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March 13, 2012

Energy Aware IPv6 Neighbor Discovery Optimizations
draft-chakrabarti-nordmark-energy-aware-nd-02

Abstract

IPv6 Neighbor Discovery (RFC 4861) protocol has been designed for neighbor's address resolution, unreachability detection, address autoconfiguration, router advertisement and solicitation. With the progress of Internet adoption on various industries including home, wireless and machine-to-machine communications, there is a desire for optimizing legacy IPv6 Neighbor Discovery protocol to be more efficient in terms of number of signaling messages in the network. Efficient IPv6 Neighbor Discovery is useful for energy-efficient networks and as well for overlay networks such as VLANs with large number of nodes. This document describes a method of optimizations by reducing periodic multicast messages, frequent Neighbor Solicitation messages and discusses interoperability with legacy IPv6 nodes. It also addresses the ND denial of service issues by introducing node Registration procedure.

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1. Introduction

IPv6 ND [ND] is based on multicast signaling messages on the local link in order to avoid broadcast messages. Following power-on and initialization of the network in IPv6 Ethernet networks, a node joins the solicited-node multicast address on the interface and then performs duplicate address detection (DAD) for the acquired link-local address by sending a solicited-node multicast message to the link. After that it sends multicast router solicitation (RS) messages to the all-router address to solicit router advertisements. Once the host receives a valid router advertisement (RA) with the "A" flag, it autoconfigures the IPv6 address with the advertised prefix in the router advertisement (RA). Besides this, the IPv6 routers usually send router advertisements periodically on the network. RAs are sent to the all-node multicast address. Nodes send Neighbor Solicitation (NS) and Neighbor Advertisement (NA) messages to resolve the IPv6 address of the destination on the link. These NS/NA messages are also often multicast messages and it is assumed that the node is on the same link and relies on the fact that the destination node is always powered and generally available.

The periodic RA messages in IPv6 ND [ND], and NS/NA messages require all IPv6 nodes in the link to be in listening mode even when they are in idle cycle. It requires energy for the sleepy nodes which may otherwise be sleeping during the idle period. Non-sleepy nodes also save energy if instead of continuous listening, they actually pro-actively synchronize their states with one or two entities in the network. With the explosion of Internet-of-things and machine to machine communication, more and more devices would be using IPv6 addresses in the near future. Today, most electricity usage in United States and in developing countries are in the home buildings and commercial buildings; the electronic Internet appliances/tablets etc. are gaining popularities in the modern home networks. These network of nodes must be conscious about saving energy in order to reduce user-cost. This will eventually reduce stress on electrical grids and carbon foot-print.

IPv6 Neighbor Discovery Optimization for 6LoWPAN [6LOWPAN-ND] addresses many of the concerns described above by optimizing the Router advertisement, minimizing periodic multicast packets in the network and introducing two new options - one for node registration and another for prefix dissemination in a network where all nodes in the network are uniquely identified by their 64-bit Interface Identifier. EUI-64 identifiers are recommended as unique Interface Identifiers, however if the network is isolated from the Internet, uniqueness of the identifiers may be obtained by other mechanisms such as a random number generator with lowest collision rate. Although, the ND optimization [6LOWPAN-ND] applies to 6LoWPAN

[LOWPAN] network, the concept is mostly applicable to a power-aware IPv6 network. Therefore, this document generalizes the address registration and multicast reduction in [6LOWPAN-ND] to all IPv6 links.

Thus optimizing the regular IPv6 Neighbor Discovery [ND] to minimize total number of related signaling messages without losing generality of Neighbor Discovery and autoconfiguration and making host and router communication reliable, is desirable in any IPv6 energy-aware networks such as Home or Enterprise building networks and as well as Data Centers.

The goal of this document is to provide energy-aware and optimized Neighbor Discovery Protocols in the general IPv6 subnets and links. Research indicates that often networked- nodes require more energy than stand-alone nodes because a node's energy usage depends on network messages it receives and responds. While reducing energy consumption is essential for battery operated nodes in some machines, saving energy actually a cost factor in business in general as the explosion of more device usage is leading to usage of more servers and network infrastructure in all sectors of the society and business. Thus this document introduces the node registration concept discussed in 6LoWPAN [LOWPAN], without handling the 'multi-level subnets' scenarios that are not the typical usecases in classic IPv6 subnets.

In the process, the node registration method is also deemed to be useful for preventing Neighbor Discovery denial of service (DOS) attacks.

The proposed changes can be used in two different ways. In one case all the hosts and routers on a link implement the new mechanisms, which gives the maximum benefits. In another case the link has a mixture of new hosts and/or routers and legacy [RFC4861] hosts and routers, operating in a mixed-mode providing some of the benefits.

In the following sections the document describes the basic operations of registration methods, optimization of Neighbor Discovery messages, interoperability with legacy IPv6 implementations and provides a section on use-case scenarios where it can be typically applicable.

2. Definition Of Terms

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].

multi-level Subnets:
It is a wireless link determined by one IPv6 off-link prefix in a network where in order to reach a destination with same prefix a packet may have to travel throguh one more 'intermediate' routers which relays the packet to the next 'intermediate' router or the host in its own.

Border Rotuer(BR):
A border router is typically located at the junction Internet and Home Network. An IPv6 router with one interface connected to IPv6 subnet and other interface connecting to a non-classic IPv6 interface such as 6LoWPAN interface. Border router is usually the gateway to the IPv6 network or Internet.

IPv6 ND-energy-aware Rotuer(NEAR):
It is the default Router of the single hop IPv6 subnet. This router implements the optimizations specified in this document. This router should be able to handle both legacy IPv6 nodes and nodes that sends registration request.

Enery-Aware Host(EAH):
A host in a IPv6 network is considered a IPv6 node without routing and forwarding capability. The EAH is the host which implements the host functionality for optimized Neighbor Discovery mentioned in this document.

Legacy IPv6 Host:
A host in a IPv6 network is considered a IPv6 node without routing and forwarding capability and implements RFC 4861 host functions.

Legacy IPv6 Router:
An IPv6 Router which implements RFC 4861 Neighbor Discovery protocols.

EUI-64:
It is the IEEE defined 64-bit extended unique identifier formed by concatenation of 24-bit or 36-bit company id value by IEEE Registration Authority and the extension identifier within that company-id assignment. The extension identifiers are 40-bit (for 24-bit company-id) or 28-bit (for the 36-bit company-id) respectively.

3. Assumptions for energy-aware Neighbor Discovery

- The energy-aware nodes in the network carry unique interface ID in the network in order to form the auto-configured IPv6 address uniquely. An EUI-64 interface ID required for global communication.
- All nodes are single IPv6-hop away from their default router in the subnet.
- /64-bit IPv6 prefix is used for Stateless Auto-address configuration (SLAAC). The IPv6 Prefix may be distributed with Router Advertisement (RA) from the default router to all the nodes

in that link.

4. The set of Requirements for Energy-awareness and optimization

In future homes, machine-to-machine networks and Data-center Virtual networks, it is essential to reduce unnecessary number of IPv6 Neighbor Discovery signalings for saving energy and saving bits in the network.

In the cloud computing environment, the concept of IPv6-subnet of link-local nodes is often extended across different networks over a Virtual LAN. Thus reducing Neighbor Discovery signaling messages is a key for enhanced services.

- o Node Registration: Node initiated Registration and address allocation is done in order to avoid periodic multicast Router Advertisement messages and often Neighbor Address resolution can be skipped as all packets go via the default router which now knows about all the registered nodes. Node Registration enables reduction of all-node and solicited-node multicast messages in the subnet.
- o Address allocation of registered nodes [ND] are performed using IPv6 Autoconfiguration [AUTOCONF].
- o Host initiated Registration and Refresh is done by sending a Router Solicitation and then a Neighbor Solicitation Messge using Address Registration Option (described below).
- o The node registration may replace the requirement of doing Duplicate Address Detection.
- o Sleepy hosts are supported by this Neighbor Discovery procedures as they are not woken up periodically by Router Advertisement multicast messages or Neighbor Solicitation multicast messages. Sleepy nodes may wake up in its own schedule and send unicast registration refresh messages when needed.
- o Since this document requires formation of an IPv6 address with an unique 64-bit Interface ID(EUI-64) is required for global IPv6 addresses. If the network is an isolated one and uses ULA [ULA] as its IPv6 address then the deployment should make sure that each MAC address in that network has unique address and can provide a unique 64-bit ID for each node in the network.
- o /64-bit Prefix is required to form the IPv6 address.
- o MTU requirement is same as IPv6 network.

5. Basic Operations

In the energy-aware IPv6 Network, the NEAR routers are the default routers for the energy-aware hosts (EAH). During the startup or

joining the network the host does not wait for the Router Advertisements as the NEAR routers do not perform periodic multicast RA as per RFC 4861. Instead, the EAH sends a multicast RS to find out a NEAR router in the network. The RS message is the same as in RFC 4861. The advertising routers in the link responds to the RS message with RA with Prefix Information Option and any other options configured in the network. If EAH hosts will look for a RA from a NEAR (E-flag) and choose a NEAR as its default router and consequently sends a unicast Neighbor Solicitation Message with ARO option in order to register itself with the default router. The EAH does not do Duplicate Address Detection or NS Resolution of addresses. NEAR maintains a binding of registered nodes and registration life-time information along with the neighbor Cache information. The NEAR is responsible for forwarding all the messages from its EAH including on-link messages from one EAH to another. For details of protocol operations please see the sections below.

When a IPv6 network consists of both legacy hosts and EAH, and if the NEAR is configured for 'mixed mode' operation, it should be able to handle ARO requests and send periodic RA. Thus it should be able to serve both energy-aware hosts and legacy hosts. Similarly, a legacy host compatible EAH falls back to RFC 4861 host behavior if a NEAR is not present in the link. See the section on 'Mixed Mode Operations' for details below.

6. Applicability Statement

This document aims to guide the implementors to choose an appropriate IPv6 neighbor discovery and Address configuration procedures suitable for any efficient IPv6 network. These optimization is useful for the classical IPv6 subnet i.e home networks, Data-Center IPv6 overlay networks where saving Neighbor Discovery messages will reduce cost of control signaling and network bandwidth and as well as energy of the connected nodes. See use cases towards the end of the document.

Note that the specification allows 'Mixed-mode' operation in the energy-aware nodes for backward compatibility and transitioning to a complete energy-aware network of hosts and routers. Though the energy-aware only nodes will minimize the ND signalling and DOS attacks in the LAN.

Applicability of this solution is limited to the legacy IPv6 nodes and subnets and it optimizes the generic IPv6 siganling activities at network layer. However, further optimization at the application layers are possible for increased efficiency based on particular usecases and applications.

7. New Neighbor Discovery Options and Messages

This section will discuss the registration and de-registration procedure of the hosts in the network.

7.1. Address Registration Option

The Address Registration Option(ARO) is useful for avoiding Duplicate Address Detection messages since it requires a unique ID for registration. The address registration is used for maintaining reachability of the node or host by the router. This option is exactly the same as in [6LOWPAN-ND] which is reproduced here for the benefits of the readers.

The routers keep track of host IP addresses that are directly reachable and their corresponding link-layer addresses. This is useful for lossy and lowpower networks and as well as wired networks. An Address Registration Option (ARO) can be included in unicast Neighbor Solicitation (NS) messages sent by hosts. Thus it can be included in the unicast NS messages that a host sends as part of Neighbor Unreachability Detection to determine that it can still reach a default router. The ARO is used by the receiving router to reliably maintain its Neighbor Cache. The same option is included in corresponding Neighbor Advertisement (NA) messages with a Status field indicating the success or failure of the registration. This option is always host initiated.

The ARO is required for reliability and power saving. The lifetime field provides flexibility to the host to register an address which should be usable (the reachability information may be propagated to the routing protocols) during its intended sleep schedule of nodes that switches to frequent sleep mode.

The sender of the NS also includes the EUI-64 of the interface it is registering an address from. This is used as a unique ID for the detection of duplicate addresses. It is used to tell the difference between the same node re-registering its address and a different node (with a different EUI-64) registering an address that is already in use by someone else. The EUI-64 is also used to deliver an NA carrying an error Status code to the EUI-64 based link-local IPv6 address of the host.

When the ARO is used by hosts an SLLA option MUST be included and the address that is to be registered MUST be the IPv6 source address of the Neighbor Solicitation message.

```
 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            |     Registration Lifetime     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+               EUI-64 or equivalent                            +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Fields:
Type: TBD1 (See [6LOWPAN-ND])
Length: 8-bit unsigned integer. The length of the option in units of 8 bytes. Always 2.
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.
Registration Lifetime: 16-bit unsigned integer. The amount of time in a unit of 10 seconds that the router should retain the Neighbor Cache entry for the sender of the NS that includes this option.
EUI-64: 64 bits. This field is used to uniquely identify the interface of the registered address by including the EUI-64 identifier assigned to it unmodified.

The Status values used in Neighbor Advertisements are:

Status	Description
0	Success
1	Duplicate Address
2	Neighbor Cache Full
3-255	Allocated using Standards Action [RFC2434]

Table 1

7.2. Refresh and De-registration

A host SHOULD send a Registration messge in order to renew its registration before its registration lifetime expires in order to continue its connectivity with the network. If anytime, the node

decides that it does not need the default router's service anymore, it MUST send a de-registration message - i,e, a registration message with lifetime being set to zero. A mobile host SHOULD first de-register with the default router before it moves away from the subnet.

7.3. A New Router Advertisement Flag

A new Router Advertisment flag [RF] is needed in order to distnguish a router advertisement from a energy-aware default router or a legacy IPv6 router. This flag is ignored by the legacy IPv6 hosts. EAH hosts use this flag in oder to discover a NEAR router if it receives multiple RA from both legacy and NEAR routers.

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|M|O|H|Prf|P|E|R|
+-+-+-+-+-+-+-+-+
```

The 'E' bit above MUST be 1 when a IPv6 router implements and configures the Energy-aware Router behavior for Neighbor Discovery as per this document. All other cases E bit is 0.

The legacy IPv6 hosts will ignore the E bit in RA advertisement. All EAH MUST look for E bit in RA in order to determine the Energy-aware support in the default router in the link.

This document assumes that an implementation will have configuration knobs to determine whether it is running in classical IPv6 ND [ND] or Optimized Energy Aware ND (this document) mode or both(Mixed mode).

8. Energy-aware Neighbor Discovery Messages

Router Advertisement(RA): Periodic RAs SHOULD be avoided. Only solicited RAs are RECOMMENDED. An RA MUST contain the Source Link-layer Address option containing Router's link-layer address (this is optional in [ND]. An RA MUST carry Prefix information option with L bit being unset, so that hosts do not multicast any NS messages as part of address resolution. A new flag (E-flag) is introduced in the RA in order to characterize the energy-aware mode support. Unlike RFC4861 which suggests multicast

Router Advertisements, this specification optimizes the exchange by always unicasting RAs in response to RS. This is possible since the RS always includes a SLLA option, which is used by the router to unicast the RA.

Router Solicitation(RS): Upon system startup, the node sends a multicast or link broadcast (when multicast is not supported at the link-layer) RS to find out the available routers in the link. An RS may be sent at other times as described in section 6.3.7 of RFC 4861. A Router Solicitation MUST carry Source Link-layer Address option. Since no periodic RAs are allowed in the energy-aware IPv6 network, the host may send periodic unicast RS to the routers. The time-periods for the RS varies on the deployment scenarios and the Default Router Lifetime advertised in the RAs.

Default Router Selection: Same as in section 6.3.6 of RFC 4861[ND].

Neighbor Solicitation (NS): Neighbor solicitation is used between the hosts and the default-router as part of NUD and registering the host's address(es). An NS message MUST use the Address Registration option in order to accomplish the registration.

Neighbor Advertisement (NA): As defined in [ND] and ARO option.

Redirect Messages: A router SHOULD NOT send a Redirect message to a host since the link has non-transitive reachability. The host behavior is same as described in section 8.3 of RFC 4861[ND], i,e. a host MUST NOT send or accept redirect messages when in energy-aware mode. Same as in RFC 4861[ND]

MTU option: As per the RFC 4861.

Address Resolution: No NS/NA are sent as the prefixes are treated as off-link. Thus no address resolution is performed at the hosts. The routers keep track of Neighbor Solicitations with Address Registration options(ARO) and create an extended neighbor cache of reachable addresses. The router also knows the nexthop link-local address and corresponding link-layer address when it wants to route a packet.

Neighbor Unreachability Detection(NUD): NUD is performed in "forward-progress" fashion as described in section 7.3.1 of RFC 4861[ND]. However, if Address Registration Option is used, the NUD SHOULD be combined with the Re-registration of the node. This way no extra message for NUD is required.

9. Energy-Aware Host Behavior

A host sends Router Solicitation at the system startup and also when it suspects that one of its default routers have become unreachable(after NUD fails). The EAH MUST process the E-bit in RA as described in this document. The EAH MUST use ARO option to register with the neighboring NEAR router.

A host SHOULD be able to autoconfigure its IPv6 addresses using the IPv6 prefix obtained from Router Advertisement. The host SHOULD form its link-local address from the EUI-64 as specified by IEEE Registration Authority and RFC 2373. If this draft feature is implemented and configured, the host MUST NOT re-direct Neighbor Discovery messages. The host does not require to join solicited-node multicast address but it MUST join the all-node multicast address.

A host always sends packets to (one of) its default router(s). This is accomplished by the routers never setting the 'L' flag in the Prefix options.

The host is unable to forward routes or participate in a routing protocol. A legacy IPv6 Host compliant EAH SHOULD be able to fall back to RFC 4861 host behavior if there is no energy-aware router (NEAR) in the link.

The energy-aware host MUST NOT send or accept re-direct messages. It does not join solicited node multicast address.

10. The Energy Aware Default Router (NEAR) Behavior

The main purpose of the default router in the context of this document is to receive and process the registration request, forward packets from one neighbor to the other, informs the routing protocol about the un-availability of the registered nodes if the routing protocol requires this information for the purpose of mobility or fast convergence. A default router (NEAR) behavior may be observed in one or more interfaces of a Border Router(BR).

A Border Router normally may have multiple interfaces and connects the nodes in a link like a regular IPv6 subnet(s) or acts as a gateway between separate networks such as Internet and home networks . The Border Router is responsible for distributing one or more /64 prefixes to the nodes to identify a packet belonging to the particular network. One or more of the interfaces of the Border Router may be connected with the energy-aware hosts or a energy-aware router(NEAR).

The Energy-Aware default router MUST not send periodic RA unless it is configured to support both legacy IPv6 and energy-aware hosts. If the Router is configured for Energy-Aware hosts support, it MUST send Router Advertisments with E-bit flag ON and MUST NOT set 'L' bit in the advertisements.

The router SHOULD NOT garbage collect Registered Neighbor Cache entries since they need to retain them until the Registration Lifetime expires. If a NEAR receives a NS message from the same host one with ARO and another without ARO then the NS message with ARO gets the precedence and the NS without ARO is ignored. This behavior protects the router from Denial Of Service attacks. Similarly, if Neighbor Unreachability Detection on the router determines that the host is UNREACHABLE (based on the logic in [ND]), the Neighbor Cache entry SHOULD NOT be deleted but be retained until the Registration Lifetime expires. If an ARO arrives for an NCE that is in UNCREACHABLE state, that NCE should be marked as STALE.

A default router keeps a cache for all the nodes' IP addresses, created from the Address Registration processing.

10.1. Router Configuration Modes

An energy-aware Router(NEAR) MUST be able to configure in energy-aware-only mode where it will expect all hosts register with the router following RS; thus will not support legacy hosts. However, it will create legacy NCE for NS messages for other routers in the network. This mode is able to prevent ND flooding on the link.

An energy-aware Router(NEAR) SHOULD be able to have configuration knob to configure itself in Mixed-Mode where it will support both energy-aware hosts and legacy hosts. However even in mixed-mode the router should check for duplicate entries in the NCE before creating a new ones and it should rate-limit creating new NCE based on requests from the same host MAC address.

The RECOMMENDED default mode of operation for the energy-aware router is Mixed-mode.

11. NCE Management in Energy-Aware Routers

The use of explicit registrations with lifetimes plus the desire to not multicast Neighbor Solicitation messages for hosts imply that we manage the Neighbor Cache entries slightly differently than in [ND]. This results in two different types of NCEs and the types specify how those entries can be removed:

Legacy: Entries that are subject to the normal rules in [ND] that allow for garbage collection when low on memory. Legacy entries are created only when there is no duplicate NCE. In mixed-mode and energy-aware mode the legacy entries are converted to the registered entries upon successful processing of ARO. Legacy type can be considered as union of garbage-collectible and Tentative Type NCEs described in [6LOWPAN-ND].

Registered: Entries that have an explicit registered lifetime and are kept until this lifetime expires or they are explicitly unregistered.

Note that the type of the NCE is orthogonal to the states specified in [ND].

When a host interacts with a router by sending Router Solicitations that does not match with the existing NCE entry of any type, a Legacy NCE is first created. Once a node successfully registers with a Router the result is a Registered NCE. As Routers send RAs to legacy hosts, or receive multicast NS messages from other Routers the result is Legacy NCEs. There can only be one kind of NCE for an IP address at a time.

A Router Solicitation might be received from a host that has not yet registered its address with the router or from a legacy[ND] host in the Mixed-mode of operation.

In the 'Enrgy-aware' only mode the router MUST NOT modify an existing Neighbor Cache entry based on the SLLA option from the Router Solicitation. Thus, a router SHOULD create a tentative Legacy Neighbor Cache entry based on SLLA option when there is no match with the existing NCE. Such a legacy Neighbor Cache entry SHOULD be timed out in TENTATIVE_LEGACY_NCE_LIFETIME seconds unless a registration converts it into a Registered NCE.

However, in 'Mixed-mode' operation, the router does not require to keep track of TENTATIVE_LEGACY_NCE_LIFETIME as it does not know if the RS request is from a legacy host or the energy-aware hosts.

However, it creates the legacy type of NCE and updates it to a registered NCE if the ARO NS request arrives corresponding to the legacy NCE. Successful processing of ARO will complete the NCE creation phase.

If ARO did not result in a duplicate address being detected, and the registration life-time is non-zero, the router creates and updates the registered NCE for the IPv6 address. if the Neighbor Cache is full and new entries need to be created, then the router SHOULD respond with a NA with status field set to 2. For successful creation of NCE, the router SHOULD include a copy of ARO and send NA to the requestor with the status field 0. A TLLA(Target Link Layer) Option is not required with this NA.

Typically for energy-aware routers (NEAR), the registration life-time and EUI-64 are recorded in the Neighbor Cache Entry along with the existing information described in [ND]. The registered NCE are meant to be ready and reachable for communication and no address resolution is required in the link. The energy-aware hosts will renew their registration to keep maintain the state of reachability of the NCE at the router. However the router may do NUD to the idle or unreachable hosts as per [ND].

11.1. Handling ND DOS Attack

IETF community has discussed possible issues with /64 DOS attacks on the ND networks when a attacker host can send thousands of packets to the router with a on-link destination address or sending RS messages to initiate a Neighbor Solicitation from the neighboring router which will create a number of INCOMPLETE NCE entries for non-existent nodes in the network resulting in table overflow and denial of service of the existing communications.

The energy-aware behavior documented in this specification avoids the ND DOS attacks by:

- o Having the hosts register with the default router
- o Having the hosts send their packets via the default router
- o Not resolving addresses for the Routing Solicitor by mandating SLLA option along with RS
- o Checking for duplicates in NCE before the registration
- o Checking against the MAC-address and EUI-64 id is possible now for NCE matches
- o On-link IPv6-destinations on a particular link must be registered else these packets are not resolved and extra NCEs are not created

It is recomended that Mixed-mode operation and legacy hosts SHOULD NOT be used in the IPv6 link in order to avoid the ND DOS attacks.

For the general case of Mixed-mode the router does not create INCOMPLETE NCEs for the registered hosts, but it follows the [ND] steps of NCE states for legacy hosts.

12. Mixed-Mode Operations

Mixed-Mode operation discusses the protocol behavior where the IPv6 subnet is composed with legacy IPv6 Neighbor Discovery compliant nodes and energy-aware IPv6 nodes implementing this specification.

The mixed-mode model SHOULD support the following configurations in the IPv6 link:

- o The legacy IPv6 hosts and energy-aware-hosts in the network and a NEAR router
- o legacy IPv6 default-router and energy-aware hosts(EAH) in the link
- o one router is in mixed mode and the link contains both legacy IPv6 hosts and EAH
- o A link contains both energy-aware IPv6 router and hosts and legacy IPv6 routers and hosts and each host should be able to communicate with each other.

In mixed-mode operation, a NEAR MUST be configured for mixed-mode in order to support the legacy IPv6 hosts in the network. In mixed-mode, the NEAR MUST act as proxy for Neighbor Solicitation for DAD and Address Resolution on behalf of its registered hosts on that link. It should follow the NCE management for the EAH as described in this document and follow RFC 4861 NCE management for the legacy IPv6 hosts. Both in mixed-mode and energy-aware mode, the NEAR sets E-bit flag in the RA and does not set 'L' on-link bit.

If a NEAR receives NS message from the same host one with ARO and another without ARO then the NS message with ARO gets the precedence.

An Energy-Aware Host implementation SHOULD support falling back to legacy IPv6 node behavior when no energy-aware routers are available in the network during the startup. If the EAH was operational in energy-aware mode and it determines that the NEAR is no longer available, then it should send a RS and find an alternate default router in the link. If no energy-aware router is indicated from the RA, then the EAH SHOULD fall back into RFC 4861 behavior. On the otherhand, in the energy-aware mode EAH SHOULD ignore multicast Router Advertisements(RA) sent by the legacy and Mixed-mode routers in the link.

The routers that are running on energy-aware mode or legacy mode SHOULD NOT dynamically switch the mode without flushing the Neighbor Cache Entries.

13. Bootstrapping

If the network is a energy-aware IPv6 subnet, and the energy-aware Neighbor Discovery mechansim is used by the hosts and routers as described in this document. At the start, the node uses its link-local address to send Router Solicitation and then it sends the Node Registration message as described in this document in order to form the address. The Duplicate address detection process should be skipped if the network is guaranteed to have unique interface identifiers which is used to form the IPv6 address.

```
   Node                                                    Router

     |                                                       |

1.   |       ---------- Router Solicitation -------->        |

     |                     [SLLAO]                           |

2.   |       <-------- Router Advertisement ---------        |

     |                     [PIO + SLLAO]                     |
     |                                                       |

3.   |       ----- Address Registration (NS) -------->       |

     |                     [ARO + SLLAO]                     |

4.   |       <-------- Neighbor Advertisement -------        |

     |                    [ARO with Status code]             |

5. ====> Address Assignment Complete
```

Figure 1: Neighbor Discovery Address Registration and bootstrapping

In the mixed mode operation, it is expected that logically there will be at least one legacy IPv6 router and another NEAR router present in the link. The legacy IPv6 router will follow RFC 4861 behavior and NEAR router will follow the energy-aware behavior for registration, NCE maintenance, forwarding packets from a EAH and it will also act as a ND proxy for the legacy IPv6 hosts querying to resolve a EAH node.

A legacy IPv6 host and EAH are not expected to see a difference in their bootstrapping if both legacy and energy-aware functionalities

of rotuers are available in the network. It is RECOMMEDED that the EAH implementation SHOULD be able to behave like a legacy IPv6 host if it discovers that no energy-aware routing support is present in the link.

14. Handling Sleepy Nodes

The solution allows the sleepy nodes to complete its sleep schedule without waking up due to periodic Router Advertisement messages or due to Multicast Neighbor Solicitation for address resolution. The node registration lifetime SHOULD be synchronized with its sleep interval period in order to avoid waking up in the middle of sleep for registration refresh. Depending on the application, the registration lifetime SHOULD be equal to or integral multiple of a node's sleep interval period.

15. Use Case Analysis

This section provides applicability scenarios where the energy-aware Neighbor Discovery will be most beneficial.

15.1. Data Center Routers on the link

Energy-aware Routers and hosts are useful in IPv6 networks in the Data Center as they produce less signaling and also provides ways to minimize the ND flood of messages. Moreover, this mechanism will work with data-center nodes which are deliberately in sleep mode for saving energy.

This solution will work well in Data Center Virtual network and VM scenarios where number of VLANs are very high and ND signalings are undesirably high due the multicast messaging and periodic Router Advertisments and Neighbor Unreachability detections.

15.2. Edge Routers and Home Networks

An Edge Router in the network will also benefit implementing the energy-aware Neighbor Discovery behavior in order to save the signaling and keeping track of the registered nodes in its domain. A BNG sits at the operator's edge network and often the BNG has to handle a large number of home CPEs. If a BNG runs Neighbor Discovery protocol and acts as the default router for the CPE at home, this solution will be helpful for reducing the control messages and improving network performances.

The same solution can be run on CPE or Home Residential Gateways to

assign IPv6 addresses to the wired and wireless home devices without the problem of ND flooding issues and consuming less power. It provides mechanism for the sleepy nodes to adjust their registration lifetime according to their sleep schedules.

15.3. M2M Networks

Any Machine-to-machine(M2M) networks such as IPv6 surveilance networks, wireless monitoring networks and other m2m networks desire for energy-aware control protocols and dynamic address allocation. The in-built address allocation and autoconfiguration mechanism in IPv6 along with the default router capability will be useful for the simple small-scale networks without having the burden of DHCPv6 service and Routing Protocols.

16. Mobility Considerations

If the hosts move from one subnet to another, they MUST first de-register and then register themselves in the new subnet or network. Otherwise, the regular IPv6 Mobility [IPV6M]behavior applies.

17. Other Considerations

IPv6 DNA[DNA] also uses unicast ND probes to detect movement of its network attachments. However DNA [DNA] optimizes the IPv6 address operability while a node is moving and its network attachments are changing with respect to the neighboring routers. This document does not expect Router Advertisements from the neighboring routers, thus this solution will rely on the ND probes for movement detection and as well as link-layer indication.

Although the solution described in this document prevents unnecesary multicast messages in the IPv6 ND procedure, it does not affect normal IPv6 multicast packets and ability of nodes to join and leave the multicast group or forwarding multicast traffic or responding to multicast queries.

ND proxy support in mixed-mode operation [TBD].

18. Updated Neighbor Discovery Constants

This section discusses the updated default values of ND constants based on [ND] section 10. New and changed constants are listed only for energy-aware-nd implementation.

Router Constants:

MAX_RTR_ADVERTISEMENTS(NEW)	3 transmissions
MIN_DELAY_BETWEEN_RAS(CHANGED)	1 second
TENTATIVE_LEGACY_NCE_LIFETIME(NEW)	30 seconds

Host Constants:

MAX_RTR_SOLICITATION_INTERVAL(NEW)	60 seconds

19. Security Considerations

These optimizations are not known to introduce any new threats against Neighbor Discovery beyond what is already documented for IPv6 [RFC 3756].

Section 11.2 of [ND] applies to this document as well.

This mechanism minimizes the possibility of ND /64 DOS attacks in energy-aware mode. See Section 11.1.

20. IANA Considerations

A new flag (E-bit) in RA has been introduced. IANA assignment of the E-bit flag is required upon approval of this document.

21. Changelog

Changes from 00 to 01:
- o Removed ABRO options and Multi-level subnet concept
- o Removed intermediate-router concept, behavior and definition
- o Added use-cases, Support for Mixed-mode operations and a diagram for bootstrapping scenario.
- o Added updates to ND constant values
- o A new co-author has beed added
- o Text for NCE Management and ND-DOS handling has been added
- o A new Router Advertisement flag has been added

22. Acknowledgements

The primary idea of this document are from 6LoWPAN Neighbor Discovery document [6LOWPAN-ND] and the discussions from the 6lowpan working group members, chairs Carsten Bormann and Geoff Mulligan and through our discussions with Zach Shelby, editor of the [6LOWPAN-ND].

The inspiration of such a IPv6 generic document came from Margaret

Wasserman who saw a need for such a document at the IOT workshop at Prague IETF.

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