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An Update to 6LoWPAN ND
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Abstract

This specification updates 6LoWPAN Neighbor Discovery (RFC6775), to clarify the role of the protocol as a registration technique, simplify the registration operation in 6LoWPAN routers, and provide enhancements to the registration capabilities, in particular for the registration to a backbone router for proxy ND operations.

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1. Introduction

The scope of this draft is an IPv6 Low Power Lossy Network (LLN), which can be a simple star or a more complex mesh topology. The LLN may be anchored at an IPv6 Backbone Router (6BBR). The Backbone Routers interconnect the LLNs over a Backbone Link and emulate that the LLN nodes are present on the Backbone using proxy-ND operations.

IPv6 Neighbor Discovery (ND) Optimization for IPv6 over Low-Power Wireless Personal Area Networks(6LoWPANs) [RFC6775] introduced a proactive registration mechanism to IPv6 ND services for nodes belonging to a LLN.

This specification modifies and extends the behaviour and protocol elements of [RFC6775] to enable additional capabilities, in particular the registration to a 6BBR for proxy ND operations [I-D.ietf-6lo-backbone-router].

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 "Neighbor Discovery for IP version 6" [RFC4861], "IPv6 Stateless Address Autoconfiguration" [RFC4862], "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] and "Multi-link Subnet Support in IPv6" [I-D.ietf-ipv6-multilink-subnets].

Additionally, this document uses terminology from "Terms Used in Routing for Low-Power and Lossy Networks" [RFC7102] and [I-D.ietf-6tisch-terminology], as well as this additional terminology:

Backbone This is an IPv6 transit link that interconnects 2 or more Backbone Routers. It is expected to be deployed as a high speed backbone in order to federate a potentially large set of LLNS. Also referred to as a LLN backbone or Backbone network.

Backbone Router An IPv6 router that federates the LLN using a Backbone link as a backbone. A 6BBR acts as a 6LoWPAN Border Routers (6LBR) and an Energy Aware Default Router (NEAR).

Extended LLN This is the aggregation of multiple LLNs as defined in [RFC4919], interconnected by a Backbone Link via Backbone Routers, and forming a single IPv6 MultiLink Subnet.

Registration The process during which a wireless Node registers its address(es) with the Border Router so the 6BBR can proxy ND for it over the backbone.

Binding The state in the 6BBR that associates an IP address with a MAC address, a port and some other information about the node that owns the IP address.

Registered Node The node for which the registration is performed, which owns the fields in the EARO option.

Registering Node The node that performs the registration to the 6BBR, either for one of its own addresses, in which case it is Registered Node and indicates its own MAC Address as SLLA in the NS(ARO), or on behalf of a Registered Node that is reachable over a LLN mesh. In the latter case, if the Registered Node is reachable from the 6BBR over a Mesh-Under mesh, the Registering Node indicates the MAC Address of the Registered Node as SLLA in the NS(ARO). Otherwise, it is expected that the Registered Device is reachable over a Route-Over mesh from the Registering Node, in which case the SLLA in the NS(ARO) is that of the Registering Node, which causes it to attract the packets from the 6BBR to the Registered Node and route them over the LLN.

Registered Address The address owned by the Registered Node node that is being registered.

3. Updating RFC 6775

The support of this specification is signaled in Router Advertisement (RA) messages by 6LoWPAN Router (6LR) (how: tbd). Support for this specification can also be inferred from the update of the ARO option in the ND exchanges

. A Registering Node that supports this specification will favor registering to a 6LR that indicates support for this specification over that of [RFC6775].

3.1. Extended Address Registration Option

This specification extends the Address Registration Option (ARO) used for the process of address registration. The new ARO is referred to as Extended ARO (EARO), and its semantics are modified as follows:

The address that is being registered with a Neighbor Solicitation (NS) with an EARO is now the Target Address, as opposed to the Source Address as specified in [RFC6775]. This change enables a 6LBR to use an address of his as source to the proxy-registration of an address that belongs to a LLN Node to a 6BBR. This also limits the use of an address as source address before it is registered and the associated Duplicate Address Detection (DAD) is complete.

The Unique ID in the EARO option does no more have to be a MAC address. A new TLV format is introduced and a IANA registry is created for the type (TBD). This enables in particular the use of a Provable Temporary UID (PT-UID) as opposed to burn-in MAC address, the PT-UID providing a trusted anchor by the 6LR and 6LBR to protect the state associated to the node.

The specification introduces a Transaction ID (TID) field in the EARO. The TID MUST be provided by a node that supports this specification and a new T flag MUST be set to indicate so. The T bit can be used to determine whether the peer supports this specification.

3.2. Registering the Target Address

One of the requirements that this specification serves is the capability by a router such as a RPL root to proxy-register an address to a 6BBR on behalf of a 6LN, as discussed in Appendix A.4. In order to serve that requirement, this specification changes the behaviour of the 6LN and the 6LR so that the Registered Address is found in the Target Address field of the NS and NA messages as opposed to the Source Address.

With this convention, a TLLA option would indicate the link-layer address of the 6LN that owns the address, whereas the SLLA Option in a NS message indicates that of the Registering Node, which can be the owner device, or a proxy.

Since the Registering Node is the one that has reachability with the 6LR, and is the one expecting packets for the 6LN, it makes sense to maintain compatibility with [RFC6775], and it is REQUIRED that an SLLA Option is always placed in a registration NS(EARO) message.

3.3. Link-local Addresses and Registration

Considering that LLN nodes are often not wired and may move, there is no guarantee that a link-local address stays unique between a potentially variable and unbounded set of neighboring nodes. Compared to [RFC6775], this specification only requires that a link-local address is unique from the perspective of the peering nodes. This simplifies the Duplicate Address Detection (DAD) for link-local addresses, and there is no DAR/DAC exchange between the 6LR and a 6LBR for link-local addresses.

Additionally, [RFC6775] requires that a 6LoWPAN Node (6LN) uses an address being registered as the source of the registration message. This generates complexities in the 6LR to be able to cope with a potential duplication, in particular for global addresses. To simplify this, a 6LN and a 6LR that conform this specification always use link-local addresses as source and destination addresses for the registration NS/NA exchange. As a result, the registration is globally faster, and some of the complexity is removed.

In more details:

An exchange between two nodes using link-local addresses implies that they are reachable over one hop and that at least one of the 2 nodes acts as a 6LR. A node MUST register a link-local address to a 6LR in order to obtain reachability from that 6LR beyond the current exchange, and in particular to use the link-local address as source address to register other addresses, e.g. global addresses. If there is no collision with an address previously registered to this 6LR by another 6LN, then, from the standpoint of this 6LR, this link-local address is unique and the registration is acceptable. Conversely, it may possibly happen that two different 6LRs expose a same link-local address but different link-layer addresses. In that case, a 6LN may only interact with one of the 6LR so as to avoid confusion in the 6LN neighbor cache.

The DAD process between the 6LR and a 6LoWPAN Border Router (6LBR), which is based on a Duplicate Address Request (DAR) / Duplicate Address Confirmation (DAC) exchange as described in [RFC6775], does not need to take place for link-local addresses.

It is desired that a 6LR does not need to modify its state associated to the Source Address of an NS(EARO) message. For that reason, when possible, it is RECOMMENDED to use an address that is already registered with a 6LR

When registering to a 6LR that conforms this specification, a node MUST use a link-local address as the source address of the registration, whatever the type of IPv6 address that is being registered. That link-local Address MUST be either already registrered, or the address that is being registered.

When a Registering Node does not have an already-registered address, it MUST register a link-local address, using it as both the Source and the Target Address of an NS(EARO) message. In that case, it is RECOMMENDED to use a link-local address that is (expected to be) globally unique, e.g. derived from a burn-in MAC address. An EARO option in the response NA indicates that the 6LR supports this specification.

Since there is no DAR/DAC exchange for link-local addresses, the 6LR may answer immediately to the registration of a link-local address, based solely on its existing state and the Source Link-Layer Option that MUST be placed in the NS(EARO) message as required in [RFC6775].

A node needs to register its IPv6 Global Unicast IPv6 Addresses (GUA) to a 6LR in order to obtain a global reachability for these addresses via that 6LR. As opposed to a node that complies to [RFC6775], a Registering Node registering a GUA does use that GUA as Source Address for the registration to a 6LR that conforms this

specification. The DAR/DAC exchange MUST take place for non-link-local addresses as prescribed by [RFC6775].

4. Applicability and Requirements Served

This specification extends 6LoWPAN ND to sequence the registration and serves the requirements expressed Appendix A.1 by enabling the mobility of devices from one LLN to the next based on the complementary work in [I-D.ietf-6lo-backbone-router].

In the context of the the TimeSlotted Channel Hopping (TSCH) mode of [IEEE802154], the 6TiSCH architecture [I-D.ietf-6tisch-architecture] introduces how a 6LoWPAN ND host could connect to the Internet via a RPL mesh Network, but this requires additions to the 6LOWPAN ND protocol to support mobility and reachability in a secured and manageable environment. This specification details the new operations that are required to implement the 6TiSCH architecture and serves the requirements listed in Appendix A.2.

The term LLN is used loosely in this specification to cover multiple types of WLANs and WPANs, including Low-Power Wi-Fi, BLUETOOTH(R) Low Energy, IEEE802.11AH and IEEE802.15.4 wireless meshes, so as to address the requirements discussed in Appendix A.3

This specification can be used by any wireless node to associate at Layer-3 with a 6BBR and register its IPv6 addresses to obtain routing services including proxy-ND operations over the backbone, effectively providing a solution to the requirements expressed in Appendix A.4.

Efficiency aware IPv6 Neighbor Discovery Optimizations [I-D.chakrabarti-nordmark-6man-efficient-nd] suggests that 6LoWPAN ND [RFC6775] can be extended to other types of links beyond IEEE802.15.4 for which it was defined. The registration technique is beneficial when the Link-Layer technique used to carry IPv6 multicast packets is not sufficiently efficient in terms of delivery ratio or energy consumption in the end devices, in particular to enable energy-constrained sleeping nodes. The value of such extension is especially apparent in the case of mobile wireless nodes, to reduce the multicast operations that are related to classical ND ([RFC4861], [RFC4862]) and plague the wireless medium. This serves scalability requirements listed in Appendix A.6.

5. The Enhanced Address Registration Option (EARO)

With the ARO option defined in 6LoWPAN ND [RFC6775], the address being registered and its owner can be uniquely identified and matched with the Binding Table entries of each Backbone Router.

The Enhanced Address Registration Option (EARO) is intended to be used as a replacement to the ARO option within Neighbor Discovery NS and NA messages between a LLN node and its 6LoWPAN Router (6LR), as well as in Duplicate Address Request (DAR) and the Duplicate Address Confirmation (DAC) messages between 6LRs and 6LBRs in LLNs meshes such as 6TiSCH networks.

An NS message with an EARO option is a registration if and only if it also carries an SLLAO option. The AERO option also used in NS and NA messages between Backbone Routers over the backbone link to sort out the distributed registration state, and in that case, it does not carry the SLLAO option and is not confused with a registration.

The EARO extends the ARO and is recognized by the setting of the TID bit. A node that supports this specification MUST always use an EARO as a replacement to an ARO in its registration to a router. This is harmless since the TID bit and fields are reserved in [RFC6775] are ignored by a legacy router. A router that supports this specification answers to an ARO with an ARO and to an EARO with an EARO.

This specification changes the behavior of the peers in a registration flows. To enable backward compatibility, a node that registers to a router that is not known to support this specification MUST behave as prescribed by [RFC6775]. Once the router is known to support this specification, the node MUST obey this specification.

When using the EARO option, the address being registered is found in the Target Address field of the NS and NA messages. This differs from 6LoWPAN ND [RFC6775] which specifies that the address being registered is the source of the NS.

The reason for this change is to enable proxy-registrations on behalf of other nodes in Route-Over meshes, for instance to enable that a RPL root registers addresses on behalf LLN nodes that are deeper in a 6TiSCH mesh. In that case, the Registering Node MUST indicate its own address as source of the ND message and its MAC address in the Source Link-Layer Address Option (SLLAO), since it still expects to get the packets and route them down the mesh. But the Registered Address belongs to another node, the Registered Node, and that address is indicated in the Target Address field of the NS message.

One way of achieving all the above is for a node to first register an address that it owns in order to validate that the router supports this specification, placing the same address in the Source and Target Address fields of the NS message. The node may for instance register an address that is based on EUI-64. For such address, DAD is not

required and using the SLLAO option in the NS is actually more amenable with older ND specifications such as ODAD [RFC4429].

Once that first registration is complete, the node knows from the setting of the TID in the response whether the router supports this specification. If this is verified, the node may register other addresses that it owns, or proxy-register addresses on behalf some another node, indicating those addresses being registered in the Target Address field of the NS messages, while using one of its own, already registered, addresses as source.

The format of the EARO option is as follows:

```
   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 = 2  |    Status     |   Reserved    |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |   Reserved  |T|     TID       |     Registration Lifetime     |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |                                                               |
  +         Owner Unique ID   (EUI-64 or equivalent)              +
  |                                                               |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1: EARO

Option Fields

Type:

Length: 2

Status:

Value	Description
0..2	See [RFC6775]. Note that a Status of 1 "Duplicate Address" applies to the Registered Address. If the Source Address conflicts with an existing registration, "Duplicate Source Address" should be used instead
3	Moved: The registration fails because it is not the freshest
4	Removed: The binding state was removed. This may be placed in an asynchronous NS(ARO) message, or as the rejection of a proxy registration to a Backbone Router
5	Proof requested: The registering node is challenged for owning the registered address or for being an acceptable proxy for the registration
6	Duplicate Source Address: The address used as source of the NS(ARO) conflicts with an existing registration.
7	Administrative Rejection: The address being registered is reserved for another use by an administrative decision (e.g. placed in a DHCPv6 pool); The Registering Node is requested to form a different address and retry
8	Invalid Registered Address: The address being registered is not usable on this link, e.g. it is not topologically correct
9	Invalid Source Address: The address used as source of the NS(ARO) is not usable on this link, e.g. it is not topologically correct

Table 1

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

T: One bit flag. Set if the next octet is a used as a TID.

TID: 1-byte integer; a transaction id that is maintained by the node and incremented with each transaction. it is recommended that the node maintains the TID in a persistent storage.

Registration Lifetime: 16-bit integer; expressed in minutes. 0 means that the registration has ended and the state should be removed.

Owner Unique Identifier (OUI): A globally unique identifier for the node associated. This can be the EUI-64 derived IID of an interface, or some provable ID obtained cryptographically.

New status values are introduced, their values to be confirmed by IANA:

Moved: This status indicates that the registration is rejected because another more recent registration was done, as indicated by a same OUI and a more recent TID. One possible cause is a stale registration that has progressed slowly in the network and was passed by a more recent one. It could also indicate a OUI collision.

Removed: This status is expected in asynchronous messages from a registrar (6LR, 6LBR, 6BBR) to indicate that the registration state is removed, for instance due to time out of a lifetime, or a movement. It is used for instance by a 6BBR in a NA(ARO) message to indicate that the ownership of the proxy state on the backbone was transfered to another 6BBR, which is indicative of a movement of the device. The receiver of the NA is the device that has performed a registration that is now stale and it should clean up its state.

6. Backward Compatibility

6.1. Legacy 6LoWPAN Node

A legacy 6LN will use the registered address as source and will not use an EARO option. In order to be backward compatible, an updated 6LR needs to accept that registration if it is valid per [RFC3972], and manage the binding cache accordingly.

The main difference with [RFC3972] is that DAR/DAC exchange for DAD may be avoided for link-local addresses. Additionally, the 6LR SHOULD use an EARO in the reply, and may use all the status codes defined in this specification.

6.2. Legacy 6LoWPAN Router

The first registration by a an updated 6LN is for a link-local address, using that link-local address as source. A legacy 6LN will not makes a difference and accept -or reject- that registration as if the 6LN was a legacy node.

An updated 6LN will always use an EARO option in the registration NS message, whereas a legacy 6LN will always areply with an ARO option in the NA message. So from that first registration, the updated 6LN can figure whether the 6LR supports this specification or not.

When facing a legacy 6LR, an updated 6LN may attempt to find an alternate 6LR that is updated. In order to be backward compatible, based on the discovery that a 6LR is legacy, the 6LN needs to fallback to legacy behaviour and source the packet with the registrered address.

The main difference is that the updated 6LN SHOULD use an EARO in the request regardless of the type of 6LN, legacy or updated

6.3. Legacy 6LoWPAN Border Router

With this specification, the DAR/DAC transports an EARO option as opposed to an ARO option. As described for the NS/NA exchange, devices that support this specification always use an EARO option and all the associated behaviour.

7. Security Considerations

This specification expects that the link layer is sufficiently protected, either by means of physical or IP security for the Backbone Link or MAC sublayer cryptography. In particular, it is expected that the LLN MAC provides secure unicast to/from the Backbone Router and secure Broadcast from the Backbone Router in a way that prevents tempering with or replaying the RA messages.

The use of EUI-64 for forming the Interface ID in the link-local address prevents the usage of Secure ND ([RFC3971] and [RFC3972]) and address privacy techniques. This specification RECOMMENDS the use of additional protection against address theft such as provided by [I-D.sarikaya-6lo-ap-nd], which guarantees the ownership of the OUID.

When the ownership of the OUID cannot be assessed, this specification limits the cases where the OUID and the TID are multicasted, and obfuscates them in responses to attempts to take over an address.

The LLN nodes depend on the 6LBR and the 6BBR for their operation. A trust model must be put in place to ensure that the right devices are acting in these roles, so as to avoid threats such as black-holing, or bombing attack whereby an impersonated 6LBR would destroy state in the network by using the "Removed" status code.

8. IANA Considerations

This document requires the following additions:

Address Registration Option Status Values Registry

Status	Description
3	Moved
4	Removed
5	Proof requested
6	Invalid Source Address
7	Administrative Rejection

IANA is required to change the registry accordingly

Table 2: New ARO Status values

9. Acknowledgments

Kudos to Eric Levy-Abegnoli who designed the First Hop Security infrastructure at Cisco.

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Appendix A. Requirements

This section lists requirements that were discussed at 6lo for an update to 6LoWPAN ND. This specification meets most of them, but those listed in Appendix A.5 which are deferred to a different specification such as [I-D.sarikaya-6lo-ap-nd].

A.1. Requirements Related to Mobility

Due to the unstable nature of LLN links, even in a LLN of immobile nodes a 6LN may change its point of attachment to a 6LR, say 6LR-a, and may not be able to notify 6LR-a. Consequently, 6LR-a may still attract traffic that it cannot deliver any more. When links to a 6LR change state, there is thus a need to identify stale states in a 6LR and restore reachability in a timely fashion.

Req1.1: Upon a change of point of attachment, connectivity via a new 6LR MUST be restored timely without the need to de-register from the previous 6LR.

Req1.2: For that purpose, the protocol MUST enable to differentiate between multiple registrations from one 6LoWPAN Node and registrations from different 6LoWPAN Nodes claiming the same address.

Req1.3: Stale states MUST be cleaned up in 6LRs.

Req1.4: A 6LoWPAN Node SHOULD also be capable to register its Address to multiple 6LRs, and this, concurrently.

A.2. Requirements Related to Routing Protocols

The point of attachment of a 6LN may be a 6LR in an LLN mesh. IPv6 routing in a LLN can be based on RPL, which is the routing protocol that was defined at the IETF for this particular purpose. Other

routing protocols than RPL are also considered by Standard Defining Organizations (SDO) on the basis of the expected network characteristics. It is required that a 6LoWPAN Node attached via ND to a 6LR would need to participate in the selected routing protocol to obtain reachability via the 6LR.

Next to the 6LBR unicast address registered by ND, other addresses including multicast addresses are needed as well. For example a routing protocol often uses a multicast address to register changes to established paths. ND needs to register such a multicast address to enable routing concurrently with discovery.

Multicast is needed for groups. Groups MAY be formed by device type (e.g. routers, street lamps), location (Geography, RPL sub-tree), or both.

The Bit Index Explicit Replication (BIER) Architecture [I-D.ietf-bier-architecture] proposes an optimized technique to enable multicast in a LLN with a very limited requirement for routing state in the nodes.

Related requirements are:

Req2.1: The ND registration method SHOULD be extended in such a fashion that the 6LR MAY advertise the Address of a 6LoWPAN Node over the selected routing protocol and obtain reachability to that Address using the selected routing protocol.

Req2.2: Considering RPL, the Address Registration Option that is used in the ND registration SHOULD be extended to carry enough information to generate a DAO message as specified in [RFC6550] section 6.4, in particular the capability to compute a Path Sequence and, as an option, a RPLInstanceID.

Req2.3: Multicast operations SHOULD be supported and optimized, for instance using BIER or MPL. Whether ND is appropriate for the registration to the 6BBR is to be defined, considering the additional burden of supporting the Multicast Listener Discovery Version 2 [RFC3810] (MLDv2) for IPv6.

A.3. Requirements Related to the Variety of Low-Power Link types

6LoWPAN ND [RFC6775] was defined with a focus on IEEE802.15.4 and in particular the capability to derive a unique Identifier from a globally unique MAC-64 address. At this point, the 6lo Working Group is extending the 6LoWPAN Header Compression (HC) [RFC6282] technique to other link types ITU-T G.9959 [RFC7428], Master-Slave/Token-Passing [I-D.ietf-6lo-6lobac], DECT Ultra Low Energy

[I-D.ietf-6lo-dect-ule], Near Field Communication [I-D.ietf-6lo-nfc], IEEE802.11ah [I-D.delcarpio-6lo-wlanah], as well as IEEE1901.2 Narrowband Powerline Communication Networks [I-D.popa-6lo-6loplc-ipv6-over-ieee19012-networks] and BLUETOOTH(R) Low Energy [RFC7668].

Related requirements are:

Req3.1: 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 an "IPv6 over foo" specification exists, as well as Low-Power Wi-Fi.

Req3.2: 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.

Req3.3: The Address Registration Option used in the ND registration SHOULD be extended to carry the relevant forms of unique Identifier.

Req3.4: The Neighbour Discovery should specify the formation of a site-local address that follows the security recommendations from [RFC7217].

A.4. Requirements Related to Proxy Operations

Duty-cycled devices may not be able to answer themselves to a lookup from a node that uses classical ND on a backbone and may need a proxy. Additionally, the duty-cycled device may need to rely on the 6LBR to perform registration to the 6BBR.

The ND registration method SHOULD defend the addresses of duty-cycled devices that are sleeping most of the time and not capable to defend their own Addresses.

Related requirements are:

Req4.1: The registration mechanism SHOULD enable a third party to proxy register an Address on behalf of a 6LoWPAN node that may be sleeping or located deeper in an LLN mesh.

Req4.2: The registration mechanism SHOULD be applicable to a duty-cycled device regardless of the link type, and enable a 6BBR to operate as a proxy to defend the registered Addresses on its behalf.

Req4.3: The registration mechanism SHOULD enable long sleep durations, in the order of multiple days to a month.

A.5. Requirements Related to Security

In order to guarantee the operations of the 6LoWPAN ND flows, the spoofing of the 6LR, 6LBR and 6BBRs roles should be avoided. Once a node successfully registers an address, 6LoWPAN ND should provide energy-efficient means for the 6LBR to protect that ownership even when the node that registered the address is sleeping.

In particular, the 6LR and the 6LBR then should be able to verify whether a subsequent registration for a given Address comes from the original node.

In a LLN it makes sense to base security on layer-2 security. During bootstrap of the LLN, nodes join the network after authorization by a Joining Assistant (JA) or a Commissioning Tool (CT). After joining nodes communicate with each other via secured links. The keys for the layer-2 security are distributed by the JA/CT. The JA/CT can be part of the LLN or be outside the LLN. In both cases it is needed that packets are routed between JA/CT and the joining node.

Related requirements are:

Req5.1: 6LoWPAN ND security mechanisms SHOULD provide a mechanism for the 6LR, 6LBR and 6BBR to authenticate and authorize one another for their respective roles, as well as with the 6LoWPAN Node for the role of 6LR.

Req5.2: 6LoWPAN ND security mechanisms SHOULD provide a mechanism for the 6LR and the 6LBR to validate new registration of authorized nodes. Joining of unauthorized nodes MUST be impossible.

Req5.3: 6LoWPAN ND security mechanisms SHOULD lead to small packet sizes. In particular, the NS, NA, DAR and DAC messages for a re-registration flow SHOULD NOT exceed 80 octets so as to fit in a secured IEEE802.15.4 frame.

Req5.4: Recurrent 6LoWPAN ND security operations MUST NOT be computationally intensive on the LoWPAN Node CPU. When a Key hash calculation is employed, a mechanism lighter than SHA-1 SHOULD be preferred.

Req5.5: The number of Keys that the 6LoWPAN Node needs to manipulate SHOULD be minimized.

Req5.6: The 6LoWPAN ND security mechanisms SHOULD enable CCM* for use at both Layer 2 and Layer 3, and SHOULD enable the reuse of security code that has to be present on the device for upper layer security such as TLS.

Req5.7: Public key and signature sizes SHOULD be minimized while maintaining adequate confidentiality and data origin authentication for multiple types of applications with various degrees of criticality.

Req5.8: Routing of packets should continue when links pass from the unsecured to the secured state.

Req5.9: 6LoWPAN ND security mechanisms SHOULD provide a mechanism for the 6LR and the 6LBR to validate whether a new registration for a given address corresponds to the same 6LoWPAN Node that registered it initially, and, if not, determine the rightful owner, and deny or clean-up the registration that is duplicate.

A.6. Requirements Related to Scalability

Use cases from Automatic Meter Reading (AMR, collection tree operations) and Advanced Metering Infrastructure (AMI, bi-directional communication to the meters) indicate the needs for a large number of LLN nodes pertaining to a single RPL DODAG (e.g. 5000) and connected to the 6LBR over a large number of LLN hops (e.g. 15).

Related requirements are:

Req6.1: The registration mechanism SHOULD enable a single 6LBR to register multiple thousands of devices.

Req6.2: The timing of the registration operation should allow for a large latency such as found in LLNs with ten and more hops.

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