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RPL Capabilities
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Abstract

   This draft enables the discovery, advertisement and query of
   capabilities for RPL nodes.

Status of This Memo

   This Internet-Draft is submitted in full conformance with the
   provisions of BCP 78 and BCP 79.

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   time. It is inappropriate to use Internet-Drafts as reference
   material or to cite them other than as "work in progress."

   This Internet-Draft will expire on August 13, 2020.

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1. Introduction

RPL [RFC6550] specifies a proactive distance-vector based routing
scheme. The protocol creates a DAG-like structure which operates
with a given "Mode of Operation" (MOP) determining the minimal and
mandatory set of primitives to be supported by all the participating
nodes.

This document adds a notion of capabilities using which the nodes in
the network could inform its peers about its additional capabilities/
features. This document highlights the differences of capabilities
from that of Mode of operation and explains the necessity of it.

1.1. Requirements Language and 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].

MOP: Mode of Operation. Identifies the mode of operation of the RPL
Instance as administratively provisioned at and distributed by the
DODAG root.

MOPex: Extended MOP: As defined in [I-D.jadhav-roll-mopex].

Capabilities: Additional features or capabilities which might
possibly be optional that are supported by the node.

DAO: DODAG Advertisement Object. An RPL message used to advertise
the target information in order to establish routing adjacencies.

DIO: DODAG Information Object. An RPL message initiated by the root
and is used to advertise the network configuration information.

Current parent: Parent 6LR node before switching to the new path.

NPDAO: No-Path DAO. A DAO message which has target with lifetime 0.

MOPex: MOP extension as defined in this document.

Upstream path/direction: Path or direction from the node to the Root
in a DAG.

Downstream path/direction: Path or direction to the node from the
Root in a DAG.

This document uses terminology described in [RFC6550]. For the sake
of readability all the known relevant terms are repeated in this
section.

1.2. What are Capabilities?

Currently RPL specification does not have a mechanism whereby a node
can signal the set of features that are available on its end. Such a
mechanism could help the root to advertise its capabilities and in
response also determine some advanced information about the
capabilities of the joining nodes. This document defines
Capabilities which could be supported by the nodes and handshaked as
part of RPL signaling. Capabilities are embedded as RPL control
message option as defined Section 6.7 of [RFC6550] in the base
messages of DIO, DAO and DAO-ACK signaling.

2. Requirements for this document

Following are the requirements considered for this documents:

REQ1:   Backwards compatibility. The new options and new fields in
        the DIO message should be backward compatible i.e. if there
        are nodes which support old MOPs they could still operate in
        their own instances.

REQ2:   Optional capabilities handshake. Capabilities are features,
        possibly optional, which could be handshaked between the nodes
        and the root within an RPL Instance.

REQ3:   Capabilities handshake could be optionally added with existing
        MOPs. Capabilities been optional in nature could be put to
        use with existing MOPs. Capabilities and MOP-extension is
        mutually independent i.e. a DIO can have a capabilities
        option, MOP-extension option or both in the same message.

REQ4:   Capabilities could be explicitly queried.

2.1. How are Capabilities different from MOP or DIO Configuration Option?

The Mode of Operation (MOP) field in RPL mandates the operational
requirement for the nodes joining as routers. MOP and DIO
Configuration Option is strictly controlled by the Root node in RPL.
Intermediate 6LRs could not modify the values. Also, the MOP never
changes for the lifetime of the RPL Instance. Changes in DIO
Configuration Option are possible but are very rare. Capabilities,
on the other hand, might change more dynamically.

RPL DIO message also carries routing metrics and constraints as
specified in [RFC6551]. Metrics and constraints are used as part of
objective function which aids in node's rank calculation. A router
may use capabilities carried in DIO message as additional metrics/
constraints. However, capabilities have a larger scope and may be
carried in other messages other than DIO and can flow in both the
directions (upstream and downstream).

3. Capabilities

Handling of Capabilities MUST be supported if the network uses MOPex
[I-D.jadhav-roll-mopex].

Note that capabilities and MOPex are mutually exclusive and it is
possible for an implementation to support either or both of the
options.

3.1. Capability Catagories

Capabilities can be divided into two broad categories:

Global Capabilities: It will include the features and capability
supported across an RPL instance. These capabilities can be
advertised by the Root or 6LRs of the DODAG. If a Node in the LLN
doesn't support a paticular global capability it may have to join the
RPL instance as a leaf node, as indicated by that individual
capability option. Example of such capabilities are Compression
Methods Supported, Support for TE paths (P-DAO).

Local Capabilities: It will include the cpabilities very specific to
a Node in the LLN. Example of such capabilities are NBR Cache
information, Routing Table Information.

Note that some capabilities can be either global or local depending
upon the context they are used ex.P-DAO [TODO: This is not clear]

3.2. Capability Control Message Option

```
 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 = TODO | Option Length | Capabilities TLVs
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
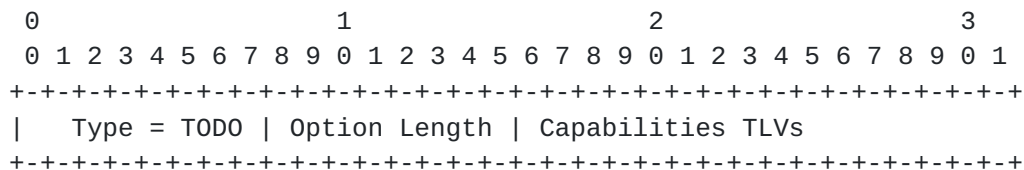
Figure 1: Capabilities Option

Multiple capabilities could be sent in the same message. The length
field allows the message parser to skip the capability TLV parsing.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   CAPType     |G|I|. . . . . .| CAPInfo(Opt)
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
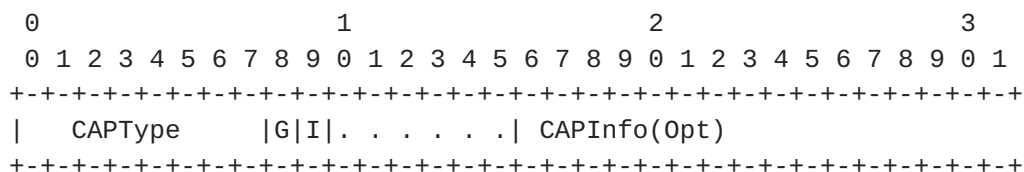
Figure 2: Capabilities TLV

Every capability is identified by its type and it may have an
optional Capability Info. Note that a given capability may or may
not be diseminated with additional information depending on the scope
of the capability indicated by the G bit. The first Bit of the
CAPType indicates if the capability is mandatory or optional Value of
1 indicates its a mandatory capability and 0 indicates its an
optional capability

G = If set indicates a Global Capability else its a local. For a
capability if it's mandatory and global bit is set then node those
either doesn't understand the capability or doesn't have this
capability should not join the DODAG as a router. All the global
capablities MUST be diseminated across the network.

I = Cap Info present

```
   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
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |   CAPLen      | Cap Info(format decided by individual cap spec)
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
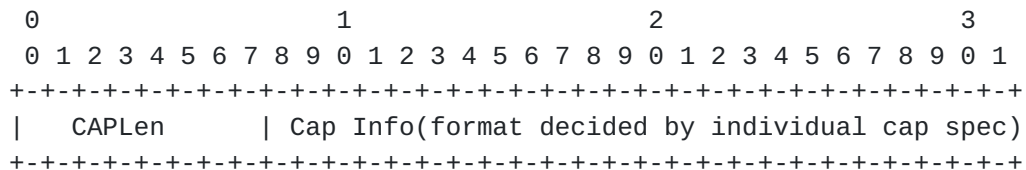
                        Figure 3: Capabilities Info

Capability Information provides additional information for the given
capability. The format of this field should be defined as part the
individual capability specification and is beyond the scope of this
document. This document provides a container format for carrying the
capability and its context information.

3.3. Capabilities Handshake

The root node could advertise the set of capabilities it supports in
the DIO message. A node could take advantage of the knowledge that
the root supports a particular capability. Similarly a node could
advertise its capabilities in the DAO message using the capability
control message option defined in this document. Capabilities
advertised by non-root nodes are strictly a subset of the
capabilities advertised by the root.

In storing MOP, the DAO message from the 6LR could contain multiple
target options because of the DAO-Aggregation. The targets of the
capabilities option are indicated by one or more Target options that
precede the Capabilties Option. This handling is similar to the
Transit Information Option as supported in Section 6.7.8. of
[RFC6550].

3.4. ROLL Capabilities

3.4.1. Projected Route Capability

[I-D.ietf-roll-dao-projection] proposes mechanisms to compute and
install traffic engineered paths in the RPL network. It enables an
RPL Root to install and maintain Projected Routes based on requested
path metric, within its DODAG, along with a selected set of nodes
that may or may not include self, for a chosen duration. Projected

Route Capability will be used to enable this TE path calculation.
PRC will be an optional global capability. Any node that does not
understand or support the projected route functions can still act as
an LR.

The DODAG root will use projected routes capability to advertise the
support of projected routes with the possible mode of operations and
set of path metrics it can use to calculate a projected route. DODAG
root will add the PRC to DIO message so that it can disseminate the
information in entire DODAG. Router nodes in the LLN receiving DIOs
with PRC MUST forward the same into their sub-DODAG without any
change even though they don't understand or support the projected
route feature.LR will use the path metric information advertised by
the DODAG root to learn these metrics from the network and neighbors.
The same information they will use to advertise in the sibling
information option. LR will also use these path metrics information
to request traffic-engineered routes optimizing a or set of specific
network metric(s).

LRs in the network will use this capability to inform the PCE if they
can be part of a storing or non-storing or both mode of projected
routes. Here the PRC will be part of the DAO message.

The capability will convey the below information. The PRC MUST have
either of the information or both depending upon the node type.If
originator is BR, then both the information MUST be there.

I: Supports projected route for both storing and non-storing
        mode.

II: List of supported path metrics that supported that can be used
        to compute projected routes

III: [To Decide] Can we add the PCE address information to this?

3.4.1.1. Format of Projected Route Capability

```
                                 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=0x01     |G|I|. . . . . .|     CAPLen    | MOP |  Resvd  |
                                 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                 |     Routing Metric 1          |      Routing Metric 1         |
```

```
                           +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
+-+-+-+-+-+-+-+-+-+
                           |       Routing Metric n-1     |      Routing
Metric n          |
                           +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
+-+-+-+-+-+-+-+-+-+
```
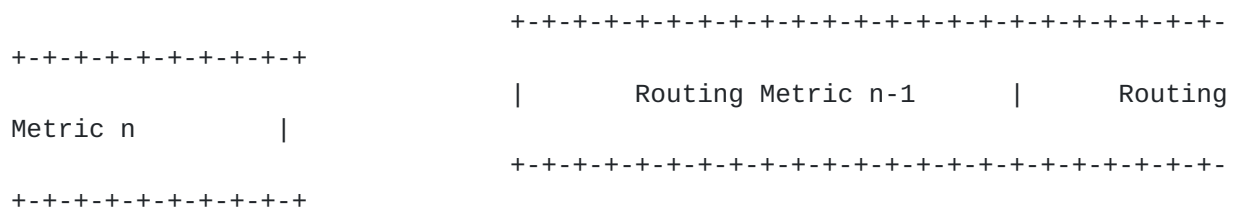
                 Figure 4: Projected Route Capability TLV

   Type: 0x01.

   Flags: DODAG root MUST set G bit to 1 plus LRs MUST set it to 0. I
   bit will always be set to 1.

   CAPLen: 8-bit unsigned integer, representing the length in octets of
   the option, not including the Option Type and Length fields.

   MOP: 3-bit field indicating the mode of operation of projected route
   capability.

   Resvd: 5-bit unused fields.They MUST be initialized to zero by the
   sender and MUST be ignored by the receiver.

   Routing Merric: 16 bit unsigned integer represetning the the routing
   metric to be used for TE path calculation. There can be n number of
   such routing metric fields. These fileds are alowed with the PRC
   sent by the DODAG ROOT. LRs MUST not send routing metric information
   with PRC.

```
                                  0                   1
                                  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6
                                  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                  | Type=0x01     |     Resvd     |
                                  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
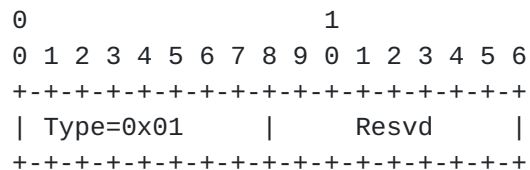
                      Figure 5: Routing Metric Information

3.4.2. 6LoRH Capability

   [RFC8138] introduces a new 6LoWPAN Routing Header (6LoRH) to carry
   IPv6 routing information. The 6LoRH may contain source routing
   information such as a compressed form of SRH, and other sorts of
   routing information such as the RPI and IP-in-IP encapsulation

   The transition to [RFC8138] in a network can only be done when all
   nodes support the specification. In a mixed case with both
   RFC8138-capable and non-capable nodes it would not be posssible to
   take advantage of 6LoRH.[I-D.thubert-roll-turnon-rfc8138] defines a
   mechanism to control the use of 6LoRH in a DODAG by using "T" flag
   bit in RPL configuration option. To assist DODAG root to decide if
   it has to set "T" flag bit in RPL Configuration Option to enable
   6LoRH within its DODAG, all LRs in DODAG MUST inform their support of
   [RFC8138] by adding 6LoRH capability TLV to their advertised
   capability control message option.

   DODAG root MUST use 6LoRH capability TLV to inform all the nodes in
   the DODAG, that DODAG is [RFC8138] compliance. 6LoRH is an optional
   local capability.

   Any LR joining the DODAG MUST add 6LoRH capability TLV to the
   capability control message option in its DAO message to inform BR
   that it supports RFC8138.If received DAO message doesn't have 6LoRH
   capability TLV, DODAG Root MUST conclude the target node doesn't
   support RFC 8138.So if DODAG is still not using 6LoRH, it MUST
   refrain from using the compression and if it is already using it, it
   MUST deny the LR from joining the DODAG with proper error code.
   [TODO- Need to add new Error code].

   6LoRH capability is an optional capability any node that doesn't
   understand or support the 6LoRH can join the DODAG if the "T" flag in
   the RPL Configuration option is not set otherwise it MUST join the
   network as a leaf node.

3.4.2.1. Format of 6LoRH Capability

```
                                 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=0x02     |G|I|. . . . . .|
Reserved          |
                                 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
+-+-+-+-+-+-+-+-+
```
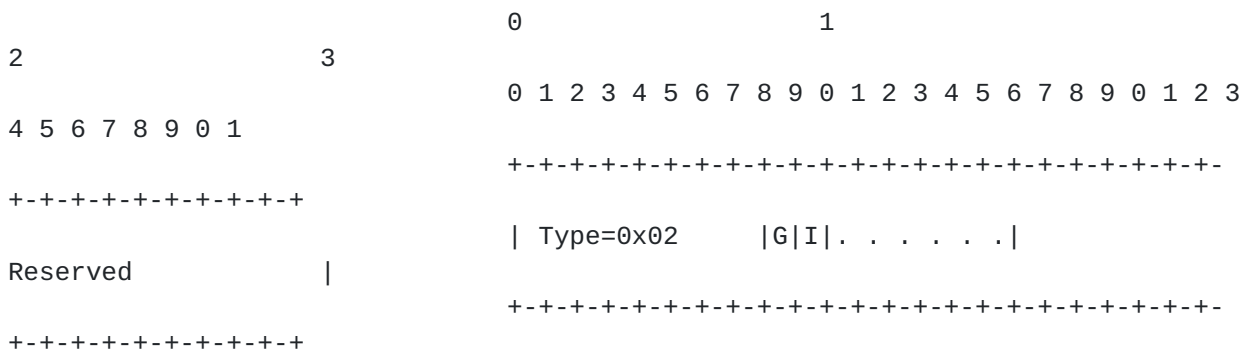
                     Figure 6: 6LoRH Capability TLV

   Type: 0x02.

   Flags: LRs MUST set it to 0. I bit will always be set to 0.

   Reserved: 16-bit unsigned integer, they MUST be initialized to zero
   by the sender and MUST be ignored by the receiver..

3.4.3. Routing Resource Capability

   Storing mode of operation requires each intermediate router in the
   LLN to maintain routing states' information in the routing table.
   LLN routers typically operate with constraints on processing power,
   memory, and energy (battery power). Memory limits the number of
   routing states an LR and BR can maintain. When the routing table of
   an LR or BR is full, it will either reject the new DAO messages
   received or will use some replacement policy to remove a routing

entry and add the new one. Rejection of DAO messages will lead to an
increase in DAO message transmission that impacts the energy and
network convergence time. Routing state replacement leads to
downward path downtime.

One possible way to solve problems due to routing table size
constraint is to use this information to add neighbors to the DAO
parent set.Routing resource capability can be used by LR and BR to
advertise their current routing table usage details in the network.
LR or LNs in LLN can use this information in the selection of the DAO
parent set. PCE can use this information to select intermediate
routers for the projected routes. Routing Resource is an optional
local capability.

Routing reource capability TLV can occur multiple times in the
capability control message option to advertise below possible routing
table information.

I: Master Routing Table Storing

II: Storing mode P-DAO Table

III: Non-Storing mode P-DAO

Routing resource capabablity sent in DIO message has link local scope
and it MUST not be forwarded.

3.4.3.1. Format of Routing Resource Capability

```
                                  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=0x03    |G|I|. . . . . .|    CAPLen
| RT  |  Resvd  |
                                  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
+-+-+-+-+-+-+-+-+
                                  |       Total Capacity         | Used Per
|   Threshold   |
                                  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-
+-+-+-+-+-+-+-+-+
```
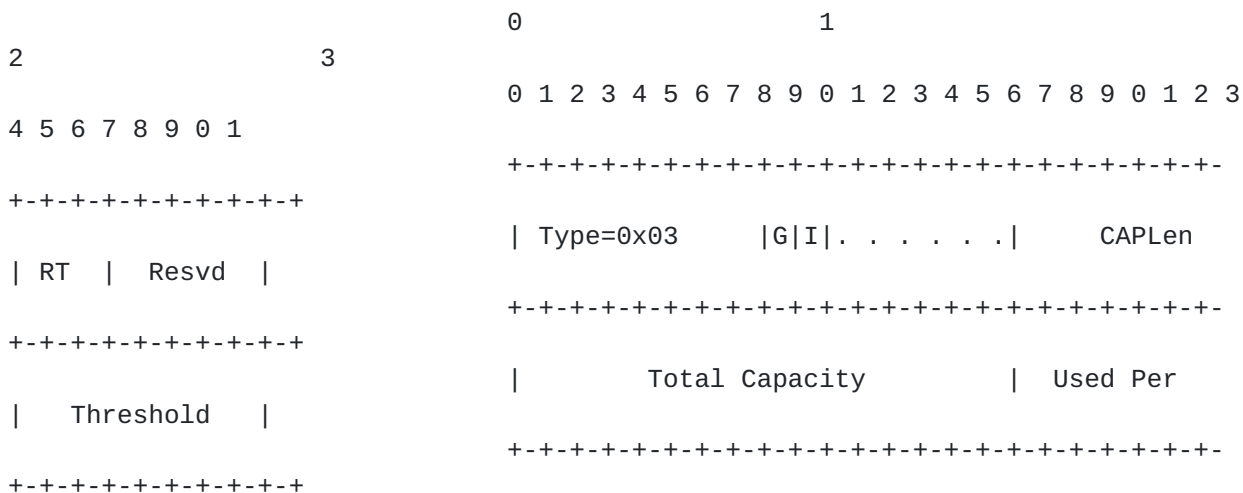
                  Figure 7: Routing Resource Capability TLV

Type: 0x03.

Flags: G bit MUST be set to 0. I bit will always be set to 1.

CAPLen: 8-bit unsigned integer, representing the length in octets of
the option, not including the Option Type and Length fields.

RT: 3-bit field indicating the routing resource type. This document

defines 3 routing resource type.

I: Master Routing Table Storing(RT = 1)

II: Storing mode P-DAO Table(RT = 2)

   III: Non-Storing mode P-DAO(RT = 3)

   Resvd: 5-bit unused field. It MUST be initialized to zero by the
   sender and MUST be ignored by the receiver.

   Total Capacity: 16 bit unsigned integer representing the the routing
   table size.

   Percentage used: 8 bit unsigned integer representing the the
   percentage of routing table space currently in use.

   Threshold: 8 bit unsigned integer representing the maximum routing
   table space that can be used. If the routing resource type is RT1
   and used Percentage is greater than or equal to a threshold, its
   siblings MUST stop using it as the preferred parent or remove it from
   the parent list. If the routing resource type is RT2 or RT3 and used
   Percentage is greater than or equal to a threshold, PCE MUST
   recompute some projected routes by excluding this node.

3.4.4. Neighbor Cache Capability

   A neighbor cache maintains neighboring one-hop connected nodes
   information such as MAC address, link-local IP address and other
   reachability state information needed for layer two
   communication.Node density has direct implications on the neighbor
   cache. In the constrained network scenario the size of the neighbor
   cache will be limited. Thus there are chances that a node may not be
   able to store all the neighboring nodes in its cache and use
   replacement algorithms to evict some of the entries to accommodate
   the new one. If the replaced neighbor has installed a DAO route on
   it then it can lead to packet loss or additional address resolution
   message exchange. To avoid unnecessary replacement of neighbor cache
   entries neighbor cache management policy
   [I-D.ietf-lwig-nbr-mgmt-policy] proposes a solution that will put a
   restriction on the connectivity to immediate neighbor depending upon
   the type of neighbor. But this won't solve the problem unless until
   the availability of neighbor cache is not taken into consideration
   while selecting the DAO parent set.

   Neighbor Cache capability can be used by LR and BR to advertise their
   neighbor cache size information. This capablity information has only
   link scope and should not be advertised in the entire network.
   [TODO-- As neighbor cache entries category is not yet standardized i
   think we can't use it in capability. With categories format of the
   TLV is going to chnage.]

3.4.4.1. Format of Neighbor Cache Capability

4. Acknowledgements

   Thanks to Georgios Papadopoulos, Li Zhao for the review and feedback.

5. IANA Considerations

5.1. New option: Capabilities

   New entry is required for supporting new Capabilities option in the
   "RPL Control Message Options" space [RFC6550].

```
              +-------+-------------+---------------+
              | Value |   Meaning   |   Reference   |
              +-------+-------------+---------------+
              |  TBD1 | Capabilities | This document |
              +-------+-------------+---------------+
```

                              New options

5.2. New Registry for Capabilities Flags

   IANA is requested to create a registry for the Capabilities flags as
   described in Section 2.1 of this document. This registry should be
   located in TODO. New Capabilities flags may be allocated only by an
   IETF review. Currently no flags are defined by this document. Each
   value is tracked with the following qualities:

   o Flag

   o Description

   o Defining RFC

6. Security Considerations

   The options defined in this document are carried in the base message
   objects as defined in [RFC6550]. The RPL control message options are
   protected by the same security mechanisms that protect the base
   messages.

   Capabilities flag can reveal that the node has been upgraded or is
   running a old feature set. This document assumes that the base
   messages that carry these options are protected by RPL security
   mechanisms and thus are not visible to a malicious node.

7. References

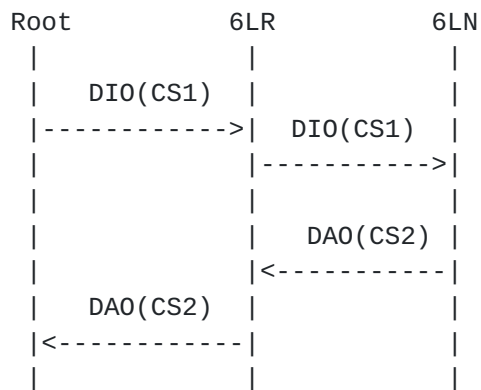### 7.1. Normative References

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          "Neighbor Management Policy for 6LoWPAN", draft-ietf-lwig-
          nbr-mgmt-policy-03 (work in progress), February 2019.

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          Thubert, P., Jadhav, R., and M. Gillmore, "Root initiated
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          (work in progress), November 2019.

[I-D.thubert-roll-turnon-rfc8138]
          Thubert, P. and L. Zhao, "Configuration option for RFC
          8138", draft-thubert-roll-turnon-rfc8138-03 (work in
          progress), July 2019.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate
          Requirement Levels", BCP 14, RFC 2119,
          DOI 10.17487/RFC2119, March 1997,
          <https://www.rfc-editor.org/info/rfc2119>.

[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,
          DOI 10.17487/RFC6550, March 2012,
          <https://www.rfc-editor.org/info/rfc6550>.

[RFC8138] Thubert, P., Ed., Bormann, C., Toutain, L., and R. Cragie,
          "IPv6 over Low-Power Wireless Personal Area Network
          (6LoWPAN) Routing Header", RFC 8138, DOI 10.17487/RFC8138,
          April 2017, <https://www.rfc-editor.org/info/rfc8138>.

7.2. Informative References

[RFC6551] Vasseur, JP., 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,
          DOI 10.17487/RFC6551, March 2012,
          <https://www.rfc-editor.org/info/rfc6551>.

Appendix A. Capability Handshake Example

```
              Root            6LR           6LN
               |               |             |
               |   DIO(CS1)    |             |
               |------------->|  DIO(CS1)   |
               |              |----------->|
               |              |             |
               |              |  DAO(CS2)  |
               |              |<-----------|
               |   DAO(CS2)   |             |
               |<------------|             |
               |              |             |
              CS: Capabilities Set
              CS1: Capabilities set advertised by root
              CS2: Capabilities set advertised by node. CS2 is a subset
of CS1.
```

                   Figure 8: Capabilities Option

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