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Generic Address Assignment Option for 6LoWPAN Neighbor Discovery
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Abstract

This document specifies a new extension to the IPv6 Neighbor Discovery in Low Power and Lossy Networks (LLNs), enabling a node to request to be assigned an address or a prefix from neighbor routers. Such mechanism allows to algorithmically assign addresses and prefixes to nodes in a 6LoWPAN deployment.

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1. Introduction

Low Power and Lossy Networks (LLNs) have adapted the design of Internet protocols to more constrained environments, by taking into consideration of energy saving, limited memory capacity, and duty cycling of the LLN devices, as well as low-power lossy transmissions. Since the wireless interface is a major energy drain, protocols aiming at being deployed over LLN must be designed in such a way to reduce as much as possible transmissions, allowing to turn off the radio interface or put the interface or the whole node in the sleeping mode.

IPv6 Neighbor Discovery has been also adapted to the LLN environment in [RFC6775], later updated by [RFC8505], [RFC8929], and [RFC9010]. The target being to design protocols that reduce energy consumption, especially in LLNs, though in general their design could be applied in any context targeting lowering carbon emissions. In particular, interface address assignment relies on address auto-configuration [RFC4862], since the use of Dynamic Host Configuration Protocol (DHCP [RFC8415]) is not adapted, from an energy and bandwidth perspective, to LLN deployments. Indeed, LLN environments aim at avoiding as much as possible asynchronous multicast operations, because that would keep nodes awake and listening. Furthermore, it is also preferable to reduce as much as possible the number of nodes involved in control plane operations, because of energy and bandwidth constraints typical of LLN. DHCP can still be used in Internet-of-Things (IoT) deployments where energy and bandwidth are not an issue.

To avoid multicast operations and to limit the number of nodes involved in address assignment in LLN, mechanisms to register self-generated addresses have been designed ([RFC6775], [I-D.ietf-6lo-prefix-registration], [RFC8505], [RFC9685]).

Recent use cases show, however, that there are some advantages in assigning addresses in an algorithmically managed way. In particular, in some scenarios, routing and forwarding can be simplified ([RFC9453], [I-D.ietf-6lo-path-aware-semantic-addressing], [SHENOY21], [BLESS22], [RIDOUX05]), hence reducing the power consumption and memory footprint. Algorithmic address assignment has its own pros and cons, as well as deployment requirements. However, they have the common benefit of being easily distributed. In other words, it is not necessary to have a centralized approach, like DHCP, rather address assignment is distributed by construction and a node can obtain an address from one of its neighbors who simply runs a distributed algorithm.

This situation highlights an existing gap that this document tries to fill: 6LoWPAN nodes have no means to directly request an address (or address prefix) from routers that are their direct neighbors. Currently, either auto-configuration is used, or DHCP has to be deployed. The former is energy efficient, but makes it hard to implement solutions like [I-D.ietf-6lo-path-aware-semantic-addressing], [SHENOY21], [BLESS22], and [RIDOUX05]. The latter, on the opposite, allows the use of sophisticated assignment algorithms, but remains inefficient from an energy and bandwidth consumption viewpoint.

This document proposes a new Neighbor Discovery Option, namely the Generic Address Assignment Option (GAAO), in order for a node to issue an address or prefix request to neighboring routers. GAAO

complements the Extended Address Registration Option (EARO), defined in [RFC8505], further extended in [I-D.ietf-6lo-prefix-registration] and [RFC9685].

2. Terminology

2.1. Requirements Notation

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.

2.2. Acronyms

This document assumes familiarity with the terminology defined in [RFC6775] and [RFC8505]. In particular for the following acronyms:

6CIO: Capability Indication Option

6LBR: 6LoWPAN Border Router

6LN: 6LoWPAN Node

6LoWPAN: IPv6 over Low-Power Wireless Personal Area Network

6LR: 6LoWPAN Router

AAF: Address Assignment Function

ARO: Address Registration Option

EARO: Extended Address Registration Option

GAAO: Generic Address Assignment Option

IID: Interface IDentifier

LLN: Low-Power and Lossy Network

NA: Neighbor Advertisement

ND: Neighbor Discovery

NS: Neighbor Solicitation

Pfxlen: Prefix Length

RA: Router Advertisement

RS: Router Solicitation

SLAAC: State-Less Address Auto-Configuration

SLLAO: Source Link-Layer Address Option

TLLAO: Target Link-Layer Address Option

2.3. Definition of Terms

Address Assignment Function (AAF): The Address Assignment Function (AAF) is an implementation of the algorithm used by 6LRs to assign an address/prefix to requesting nodes. In order to avoid addressing issues, only one single AAF is used in a deployment.

GAAO: Generic Address Assignment Option defined in the present document (Section 4).

3. Algorithmically Assigned Addresses and Prefixes

The IPv6 address assignment model inside a local domain is based on randomly assigned Interface IDentifier (IID), either done in a centralized way using DHCP, which can guarantee no address collision, or by decentralized State-Less Address Auto-Configuration (SLAAC [RFC4862]), which needs additional mechanisms to ensure the uniqueness of addresses. However, there is a third approach for address assignment, which is distributed and collision-free: algorithmically generated addresses (e.g., [SHENOY21], [BLESS22], [RIDOUX05], [ERIKSSON04]).

The main idea is to use an Address Assignment Function (AAF) to assign addresses and prefixes to nodes joining a network. All nodes, 6LNs, 6LRs, and 6LBRs, MUST use the same AAF in the same network instance. Each node acquiring an address firstly needs to select a neighbor 6LR by choosing among the nodes that replied with a Router Advertisement (RA) after an initial Router Solicitation (RS), as defined in [RFC6775]. Then, the node explicitly requests an address (or prefix) to the selected 6LR. Depending on the underlying technology and algorithm used, the node may optionally ratify its usage. The high-level sequence of actions is depicted in Figure 1.

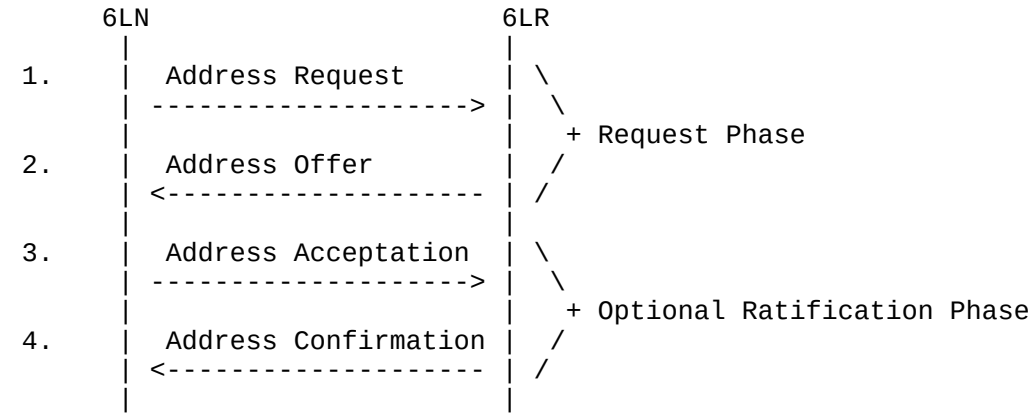

Figure 1: Address/Prefix assignment sequence.

The optional ratification phase (namely step 3 and 4), is implemented by using the address registration procedure defined in [RFC8505], [RFC9685], or [I-D.ietf-6lo-prefix-registration]. Basically, it uses an EARO and SLLAO messages to register an address, which in this case is not a self-generated address. However, in order to issue the initial request, namely steps 1 and 2, a new Generic Address Assignment Option (GAAO) is required and proposed, since no existing mechanism can be readily used for this purpose. In the remaining of this document, the format of this option is firstly defined (Section 4), followed by a revised Address/Prefix assignment messages sequence and processing (Section 5).

4. Generic Address Assignment Option

In order for a 6LN to request the assignment of an address or prefix, the Generic Address Assignment Option (GAAO) message is used. The format of the GAAO message is shown in Figure 2.

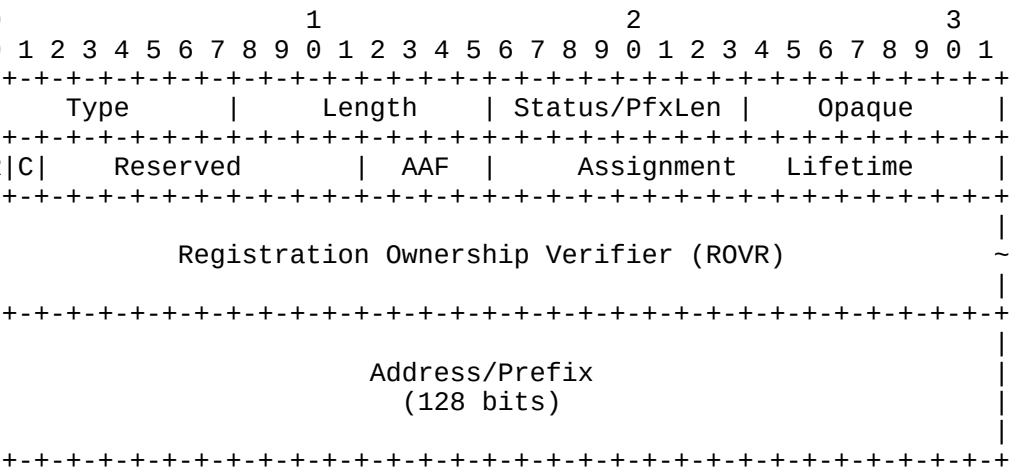

Figure 2: Generic Address Assignment Option format.

Generic Address Assignment Option Fields:

Type: TBD

Length: 8-bit unsigned integer. The length of the option in units of 8 bytes. This field is set to 1 plus the size of the ROVR field when the option is used in NS messages. It is augmented by 2 (16 bytes) when this option is used in NA messages because the assigned address/prefix is appended to the option.

Status/PfxLen: 8-bits unsigned integer. This field has two purposes. It indicates the Prefix Length of the assigned address if the assignment is successful or an error code otherwise.

* On success, the returned GAAO message MUST have 16 bytes of the assigned address/prefix appended to it, which means that the Length field will increased by 2 (cf. Length field).

* In case of failure, when no address/prefix is returned, this field indicates an error code (See table 1 in [RFC8505] and Section 5.4 for error codes). In this case, the returned GAAO message will not have any address/prefix appended to it and the Length field has not been increased. A returning GAAO with the same length as the one sent indicates error condition, whose code MUST be is indicated in this field.

This field MUST be set to 0 on transmission and ignored on reception in NS messages.

Opaque: As defined in [RFC8505].

R: 1-bit flag for Ratification requested. It MUST be initialized to 0 in NS(GAAO) messages by the requester and MUST be ignored by the receiver. The 6LR/6LBR replying to the request with an NA(GAAO) message MAY set this bit to indicate that it requests a confirmation that the address/prefix is accepted and will be used. When the requester receives an NA(GAAO) message with this bit set, it MUST explicitly register the received address/prefix to the same 6LR using the procedures defined in [RFC8505], [I-D.ietf-6lo-prefix-registration], and [RFC9685], according to the type of the assigned address/prefix.

C: 1-bit flag for Crypto-ID used for ROVR as defined [RFC8928] and [I-D.ietf-6lo-updating-rfc-8928]. This flag MUST be set when the ROVR field contains a Crypto-ID.

Reserved: 10-bit reserved field for future use. It MUST be initialized to 0 by the sender and MUST be ignored by the receiver.

Address Assignment Function(AAF): 4-bit unsigned integer. Describe the Address Assignment Function (AAF), i.e. the algorithm, used to assign the address/prefix. 0 is a special value indicating that the field is not used. On request in an NS message, it is RECOMMENDED to set this field to 0 to indicate there is no preference on how the address is assigned. However, a 6LN MAY use a value different from 0, meaning that it is requested to use a specific known AAF to assign the address/prefix (see also Section 5.4). Section 7.4 describes possible values of this field.

Assignment Lifetime: 16-bit unsigned integer, expressed in minutes. In an NS message, the field expresses a desired lifetime. It MAY be set to zero in the NS(GAAO) message, indicating no particular desired lifetime. In NA(GAAO) messages it expresses the granted maximum lifetime. A node MUST NOT use the address/prefix after expiration of the lifetime. Address/prefix lifetime SHOULD be configurable according to the AAF in use and as mitigation of certain attacks (see Section 8).

ROVR: As defined in [RFC8505] and extended in [RFC8928] and [I-D.ietf-6lo-updating-rfc-8928].

Address/Prefix: 128-bit address or prefix returned in a NA(GAAO)

message. This field MUST NOT be present in NS(GAAO) request messages and in NA(GAAO) messages when an error occurs. This field MUST be present in NA(GAAO) messages that return a successful address/prefix allocation.

5. Messages Sequence and Processing

When a node bootstraps, it typically does multicast a RS and receives one or more unicast RA messages from neighbor 6LRs. The node MAY choose one or more 6LRs from which to request address(es) or prefix(es). A node MAY perform an address request at any time, not necessarily at boot time using NS and NA messages.

5.1. Request Phase

When the node requests an address, the node will go through the following steps:

1. The node will issue an NS(GAAO) request for an address assignment. In this initial request, GAAO MUST have a length equal to ROVR's length as a multiple of 8 bytes plus one (no 16-bytes address appended), Status/PfxLen field set to 0. Opaque, ROVR, and C-flag is set according to local the configuration. The R-flag is set to zero. The AAF field SHOULD be set to zero unless by configuration there is a preference for the assignment algorithm. The address Assignment Lifetime field MAY be set to the desired lifetime, or zero otherwise.

2. Assuming no errors occur, the node will receive an NA(GAAO) message with a length increased by two, compared to the corresponding NS(GAAO) message, because of the presence of the address/prefix field. All fields have been copied back except for:

   * Pfxlen: Now indicating the length of the prefix.

   * R: The R-bit is set if the 6LR requests a ratification via a registration procedure.

   * AAF: It is the algorithm, used to assign the address/prefix. If the node is a 6LR it MUST use the same AAF to generate addresses/prefixes to requesting neighbor nodes.

   * Assignment Lifetime: The maximum lifetime of the assigned address/prefix.

The message sequence is depicted in Figure 3.

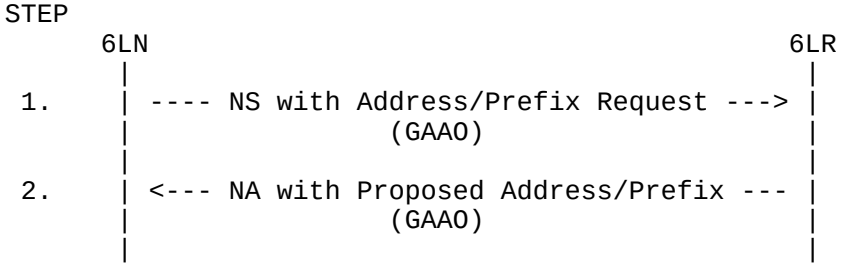

Figure 3: Address/Prefix assignment with GAAO message sequence and no confirmation request.

5.2. Optional Ratification Phase

Depending on the algorithm in use and the underlying technology the address assignment procedure terminates after these two messages. This may be sufficient for instance in deployments where the link layer offers reliable packet delivery. The use of this option is done by configuration. Documents defining Address Allocation Function MUST explicitly state whether this phase remains optional or is mandatory due to factors specific to the proposed algorithm.

If the R-flag is set, to ratify the acceptance and usage of the proposed address/prefix received in the NA(GAAO) message, the 6LN MUST register with the obtained address by following the procedures in [RFC8505], [RFC9685], or [I-D.ietf-6lo-prefix-registration] depending on the type of address. When setting the R-flag, and as for [RFC4861], the 6LR is expect to receive a registration within RETRANS_TIMER multiplied by MAX_UNICAST_SOLICIT. If no registration is received within this amount of time the 6LR will consider that address/prefix is not in use by the requesting 6LN.

The complete sequence of actions is depicted in Figure 4.

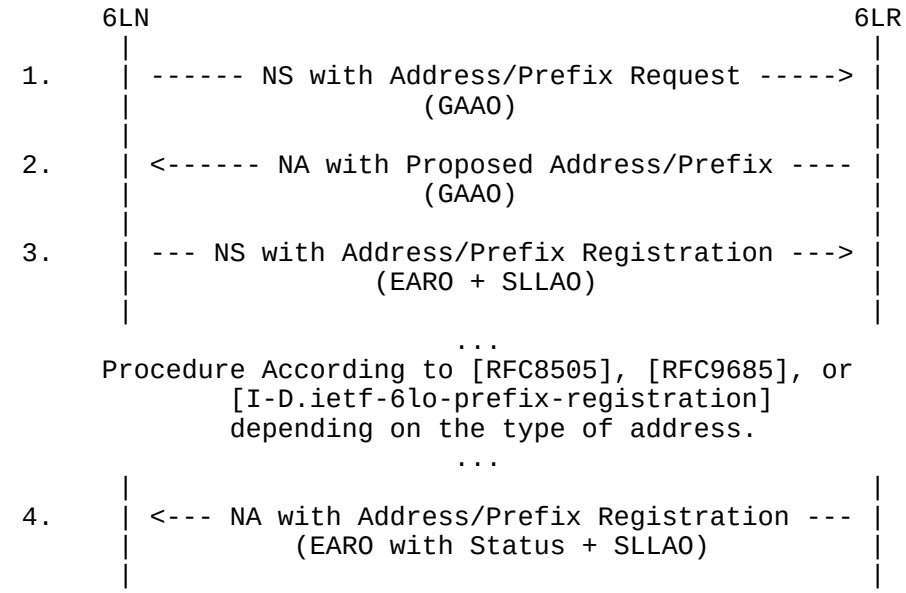

Figure 4: Address/Prefix Assignment with GAAO Message sequence.

The specifications in [RFC8505], [RFC9685], and [I-D.ietf-6lo-prefix-registration], define how nodes keep address/prefix registering state so to maintain addressing in case of reboot. When needed, in order to use this feature with GAAO, after reboot the optional ratification phase MUST be used to perform an explicit registration. However, when using GAAO, and when preforming the re-registering, if a "Registration Refresh Request" or "Invalid Registration" status value is returned, the node MUST restart from the top with the initial request phase.

5.3. Message Exchange Optimization

Prefix/address requests utilize NS/NA transactions, similar to prefix/address registration. To minimize the number of transactions, GAAO MAY be used at the same time like the EARO option. In other words GAAO can be piggybacked on other transactions, hence it does not necessarily introduce additional NS/NA transactions. For instance, it can be piggybacked in an link-layer address registration, as shown in Figure 5. In this case the returning NA(GAAO+EARO) will contain an address directly appended in GAAO, namely the offered prefix/address.

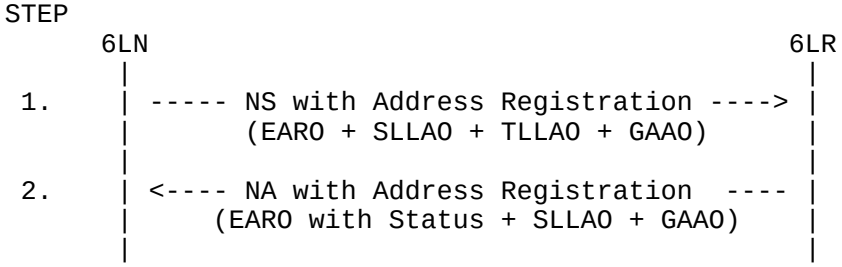

Figure 5: Message sequence when GAAO is piggybacked on a link-layer registration transaction.

When prefix/address request is performed at boot time, the GAAO request MAY be appended as an option of the first RS message, implicitly signaling that the node sending the RS message supports the specifications in the present document. In the same way, the responding routers that support this document MUST send back a prefix/address offer in a GAAO appended to the returning RA message, as depicted in Figure 6.

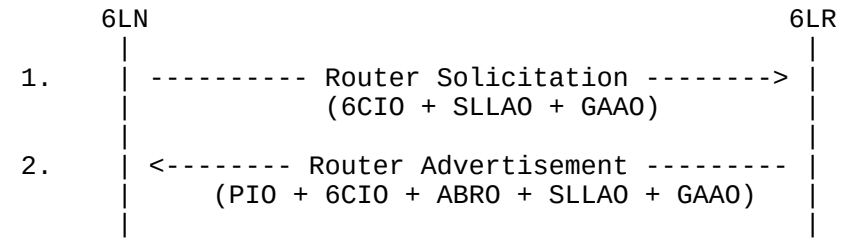

Figure 6: Message sequence when GAAO is used with the RS/RA transaction.

6LRs that do not support GAAO will simply ignore the option, and the corresponding RA, which will not include a GAAO, implicitly signaling that the feature is not supported.

5.4. Error Conditions

GAAO uses error codes defined in [RFC6775] and [RFC8505], revised in [RFC9010]. This specification introduces a new status code when the AAF in GAAO in an NS message is not in use in the 6LoWPAN network, as follows (see also Section 7):

AAF Not Used: The AAF in GAAO in the NS message is not in use in the 6LoWPAN network.

This status MUST be used when a node requesting an address/prefix did put an AAF value, in the corresponding field, which is not in use in the 6LoWPAN network. When the node receives this status back it SHOULD perform one of the following actions:

* Re-issue the same request without specifying an AAF. Meaning set the AAF field to 0. The 6LR will return the AAF in use in the 6LoWPAN network and employed to generate the returned address/ prefix. If the requesting node does not support the returned AAF it does not participate in the AAF-based 6LoWPAN network and does not use the proposed address/prefix.

* Re-issue the same request with a different AAF. The 6LoWPAN network is not using the requested AAF but may be using a different one. Note that such an approach may lead to repeated requests that may consume bandwidth and energy.

* Do nothing and do not participate in the AAF-based 6LoWPAN network.

The action to be used is selected by configuration. When nodes fail to participate in the AAF-based 6LoWPAN network they MAY still use a different mechanism (e.g., [RFC8505]) to configure addresses.

6. Signaling GAAO Support

This specification defines one new capability bit for use in the 6CIO as defined by [RFC7400] ("6LoWPAN-GHC: Generic Header Compression for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)"), for use in IPv6 ND messages. A 6LoWPAN node that supports this specification MUST set the M flag.

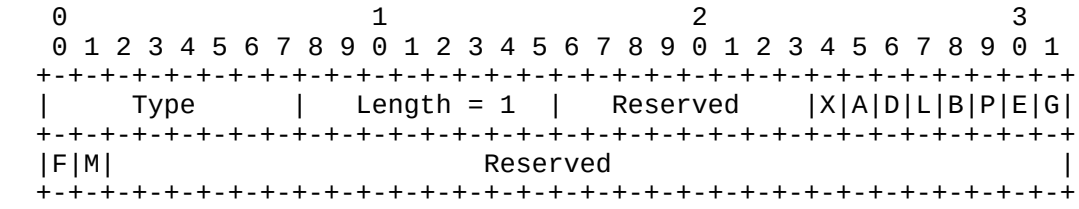

Figure 7: New GAAO Capability Bit in the 6CIO.

M: The node supports managed addresses via the Generic Address Assignment Capability.

7. IANA Considerations

This section provides guidance to the Internet Assigned Numbers Authority (IANA) regarding registration of values related to the GAAO specification, in accordance with BCP 26 [RFC8126].

7.1. IPv6 ND Option Types

IANA is requested to make an addition to the "IPv6 Neighbor Discovery Option Formats" registry under the heading "Internet Control Message Protocol version 6 (ICMPv6) Parameters" as indicated in Table 1:

Type	Description	Reference
TBD	Generic Address Assignment Option	[This Document]

Table 1: New Generic Address Assignment Option.

7.2. 6LoWPAN Capability Bits

IANA is requested to make an addition to the "6LoWPAN Capability Bits" registry under the registry group "Internet Control Message Protocol version 6 (ICMPv6) Parameters" as indicated in Table 2:

Bit	Description	Reference
TBD	Generic Address Assignment Capability (M) Flag	[This Document]

Table 2: New 6LoWPAN Capability Bit.

7.3. GAAO Error code

IANA is requested to make an addition to the "Address Registration Option Status Values" registry under the registry group "Internet Control Message Protocol version 6 (ICMPv6) Parameters" as indicated in Table 3:

Value	Description	Reference
13 (Suggested)	AAF Not Used	[This Document]

Table 3: New address registration option value.

7.4. Address Assignment Function Registry

IANA is asked to create a registry group named "Generic Address Assignment Option".

Such registry group should be populated with a one-octet registry named "Address Assignment Function" and used to identify the used AAF used. The registry is populated as shown in Table 4:

Value	AAF Name	Reference
0x0	No AAF. This can be used only in NS message to indicate that no specific AAF is demanded.	[This Document]
0x1-0xE	Un-assigned	
0xF	Experimental Use. Used for experimental purposes during implementation of new AAFs.	[This Document]

Table 4: Allocation Function sub-registry

Values can be assigned by IANA on a "First Come, First Served" basis according to [RFC8126].

8. Security Considerations

This document extends [RFC8505], which already extended [RFC6775], as such the security considerations of both documents apply to this specification. In particular, the link layer SHOULD provide sufficient protection to prevent potential attacks. Recommendations listed in Section 7 of [RFC8505] SHOULD be applied as well to this specification.

Depending on the Assignment Function in use, the number of available addresses may encounter limitations. A rouge node may leverage on this knowledge to carry out address exhaustion attacks by

impersonating different nodes and performing multiple requests. To mitigate such risks the reccomendation about the lifetime and number of addresses per node described in Section 7 of [RFC8505] remain valid.

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