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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.

Status of This Memo

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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 (such as Stateless Address Autoconfiguration (SLAAC)[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/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: Stateless 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/6LBR to assign an address/prefix to requesting nodes. In order to avoid addressing issues, only one single AAF is used in a deployment. An AAF assigns either addresses or prefixes but not both. This allows in certain cases to indicate whether a node is requesting an address or a prefix.

GAAO: Generic Address Assignment Option defined in this specification (Section 4).

3. Algorithmically Assigned Addresses and Prefixes

The IPv6 address assignment model within a local domain relies on randomly generated Interface Identifiers (IIDs). These can be assigned in two ways: a centralized approach using DHCPv6 ([RFC8415]), which guarantees collision-free addresses, or a decentralized approach using SLAAC ([RFC4862]). In the latter case, additional mechanisms are required to ensure address uniqueness and security, including Duplicate Address Detection (DAD) [RFC4862], Cryptographically Generated Addresses (CGA) [RFC3972], and Secure Neighbor Discovery (SEND) [RFC3971]. 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 Address Assignment Function (AAF) will work as a decentralized and distributed fashion. The AAF is used to assign addresses and prefixes to nodes as they join a network. To ensure consistency, all 6LoWPAN Nodes (6LNs), 6LoWPAN Routers (6LRs), and 6LoWPAN Boarder Routers (6LBRs) MUST use the same AAF within a given network instance. When a node needs an address/prefix, it first selects a

neighboring 6LR from those that responded to its initial Router Solicitation (RS) with a Router Advertisement (RA), as specified in [RFC6775]. The node then sends an explicit request for an address/prefix to the chosen 6LR. The 6LR assigns the address/prefix based on the AAF and automatically registers this assignment with the requesting 6LN. Depending on the specific technology and algorithm in use. The node may also need to explicitly register the assigned address/prefix to confirm its use. The overall process is illustrated in Figure 1.

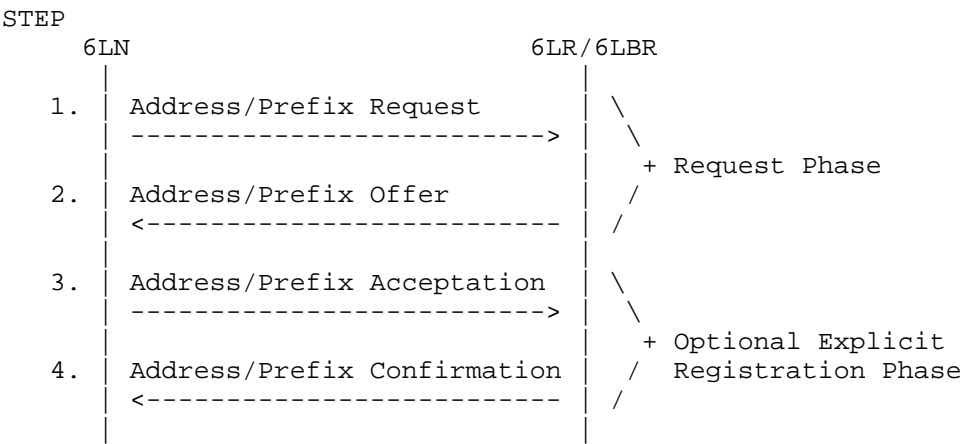


Figure 1: Address/Prefix assignment sequence.

The optional registration phase (steps 3 and 4) is implemented using the address/prefix registration procedures defined in [RFC8505], [RFC9685], or [I-D.ietf-6lo-prefix-registration]. In this phase, an Extended Address Registration Option (EARO) and Source Link-Layer Address Option (SLLAO) are used to register an address/prefix, which, in this context, is not self-generated. However, to initiate the process--specifically steps 1 and 2, a new Generic Address Assignment Option (GAAO) is required and proposed in this document. Because no existing mechanism can be readily used for this purpose. The remainder of this document first defines the format of this option (see (Section 4)), followed by a revised sequence and processing of Address/Prefix assignment messages (see (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.

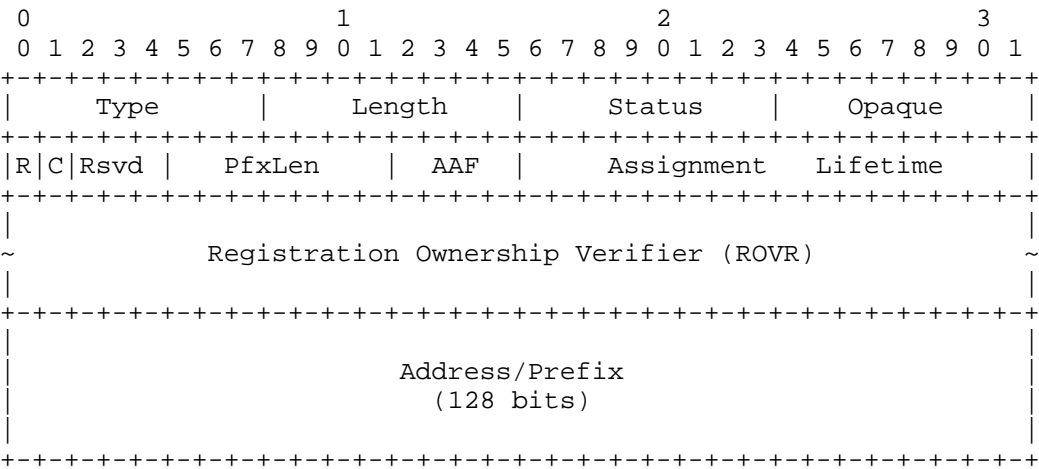


Figure 2: Generic Address Assignment Option (GAAO) format.

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 there is no address/prefix appended to the option. It is augmented by 2 (16 bytes) when an address/prefix is appended to the option.
- *Status:* As defined in [RFC8505].
- *Opaque:* As defined in [RFC8505].
- *R:* 1-bit flag for explicit Registration being requested. It MUST be initialized to 0 in Neighbor Solicitation (NS) message by the requester and MUST be ignored by the receiver. The 6LR/6LBR replying to the request with an Neighbor Advertisement (NA) message MAY set this bit to indicate that it requests a confirmation that the address/prefix is accepted and will be used. When the 6LR/6LBR sets the R-flag in a NA(GAAO) message, it indicates that no registration state has been created and that the requester 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. When the 6LR/6LBR does not set this R-flag, it implicitly indicates that the assigned address/prefix has been also registered and state created as specified in [RFC8505], [I-D.ietf-6lo-prefix-registration], and

[RFC9685], according to the type of the assigned address/prefix. In the event that the 6LN does not want to use the allocated address/prefix, it can de-register the allocation by sending an NS(EARO) setting registration lifetime to zero, as defined in [RFC8505].

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

PfxLen: 7-bit unsigned integer. It indicates the length of the prefix in bits.

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. In an NS(GAAO) message, it is RECOMMENDED to set this field to 0 to indicate there is no preference on how the address/prefix 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(GAAO) message, the field expresses a desired lifetime. It MAY be set to zero, indicating no particular desired lifetime. In NA(GAAO) message it expresses the granted 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 IPv6 address/prefix. This field MAY be present in NS(GAAO) request messages to indicate the prefix from which the address or sub-prefix has to be derived. If not present in NS(GAAO) message, it means that the returned address is implicitly used on the interface used to send the request. This field MUST be present in NA(GAAO) message that return a successful address/prefix allocation, but MUST NOT be present in case of error.

5. Messages Sequence and Processing

When a node bootstraps, it typically does multicast a RS message 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 a request at any time, not necessarily at boot time using NS and NA messages.

5.1. Request Phase

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

1. The node will issue an NS(GAAO) message to obtain the address/prefix. In this initial address request, GAAO Status field MUST be set to 0. Opaque, ROVR, and C-flag is set according to the local configuration. R-Flag MUST be set to 0. The AAF field SHOULD be set to zero unless by configuration there is a preference for the assignment algorithm. The Assignment Lifetime field MAY be set to the desired lifetime, or zero otherwise. The Address/Prefix field MAY be present to indicate the prefix from which prefix the address or sub-prefix has to be derived. In this case the PfxLen field MUST be set accordingly. If the Address/Prefix field is not present, the PfxLen field MUST be set to 0.
2. Assuming no errors occur, the node will receive an NA(GAAO) message where all fields have been copied back except for:
 - * *Pfxlen:* Now indicating the actual length of the prefix. For address assignments this field MUST be set to 64.
 - * *R:* The R-bit is set if the 6LR requests an explicit registration.
 - * *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.

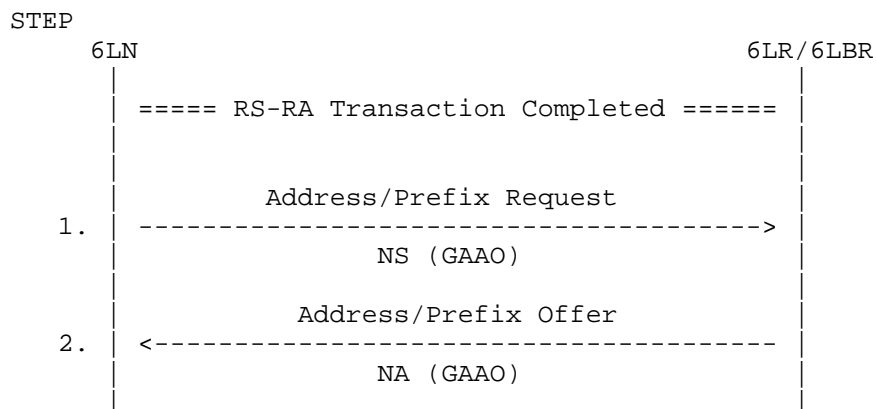


Figure 3: Address/Prefix assignment message sequence.

5.2. Explicit Registration Phase (Optional)

Depending on the algorithm in use and the underlying technology, the address/prefix 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 AAF 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 in the received NA(GAAO) message, the 6LN MUST register with the obtained address/prefix by following the procedures in [RFC8505], [RFC9685], or [I-D.ietf-6lo-prefix-registration] depending on the type of address/prefix. 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.

STEP

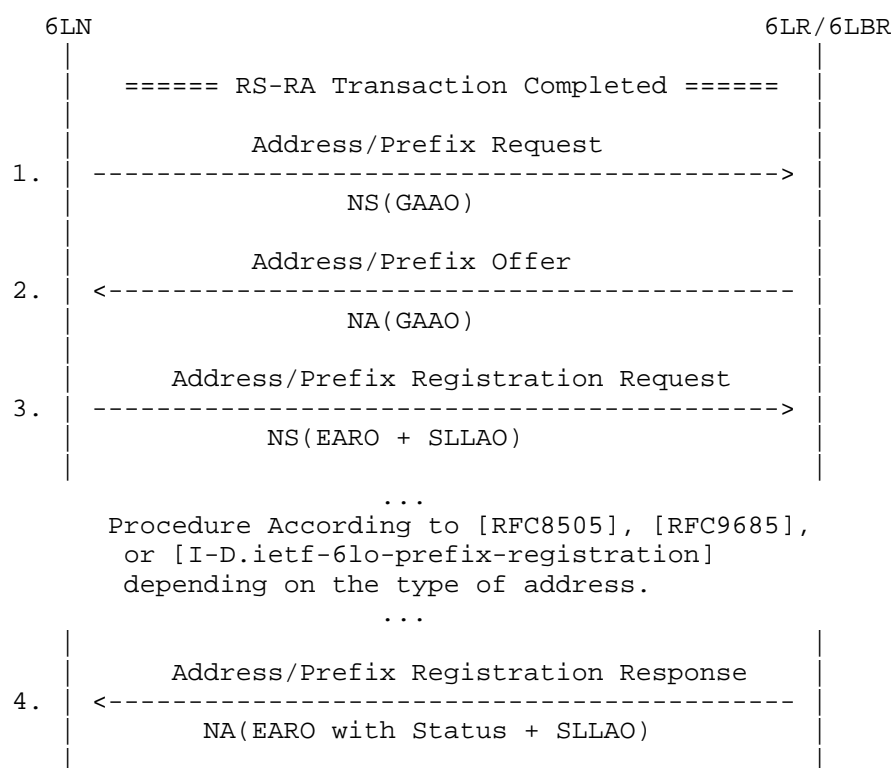


Figure 4: Address/Prefix assignment message sequence with explicit registration.

[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 registration phase **MUST** be used to perform an explicit registration and continue use the address/prefix. However, when using GAAO, and when performing 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

There are two ways to optimize the prefix/address Request Phase

5.3.1. GAAO with Address Registration

Prefix/address Registration utilize NS/NA transactions for the link-local address registration [RFC8505]. In this specification, for prefix/address Request procedure utilize an additional NS/NA transactions. To minimize the number of transactions, GAAO MAY be used together with the EARO option during address registration phase. This piggybacking approach provides flexibility and maintains compatibility with existing specifications [RFC8505]. In response the NA message will contain GAAO. Figure 5 illustrates the GAAO piggybacked within a link-layer address registration request and response.

STEP

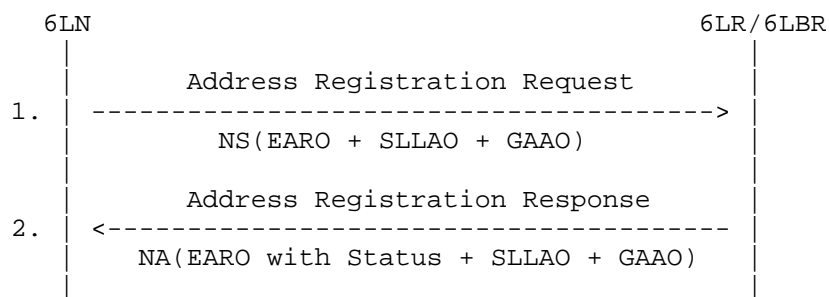


Figure 5: GAAO piggybacking with link-layer Address Registration.

5.3.2. GAAO with Router Discovery

Another optimization for prefix/address requests can be performed during the bootstrapping phase of a 6LN. The GAAO MAY be included in the initial RS message, thereby implicitly indicating that the node supports this specifications. Similarly, 6LR/6LBR that support this specification MUST include a prefix/address offer in a GAAO appended to the corresponding RA message, as depicted in Figure 6.

STEP

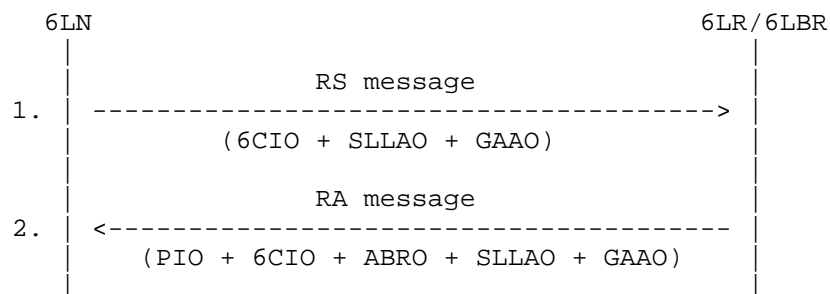


Figure 6: GAAO piggybacking with Router Discovery.

A 6LR that does not support GAAO will simply ignore this option, and the corresponding RA message will not include a GAAO. This behavior implicitly signals that the feature is not supported.

5.4. Error Conditions

GAAO Status field uses same Status values defined in [RFC6775] and [RFC8505], further revised in [RFC9010], for error reporting. This specification introduces a new Status value when the AAF in GAAO in an NS message is not in use in the 6LoWPAN network, as follows (see also Section 7):

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.

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	M-Flag for Generic Address Assignment Capability	[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 Status Field 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 an octet registry named "Address Assignment Function" and used to identify the used AAF. 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 recommendation about the lifetime and number of addresses per node described in Section 7 of [RFC8505] remain valid.

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