IPv6 Neighbor Discovery Prefix Registration

Abstract

This document updates the 6LoWPAN extensions to IPv6 Neighbor
Discovery (RFC 8505) to enable a node that owns or is directly
connected to a prefix to register that prefix to neighbor routers.
The registration indicates that the registered prefix can be reached
via the advertising node without a loop. The prefix registration
also provides a protocol-independent interface for the node to
request neighbor router(s) to redistribute the prefix to the larger
routing domain using their specific routing protocols. As an
example, this document extends RFC 9010 to enable the 6LR to inject
the registered prefix in RPL.

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1. **Introduction**

   The design of Low Power and Lossy Networks (LLNs) is generally
   focused on saving energy, which is the most constrained resource of
   all. Other design constraints, such as a limited memory capacity,
   duty cycling of the LLN devices and low-power lossy transmissions,
   derive from that primary concern. The radio (both transmitting or
   simply listening) is a major energy drain and the LLN protocols must
   be adapted to allow the nodes to remain sleeping with the radio
   turned off at most times.

The ["Routing Protocol for Low Power and Lossy Networks"](#) [[RFC6550](#)]
(RPL) provides IPv6 [[RFC8200](#)] routing services within such
constraints. To save signaling and routing state in constrained
networks, the RPL routing is only performed along a Destination-
Oriented Directed Acyclic Graph (DODAG) that is optimized to reach a
Root node, as opposed to along the shortest path between 2 peers,
whatever that would mean in each LLN.

This trades the quality of peer-to-peer (P2P) paths for a vastly
reduced amount of control traffic and routing state that would be
required to operate an any-to-any shortest path protocol.
Additionally, broken routes may be fixed lazily and on-demand, based
on dataplane inconsistency discovery, which avoids wasting energy in
the proactive repair of unused paths.

The classical "IPv6 Neighbor Discovery (IPv6 ND) Protocol" [[RFC4861](#)]
[[RFC4862](#)] was defined for serial links and shared transit media such
as Ethernet at a time when broadcast was cheap on those media while
memory for neighbor cache was expensive. It was thus designed as a
reactive protocol that relies on caching and multicast operations
for the Address Discovery (aka Lookup) and Duplicate Address
Detection (DAD) of IPv6 unicast addresses. Those multicast
operations typically impact every node on-link when at most one is
really targeted, which is a waste of energy, and imply that all
nodes are awake to hear the request, which is inconsistent with
power saving (sleeping) modes.

The original 6LoWPAN ND, ["Neighbor Discovery Optimizations for
6LoWPAN networks"](#) [[RFC6775](#)], was introduced to avoid the excessive
use of multicast messages and enable IPv6 ND for operations over
energy-constrained nodes. [[RFC6775](#)] changes the classical IPv6 ND
model to proactively establish the Neighbor Cache Entry (NCE)
associated to the unicast address of a 6LoWPAN Node (6LN) in the a
6LoWPAN Router(s) (6LR) that serves it. To that effect, [[RFC6775](#)]
defines a new Address Registration Option (ARO) that is placed in
unicast Neighbor Solicitation (NS) and Neighbor Advertisement (NA)
messages between the 6LN and the 6LR.

["Registration Extensions for 6LoWPAN Neighbor Discovery"](#) [[RFC8505](#)]
updates [[RFC6775](#)] into a generic Address Registration mechanism that
can be used to access services such as routing and ND proxy and
introduces the Extended Address Registration Option (EARO) for that
purpose. This provides a routing-agnostic interface for a host to
request that the router injects a unicast IPv6 address in the local
routing protocol and provide return reachability for that address.

["IPv6 Neighbor Discovery Multicast Address Listener Subscription"](#)
[[I-D.ietf-6lo-multicast-registration](#)] updates [[RFC8505](#)] to enable a
listener to subscribe an IPv6 anycast or multicast address; the

draft also extends [RFC9010] to enable the 6LR to inject the anycast and multicast addresses in RPL. Similarly, this specification extends [RFC8505] and [RFC9010] to add the capability for the 6LN to register prefixes as opposed to addresses, and to signal in a protocol-independant fashion to the 6LR that it is expected to redistribute the prefixes in their specific routing protocols.

2. Terminology

2.1. Requirements Language

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 BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

In addition, the terms "Extends" and "Amends" are used as per [I-D.kuehlewind-update-tag] section 3.

2.2. References

This document uses terms and concepts that are discussed in:

  * "Neighbor Discovery for IP version 6" [RFC4861] and "IPv6 Stateless address Autoconfiguration" [RFC4862],

  * Neighbor Discovery Optimization for Low-Power and Lossy Networks [RFC6775], as well as

  * "Registration Extensions for 6LoWPAN Neighbor Discovery" [RFC8505] and

  * "Using RPI Option Type, Routing Header for Source Routes, and IPv6-in-IPv6 Encapsulation in the RPL Data Plane" [RFC9008].

2.3. Glossary

This document uses the following acronyms:

6BBR 6LoWPAN Backbone Router
6BBR 6LoWPAN Border Router
6LN 6LoWPAN Node
6LR 6LoWPAN Router
6CIO Capability Indication Option
AMC Address Mapping Confirmation
AMR Address Mapping Request
ARO Address Registration Option
DAC Duplicate Address Confirmation
DAD Duplicate Address Detection

DAR Duplicate Address Request

EARO Extended Address Registration Option

EDAC Extended Duplicate Address Confirmation

EDAR Extended Duplicate Address Request

DODAG Destination-Oriented Directed Acyclic Graph

IR Ingress Replication

LLN Low-Power and Lossy Network

NA Neighbor Advertisement

NCE Neighbor Cache Entry

ND Neighbor Discovery

NS Neighbor Solicitation

ROVR Registration Ownership Verifier

RTO RPL Target Option

RA Router Advertisement

RS Router Solicitation

TID Transaction ID

TIO Transit Information Option

2.4. New terms

This document introduces the following terms:

Origin The node that issued the prefix advertisement, either in the
   form of a NS(EARO) or as a DAO(TIO, RTO)

Merge/merging The action of receiving multiple anycast or multicast
   advertisements, either internally from self, in the form of a
   NS(EARO), or as a DAO(TIO, RTO), and generating a single DAO(TIO,
   RTO). The 6RPL router maintains a state per origin for each
   advertised address, and merges the advertisements for all
   subsriptions for the same address in a single advertisement. A
   RPL router that merges becomes the origin of the merged
   advertisement and uses its own values for the Path Sequence and
   ROVR fields.

3. Overview

This specification inherits from [RFC6550], [RFC8505], and [RFC9010]
to register prefixes as opposed to addresses. Unless specified
otherwise therein, the behavior of the 6LBR that acts as RPL Root,
of the intermediate routers down the RPL graph, of the 6LR that act
as access routers and of the 6LNs that are the RPL-unaware
destinations, is the same as for unicast addresses. In particular,
forwarding a packet happens as specified in section 11 of [RFC6550],
including loop avoidance and detection, though in the case of
multicast multiple copies might be generated.

[RFC8505] is a pre-requisite to this specification. A node that
implements this MUST also implement [RFC8505]. This specification
does not introduce a new option; it modifies existing options and

updates the associated behaviors to enable the Registration for
Multicast Addresses as an extension to [RFC8505].

This specification updates the P field introduced in
[I-D.ietf-6lo-multicast-registration] for use in EARO, DAR, and RTO,
with the new value of 3 to indicate the registration of a prefix, as
detailed in Section 7.2. With this extension the 6LNs can now
attract the traffic for a full prefix, using the P field value of 3
in the EARO to signal that the registration is for a prefix.
Multiple 6LN may register the same prefix to the same 6LR or to
different 6LRs.

If the R flag is set in the registration of one or more 6LNs for the
same prefix, the 6LR is requested to redistributes the prefix in
other routing protocol (e.g., RPL), based on the longest
registration lifetime across the active registrations for the
prefix.

This specification extends 6LoWPAN work, and it is certainly
possible to leverage it between the 6LN and the 6LR where the 6LR is
a RPL router, as discussed in Section 3.1. But as for [RFC8505] in
general, this specification applies, beyond IoT use cases, to
networks that are not necessarily LLNs, and/or where the routing
protocol between the 6LR and above is not necessarily RPL. Examples
of shared links and hub links are provided in Section 3.2 and
Section 3.3, respectively.

3.1. LLN Mesh Network

This specification also extends [RFC6550] and [RFC9010] in the case
of a route-over multilink subnet based on the RPL routing protocol,
to add multicast ingress replication in Non-Storing Mode and anycast
support in both Storing and Non-Storing modes. A 6LR that implements
the RPL extensions specified therein MUST also implement [RFC9010].

Figure 1 illustrates the classical situation of an LLN as a single
IPv6 Subnet, with a 6LoWPAN Border Router (6LBR) that acts as Root
for RPL operations and maintains a registry of the active
registrations as an abstract data structure called an Address
Registrar for 6LoWPAN ND.

The LLN may be a hub-and-spoke access link such as (Low-Power) Wi-Fi
[IEEE80211] and Bluetooth (Low Energy) [IEEE802151], or a Route-Over
LLN such as the Wi-SUN and 6TiSCH meshes
[I-D.heile-lpwan-wisun-overview] that leverages 6LoWPAN [RFC4919]
[RFC6282] and RPL [RFC6550] over [IEEE802154].

```
                  |
       ----+-------+------------
          |      Wire side
       +------+
       | 6LBR |
       |(Root)|
       +------+
        o  o  o  Wireless side
     o   o o   o  o o
    o  o  o o   o  o  o
   o  o  o   LLN  o   +---+
    o  o   o  o   o  |6LR|
     o o  o o   o     +---+
      o   o   o o o  o   z
     o  o oo o   o       +---+
           o             |6LN|
                         +---+
```

                Figure 1: Wireless Mesh

   A leaf acting as a 6LN registers its unicast, multicast, and anycast
   addresses a RPL router acting as a 6LR, using a layer-2 unicast NS
   message with an EARO as specified in [RFC8505] and
   [I-D.ietf-6lo-multicast-registration]. The registration state is
   periodically renewed by the Registering Node, before the lifetime
   indicated in the EARO expires. As for unicast IPv6 addresses, the
   6LR uses an EDAR/EDAC exchange with the 6LBR to notify the 6LBR of
   the presence of the listeners. With this specification, a router
   that own a prefix of provides reachability to an external prefix but
   is not a RPL router may also register those prefixes with the R flag
   set, to enable reachability via the RPL domain. As usual

3.2. Shared Link

   A shared link is a situation where more than one Prefix is deployed
   over a L2 link (say a switched Ethernet + Wi-Fi ESS), and not
   necessarily all nodes are aware of all prefixes. Figure 2 depicts
   such a situation, with 2 routers 6LR1 and 6LR2 that own respective
   prefixes P1:: and P2::, and expose those in their RA messages over
   the same link.

```
   +-----+   +-----+   +-----+   +-----+   +-----+
   |P1::c|   |P2::d|   |P2::e|   |P1::f|   |P1::g|
   +--+--+   +--+--+   +--+--+   +--+--+   +--+--+
      |         |         |         |         |
 ----+--+------+---------+--+------+---------+---+--
         |                   |                   |
    +---+---+           +---+---+
    | P1::a |           | P2::b |
    | 6LR1  |           | 6LR2  |
    +----+--+           +-------+
         |
        ....
        . . ..
         ...
```

                    Figure 2: Shared Link

   Say that 6LR1 is the router providing access to the outside, and
   6LR2 is aware of 6LR1 as its default gateway. With this
   specification, 6LR2 registers P2:: to 6LR1 and 6LR1 installs a route
   to P2:: via 6LR2. This way, addresses that derive from P2:: can
   still be reached via 6LR1 and then 6LR2. 6LR2 may then leverage ICMP
   Redirect messages [RFC4861] to shorten the path between 6LR1 and the
   nodes that own those addresses.

   If P2 was delegated by 6LR1, then the expectation is that 6LR1
   aggregates P1:: and P2:: in its advertisements to the outside, and
   the is no need to set the R flag. But unless 6LR2 knows about such a
   situation, e.g., through configuration, it is probably safer for
   6LR2 to set the R flag requesting 6LR1 to advertise P2:: to the
   outside.

3.3. Hub Link

   A hub link is a situation where stub links are deployed around a hub
   like and interconnected by routers. Figure 3 depicts such a
   situation, with one router 6LR1 serving the hub link and at least
   one router like 6LR3 and 6LR3 providing connectivity from the stub
   links to the hub link. In this example, say that the there is one
   prefix on each link, P1:: on the hub link and P2::, P3::, etc. on
   the stub links.

```
    +-----+   +-----+   +-----+   +-----+   +-----+
    |P2::s|   |P2::d|   |P2::e|   |P2::f|   |P2::g|
    +--+--+   +--+--+   +--+--+   +--+--+   +--+--+
       |         |         |         |         |
   ----+----+----+---------+----STUB-+-LINK----+-----
            |
       +---+---+               +-------+       .
       | P2::r |               |       |    .. . .
       | 6LR2  |               | 6LR1  +--- .    . ..
       | P1::b |               | P1::a |    .      ...
       +---+---+               +---+---+      . ...
           |                       |
   -------+-+----------+--HUB-LINK--+-----+--
           |           |                 |
      +---+---+    +--+--+           +--+--+
      | P1::c |    |P1::n|           |P1::q|
      | 6LR3  |    +-----+           +-----+
      | P3::m |
      +---+---+
          |
   ----+--+------+---------+----STUB-+-LINK----+-----
       |         |         |         |         |
    +--+--+   +--+--+   +--+--+   +--+--+   +--+--+
    |P3::h|   |P3::i|   |P3::j|   |P3::k|   |P3::a|
    +-----+   +-----+   +-----+   +-----+   +-----+
```

Figure 3: Hub and Stubs

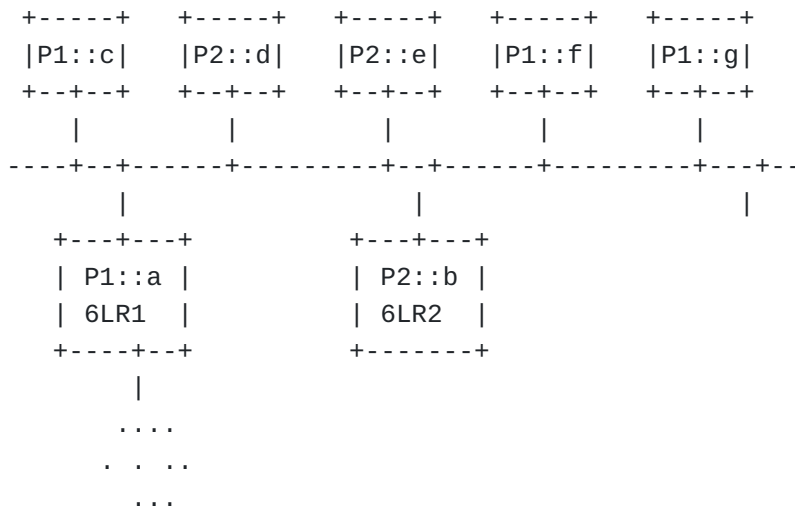As before, say that 6LR1 is the router providing access to the
outside, and 6LR2 is aware of 6LR1 as its default gateway. With this
specification, 6LR2 registers P2:: to 6LR1 and 6LR1 installs a route
to P2:: via 6LR2. This way, nodes on the stub link behind 6LR2 that
derive their addresses from P2:: can still be reached via 6LR1 and
then 6LR2. The same goes for 6LR3 and all other routers serving stub
links.

If P2 was delegated by 6LR1, then the expectation is that 6LR1
aggregates P1:: and P2:: in its advertisements to the outside, and
the is no need to set the R flag. But unless 6LR2 knows about such a
situation, e.g., through configuration, it is probably safer for
6LR2 to set the R flag requesting 6LR1 to advertise P2:: to the
outside.

4. Updating RFC 4861

[RFC4861] expects that the NS/NA exchange is for a unicast address,
which is indicated in the Target Address field of the ND message.

This specification Amends [RFC4861] by allowing to advertise a
prefix in the Target Address field when the NS or NA message is used
for a registration, per section 5.5 of [RFC8505]; in that case, the
prefix length is indicated in the EARO of the NS message,
overloading the field that is used in the NA response for the
Status.

5. Extending RFC 7400

This specification Extends "6LoWPAN-GHC: Generic Header Compression
for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)"
[RFC7400] by defining a new capability bit for use in the 6CIO.
[RFC7400] was already extended by [RFC8505] for use in IPv6 ND
messages.

The new "Registration for prefixes Supported" (F) flag indicates to
the 6LN that the 6LR accepts IPv6 prefix registrations as specified
in this document and will ensure that packets for the addresses that
match this prefix will be routed to the 6LNs that registered the
prefix, and the route to the prefix will be redistributed if the R
flag is set to 1.

Figure 4 illustrates the X flag in its suggested position (7,
counting 0 to 15 in network order in the 16-bit array), to be
confirmed by IANA.

```
 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      |  Length = 1   |   Reserved   |F|X|A|D|L|B|P|E|G|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Reserved                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
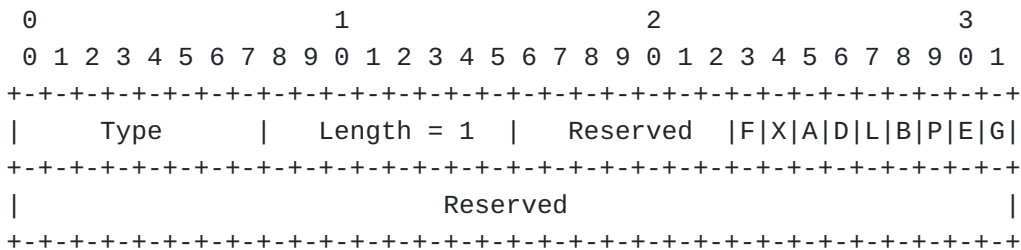
Figure 4: New Capability Bit in the 6CIO

New Option Field:

X 1-bit flag: "Registration for prefixes Supported"

6. Updating RFC 6550

[RFC6550] uses the Path Sequence in the Transit Information Option
(TIO) to retain only the freshest unicast route and remove stale
ones, e.g., in the case of mobility. [RFC9010] copies the TID from
the EARO into the Path Sequence, and the ROVR field into the
associated RPL Target Option (RTO). This way, it is possible to
identify both the registering node and the order of registration in

RPL for each individual advertisement, so the most recent path and lifetime values are used.

[I-D.ietf-6lo-multicast-registration] requires the use of the ROVR field as the indication of the origin of a Target advertisement in the RPL DAO messages, as specified in section 6.1 of [RFC9010]. For anycast and multicast advertisements (in NS or DAO messages), multiple origins may subscribe to the same address, in which case the multiple advertisements from the different or unknown origins are merged by the common parent; in that case, the common parent becomes the origin of the merged advertisements and uses its own ROVR value. On the other hand, a parent that propagates an advertisement from a single origin uses the original ROVR in the propagated RTO, as it does for unicast address advertisements, so the origin is recognised across multiple hops.

This specification Extends [RFC6550] to require that, for prefix routes, the Path Sequence is used between and only between advertisements for the same Target and from the same origin (i.e, with the same ROVR value); in that case, only the freshest advertisement is retained. But the freshness comparison cannot apply if the origin is not determined (i.e., the origin did not support this specification).

[RFC6550] uses the Path Lifetime in the TIO to indicate the remaining time for which the advertisement is valid for unicast route determination, and a Path Lifetime value of 0 invalidates that route. [RFC9010] maps the Address Registration lifetime in the EARO and the Path Lifetime in the TIO so they are comparable when both forms of advertisements are received.

The RPL router that merges multiple advertisement for the same prefix must use and advertise the longest remaining lifetime across all the origins of the advertisements for that prefix. When the lifetime expires, the router sends a no-path DAO (i.e. the lifetime is 0) using the same value for ROVR value as for the previous advertisements, that is either self or the single descendant that advertised the Target.

Note that the Registration Lifetime, TID and ROVR fields are also placed in the EDAR message so the state created by EDAR is also comparable with that created upon an NS(EARO) or a DAO message. For simplicity the text below mentions only NS(EARO) but applies also to EDAR.

7. Updating RFC 8505

7.1. New P field value

[I-D.ietf-6lo-multicast-registration] defines a P-field of 2 bits
and defines the values 0 to 2, leaving the value of 3 reserved. This
specification assigns the value of 3, resulting in the complete
tabel as follows:

Value	Meaning
0	Registration for a Unicast Address
1	Registration for a Multicast Address
2	Registration for an Anycast Address
3	Registration for a prefix

Table 1: P-field Values

7.2. New EARO Prefix Length Field

Section 4.1 of [RFC8505] defines the EARO as an extension to the ARO
option defined in [RFC6775].

This specification adds a new value to the P field to signal that
the Registered Address is a prefix. This means that the sender owns
the prefix and will deliver packets to the destination if the
destination address derives from the prefix. The receiver should
install a route to the prefix via the sender's address used as
source address in the NS(EARO) registration message.

This specification also adds a new F flag to signal that the
Registered Prefix is externally reachable through the Registering
Node. This means that the Registering Node can relay packets that
are sourced in the Registered Prefix to the outside, and the packets
will be topologically correct with regard to [BCP38]. The receiver
should forward packets to the sender's address when the source
address of the packets derives from the prefix, and the sender. Note
that to avoid loops, the receiver must be inside so packets sent by
the sender towards the outside may never reach the receiver.

The Status Field that is used only when the EARO is placed in an NA
message is repurposed to carry the prefix length when the EARO is
placed in an NS message.

```
     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      |    Length     |  plen/Status  |    Opaque     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    | |F| P | I |R|T|     TID       |     Registration Lifetime     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                                                               |
    ...             Registration Ownership Verifier             ...
    |                                                               |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
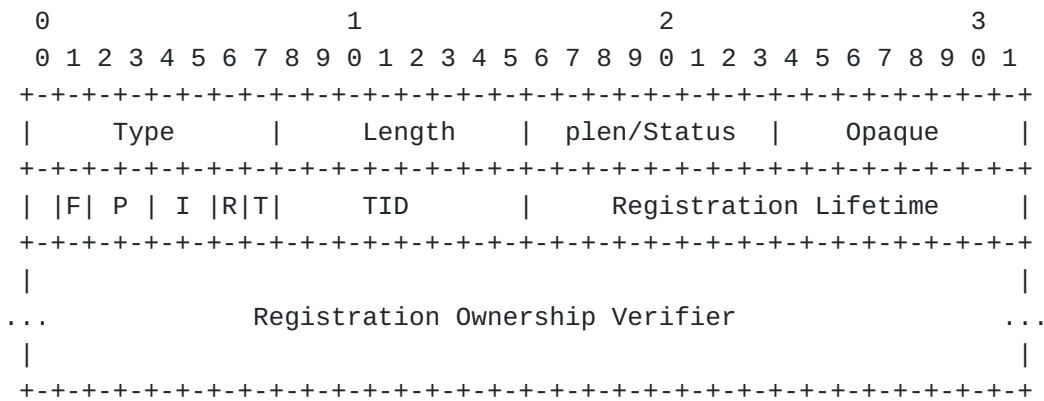
Figure 5: EARO Option Format

New and updated Option Fields:

plen/Status   8-bit field: This field contains a prefix Length
   expressed in bits if the P field is set to 3 and the EARO is
   placed in an NS message. The field contains a Status if the EARO
   is placed in an NA message regardless of the setting of the P
   flag. In all other cases it is reserved, so it MUST be set to 0
   by the sender and ignored by the receiver.

F: 1-bit flag; set to 1 to indicate that the sender expects other
   routers to forward packets to self when the packets are sourced
   with the registered prefix.

7.3. New EDAR Prefix Length Field

This specification adds the new value of 3 to the P field to signal
that the Registered Address is a prefix. When that is the case, the
prefix length is assumed to be less than 112 bits and the last 8
bits are dedicated to the prefix length.

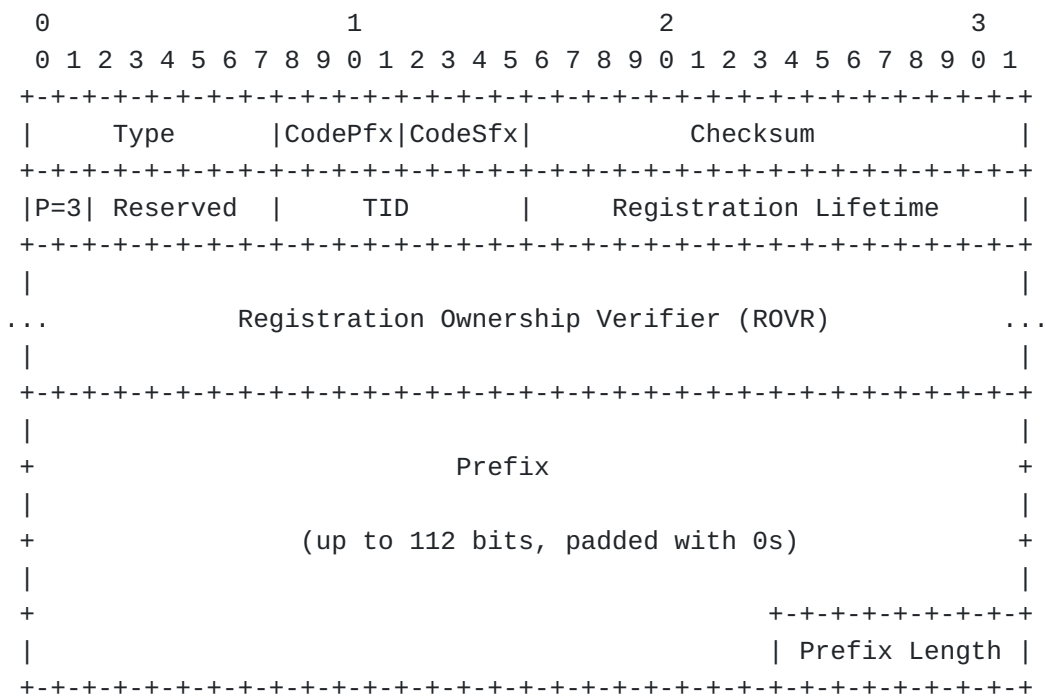Figure 6 illustrates the EDAR message when the value of the P field
is 3.

```
 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      |CodePfx|CodeSfx|            Checksum           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|P=3| Reserved  |      TID      |     Registration Lifetime     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
...           Registration Ownership Verifier (ROVR)         ...
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                            Prefix                             +
|                                                               |
+               (up to 112 bits, padded with 0s)               +
|                                                               |
+                                       +-+-+-+-+-+-+-+-+
|                                       | Prefix Length |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

                 Figure 6: EDAR Message Format with P == 3

   New and updated Option Fields:

   Reserved 6-bit field: reserved, MUST be set to 0 and ignored by the
      receiver

   Prefix 15 bytes: up to 112 bits of prefix, padded with 0s

   Prefix Length 1-bit flag: length of the prefix, in bits

7.4. Registering Extensions

   With [RFC8505]:

     *A router that expects to reboot may send a final RA message, upon
      which nodes should register elsewhere or redo the registration to
      the same router upon reboot. In all other cases, a node reboot is
      silent. When the node comes back to life, existing registration
      state might be lost if it was not persisted, e.g., in persistent
      memory.

     *Only unicast addresses can be registered.

     *The 6LN must register all its ULA and GUA with a NS(EARO).

     *The 6LN may set the R flag in the EARO to obtain return
      reachability services by the 6LR, e.g., through ND proxy
      operations, or by injecting the route in a route-over subnet.

*the 6LR maintains a registration state per Registered Address,
   including an NCE with the Link Layer Address (LLA) of the
   Registered Node (the 6LN here).

This specification adds the following behavior, similar to that
introduced by [I-D.ietf-6lo-multicast-registration] for multicast
addresses:

  *The operation for registering prefixes is similar as for
   addresses from the perspective of the 6LN, but show important
   differences on the router side, which maintains a separate state
   for each origin and merges them in its own advertisements.

  *The ARO Status indicating a "Registration Refresh Request"
   applies to prefixes as well.

   This status is used in asynchronous NA(EARO) messages to indicate
   to peer 6LNs that they are requested to reregister all addresses
   and prefixes that were previously registered to the originating
   node. The NA message may be sent to a unicast or a multicast
   link-scope address and should be contained within the L2 range
   where nodes may effectively have registered/subscribed to this
   router, e.g., a radio broadcast domain.

   A device that wishes to refresh its state, e.g., upon reboot if
   it may have lost some registration state, SHOULD send an
   asynchronous NA(EARO) with this new status value. That
   asynchronous NA(ARO) SHOULD be sent to the all-nodes link scope
   multicast address (FF02::1) and Target MUST be set to the link
   local address that was exposed previously by this node to accept
   registrations, and the TID MUST be set to 0.

   In an unreliable environment, the multicast NA(EARO) message may
   be resent in a fast sequence, in which case the TID must be
   incremented each time. A 6LN that has recently processed the
   NA(ARO) ignores the NA(EARO) with a newer TID received within the
   duration of the fast sequence. That duration depends on the
   environent and has to be configured. By default, it is of 10
   seconds.

  *Registration for prefixes is now supported. The value of 3 in the
   P field of the EARO and the EDAR message signals when the
   registration is for a prefix as opposed to an address.

  *If the 6LR acts as a router to prefixes or owns the prefixes
   entirely, it SHOULD register all those prefixes on all interface
   from which it might be needed to relay traffic to that prefix,
   and it MUST set the P field in the EARO to 3 for those prefixes.

*The 6LN MAY set the R flag in the EARO to request the 6LR to
    redistribute the prefix on other links using a routing protocol.
    The 6LR MUST NOT reregister that prefix to yet another router as
    it may create a loop.

   *The 6LR and the 6LBR are extended to accept more than one
    registration for the same prefix, since multiple 6LNs may
    register it. The Registration Ownership Verifier (ROVR) in the
    EARO identifies uniquely a registration within the namespace of
    the Registered Prefix.

   *The 6LR MUST maintain a registration state per tuple (IPv6
    prefix/length, ROVR) for all registered prefix. It SHOULD notify
    the 6LBR with an EDAR message, unless it determined that the 6LBR
    is legacy and does not support this specification. In turn, the
    6LBR MUST maintain a registration state per tuple (IPv6 prefix,
    ROVR) for all prefixes.

8. Updating RFC 9010

   With [RFC9010]:

     *The 6LR injects only unicast routes in RPL

     *Upon a registration with the R flag set to 1 in the EARO, the 6LR
      injects the address in the RPL unicast support.

     *Upon receiving a packet directed to a unicast address for which
      it has an active registration, the 6LR delivers the packet as a
      unicast layer-2 frame to the LLA the nodes that registered the
      unicast address.

   This specification adds the following behavior:

     *Upon a registration with the R flag set to 1 and the P field set
      to 3 in the EARO, the 6LR injects the prefix in RPL using a
      prefix RTO. The P field in the RTP MUST be set to 3.

     *Upon receiving a packet directed to an address that derives from
      a prefix for which it has at least one registration, the 6LR
      delivers a copy of the packet as a unicast layer-2 frame to the
      LLA of exactly one of the nodes that registered to that prefix,
      using the longest match derivation to find the best 6LN.

9. Leveraging RFC 8928

   Address-Protected Neighbor Discovery for Low-Power and Lossy
   Networks [RFC8928] was defined to protect the ownership of unicast
   IPv6 addresses that are registered with [RFC8505].

With [RFC8928], it is possible for a node to autoconfigure a pair of
public and private keys and use them to sign the registration of
addresses that are either autoconfigured or obtained through other
methods.

The first hop router (the 6LR) may then validate a registration and
perform source address validation on packets coming from the sender
node (the 6LN).

Prefixes are not always owned by one node. Multiple nodes may
register the same prefix. In that context, the method specified in
[RFC8928] cannot be used with autoconfigured keypairs to protect a
single ownership.

For a prefix, as for an anycast or a multicast address, it is still
possible to leverage [RFC8928] to enforce the right to register. If
[RFC8928] is used, a keypair MUST be associated with the prefix
before it is deployed, and a ROVR MUST be generated from that
keypair as specified in [RFC8928]. The prefix and the ROVR MUST then
be installed in the 6LBR so it can recognize the prefix and compare
the ROVR on the first registration to validate the right to
register.

The keypair MUST then be provisioned in each node that needs to
register the prefix or a prefix within, so the node can follow the
steps in [RFC8928] to register the prefix.

10. Security Considerations

This specification extends [RFC8505], and the security section of
that document also applies to this document. In particular, the link
layer SHOULD be sufficiently protected to prevent rogue access.

Section 9 leverages [RFC8928] to prevent an rogue node to register a
unicast address that it does not own. The mechanism could be
extended to anycast and multicast addresses if the values of the
ROVR they use is known in advance, but how this is done is not in
scope for this specification. One way would be to authorize in a
advance the ROVR of the valid users. A less preferred way could be
to synchronize the ROVR and TID values across the valid registering
nodes as a preshared key material.

In the latter case, it could be possible to update the keys
associated to a prefix in all the 6LNs, but the flow is not clearly
documented and may not complete in due time for all nodes in LLN use
cases. It may be simpler to install a all-new address with new keys
over a period of time, and switch the traffic to that address when
the migration is complete.

11. Backward Compatibility

A legacy 6LN will not register prefixess and the service will be the
same when the network is upgraded. A legacy 6LR will not set the F
flag in the 6CIO and an upgraded 6LN will not register prefixes.

Upon an EDAR message, a legacy 6LBR may not realize that the address
being registered is anycast or multicast, and return that it is
duplicate in the EDAC status. The 6LR MUST ignore a duplicate status
in the EDAR for anycast and multicast addresses.

12. IANA Considerations

Note to RFC Editor, to be removed: please replace "This RFC"
throughout this document by the RFC number for this specification
once it is allocated. Also, the I Field is defined in [RFC9010] but
is missing from the registry, so the bit positions must be added for
completeness.

IANA is requested to make changes under the "Internet Control
Message Protocol version 6 (ICMPv6) Parameters" [IANA.ICMP] and the
"Routing Protocol for Low Power and Lossy Networks (RPL)" [IANA.RPL]
registry groupings, as follows:

12.1. Updated P-Field Registry

This specification updates the P field introduced in
[I-D.ietf-6lo-multicast-registration] to assign the value of 3,
which is the only remaining unasssigned value for the 2-bits field.
To that effect, IANA is requested to update the "P-field values"
registry under the heading "Internet Control Message Protocol
version 6 (ICMPv6) Parameters" as indicated in Table 2:

Value	Meaning	Reference
3	Registration for a prefix	This RFC

Table 2: New P-field value

12.2. New 6LoWPAN Capability Bit

IANA is requested to make an addition to the "6LoWPAN Capability
Bits" [IANA.ICMP.6CIO] registry under the heading "Internet Control
Message Protocol version 6 (ICMPv6) Parameters" as indicated in
Table 3:

Capability Bit	Meaning	Reference
7 (suggested)	F flag: Registration for prefixes Supported (F)	This RFC

Table 3: New 6LoWPAN Capability Bits

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