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Address Protected Neighbor Discovery for Low-power and Lossy Networks
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Abstract

This document defines an extension of 6LoWPAN Neighbor Discovery for application in low-power and lossy networks. The protocol is specified to be protected and to support multi-hop operation. A node computes its Cryptographic, Unique Interface ID, and associates one or more of its Registered Addresses with that Cryptographic ID in place of the EUI-64 that is used in RFC 6775 to uniquely identify the interface of the Registered Address. Once an address is registered with a Cryptographic ID, only the owner of that ID can modify the state in the 6LR and 6LBR regarding the Registered Address.

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1. Introduction

Neighbor discovery for IPv6 [RFC4861] and stateless address autoconfiguration [RFC4862], together referred to as neighbor discovery protocols (NDP), are defined for regular hosts operating with wired/wireless links. These protocols are not suitable and require optimizations for resource constrained, low power hosts operating over a low-power and lossy network (LLN) for low-power and lossy networks. Neighbor Discovery optimizations for 6LoWPAN networks include simple optimizations such as a host address registration feature using the address registration option (ARO) which is sent in unicast Neighbor Solicitation (NS) and Neighbor Advertisement (NA) messages [RFC6775]. With 6LoWPAN ND [RFC6775], the ARO option includes a EUI-64 address to uniquely identify the interface of the Registered Address on the registering device, so as to correlate further registrations for the same address and avoid address duplication. The EUI-64 address is not secured and its ownership cannot be verified. It results that any device claiming the same EUI-64 address may take over a registration and attract the

traffic for that address.

The limitation of the mechanism in [RFC6775] is that it does not enable to prove the UID itself, so any node connected to the subnet

and aware of the address/UID mapping may effectively fake the same UID and steal an address.

In this document, we extend 6LoWPAN ND to protect the address ownership with cryptographic material, but as opposed to Secure Neighbor Discovery (SEND) [RFC3971], [RFC3972], the cryptographic material is not embedded in the Interface ID (IID) in an IPv6 address but used as a correlator associated to the registration of the IPv6 address. This approach is made possible with 6LoWPAN ND [RFC6775], where the 6LR and the 6LBR maintain a state for each Registered Address. If a cryptographic ID is associated with an original 6LoWPAN ND registration and stored in the registration state, then it can be used to validate that any update to the registration state is made by the owner of that ID.

To achieve this, this specification replaces the EUI-64 address, that is used in 6LoWPAN ND to avoid address duplication, with cryptographic material whose ownership can be verified; it also provides new means for the 6LR to validate ownership of the registration thus that of the registered address by the registering device. The resulting protocol is called Protected Address Registration protocol (ND-PAR).

A node generates one 64-bit cryptographic ID and uses it as Unique Interface ID in the registration of (one or more of) its addresses with the 6LR, which it attaches to and uses as default router. The 6LR validates ownership of the cryptographic ID typically upon creation or update of a registration state, for instance following an apparent movement from a point of attachment to another. The ARO option is modified to carry the Unique Interface ID, and through the DAR/DAC exchange, the 6LBR is kept aware that this is the case, i.e. unique and whether the 6LR has verified the claim.

Compared with SeND, this specification saves ~1Kbytes in every NS/NA message. Also SeND requires one cryptographic address per IPv6 address. This specification separates the crypto from the IPv6

address so we can have more than one IPv6 address protected by the same crypto. SeND forces the IPv6 address to be cryptographic since it integrates the CGA as an IID. 6LoWPAN derives the IPv6 address from other things like a short address in 802.15.4 to enable a better compression. Looking from securing neighbor discovery protocol point of view the cryptographical ID protocol presented in this specification secures 6LoWPAN ND for Low-power and Lossy Networks.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

Readers are expected to be familiar with all the terms and concepts that are discussed in [RFC3971], [RFC3972], "Neighbor Discovery for IP version 6" [RFC4861], "IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals" [RFC4919], Neighbor Discovery Optimization for Low-power and Lossy Networks [RFC6775] where the 6LoWPAN Router (6LR) and the 6LoWPAN Border Router (6LBR) are introduced, and [I-D.ietf-6lo-backbone-router], which proposes an evolution of [RFC6775] for a larger applicability.

This document defines Crypto-ID as an identifier of variable size, while in most cases being 64 bits generated using cryptographical means explained in this document.

The document also conforms to the terms and models described in [RFC5889] and uses the vocabulary and the concepts defined in [RFC4291] for the IPv6 Architecture.

This document uses [RFC7102] for Terminology in Low power And Lossy Networks.

3. Requirements

In this section we state requirements of a secure neighbor discovery protocol for low-power and lossy networks.

The protocol MUST be based on the Neighbor Discovery Optimization for Low-power and Lossy Networks protocol defined in [RFC6775] due to the host-initiated interactions to allow for sleeping hosts, elimination of multicast-based address resolution for hosts, etc.

New options to be added to Neighbor Solicitation messages MUST lead to smaller packet sizes, especially compared with SEcure Neighbor Discovery (SEND). Smaller packet sizes facilitate low-power transmission by resource constrained nodes on lossy links.

The support of the registration mechanism SHOULD be extended to more LLN links than IEEE 802.15.4, matching at least the LLN links for which a 6lo "IPv6 over foo" specification exists, as well as Low-Power Wi-Fi.

As part of this extension, a mechanism to compute a unique Identifier should be provided, with the capability to form a Link Local Address that SHOULD be unique at least within the LLN connected to a 6LBR discovered by ND in each node within the LLN.

The Address Registration Option used in the ND registration SHOULD be extended to carry the relevant forms of Unique Interface IDentifier.

The Neighbour Discovery should specify the formation of a site-local address that follows the security recommendations from [RFC7217].

4. Protocol Interactions

Protected address and registration neighbor discovery protocol (ND-PAR) modifies Neighbor Discovery Optimization for Low-power and Lossy Networks [RFC6775] as explained in this section.

4.1. Overview

The scope of the present work is a 6LoWPAN Low Power Lossy Network (LLN), typically a stub network connected to a larger IP network via a Border Router called a 6LBR per [RFC6775].

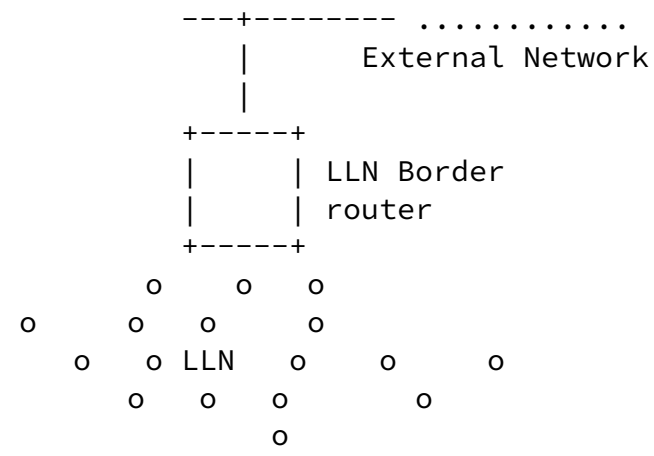


Figure 1: Basic Configuration

The 6LBR maintains a registration state for all devices in the attached LLN, and, in conjunction with the first-hop router (the 6LR), is in position to validate uniqueness and grant ownership of an IPv6 address before it can be used in the LLN. This is a fundamental difference with a classical network that relies on IPv6 address auto-configuration [RFC4862], where there is no guarantee of ownership from the network, and any IPv6 Neighbor Discovery packet must be individually secured [RFC3971].

In a route-over mesh network, the 6LR is directly connected to the host device; this specification expects that peer-wise Layer-2 security is deployed so that all the packets from a particular host are identified as such by the 6LR. The 6LR may be multiple hops away from the 6LBR. Packets are routed between the 6LR and the 6LBR via other 6LRs; this specification expects that a chain of trust is established so that a packet that was validated by the first 6LR can be safely routed by the next 6LRs to the 6LBR.

The [I-D.ietf-6tisch-architecture] suggests to use RPL [RFC6550] as the routing protocol between the 6LRs and the 6LBR, and to leverage [I-D.ietf-6lo-backbone-router] to extend the LLN in a larger multilink subnet [RFC4903]. In that model, a registration flow happens as shown in Figure 2. Note that network side of 6LBR is out of scope in this document.

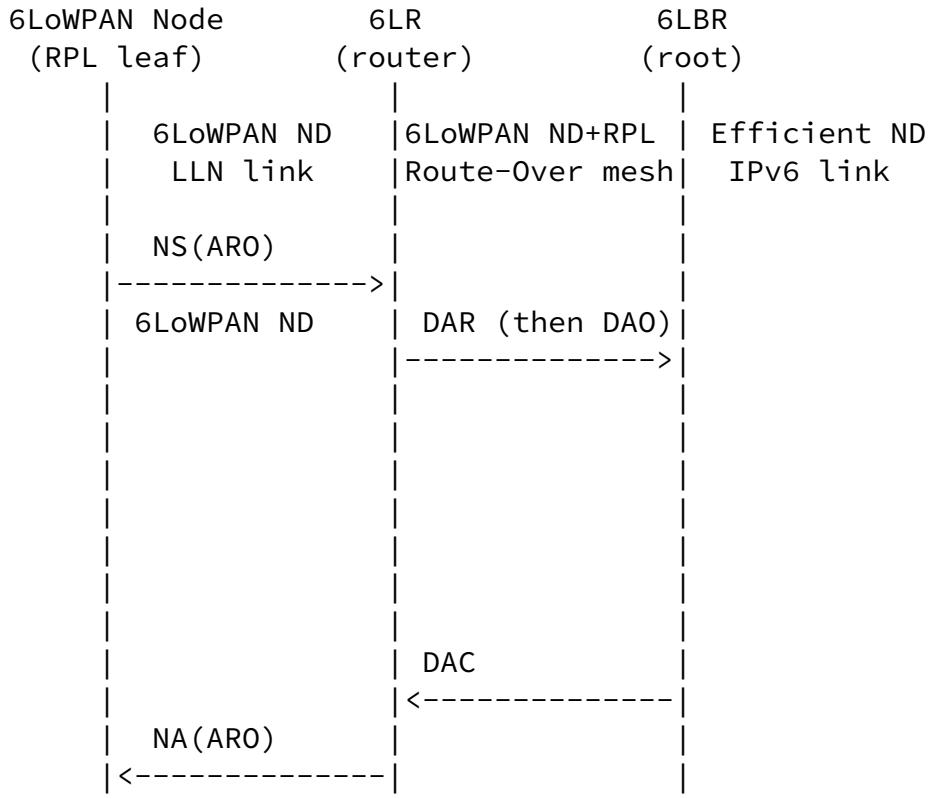


Figure 2: (Re-)Registration Flow over Multi-Link Subnet

A new device that joins the network auto-configures an address and performs an initial registration to an on-link 6LR with an NS message that carries a new Address Registration Option (ARO) [RFC6775]. The 6LR validates the address with the central 6LBR using a DAR/DAC exchange, and the 6LR confirms (or infirms) the address ownership with an NA message that also carries an Address Registration Option.

The registration mechanism in [RFC6775] was created for the original purpose of Duplicate Address Detection (DAD), whereby use of an address would be granted as long as the address is not already present in the subnet. But [RFC6775] does not require that the 6LR use the registration for source address validation (SAVI) [RFC7039].

Protected address registration protocol proposed in this document enforces SAVI. With this we ensure that only the owner uses the

source address. One consequence is that the onlink destination can trust that the source is the owner without doing SeND. In ND-PAR, since the addresses are not on link there is never a (NS Look-Up based) DNS resolution, all packets go to the router, 6LR first. 6LR has a state for the registered router (?) with the link and the MAC address, and usually L2 crypto associated. The 6LR only delivers packets to the real owner based on the state it has. 6LR can check a source as being the owner.

In order to validate address ownership, the registration mechanism (that goes all the way to the 6LBR with the DAR/DAC) enables the 6LBR to correlate further claims for a registered address with the device to which it is granted, based on a Unique Interface IDentifier (UID) that is derived from the MAC address of the device (EUI-64).

This document uses a randomly generated value as an alternate UID for the registration. Proof of ownership of the UID is passed with the first registration to a given 6LR, and enforced at the 6LR, which validates the proof. With this new operation, the 6LR allows only packets from a connected host if the connected host owns the registration of the source address of the packet.

In a multihop 6LoWPAN, the registration with Crypto-ID is propagated to 6LBR as described in Section 4.3. If a chain of trust is present between the 6LR and the 6LBR, then there is no need to propagate the proof of ownership to the 6LBR. All the 6LBR needs to know is that this particular UID is randomly generated, so as to enforce that any update via a different 6LR is also random.

4.2. Updating RFC 6775

Protocol interactions are as defined in Figure 2. The Crypto-ID is calculated as described in Section 4.2.1.

The Target Address field in NS message is set to the prefix concatenated with the node's address. This address does not need duplicate address detection as Crypto-ID is globally unique. So a host cannot steal an address that is already registered unless it has the key for the Crypto-ID. The same Crypto-ID can thus be used to

protect multiple addresses e.g. when the node receives a different

prefix.

Local or on-link protocol interactions are given in Figure 3. Crypto-ID and ARO are passed to and stored by the 6LR/6LBR on the first NS and not sent again in the next NS. The operation starts with 6LR sending a Router Advertisement (RA) message to 6LN.

The 6LR/6LBR ensures first-come/first-serve by storing the ARO and the Crypto-ID correlated to the target being registered. Then, if the node is the first to claim any address it likes, then it becomes owner of that address and the address is bound to the Crypto-ID in the 6LR/6LBR registry. This procedure avoids the constrained device to compute multiple keys for multiple addresses. The registration process allows the node to tie all the addresses to the same Crypto-ID and have the 6LR/6LBR enforce first come first serve after that.

6LN using multiple IPv6 addresses may happen when the node moves at a different place and receives a different prefix. The node uses the same Crypto-ID to protect its new IP address from other nodes stealing this address and trying to use it as their source address.

Note that if the device that moves always forms new MAC and IP address [RFC6775] can be used for registration. In case of a collision of the new MAC and therefore IP address, the node can easily form a new IPv6 address. This is one case where the use of Crypto-ID would not be needed. Crypto-ID or ND-PAR should be activated when when the IP address is claimed at another place, or for a different MAC address at the same place, e.g. for MAC address privacy [I-D.ietf-6man-ipv6-address-generation-privacy].

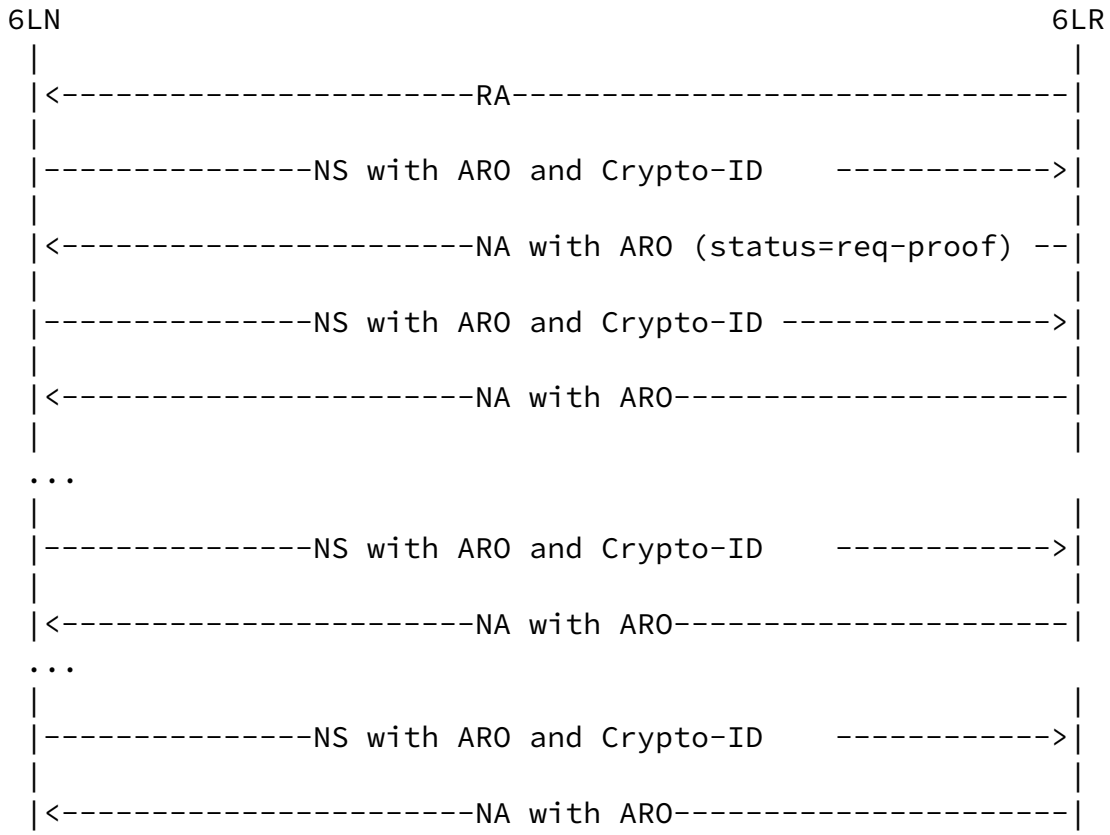


Figure 3: On-link Protocol Operation

Elliptic Curve Cryptography (ECC) is used in the calculation of cryptographical identifier. The digital signature is constructed by using the 6LN's private key over its EUI-64, i.e. its MAC address. The signature value is computed using the ECDSA signature algorithm and hash function used is SHA-256 [RFC6234]. Public Key is the most important parameter in CGA Parameters (sent by 6LN in an NS message). ECC Public Key could be in uncompressed form or in compressed form where the first octet of the OCTET STRING is 0x04 and 0x02 or 0x03, respectively. Point compression using secp256r1 reduces the key size by 32 octets.

After the calculation, 6LN sends it along with the CGA parameters in the first NS message, see Figure 3. In order to send Cryptographical Identifier a modified address registration option called Enhanced Address Registration Option (EARO) is defined in Figure 4. As defined in the figure this ID is variable length, varying between 64 to 128 bits. This ID is 128 bits long only if it is used as IPv6 address. This may happen when some application uses one IP address of the device as device ID. It would make sense in that case to build a real CGA IPv6 address. The prefix of the address would be

obtained from prefix information option (PIO in RA) [RFC4861].

6LN also sends some other parameters to enable 6LR or 6LBR to verify the Crypto-ID. The option shown in Figure 5 can be used. In that figure, CGA Parameters field contains the public key, prefix and some other values. It is simplified form of CGA Option defined in [RFC3971].

4.2.1. Crypto-ID Calculation

First, the modifier is set to a random or pseudo-random 128-bit value. Next, concatenate from left to right the modifier, 9 zero octets and the ECC public key. NIST P-256 or SHA-2 algorithm is applied on the concatenation. The 112 leftmost bits of the hash value is taken. Concatenate from left to right the modifier value, the subnet prefix and the encoded public key. NIST P-256 is executed on the concatenation. The leftmost bits of the result is used as the Crypto-ID. The length is normally 64 bits, it could be 128 bits.

In respecting the cryptographical algorithm agility [RFC7696], Curve 25519 [RFC7748] can also be used instead of NIST P-256. This is indicated by 6LN by setting the Crypto Type field in CGA Parameters Option to a value of 1. If 6LBR does not support Curve 25519, it will set Crypto Type field to zero. This means that the default algorithm will be used.

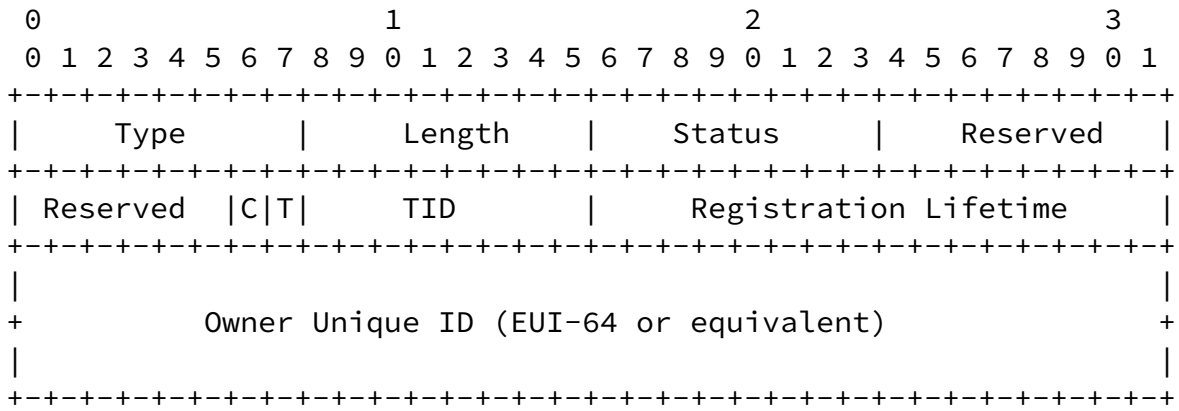


Figure 4: Enhanced Address Registration Option

Type:

TBA1

Length:

8-bit unsigned integer. The length of the option (including the type and length fields) in units of 8 bytes. The value 0 is

invalid. A value of 3 with the C flag set indicates a Crypto-ID of 128 bits.

Status:

8-bit unsigned integer. Indicates the status of a registration in the NA response. MUST be set to 0 in NS messages. See below.

Reserved:

This field is unused. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.

C:

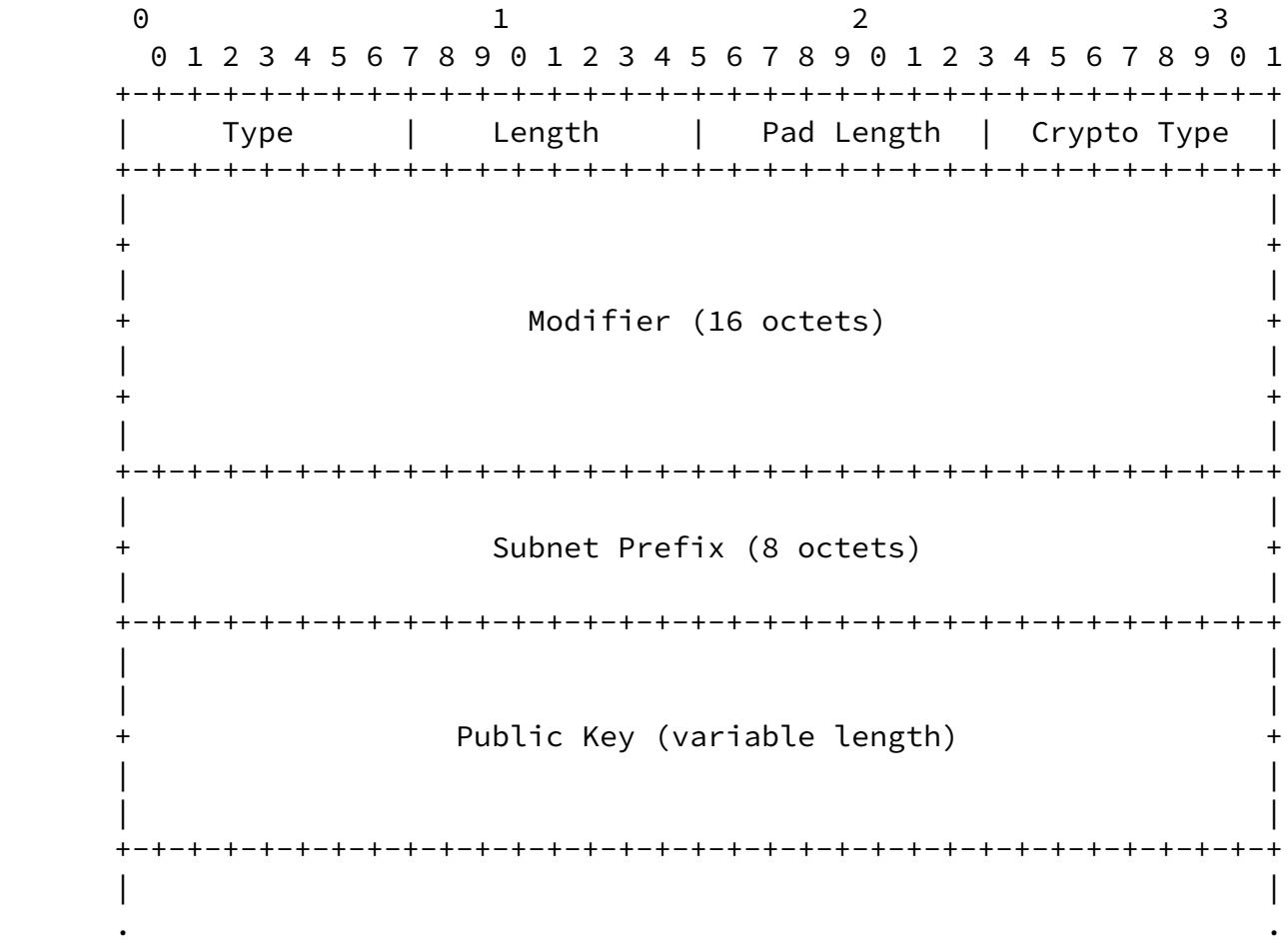
C bit when set is used to indicate that Owner Unique ID fields contains Crypto-ID.

T and TID:

Defined in [I-D.ietf-6lo-backbone-router].

Owner Unique ID:

In this specification, this field contains Crypto-ID, a variable length field to carry the cryptographical identifier or random UID. This field is normally 64 bits long. It could be 128 bits long if IPv6 address is used as the Crypto-ID.


0 1 2 3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
Type
Length
Pad Length
Crypto Type
Modifier (16 octets)
Subnet Prefix (8 octets)
Public Key (variable length)

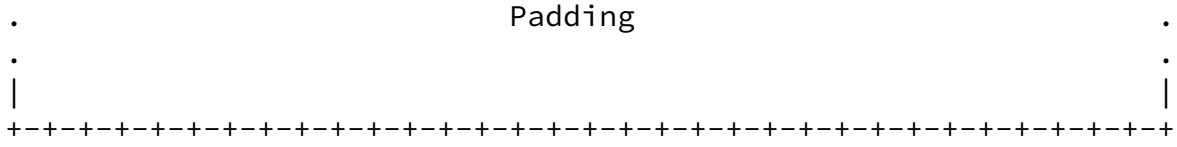


Figure 5: CGA Parameters Option

Type:

TBA2

Length:

The length of the option in units of 8 octets.

Pad Length:

The length of the Padding field.

Crypto Type:

The type of cryptographical algorithm used in calculation Crypto-ID. Default value of all zeros indicate NIST P-256. A value of 1 is assigned for Curve 25519.

Modifier:

128 bit random value.

Subnet Prefix:

64 bit subnet prefix.

Public Key:

ECC public key of 6LN.

Padding:

Padding A variable-length field making the option length a multiple of 8, containing as many octets as specified in the Pad Length field.

4.3. Multihop Operation

In multihop 6LoWPAN, 6LBR sends RAs with prefixes downstream and it is the 6LR that receives and relays them to the nodes. 6LR and 6LBR communicate with the ICMPv6 Duplicate Address Request (DAR) and the Duplicate Address Confirmation (DAC) messages. The DAR and DAC use the same message format as NS and NA with different ICMPv6 type values.

In ND-PAR we extend DAR/DAC messages to carry cryptographically generated UID.

In a multihop 6LoWPAN, the node exchanges the messages shown in Figure 2. The 6LBR must be aware of who owns an address (EUI-64) to defend the first user if there is an attacker on another 6LR. Because of this the content that the source signs and the signature needs to be propagated to the 6LBR in DAR message. For this purpose the DAR message sent by 6LR to 6LBR MUST contain CGA Parameters and Digital Signature Option carrying the CGA that the node calculates and its public key. DAR message also contains ARO.

It is possible that occasionally, 6LR may miss the node's UID (that it received in ARO). 6LR should be able to ask for it again. This is done by restarting the exchanges shown in Figure 3. The result enables 6LR to refresh the information that was lost. 6LR MUST send DAR message with ARO to 6LBR. 6LBR as a reply forms a DAC message

with the information copied from the DAR and the Status field is set to zero. With this exchange, the 6LBR can (re)validate and store the information to make sure that the 6LR is not a fake.

In some cases 6LBR may use DAC message to signal to 6LR that it expects Crypto-ID from 6LR also askss 6LR to verify the EUI-64 6LR received from 6LN. This may happen when a 6LN node is compromised and a fake node is sending the Crypto-ID as if it is the node's EUI-64. Note that the detection in this case can only be done by 6LBR not by 6LR.

5. Security Considerations

The same considerations regarding the threats to the Local Link Not Covered (as in [RFC3971]) apply.

The threats discussed in Section 9.2 of [RFC3971] are countered by the protocol described in this document as well.

As to the attacks to the protocol itself, denial of service attacks that involve producing a very high number of packets are deemed unlikely because of the assumptions on the node capabilities in low-power and lossy networks.

A collision of ID in ND-PAR is a really rare event that does not prevent the protocol operation though it opens a window for a node to hijack an address from another. The nodes would normally not be aware that they are in this situation, and the only thing they could do if they knew would be to steal addresses from one another, so the damage is limited to these 2 nodes.

6. IANA considerations

IANA is requested to assign two new option type values, TBA1 and TBA2 under the subregistry "IPv6 Neighbor Discovery Option Formats".

7. Acknowledgements

We are grateful to Mohit Sethi and Rene Struik for their comments that lead to many improvements in the document.

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