

Workgroup: 6lo

Updates: [4861](#), [6550](#), [6553](#), [8505](#), [9010](#)
(if approved)

Published: 8 March 2023

Intended Status: Standards Track

Expires: 9 September 2023

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IPv6 Neighbor Discovery Multicast and Anycast Address Listener Subscription

Abstract

This document updates the 6LoWPAN extensions to IPv6 Neighbor Discovery (RFC 8505) to enable a listener to subscribe to an IPv6 anycast or multicast address; the document updates RPL (RFC 6550) to add a new Non-Storing Multicast Mode and a new support for anycast addresses in Storing and Non-Storing Modes. This document extends RFC 9010 to enable the 6LR to inject the anycast and multicast addresses 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.

Section 12 of [RFC6550] details the "Storing Mode of Operation with multicast support" with source-independent multicast routing in RPL.

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.

["Routing for RPL Leaves" \[RFC9010\]](#) provides the router counterpart of the mechanism for a host that implements [\[RFC8505\]](#) to inject its unicast Unique Local Addresses (ULAs) and Global Unicast Addresses (GUAs) in RPL. But though RPL also provides multicast routing, 6LoWPAN ND supports only the registration of unicast addresses and there is no equivalent of [\[RFC9010\]](#) to specify the 6LR behavior upon the subscription of one or more multicast address.

The ["Multicast Listener Discovery Version 2 \(MLDv2\) for IPv6" \[RFC3810\]](#) enables the router to learn which node listens to which multicast address, but as the classical IPv6 ND protocol, MLD relies on multicasting Queries to all nodes, which is unfit for low power operations. As for IPv6 ND, it makes sense to let the 6LNs control when and how they maintain the state associated to their multicast addresses in the 6LR, e.g., during their own wake time. In the case of a constrained node that already implements [\[RFC8505\]](#) for unicast reachability, it makes sense to extend to that support to subscribe the multicast addresses they listen to.

This specification extends [\[RFC8505\]](#) and [\[RFC9010\]](#) to add the capability for the 6LN to subscribe anycast and multicast addresses and for the 6LR to inject them in RPL when appropriate.

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
6LBR 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
RT0 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 an anycast or multicast advertisement, either in the form of a NS(EARO) or as a DAO(TIO, RT0)

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, RT0), and generating a single DAO(TIO,

RT0). The 6RPL router maintains a state per origin for each advertised address, and merges the advertisements for all subscriptions 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.

Subscribe/subscription The special form of registration that leverages NS(EAR0) to register (subscribe) a multicast or an anycast address.

3. Overview

This specification extends [[RFC8505](#)] and inherits from [[RFC8928](#)] to provide a registration method - called subscription in this case - for anycast and multicast address. [[RFC8505](#)] is agnostic to the routing protocol in which the address may be redistributed.

As opposed to unicast addresses, there is no concept of duplication with multicast and anycast addresses, and there might be multiple registrations from multiple parties for the same address. The router conserves one registration per party per multicast or anycast address, but injects the route into the routing protocol only once for each address, asynchronously to the registration. On the other hand, the validation exchange with the registrar (6LBR) is still needed if the router checks the right for the host to listen to the anycast or multicast address.

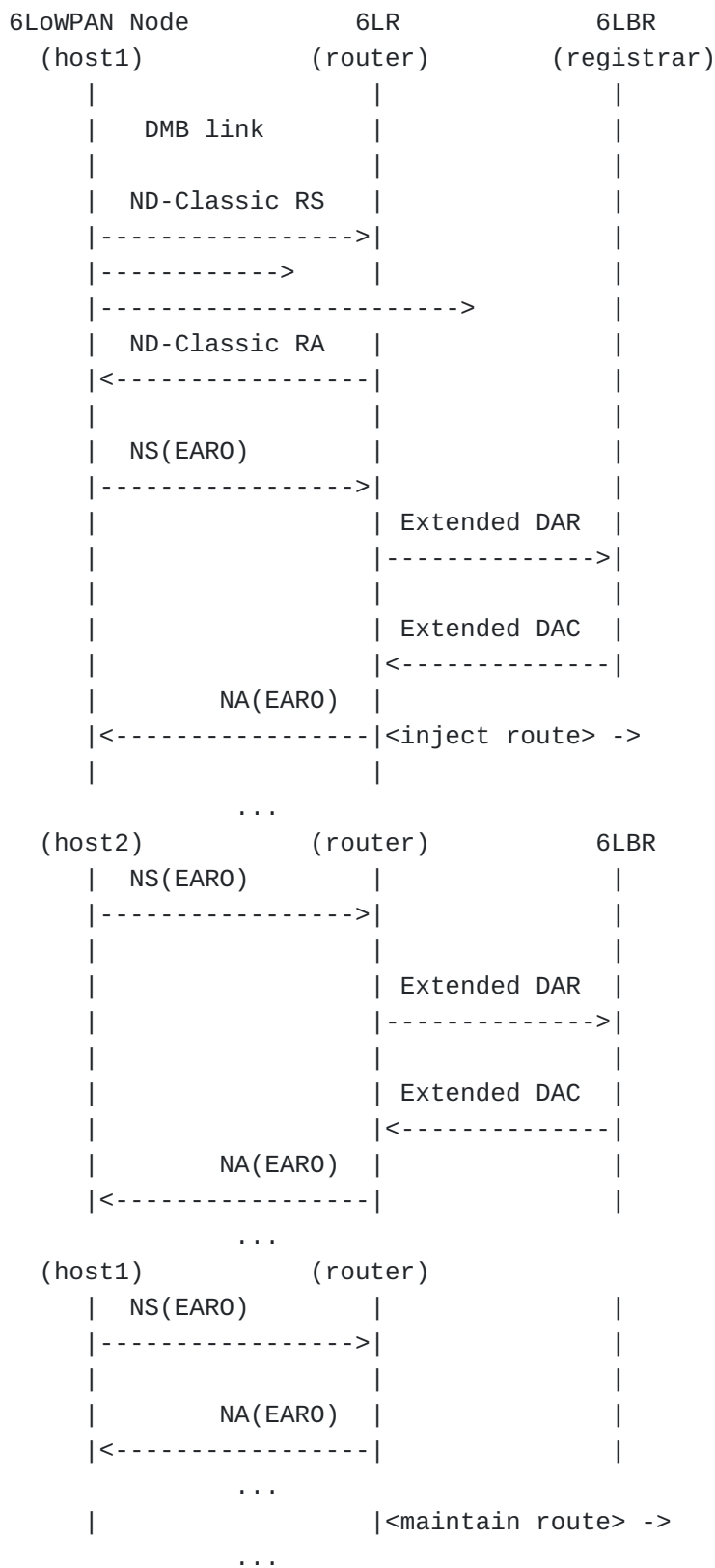


Figure 1: Registration Flow for an anycast or multicast Address

In classical networks, [[RFC8505](#)] may be used for an ND proxy operation as specified in [[RFC8929](#)], or redistributed in a full-

fledged routing protocol such as EVPN [[I-D.thubert-bess-secure-evpn-mac-signaling](#)] or RIFT [[I-D.ietf-rift-rift](#)]. The device mobility can be gracefully supported as long as the routers can exchange and make sense of the sequence counter in the TID field of the EARO.

In the case of LLNs, RPL [[RFC6550](#)] is the routing protocol of choice and [[RFC9010](#)] specifies how the unicast address advertised with [[RFC8505](#)] is redistributed in RPL. This specification also provides RPL extensions for anycast and multicast address operation and redistribution. In the RPL case and unless specified otherwise, 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. 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 modifies existing options and updates the associated behaviors to enable the Registration for Multicast Addresses as an extension to [[RFC8505](#)]. As for the unicast address registration, the subscription to anycast and multicast addresses is agnostic to the routing protocol in which this information may be redistributed, though protocol extensions would be needed in the protocol when multicast services are not available.

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 2](#) 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 [[IEEE Std 802.11](#)] and Bluetooth (Low Energy) [[IEEE Std 802.15.1](#)], or a Route-Over LLN such as the Wi-SUN [[Wi-SUN](#)] and 6TiSCH [[RFC9030](#)] meshes that leverages 6LoWPAN [[RFC4919](#)] [[RFC6282](#)] and RPL [[RFC6550](#)] over [[IEEE Std 802.15.4](#)].

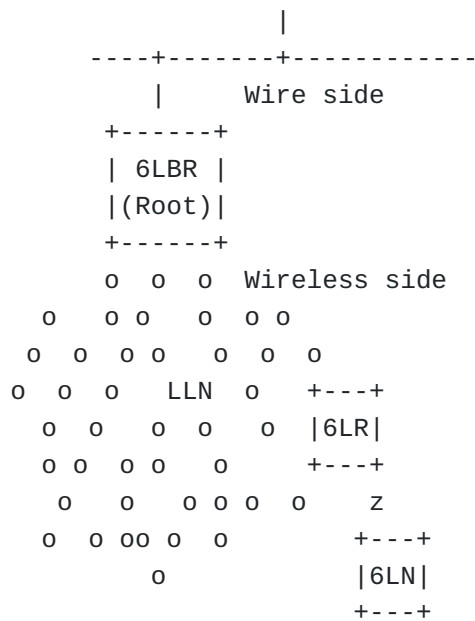


Figure 2: Wireless Mesh

A leaf acting as a 6LN registers its unicast addresses to a RPL router acting as a 6LR, using a layer-2 unicast NS message with an EARO as specified in [[RFC8505](#)]. 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.

This specification updates the EARO with a new two-bit field, the P field, as detailed in [Section 7.1](#). The existing R flag that requests reachability for the registered address gets new behavior. With this extension the 6LNs can now subscribe to the anycast and multicast addresses they listen to, using a new P field in the EARO to signal that the registration is for a multicast address. Multiple 6LN may subscribe to the same multicast address to the same 6LR. Note the use of the term "subscribe": using the EARO registration mechanism, a node registers the unicast addresses that it owns, but subscribes to the multicast addresses that it listens to.

With this specification, the 6LNs can also subscribe the anycast addresses they accept, using a new P field in the EARO to signal that the registration is for an anycast address. As for multicast, multiple 6LN may subscribe the same anycast address to the same 6LR.

If the R flag is set in the subscription of one or more 6LNs for the same address, the 6LR injects the anycast addresses and multicast addresses of a scope larger than link-scope in RPL, based on the longest subscription lifetime across the active subscriptions for the address.

In the RPL "Storing Mode of Operation with multicast support", the DAO messages for the multicast address percolate along the RPL preferred parent tree and mark a subtree that becomes the multicast tree for that multicast address, with 6LNs that subscribed to the address as the leaves. As prescribed in section 12 of [[RFC6550](#)], the 6LR forwards a multicast packet as an individual unicast MAC frame to each peer along the multicast tree, excepting to the node it received the packet from.

In the new RPL "Non-Storing Mode of Operation with multicast support" that is introduced here, the DAO messages announce the multicast addresses as Targets though never as Transit. The multicast distribution is an ingress replication whereby the Root encapsulates the multicast packets to all the 6LRs that are transit for the multicast address, using the same source-routing header as for unicast targets attached to the respective 6LRs.

Broadcasting is typically unreliable in LLNs (no ack) and forces a listener to remain awake, so it generally discouraged. The expectation is thus that in either mode, the 6LRs deliver the multicast packets as individual unicast MAC frames to each of the 6LNs that subscribed to the multicast address.

With this specification, anycast addresses can be injected in RPL in both Storing and Non-Storing modes. In Storing Mode the RPL router accepts DAO from multiple children for the same anycast address, but only forwards a packet to one of the children. In Non-Storing Mode, the Root maintains the list of all the RPL nodes that announced the anycast address as Target, but forwards a given packet to only one of them.

For backward compatibility, this specification allows to build a single DODAG signaled as MOP 1, that conveys anycast, unicast and multicast packets using the same source routing mechanism, more in [Section 11](#).

It is also possible to leverage this specification between the 6LN and the 6LR for the registration of unicast, anycast and multicast IPv6 addresses in networks that are not necessarily LLNs, and/or where the routing protocol between the 6LR and above is not necessarily RPL. In that case, the distribution of packets between the 6LR and the 6LNs may effectively rely on a broadcast or multicast support at the lower layer, e.g., using this specification as a replacement to MLD in an Ethernet bridged domain and still using either plain MAC-layer broadcast or snooping this protocol to control the flooding. It may also rely on overlay services to optimize the impact of Broadcast, Unknown and Multicast (BUM) over a fabric, e.g. registering with

[[I-D.thubert-bess-secure-evpn-mac-signaling](#)] and forwarding with [[I-D.ietf-bess-evpn-optimized-ir](#)].

For instance, it is possible to operate a RPL Instance in the new "Non-Storing Mode of Operation with multicast support" (while possibly signaling a MOP of 1) and use "[Multicast Protocol for Low-Power and Lossy Networks \(MPL\)](#)" [[RFC7731](#)] for the multicast operation. MPL floods the DODAG with the multicast messages independently of the RPL DODAG topologies. Two variations are possible:

- *In one possible variation, all the 6LNs set the R flag in the EARO for a multicast target, upon which the 6LRs send a unicast DAO message to the Root; the Root filters out the multicast messages for which there is no listener and only floods when there is.

- *In a simpler variation, the 6LNs do not set the R flag and the Root floods all the multicast packets over the whole DODAG. Using configuration, it is also possible to control the behavior of the 6LR to ignore the R flag and either always or never send the DAO message, and/or to control the Root and specify which groups it should flood or not flood.

Note that if the configuration instructs the 6LR not to send the DAO, then MPL can really be used in conjunction with RPL Storing Mode as well.

4. Updating RFC 4861

Section 7.1 of [[RFC4861](#)] requires to silently discard NS and NA packets when the Target Address is a multicast address. This specification Amends [[RFC4861](#)] by allowing to advertise multicast and anycast addresses in the Target Address field when the NS message is used for a registration, per section 5.5 of [[RFC8505](#)].

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 xcast Address Supported" (X) flag indicates to the 6LN that the 6LR accepts unicast, multicast, and anycast address registrations as specified in this document and will ensure that packets for the Registered Address will be routed to the 6LNs that registered with the R flag set appropriately.

[Figure 3](#) illustrates the X flag in its suggested position (8, counting 0 to 15 in network order in the 16-bit array), to be confirmed by IANA.

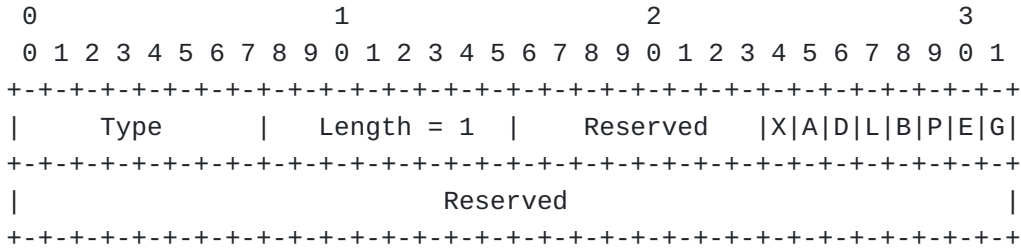


Figure 3: New Capability Bits in the 6CIO

New Option Field:

X 1-bit flag: "Registration for Unicast, Multicast, and Anycast Addresses 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.

This specification 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 anycast and multicast advertisements, 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 anycast or multicast addresses MUST use and advertise the longest remaining lifetime across all the origins of the advertisements for that address. 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.

6.1. Updating MOP 3

RPL supports multicast operations in the "Storing Mode of Operation with multicast support" (MOP 3) which provides source-independent multicast routing in RPL, as prescribed in section 12 of [[RFC6550](#)]. MOP 3 is a storing Mode of Operation. This operation builds a multicast tree within the RPL DODAG for each multicast address. This specification provides additional details for the MOP 3 operation.

The expectation in MOP 3 is that the unicast traffic also follows the Storing Mode of Operation. But this is rarely the case in LLN deployments of RPL where the "Non-Storing Mode of Operation" (MOP 1) is the norm. Though it is preferred to build separate RPL Instances, one in MOP 1 and one in MOP 3, this specification allows to hybrid the Storing Mode for multicast and Non-Storing Mode for unicast in the same RPL Instance, more in [Section 11](#).

For anycast and multicast advertisements, including MOP 3, the ROVR field is placed in the RPL Target Option as specified in [[RFC9010](#)] for both MOP 3 and MOP 5 as it is for unicast advertisements.

Though it was implicit with [[RFC6550](#)], this specification clarifies that the freshness comparison based on the Path Sequence is not used when the origin cannot be determined, which is the case there. The comparison is to be used only between advertisements from the same

origin, which is either an individual subscriber, or a descendant that merged multiple advertisements.

A RPL router maintains a remaining Path Lifetime for each DAO that it receives for a multicast target, and sends its own DAO for that target with the longest remaining lifetime across its listening children. If the router has only one descendant listening, it propagates the TID and ROVR as received. Conversely, if the router merges multiple advertisements (including possibly one for self as a listener), the router uses its own ROVR and TID values.

6.2. New Non-Storing Multicast MOP

This specification adds a "Non-Storing Mode of Operation with ingress replication multicast support" (MOP to be assigned by IANA) whereby the non-storing Mode DAO to the Root may advertise a multicast address in the RPL Target Option (RTO), whereas the Transit Information Option (TIO) cannot.

In that mode, the RPL Root performs an ingress replication (IR) operation on the multicast packets, meaning that it transmits one copy of each multicast packet to each 6LR that is a transit for the multicast target, using the same source routing header and encapsulation as it would for a unicast packet for a RPL Unaware Leaf (RUL) attached to that 6LR.

For the intermediate routers, the packet appears as any source routed unicast packet. The difference shows only at the 6LR, that terminates the source routed path and forwards the multicast packet to all 6LNs that registered for the multicast address.

For a packet that is generated by the Root, this means that the Root builds a source routing header as shown in section 8.1.3 of [\[RFC9008\]](#), but for which the last and only the last address is multicast. For a packet that is not generated by the Root, the Root encapsulates the multicast packet as per section 8.2.4 of [\[RFC9008\]](#). In that case, the outer header is purely unicast, and the encapsulated packet is purely multicast.

For anycast and multicast advertisements in NA (at the 6LR) and DAO (at the Root) messages, as discussed in [Section 6.1](#), the freshness comparison based on the TID field is applied only between messages from the same origin, as determined by the same value in the ROVR field.

The Root maintains a remaining Path Lifetime for each advertisement it receives, and the 6LRs generate the DAO for multicast addresses with the longest remaining lifetime across its registered 6LNs, using its own ROVR and TID when multiple 6LNs subscribed, or if this 6LR is one of the subscribers.

For this new mode as well, this specification allows to enable the operation in a MOP 1 brown field, more in [Section 11](#).

6.3. RPL Anycast Operation

With multicast, the address has a recognizable format, and a multicast packet is to be delivered to all the active subscribers. In contrast, the format of an anycast address is not distinguishable from that of unicast. A legacy node may issue a DAO message without setting the P field to 2, the unicast behavior may apply to anycast traffic in a subDAGs. That message will be undistinguishable from a unicast advertisement and the anycast behavior in the dataplane can only happen if all the nodes that advertise the same anycast address are synchronized with the same TID. That way, the multiple paths can remain in the RPL DODAG.

With the P field set to 2, this specification alleviates the issue of synchronizing the TIDs and ROVR fields. As for multicast, the freshness comparison based on the TID (in EARO) and the Path Sequence (in TIO) is ignored unless the messages have the same origin, as inferred by the same ROVR in RTO and/or EARO, and the latest value of the lifetime is retained for each origin.

A RPL router that propagates an advertisement from a single origin uses the ROVR and Path Sequence from that origin, whereas a router that merges multiple subscriptions uses its own ROVR and Path Sequence and the longest lifetime over the different advertisements. A target is routed as anycast by a parent (or the Root) that received at least one DAO message for that target with the P field set to 2.

As opposed to multicast, the anycast operation described therein applies to both addresses and prefixes, and the P field can be set to 2 for both. An external destination (address or prefix) that may be injected as a RPL target from multiple border routers should be injected as anycast in RPL to enable load balancing. A mobile target that is multihomed should in contrast be advertised as unicast over the multiple interfaces to favor the TID comparison and vs. the multipath load balancing.

For either multicast and anycast, there can be multiple subscriptions from multiple origins, each using a different value of the ROVR field that identifies the individual subscription. The 6LR maintains a subscription state per value of the ROVR per multicast or anycast address, but inject the route into RPL only once for each address, and in the case of a multicast address, only if its scope is larger than link-scope (3 or more). Since the subscriptions are considered separate, the check on the TID that acts as subscription sequence only applies to the subscription with the same ROVR.

Like the 6LR, a RPL router in Storing Mode propagates the merged advertisement to its parent(s) in DAO messages once and only once for each address, but it retains a routing table entry for each of the children that advertised the address.

When forwarding multicast packets down the DODAG, the RPL router copies all the children that advertised the address in their DAO messages. In contrast, when forwarding anycast packets down the DODAG, the RPL router MUST copy one and only one of the children that advertised the address in their DAO messages, and forward to one parent if there is no such child.

6.4. New P-Field

The new P-field is created for use in RPL Target Option, EAR0, and EDAR messages. The P-Field is a 2-bits field, capable of storing 4 values, and used to indicate the type of advertisement.

The P field can take the following values:

Value	Meaning
0	Registration for a Unicast Address
1	Registration for a Multicast Address
2	Registration for an Anycast Address
3	Reserved, MUST be ignored by the receiver

Table 1: P-field Values

6.5. New RPL Target Option P-Field

[[RFC6550](#)] recognizes a multicast address by its format (as specified in section 2.7 of [[RFC4291](#)]) and applies the specified multicast operation if the address is recognized as multicast. This specification updates [[RFC6550](#)] to add the 2-bits P field (see [Section 6.4](#)) to the RT0 to indicate that the target address is to be processed as unicast, multicast or anycast.

*An RT0 that has the P field set to 0 is called a unicast RT0.

*An RT0 that has the P field set to 1 is called a multicast RT0.

*An RT0 that has the P field set to 2 is called an anycast RT0.

The suggested position for the P field is 2 counting from 0 to 7 in network order as shown in [Figure 4](#), based on figure 4 of [[RFC9010](#)] which defines the flags in position 0 and 1:

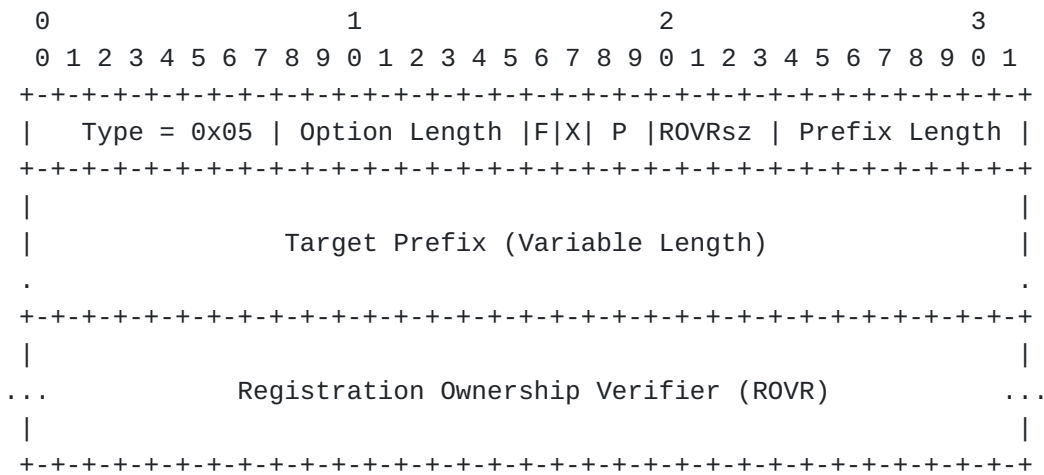


Figure 4: Format of the RPL Target Option

New and updated Option Fields:

P: 2-bit field; see [Section 6.4](#)

7. Updating RFC 8505

7.1. Placing the New P field in the EARO

Section 4.1 of [\[RFC8505\]](#) defines the EARO as an extension to the ARO option defined in [\[RFC6775\]](#). This specification adds a new P field placed in the EARO flags that is set as follows:

*The P field is set to 1 to signal that the Registered Address is a multicast address. When the P field is 1 and the R flag is set to 1 as well, the 6LR that conforms to this specification joins the multicast stream, e.g., by injecting the address in the RPL multicast support that is extended in this specification for Non-Storing Mode.

*The P field is set to 2 to signal that the Registered Address is an anycast address. When the P field is 2 and the R flag is 1, the 6LR that conforms to this specification injects the anycast address in the routing protocol(s) that it participates to, e.g., in the RPL anycast support that is introduced in this specification for both Storing and Non-Storing Modes.

[Figure 5](#) illustrates the P field in its suggested positions (2, counting 0 to 7 in network order in the 8-bit array), to be confirmed by IANA.

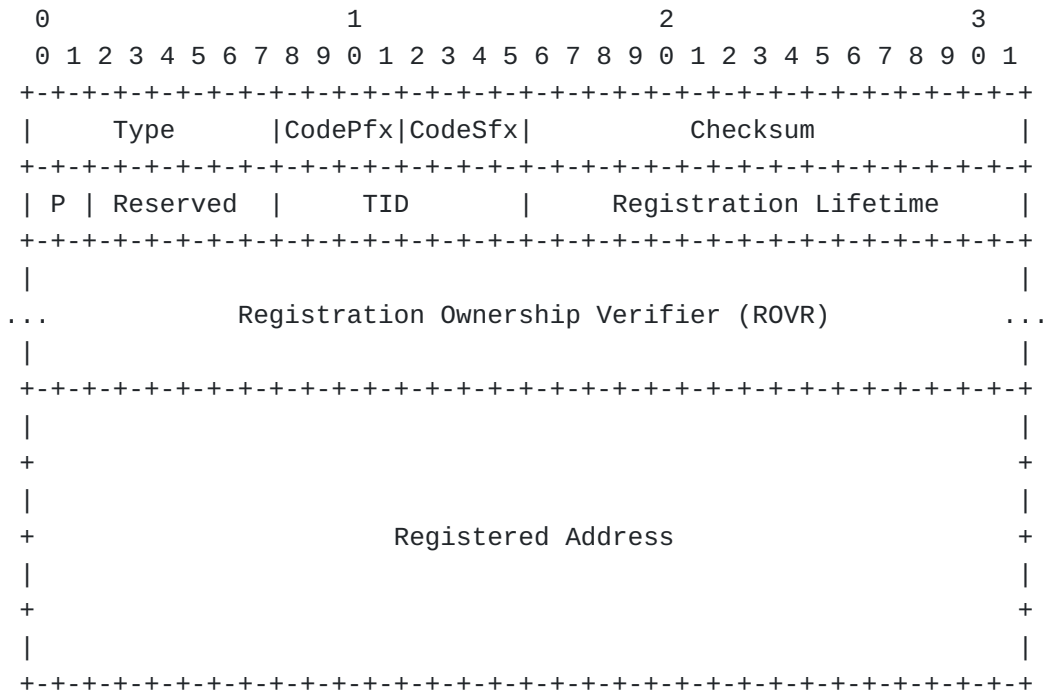


Figure 6: Extended Duplicate Address Request Message Format

New and updated Option Fields:

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

P: 2-bit field; see [Section 6.4](#)

7.3. Registering Extensions

[RFC8505] specifies the following behaviours:

*A router that expects to reboot may send a final RA message, upon which nodes should subscribe elsewhere or redo the subscription 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:

*The concept of subscription is introduced for anycast and multicast addresses as an extension to the unicast address registration. The respective operations are similar 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.

*A new ARO Status is introduced to indicate a "Registration Refresh Request" (see [Table 9](#)).

This status is used in asynchronous NA(EAR0) messages to indicate to peer 6LNs that they are requested to reregister all addresses 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(EAR0) with this new status value. That asynchronous multicast NA(EAR0) 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.

The TID field in the multicast NA(EAR0) is the one associated to the Target and follows the same rules as the TID in the NS(EAR0) for the same Target, see section 5.2 of [[RFC8505](#)]. It is incremented by the sender each time it sends a new series of NS and/or NA with the EAR0 about the Target. By default the TID initial setting is 252. The TID indicates a reboot when it is in the "straight" part of the lollipop, between the initial value and 255. After that the TID remains below 128 as long as the device is alive. An asynchronous multicast NA(EAR0) with a TID below 128 MUST NOT be considered as indicating a reboot.

In an unreliable environment, the asynchronous multicast NA(EAR0) message MAY be resent in a fast sequence for reliability, in which case the TID MUST be incremented each time. If the sender is a 6LN that also registers the Target to one or more 6LR(s), then it MUST reregister before the current value of the TID and

the last registered value are no more comparable, see section 7.2 of [[RFC6550](#)].

The multicast NA(EAR0) SHOULD be resent enough times for the TID to be issued with the value of 255 so the next NA(EAR0) after the initial series is outside the lollipop and not confused with a reboot. A 6LN that has recently processed the multicast NA(EAR0) indicating "Registration Refresh Request" ignores the next multicast NA(EAR0) with the same status and a newer TID received within the duration of the initial series.

By default, the duration of the initial series is 10 seconds, the interval between retries is 1 second, and the number of retries is 3. The best values for the duration, the number of retries and the TID initial setting depend on the environment and SHOULD be configurable.

*A new IPv6 ND Consistent Uptime option (CUO) is introduced to be placed in IPv6 ND messages. The CUO indicates allows to figure the state consistency between the sender and the receiver. For instance, a node that rebooted needs to reset its uptime to 0. A Router that changed information like a prefix information option has to advertise an incremented state sequence. To that effect, the CUO carries a Node State Sequence Information (NSSI) and a Node Uptime. See [Section 10](#) for the option details.

A node that receives the CUO checks whether it is indicative of a desynchronization between peers. A peer that discovers that a router has changed should reassess which addresses it formed based on the new PIOs from that router, and resync the state that it installed in the router, e.g., the registration state for its addresses. In the process, the peer may attempt to form new address and register them, deprecate old addresses and deregister them using a Lifetime of 0, and reform any potentially lost state, e.g., by re-registering an existing address that it will keep using. A loss of state is inferred if the Node Uptime of the peer is less than the time since the state was installed, or the NSSI is incremented for a consistent uptime.

*Registration for multicast and anycast addresses is now supported. The P field is added to the EAR0 to signal when the registered address is anycast or multicast.

*The Status field in the EDAR message that was reserved and not used in RFC 8505 is repurposed to transport the flags to signal multicast and anycast.

*The 6LN MUST also subscribe all the IPv6 multicast addresses that it listens to but the all-nodes link-scope multicast address

FF02::1 [[RFC4291](#)] which is implicitly registered, and it MUST set the P field to 1 in the EARO for those addresses.

*The 6LN MAY set the R flag in the EARO to obtain the delivery of the multicast packets by the 6LR, e.g., by MLD proxy operations, or by injecting the address in a route-over subnet or in the Protocol Independent Multicast [[RFC7761](#)] protocol.

*The 6LN MUST also subscribe all the IPv6 anycast addresses that it supports and it MUST set the P field in the EARO to 2 for those addresses.

*The 6LR and the 6LBR are extended to accept more than one subscription for the same address when it is anycast or multicast, since multiple 6LNs may subscribe to the same address of these types. In both cases, the Registration Ownership Verifier (ROVR) in the EARO identifies uniquely a registration within the namespace of the Registered Address.

*The 6LR MUST also consider that all the nodes that registered an address to it (as known by the SLLAO) also registered to the all nodes link-scope multicast address FF02::1 [[RFC4291](#)].

*The 6LR MUST maintain a subscription state per tuple (IPv6 address, ROVR) for both anycast and multicast types of address. 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 subscription state per tuple (IPv6 address, ROVR) for both anycast and multicast types of address.

8. Updating RFC 9010

[[RFC9010](#)] specifies the following behaviours:

*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 subscription with the R flag and the P field both set to 1 in the EARO, if the scope of the multicast address is above link-

scope [[RFC7346](#)], then the 6LR injects the address in the RPL multicast support and sets the P field in the RT0 to 1 as well.

*Upon a subscription with the R set to 1 and the P field set to 2 in the EARO, the 6LR injects the address in the new RPL anycast support and sets the P field to 2 in the RT0.

*Upon receiving a packet directed to a multicast address for which it has at least one subscription, the 6LR delivers a copy of the packet as a unicast layer-2 frame to the LLA of each of the nodes that registered to that multicast address.

*Upon receiving a packet directed to a anycast address for which it has at least one subscription, 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 multicast address.

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).

Anycast and multicast addresses are not owned by one node. Multiple nodes may subscribe to the same address. Also, anycast and multicast addresses are not used to source traffic. In that context, the method specified in [[RFC8928](#)] cannot be used with autoconfigured keypairs to protect a single ownership.

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

The keypair MUST then be provisioned in each node that needs to subscribe to the anycast or multicast address, so the node can follow the steps in [[RFC8928](#)] to subscribe the address.

10. Consistent Uptime Option

This specification introduces a new option that characterizes the uptime of the sender. The option may be used by routers in RA messages and by any node in NS, NA, and RS messages. It is used by the receiver to infer whether some state synchronization might be lost, e.g., due to reboot.

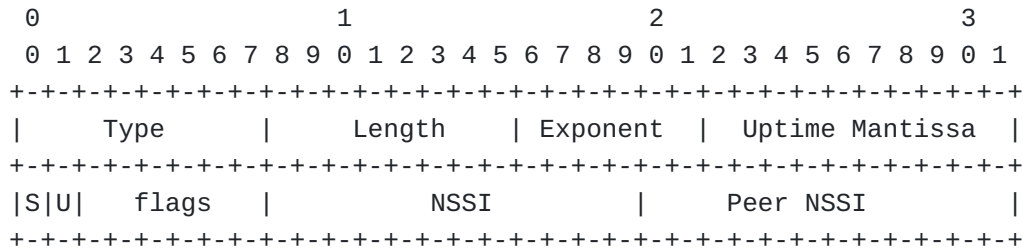


Figure 7: Consistent Uptime Option Format

Type To be assigned by IANA, see [Table 10](#)

Length 1

S 1-bit flag, set to 1 to indicate that the sender is low-power and may sleep.

U 1-bit flag, set to 1 to indicate that the Peer NSSI field is valid; it MUST be set to 0 when the message is not unicast and MUST be set to 1 when the message is unicast and the sender has an NSSI state for the intended receiver.

flags 6-bit, reserved. MUST be set to 0 by the sender and ignored by the receiver.

NSSI 12-bits unsigned integer: The Node State Sequence Information, MUST be stored by the receiver if it has a dependency on information advertised or stored at the sender.

Peer NSSI 12-bits unsigned integer: Echoes the last known NSSI from the peer.

Uptime Exponent 6-bits unsigned integer: The 2-exponent of the uptime unit

Uptime Mantissa 10-bits unsigned integer: The mantissa of the uptime value

The Node Uptime indicates how long the sender has been continuously up and running without loss of state. It is expressed by the Uptime Mantissa in units of 2 at the power of the Uptime Exponent

milliseconds. The receiver derives the boot time of the sender as the current Epoch the sender's Node Uptime. If the sender rebooted since last time state was installed, any state that was installed in the sender before it rebooted needs to be reassessed and reinstalled if it is still needed. Any state that was installed in the receiver from information by the sender before it rebooted must be removed and may or may not be reinstalled later.

The value if the uptime is reset to 0 at some point of the sender's reboot sequence, but may not be still 0 when the first message is sent, so the receiver must not expect a value of 0 as the signal of a reboot.

Mantissa	Exponent	Resolution	Uptime
1	0	1ms	1ms
5	10	1s	5 seconds
2	15	30s	1mn
2	21	33mn	1 hour

Table 2: Node Uptime Rough Values

The NSSI SHOULD be stored in persistent memory by the sender and incremented when it may have missed or lost state about a peer, or has updated some state in a fashion that will that impact a peer, e.g., a host formed a new address or a router advertises a new prefix. When persisting is not possible, then the NSSI is randomly generated loss.

Any change in the value of the NSSI from a node is an indication that the node updated some state and that the needful state should be reinstalled, e.g., addresses that where formed based on an RA with a previous NSSI should be reassessed, and the registration state updated in the peer.

11. Deployment considerations

With this specification, a RPL DODAG forms a realm, and multiple RPL DODAGs may federated in a single RPL Instance administratively. This means that a multicast address that needs to span a RPL DODAG MUST use a scope of Realm-Local whereas a multicast address that needs to span a RPL Instance MUST use a scope of Admin-Local as discussed in section 3 of ["IPv6 Multicast Address Scopes"](#) [RFC7346].

["IPv6 Addressing of IPv4/IPv6 Translators"](#) [RFC6052] enables to embed IPv4 addresses in IPv6 addresses. The Root of a DODAG may leverage that technique to translate IPv4 traffic in IPv6 and route along the RPL domain. When encapsulating an packet with an IPv4 multicast Destination Address, it MUST use a multicast address with the appropriate scope, Realm-Local or Admin-Local.

["Unicast-Prefix-based IPv6 Multicast Addresses"](#) [[RFC3306](#)] enables to form 2^{32} multicast addresses from a single /64 prefix. If an IPv6 prefix is associated to an Instance or a RPL DODAG, this provides a namespace that can be used in any desired fashion. It is for instance possible for a standard defining organization to form its own registry and allocate 32-bit values from that namespace to network functions or device types. When used within a RPL deployment that is associated with a /64 prefix the IPv6 multicast addresses can be automatically derived from the prefix and the 32-bit value for either a Realm-Local or an Admin-Local multicast address as needed in the configuration.

In a "green field" deployment where all nodes support this specification, it is possible to deploy a single RPL Instance using a multicast MOP for unicast, multicast and anycast addresses.

In a "brown field" where legacy devices that do not support this specification co-exist with upgraded devices, it is RECOMMENDED to deploy one RPL Instance in any Mode of Operation (typically MOP 1) for unicast that legacy nodes can join, and a separate RPL Instance dedicated to multicast and anycast operations using a multicast MOP.

To deploy a Storing Mode multicast operation using MOP 3 in a RPL domain, it is required that there is enough density of RPL routers that support MOP 3 to build a DODAG that covers all the potential listeners and include the spanning multicast trees that are needed to distribute the multicast flows. This might not be the case when extending the capabilities of an existing network.

In the case of the new Non-Storing multicast MOP, arguably the new support is only needed at the 6LRs that will accept multicast listeners. It is still required that each listener can reach at least one such 6LR, so the upgraded 6LRs must be deployed to cover all the 6LN that need multicast services.

Using separate RPL Instances for in the one hand unicast traffic and in the other hand anycast and multicast traffic allows to use different objective function, one favoring the link quality up for unicast collection and one favoring downwards link quality for multicast distribution.

But this might be impractical in some use cases where the signaling and the state to be installed in the devices are very constrained, the upgraded devices are too sparse, or the devices do not support more multiple instances.

When using a single RPL Instance, MOP 3 expects the Storing Mode of Operation for both unicast and multicast, which is an issue in constrained networks that typically use MOP 1 for unicast. This

specification allows a mixed mode that is signaled as MOP 1 in the DIO messages for backward compatibility, where limited multicast and/or anycast is available, under the following conditions:

- *There MUST be enough density of 6LRs that support the mixed mode to cover the all the 6LNs that require multicast or anycast services. In Storing Mode, there MUST be enough density or 6LR that support the mixed mode to also form a DODAG to the Root.
- *The RPL routers that support the mixed mode and are configured to operate in in accordance with the desired operation in the network.
- *The MOP signaled in the RPL DODAG Information Object (DIO) messages is MOP 1 to enable the legacy nodes to operate as leaves.
- *The support of multicast and/or anycast in the RPL Instance SHOULD be signaled by the 6LRs to the 6LN using a 6CIO, see [Section 5](#).
- *Alternatively, the support of multicast in the RPL domain can be globally known by other means such as configuration or external information such as support of a version of an industry standard that mandates it. In that case, all the routers MUST support the mixed mode.

12. 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 subscribers as a preshared key material.

In the latter case, it could be possible to update the keys associated to an address 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.

13. Backward Compatibility

A legacy 6LN will not subscribe multicast addresses and the service will be the same when the network is upgraded. A legacy 6LR will not set the P field in the 6CIO and an upgraded 6LN will not subscribe multicast addresses.

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.

As detailed in [Section 11](#), it is possible to add multicast on an existing MOP 1 deployment.

The combination of a multicast address and the P field set to 0 in an RTO in a MOP 3 RPL Instance is understood by the receiver that supports this specification (the parent) as an indication that the sender (child) does not support this specification, but the RTO is accepted and processed as if the P field was set to 1 for backward compatibility.

When the DODAG is operated in MOP 3, a legacy node will not set the P field and still expect multicast service as specified in section 12 of [[RFC6550](#)]. In MOP 3 an RTO that is received with a target that is multicast and the P field set to 0 MUST be considered as multicast and MUST be processed as if the P field is set to 1.

14. 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, requests to IANA must be edited to reflect the IANA actions once performed.

Note to IANA, to be removed: the I Field is defined in [[RFC9010](#)] but is missing from the registry, so the bit positions must be added for completeness in conformance with the RFC.

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:

14.1. New P-Field Registry

IANA is requested to create a new "P-field values" registry under the heading "Internet Control Message Protocol version 6 (ICMPv6) Parameters".

Registration procedure is "Standards Action" [[RFC8126](#)]. The initial allocation is as indicated in [Table 3](#):

Value	Meaning	Reference
0	Registration for a Unicast Address	This RFC
1	Registration for a Multicast Address	This RFC
2	Registration for an Anycast Address	This RFC
3	Unassigned	This RFC

Table 3: P-field values

14.2. New EDAR Message Flags Registry

IANA is requested to create a new "EDAR Message Flags" registry under the heading "Internet Control Message Protocol version 6 (ICMPv6) Parameters".

Registration procedure is "IETF Review" or "IESG Approval" [[RFC8126](#)]. The initial allocation is as indicated in [Table 4](#):

Bit Number	Meaning	Reference
0..1 (suggested)	P-field (2 bits), see Section 14.1	This RFC
2..7	Unassigned	

Table 4: EDAR Message flags

14.3. New EARO flags

IANA is requested to make additions to the "Address Registration Option Flags" [[IANA.ICMP.ARO.FLG](#)] registry under the heading "Internet Control Message Protocol version 6 (ICMPv6) Parameters" as indicated in [Table 5](#):

ARO flag	Meaning	Reference
2..3 (suggested)	P-field (2 bits), see Section 14.1	This RFC
4 and 5	"I" Field	RFC 8505

Table 5: New ARO flags

14.4. New RTO flags

IANA is requested to make additions to the "RPL Target Option Flags" [[IANA.RPL.RTO.FLG](#)] registry under the heading "Routing Protocol for Low Power and Lossy Networks (RPL)" as indicated in [Table 6](#):

Bit Number	Meaning	Reference
2..3 (suggested)	P-field (2 bits), see Section 14.1	This RFC

Table 6: New RTO flags

14.5. New RPL Mode of Operation

IANA is requested to make an addition to the "Mode of Operation" [[IANA.RPL.MOP](#)] registry under the heading "Routing Protocol for Low Power and Lossy Networks (RPL)" as indicated in [Table 7](#):

Value	Description	Reference
5 (suggested)	Non-Storing Mode of Operation with ingress replication multicast support	This RFC

Table 7: New RPL Mode of Operation

14.6. New 6LoWPAN Capability Bits

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 8](#):

Capability Bit	Meaning	Reference
8 (suggested)	X flag: Registration for Unicast, Multicast, and Anycast Addresses Supported	This RFC

Table 8: New 6LoWPAN Capability Bits

14.7. New Address Registration Option Status Values

IANA has made additions to the "Address Registration Option Status Values" registry under the heading "Internet Control Message Protocol version 6 (ICMPv6) Parameters", as follows:

Value	Description	Reference
11 (suggested)	Registration Refresh Request	This RFC

Table 9: New Address Registration Option Status Values"

14.8. New IPv6 Neighbor Discovery Option

IANA has made additions to the "IPv6 Neighbor Discovery Option Formats" registry under the heading "Internet Control Message Protocol version 6 (ICMPv6) Parameters", as follows:

Value	Description	Reference
42 (suggested)	Node Uptime Option	This RFC

Table 10: New IPv6 Neighbor Discovery Option"

15. Acknowledgments

This work is a production of an effective collaboration between the IETF 6lo WG and the Wi-Sun FAN WG. Thanks to all in both WGs who contributed reviews and productive suggestions, in particular Carsten Bormann, Paul Duffy, Klaus Hueske, Adnan Rashid, Rahul Jadhav, Gene Falendysz, Don Sturek, Dario Tedeschi, Saurabh Jain, and Chris Hett.

The Editor wishes to thank ... and Esko Dijk for their useful WGLC reviews and proposed changes.

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