Root initiated routing state in RPL
draft-ietf-roll-dao-projection-01

Abstract

   This document proposes a protocol extension to RPL that enables to
   install a limited amount of centrally-computed routes in a RPL graph,
   enabling loose source routing down a non-storing mode DODAG, or
   transversal routes inside the DODAG. As opposed to the classical
   route injection in RPL that are injected by the end devices, this
   draft enables the root of the DODAG to projects the routes that are
   needed on the nodes where they should be installed.

Status of This Memo

   This Internet-Draft is submitted in full conformance with the
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1. Introduction

The Routing Protocol for Low Power and Lossy Networks (LLN)(RPL)
[RFC6550] is a generic Distance Vector protocol that is well suited
for application in a variety of low energy Internet of Things (IoT)
networks. RPL forms Destination Oriented Directed Acyclic Graphs
(DODAGs) in which the root often acts as the Border Router to connect
the RPL domain to the Internet. The root is responsible to select
the RPL Instance that is used to forward a packet coming from the
Internet into the RPL domain and set the related RPL information in
the packets.

The 6TiSCH architecture [I-D.ietf-6tisch-architecture] leverages RPL
for its routing operation and considers the Deterministic Networking
Architecture [I-D.ietf-detnet-architecture] as one possible model
whereby the device resources and capabilities are exposed to an
external controller which installs routing states into the network
based on some objective functions that reside in that external
entity.

Based on heuristics of usage, path length, and knowledge of device capacity and available resources such as battery levels and reservable buffers, a Path Computation Element ([PCE]) with a global visibility on the system could install additional P2P routes that are more optimized for the current needs as expressed by the objective function.

This draft enables a RPL root, with optionally the assistance of a PCE, to install and maintain additional storing and non-storing mode routes within the RPL domain, along a selected set of nodes and for a selected duration, thus providing routes more suitable than those obtained with the distributed operation of RPL. Those routes may be installed in either storing and non-storing modes RPL instances, resulting in potentially hybrid situations where the mode of the projected routes is different from that of the other routes in the instance.

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].

The Terminology used in this document is consistent with and incorporates that described in `Terminology in Low power And Lossy Networks' [RFC7102] and [RFC6550].

3. New RPL Control Message Options

Section 6.7 of [RFC6550] specifies Control Message Options (CMO) to be placed in RPL messages such as the Destination Advertisement Object (DAO) message. The RPL Target Option and the Transit Information Option (TIO) are such options; the former indicates a node to be reached and the latter specifies a parent that can be used to reach that node. Options may be factorized; one or more contiguous TIOs apply to the one or more contiguous Target options that immediately precede the TIOs in the RPL message.

This specification introduces a new Control Message Option, the Via Information option (VIO). Like the TIO, the VIO MUST be preceded by one or more RPL Target options to which it applies. Unlike the TIO, the VIO are not factorized: multiple contiguous Via options indicate an ordered sequence of routers to reach the target(s), presented in the order of the packet stream, source to destination, and in which a routing state must be installed.

The Via Information option MUST contain at least one Via Address.

3.1. Via Information Option

The Via Information option MAY be present in DAO messages, and its
format is as follows:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Type = 0x0A | Option Length | Path Sequence | Path Lifetime |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
.                                                               .
.                        Via Address 1                          .
.                                                               .
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
.                            ....                               .
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
.                                                               .
.                        Via Address n                          .
.                                                               .
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
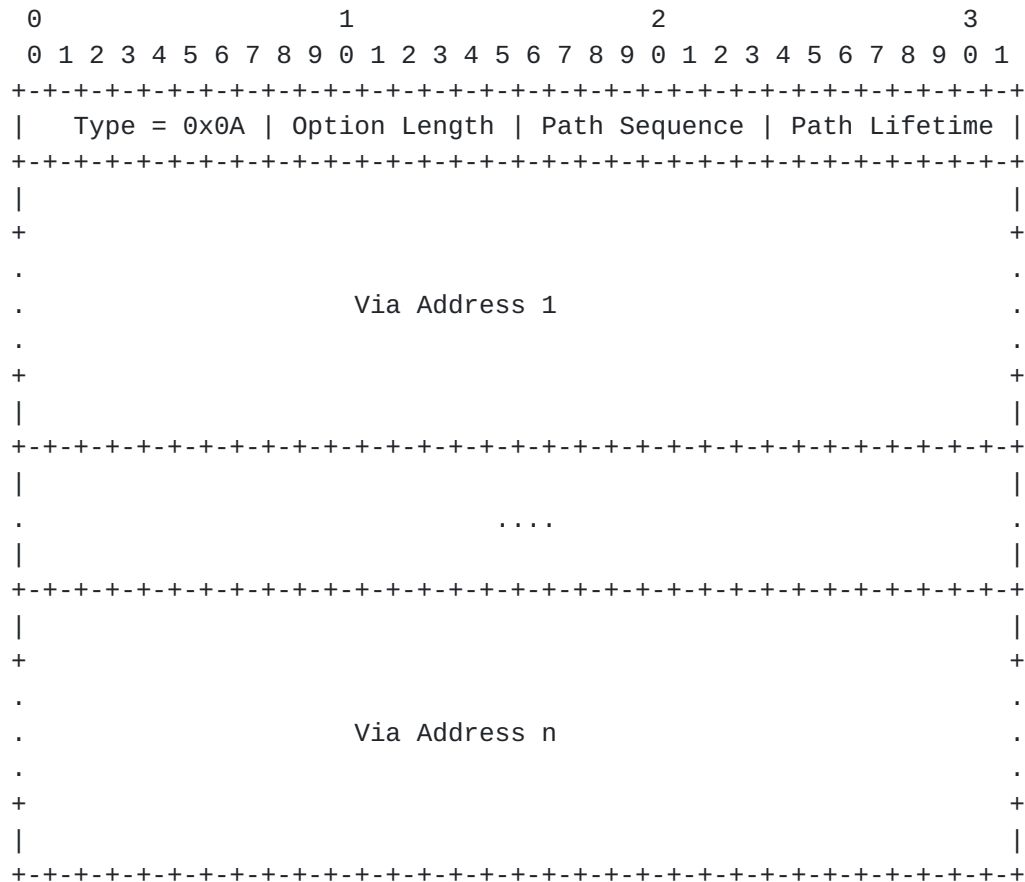
Figure 1: Via Information option format

Option Type: 0x0A (to be confirmed by IANA)

Option Length: In bytes; variable, depending on the number of Via
      Addresses.

Path Sequence: 8-bit unsigned integer. When a RPL Target option is
      issued by the root of the DODAG (i.e. in a DAO message), that
      root sets the Path Sequence and increments the Path Sequence
      each time it issues a RPL Target option with updated
      information. The indicated sequence deprecates any state for a
      given Target that was learned from a previous sequence and adds
      to any state that was learned for that sequence.

Path Lifetime: 8-bit unsigned integer. The length of time in
      Lifetime Units (obtained from the Configuration option) that
      the prefix is valid for route determination. The period starts
      when a new Path Sequence is seen. A value of all one bits
      (0xFF) represents infinity. A value of all zero bits (0x00)
      indicates a loss of reachability. A DAO message that contains
      a Via Information option with a Path Lifetime of 0x00 for a
      Target is referred as a No-Path (for that Target) in this
      document.

Via Address: 16 bytes. IPv6 Address of the next hop towards the
      destination(s) indicated in the target option that immediately
      precede the VIO. TBD: See how the /64 prefix can be elided if
      it is the same as that of (all of) the target(s). In that
      case, the Next-Hop Address could be expressed as the 8-bytes
      suffix only, otherwise it is expressed as 16 bytes, at least in
      storing mode.

4. Projected DAO

This draft adds a capability to RPL whereby the root projects a route
through an extended DAO message called a Projected-DAO (P-DAO) to an
arbitrary router down the DODAG, indicating a next hop or a sequence
of routers via which a certain destination indicated in the Target
Information option may be reached.

A P-DAO message MUST contain at least a Target Information option and
at least one VIA Information option following it.

Like a classical DAO message, a P-DAO is processed only if it is
"new" per section 9.2.2. "Generation of DAO Messages" of the RPL
specification [RFC6550]; this is determined using the Path Sequence
information from the VIO as opposed to a TIO. Also, a Path Lifetime
of 0 in a VIO indicates that a route is to be removed.

There are two kinds of P-DAO, the storing mode and the non-storing
mode ones.

   The non-storing mode P-DAO discussed in section Section 4.1 has a
   single VIO with one or more Via Addresses in it, the list of Via
   Addresses indicating the source-routed path to the target to be
   installed in the router that receives the message, which replies
   to the root directly with a DAO-ACK message.

   The storing mode P-DAO discussed in section Section 4.2 has at
   least two Via Information options with one Via Address each, for
   the ingress and the egress of the path, and more if there are
   intermediate routers. The Via Addresses indicate the routers in

   which the routing state to the target have to be installed via the
   next Via Address in the sequence of VIO. In normal operations,
   the P-DAO is propagated along the chain of Via Routers from the
   egress router of the path till the ingress one, which confirms the
   installation to the root with a DAO-ACK message. Note that the
   root may be the ingress and it may be the egress of the path, that
   it can also be neither but it cannot be both.

The root is expected to use these mechanisms optimally and with
required parsimony to limit the state installed in the devices to fit
within their resources, but how the root figures the amount of
resources that is available in each device is out of scope for this
document.

In particular, the draft expects that the root has enough information
about the capability for each node to store a number of routes, which
can be discovered for instance using a Network Management System
(NMS) and/or the RPL routing extensions specified in Routing for Path
Calculation in LLNs [RFC6551].

A route that is installed by a P-DAO is not necessarily installed
along the DODAG, though how the root and the optional PCE obtain the
additional topological information to compute other routes is out of
scope for this document

4.1. Non-storing Mode Projected DAO

As illustrated in Figure 2, the non-storing mode P-DAO enables the
root to install a source-routed path towards a target in any
particular router; with this path information the router can add a
source routed header reflecting the path to any packet for which the
current destination either is the said target or can be reached via
the target, for instance a loose source routed packet for which the
next loose hop is the target, or a packet for which the router has a
routing state to the final destination via the target.

```
              ------+---------
                 |              Internet
                 |
           +-----+
           |     | Border Router
           |     | (RPL Root)
           +-----+                    |  P   ^           |
              |                       | DAO  |  ACK       | Loose
        o    o   o    o      router   V     |           | Source
      o o   o  o    o  o  o     o  o         | P-DAO    . Route
     o  o o  o o    o   o   o  o   o         | Source   . Path
      o   o    o  o     o  o    o  o   o     | Route    . From
    o  o   o  o   o        o    o  o         | Path     . Root
      o   o  o  o           o    target      V          . To
     o        o              o   o                      | Desti-
    o            o           o    o                      | nation
                          destination             V

                  LLN
```

                 Figure 2: Projecting a non-storing route

   A router that receives a non-storing P-DAO installs a source routed
   path towards each of the consecutive targets via a source route path
   indicated in the following VIO.

   When forwarding a packet to a destination for which the router
   determines that routing happens via the target, the router inserts
   the source routing header in the packet to reach the target.

   In order to do so, the router encapsulates the packet with an IP in
   IP header and a non-storing mode source routing header (SRH)
   [RFC6554].

   In the uncompressed form the source of the packet would be self, the
   destination would be the first Via Address in the VIO, and the SRH
   would contain the list of the remaining Via Addresses and then the
   target.

   In practice, the router will normally use the IPv6 over Low-Power
   Wireless Personal Area Network (6LoWPAN) Paging Dispatch [RFC8025] to
   compress the RPL artifacts as indicated in the 6LoWPAN Routing Header
   [I-D.ietf-roll-routing-dispatch] specification. In that case, the
   router indicates self as encapsulator in an IP-in-IP 6LoRH Header,
   and places the list of Via Addresses in the order of the VIO and then
   the target in the SRH 6LoRH Header.

4.2. Storing-Mode Projected DAO

   As illustrated in Figure 3, the storing mode P-DAO enables the root
   to install a routing state towards a target in the routers along a
   segment between an ingress and an egress router; this enables the
   routers to forward along that segment any packet for which the next
   loose hop is the said target, for instance a loose source routed
   packet for which the next loose hop is the target, or a packet for
   which the router has a routing state to the final destination via the
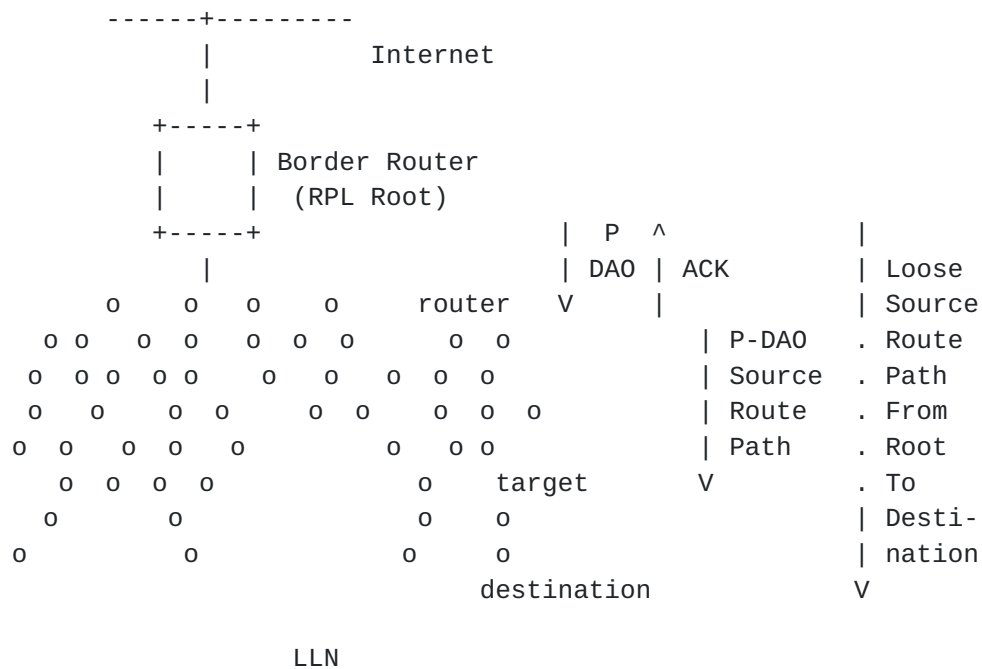   target.

```
              ------+---------
                    |              Internet
                    |
              +-----+
              |     | Border Router
              |     |  (RPL Root)
              +-----+                       |       ^         |
                    |                       | DAO | ACK      |
          o    o   o     o                  |     |          | Loose
        o o   o  o    o  o  o o    o         |   ^           | Source
       o  o o  o o     o   o   o   o   o     |   | DAO       | Route
        o   o    o  o      o  o     o  o   o | ^             |
       o  o   o  o    o         o    o  o    v | DAO         v
       o          o              o     o
```

                        LLN

                    Figure 3: Projecting a route

   Based on available topological, usage and capabilities node
   information, the root or an associated PCE computes which segment
   should be optimized and which relevant state should be installed in
   which nodes. The algorithm is out of scope but it is envisaged that
   the root could compute the ratio between the optimal path (existing
   path not traversing the root, and the current path), the application
   service level agreement (SLA) for specific flows that could benefit
   from shorter paths, the energy wasted in the network, local
   congestion on various links that would benefit from having flows
   routed along alternate paths.

   In order to install the relevant routing state along the segment
   between an ingress and an egress routers, the root sends a unicast
   P-DAO message to the egress router of the routing segment that must
   be installed. The P-DAO message contains the ordered list of hops
   along the segment as a direct sequence of Via Information options
   that are preceded by one or more RPL Target options to which they

relate. Each Via Information option contains a Path Lifetime for
which the state is to be maintained.

The root sends the P-DAO directly to the egress node of the segment,
which In that P-DAO, the destination IP address matches the Via
Address in the last VIO. This is how the egress recognizes its role.
In a similar fashion, the ingress node recognizes its role as it
matches Via Address in the first VIO.

The egress node of the segment is the only node in the path that does
not install a route in response to the P-DAO; it is expected to be
already able to route to the target(s) on its own. It may either be
the target, or may have some existing information to reach the
target(s), such as a connected route or an already installed
projected route. If one of the targets cannot be located, the node
MUST answer to the root with a negative DAO-ACK listing the target(s)
that could not be located (suggested status 10 to be confirmed by
IANA).

If the egress node can reach all the targets, then it forwards the
P-DAO with unchanged content to its loose predecessor in the segment
as indicated in the list of Via Information options, and recursively
the message is propagated unchanged along the sequence of routers
indicated in the P-DAO, but in the reverse order, from egress to
ingress.

The address of the predecessor to be used as destination of the
propagated DAO message is found in the Via Information option the
precedes the one that contain the address of the propagating node,
which is used as source of the packet.

Upon receiving a propagated DAO, an intermediate router as well as
the ingress router install a route towards the DAO target(s) via its
successor in the P-DAO; the router locates the VIO that contains its
address, and uses as next hop the address found in the Via Address
field in the following VIO. The router MAY install additional routes
towards the addresses that are located in VIOs that are after the
next one, if any, but in case of a conflict or a lack of resource, a
route to a target installed by the root has precedence.

The process recurses till the P-DAO is propagated to ingress router
of the segment, which answers with a DAO-ACK to the root.

Also, the path indicated in a P-DAO may be loose, in which case the
reachability to the next hop has to be asserted. Each router along
the path indicated in a P-DAO is expected to be able to reach its
successor, either with a connected route (direct neighbor), or by
routing, for instance following a route installed previously by a DAO

or a P-DAO message. If that route is not connected then a recursive
lookup may take place at packet forwarding time to find the next hop
to reach the target(s). If it does not and cannot reach the next
router in the P-DAO, the router MUST answer to the root with a
negative DAO-ACK indicating the successor that is unreachable
(suggested status 11 to be confirmed by IANA).

A Path Lifetime of 0 in a Via Information option is used to clean up
the state. The P-DAO is forwarded as described above, but the DAO is
interpreted as a No-Path DAO and results in cleaning up existing
state as opposed to refreshing an existing one or installing a new
one.

5. Applications

5.1. Loose Source Routing in Non-storing Mode

A RPL implementation operating in a very constrained LLN typically
uses the non-storing mode of operation whereby a RPL node indicates a
parent-child relationship to the root, using a Destination
Advertisement Object (DAO) that is unicast from the node directly to
the root, and the root typically builds a source routed path to a
destination down the DODAG by recursively concatenating this
information.

```
           ------+----------
              |            Internet
              |
         +-----+
         |     | Border Router
         |     |  (RPL Root)
         +-----+                    ^     |      |
            |                       | DAO | ACK  |
      o    o   o    o               |     |      | Strict
    o o   o  o   o o  o o    o       |     |      | Source
   o  o o  o o    o   o   o o  o      |     |      | Route
   o   o    o  o     o  o    o o  o   |     |      |
  o  o   o  o   o         o   o o     |     v      v
  o        o            o     o
               LLN
```

                Figure 4: RPL non-storing mode of operation

Based on the parent-children relationships expressed in the non-
storing DAO messages,the root possesses topological information about
the whole network, though this information is limited to the
structure of the DODAG for which it is the destination. A packet
that is generated within the domain will always reach the root, which

can then apply a source routing information to reach the destination
if the destination is also in the DODAG. Similarly, a packet coming
from the outside of the domain for a destination that is expected to
be in a RPL domain reaches the root.

It results that the root, or then some associated centralized
computation engine such as a PCE, can determine the amount of packets
that reach a destination in the RPL domain, and thus the amount of
energy and bandwidth that is wasted for transmission, between itself
and the destination, as well as the risk of fragmentation, any
potential delays because of a paths longer than necessary (shorter
paths exist that would not traverse the root).

As a network gets deep, the size of the source routing header that
the root must add to all the downward packets becomes an issue for
nodes that are many hops away. In some use cases, a RPL network
forms long lines and a limited amount of well-targeted routing state
would allow to make the source routing operation loose as opposed to
strict, and save packet size. Limiting the packet size is directly
beneficial to the energy budget, but, mostly, it reduces the chances
of frame loss and/or packet fragmentation, which is highly
detrimental to the LLN operation. Because the capability to store a
routing state in every node is limited, the decision of which route
is installed where can only be optimized with a global knowledge of
the system, a knowledge that the root or an associated PCE may
possess by means that are outside of the scope of this specification.

This specification enables to store source-routed or storing mode
state in intermediate routers, which enables to limit the excursion
of the source route headers in deep networks. Once a P-DAO exchange
has taken place for a given target, if the root operates in non
storing mode, then it may elide the sequence of routers that is
installed in the network from its source route headers to destination
that are reachable via that target, and the source route headers
effectively become loose.

5.2. Transversal Routes in storing and non-storing modes

RPL is optimized for Point-to-Multipoint (P2MP), root to leaves and
Multipoint-to-Point (MP2P) leaves to root operations, whereby routes
are always installed along the RPL DODAG. Transversal Peer to Peer
(P2P) routes in a RPL network will generally suffer from some stretch
since routing between 2 peers always happens via a common parent, as
illustrated in Figure 5:

o in non-storing mode, all packets routed within the DODAG flow all
   the way up to the root of the DODAG. If the destination is in the
   same DODAG, the root must encapsulate the packet to place a

Routing Header that has the strict source route information down
the DODAG to the destination. This will be the case even if the
destination is relatively close to the source and the root is
relatively far off.

o In storing mode, unless the destination is a child of the source,
   the packets will follow the default route up the DODAG as well.
   If the destination is in the same DODAG, they will eventually
   reach a common parent that has a route to the destination; at
   worse, the common parent may also be the root. From that common
   parent, the packet will follow a path down the DODAG that is
   optimized for the Objective Function that was used to build the
   DODAG.

```
              ------+---------
              |            Internet
              |
         +-----+
         |     | Border Router
         |     |  (RPL Root)
         +-----+
            X
      ^     v    o     o
    ^ o    o v   o  o  o o    o
    ^  o o  o v    o   o   o  o  o
    ^   o   o v    o  o    o  o  o
   S  o  o  o   D         o   o o
   o           o              o     o
                   LLN
```
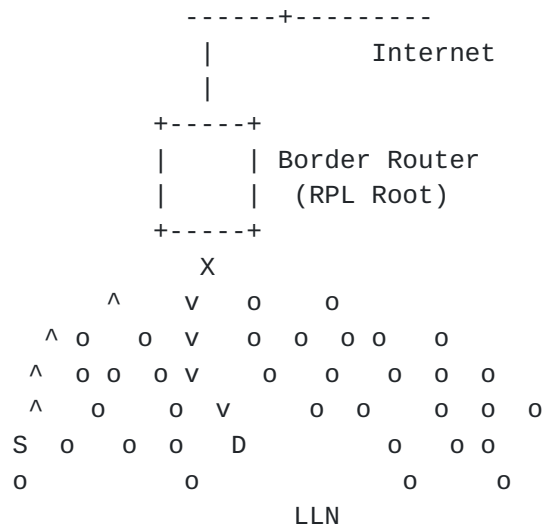
   Figure 5: Routing Stretch between S and D via common parent X

It results that it is often beneficial to enable transversal P2P
routes, either if the RPL route presents a stretch from shortest
path, or if the new route is engineered with a different objective.
For that reason, earlier work at the IETF introduced the Reactive
Discovery of Point-to-Point Routes in Low Power and Lossy Networks
[RFC6997], which specifies a distributed method for establishing
optimized P2P routes. This draft proposes an alternate based on a
centralized route computation.

```
               ------+---------
                     |              Internet
                     |
               +-----+
               |     | Border Router
               |     |  (RPL Root)
               +-----+
                  |
           o    o   o    o
        o o   o  o    o  o  o o   o
        o  o o  o o     o   o   o  o  o
         o   o    o  o     o  o    o  o  o
        S>>A>>>B>>C>>>D         o   o o
        o          o              o     o
                         LLN
```
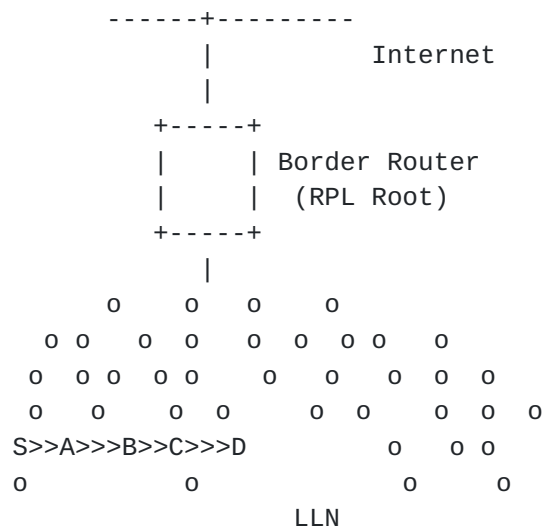
Figure 6: Projected Transversal Route

This specification enables to store source-routed or storing mode
state in intermediate routers, which enables to limit the stretch of
a P2P route and maintain the characteristics within a given SLA. An
example of service using this mechanism oculd be a control loop that
would be installed in a network that uses classical RPL for
asynchronous data collection. In that case, the P2P path may be
installed in a different RPL Instance, with a different objective
function.

6. RPL Instances

It must be noted that RPL has a concept of instance but does not have
a concept of an administrative distance, which exists in certain
proprietary implementations to sort out conflicts between multiple
sources. This draft conforms the instance model as follows:

o if the PCE needs to influence a particular instance to add better
   routes in conformance with the routing objectives in that
   instance, it may do so. When the PCE modifies an existing
   instance then the added routes must not create a loop in that
   instance. This is achieved by always preferring a route obtained
   from the PCE over a route that is learned via RPL.

o If the PCE installs a more specific (Traffic Engineering) route
   between a particular pair of nodes then it should use a Local
   Instance from the ingress node of that path. Only packets
   associated with that instance will be routed along that path.

In all cases, the path is indicated by a new Via Information option, and the flow is similar to the flow used to obtain loose source routing.

7. Security Considerations

This draft uses messages that are already present in [RFC6550] with optional secured versions. The same secured versions may be used with this draft, and whatever security is deployed for a given network also applies to the flows in this draft.

8. IANA Considerations

This document updates the IANA registry for the Mode of Operation (MOP)

       4: Non-Storing with Projected routes [this]

This document updates IANA registry for the RPL Control Message Options

       0x0A: Via descriptor [this]

9. Acknowledgments

The authors wish to acknowledge JP Vasseur and Patrick Wetterwald for their contributions to the ideas developed here.

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Appendix A. Examples

A.1. **Using storing mode P-DAO in non-storing mode MOP**

   In non-storing mode, the DAG root maintains the knowledge of the
   whole DODAG topology, so when both the source and the destination of
   a packet are in the DODAG, the root can determine the common parent
   that would have been used in storing mode, and thus the list of nodes
   in the path between the common parent and the destination. For
   instance in the diagram shown in Figure 7, if the source is node 41
   and the destination is node 52, then the common parent is node 22.

```
                ------+---------
                      |             Internet
                      |
                 +-----+
                 |     | Border Router
                 |     |  (RPL Root)
                 +-----+
                  | \   \____
                 /   \       \
              o 11    o 12    o   13
               /       |     /  \
            o 22      o 23   o 24  o 25
           /  \       | \        \
         o 31    o 32 o    o      o 35
         /       /    |     \    |    \
       o 41    o 42   o      o    o 45    o 46
       |       |      |      |     \      |
       o 51    o 52   o 53   o      o 55 o 56

                     LLN
```
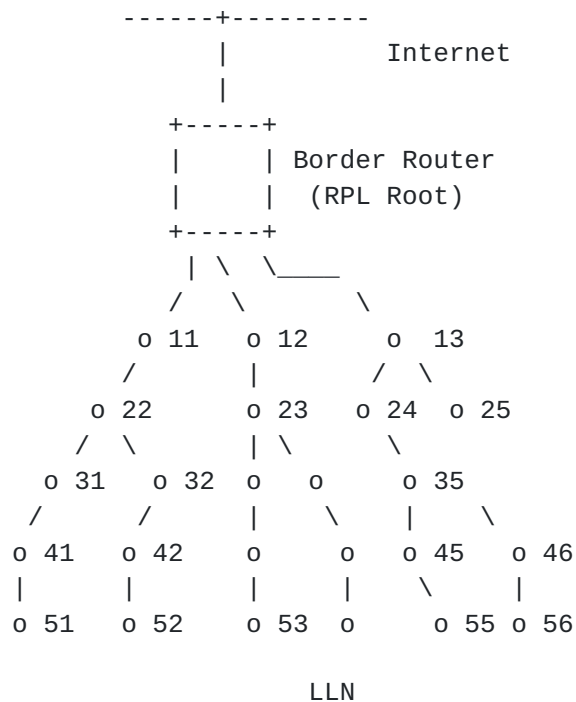
        Figure 7: Example DODAG forming a logical tree topology

   With this draft, the root can install a storing mode routing states
   along a segment that is either from itself to the destination, or
   from one or more common parents for a particular source/destination
   pair towards that destination (in this particular example, this would
   be the segment made of nodes 22, 32, 42).

   In the example below, say that there is a lot of traffic to nodes 55
   and 56 and the root decides to reduce the size of routing headers to
   those destinations. The root can first send a DAO to node 45
   indicating target 55 and a Via segment (35, 45), as well as another
   DAO to node 46 indicating target 56 and a Via segment (35, 46). This
   will save one entry in the routing header on both sides. The root
   may then send a DAO to node 35 indicating targets 55 and 56 a Via
   segment (13, 24, 35) to fully optimize that path.

   Alternatively, the root may send a DAO to node 45 indicating target
   55 and a Via segment (13, 24, 35, 45) and then a DAO to node 46
   indicating target 56 and a Via segment (13, 24, 35, 46), indicating
   the same DAO Sequence.

A.2. Projecting a storing-mode transversal route

   In this example, say that a PCE determines that a path must be
   installed between node S and node D via routers A, B and C, in order
   to serve the needs of a particular application.

   The root sends a P-DAO with a target option indicating the
   destination D and a sequence Via Information option, one for S, which
   is the ingress router of the segment, one for A and then for B, which
   are an intermediate routers, and one for C, which is the egress
   router.

```
               ------+---------
                     |          Internet
                     |
                +-----+
                |     | Border Router
                |     |  (RPL Root)
                +-----+
                  | Projected DAO message to C
           o      |  o     o
         o o    o |   o  o  o o    o
          o  o o  | o    o   o   o  o  o
          o   o  V  o     o  o    o  o  o
          S  A  B  C    D        o   o o
          o         o            o      o
                        LLN
```
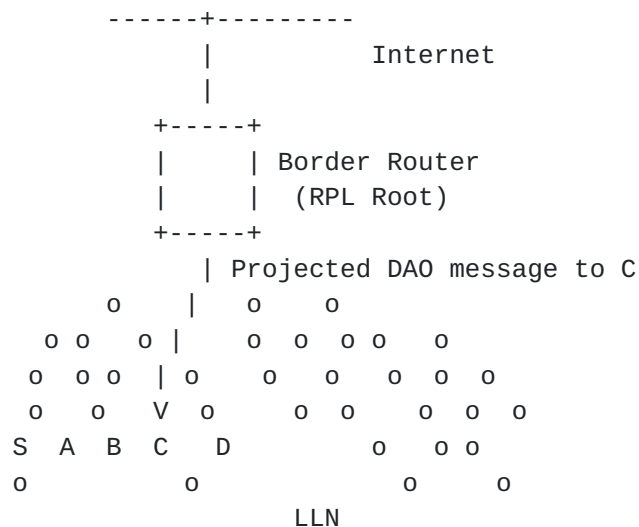
                  Figure 8: Projected DAO from root

   Upon reception of the P-DAO, C validates that it can reach D, e.g.
   using IPv6 Neighbor Discovery, and if so, propagates the P-DAO
   unchanged to B.

   B checks that it can reach C and of so, installs a route towards D
   via C. Then it propagates the P-DAO to A.

   The process recurses till the P-DAO reaches S, the ingress of the
   segment, which installs a route to D via A and sends a DAO-ACK to the
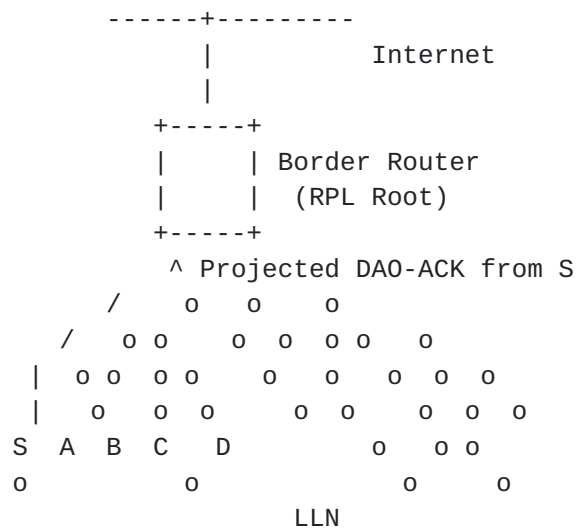   root.

```
                  ------+---------
                       |              Internet
                       |
                  +-----+
                  |     | Border Router
                  |     | (RPL Root)
                  +-----+
                   ^ Projected DAO-ACK from S
              /    o   o     o
           /    o o    o o  o o   o
          |  o o  o o     o   o   o  o  o
          |   o   o  o      o  o    o  o  o
         S  A  B  C   D        o   o o
         o           o             o     o
                        LLN
```

                Figure 9: Projected DAO-ACK to root

   As a result, a transversal route is installed that does not need to
   follow the DODAG structure.

```
                  ------+---------
                       |              Internet
                       |
                  +-----+
                  |     | Border Router
                  |     | (RPL Root)
                  +-----+
                       |
              o    o   o     o
            o o   o o   o o  o o    o
            o  o o  o o     o   o   o  o  o
            o   o   o  o      o  o    o  o  o
           S>>A>>>B>>C>>>D        o   o o
           o           o             o     o
                        LLN
```
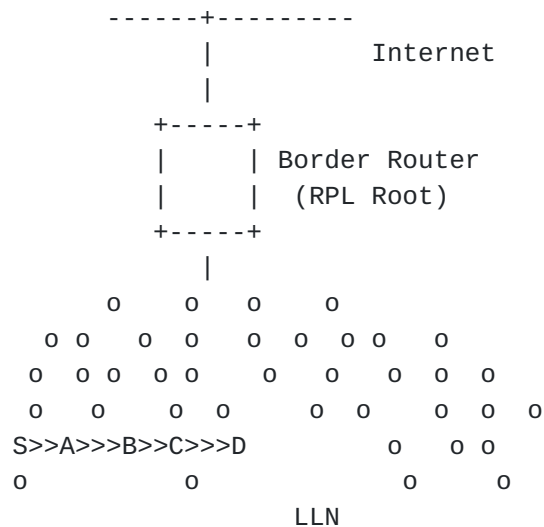
              Figure 10: Projected Transversal Route

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