This specification requires an allocated OCP. A value of 1 is requested.

9. Security Considerations

   Security considerations to be developed in accordance to the output of the WG.

10. References

10.1. Normative References

   [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

10.2. Informative References

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