6LoWPAN
Internet-Draft
Intended status: Standards Track
Expires: April 27, 2009

Z. Shelby, Ed.
Sensinode
P. Thubert
Cisco
J. Hui
Arch Rock
S. Chakrabarti
IP Infusion
E. Nordmark
Sun

October 24, 2008

Neighbor Discovery for 6LoWPAN
draft-shelby-6lowpan-nd-00

Status of this Memo

Copyright Notice

Abstract

The 6LoWPAN format allows IPv6 to be used over very low-power, low-

bandwidth wireless networks often making use of extended multihop topologies. However, the use of standard IPv6 Neighbor Discovery over 6LoWPAN networks has several problems. Standard ND was not designed for wireless links, the standard IPv6 link concept and heavy use of multicast makes it inefficient. This paper specifies Neighbor Discovery optimized for 6LoWPAN.

Table of Contents

1. Introduction

The IPv6 over IEEE 802.15.4 [RFC4944] document has specified IPv6 headers carried over an IEEE 802.15.4 network with the help of an adaptation header which comes before the IP header. A LoWPAN network is characterized as a low-power, low bit-rate, short range, low cost network. Thus, all-node multicast defined in IPv6 Neighbor Discovery [RFC4861] is not often desirable in a wireless low-power, lossy network. In addition IEEE 802.15.4 and similar wireless technologies do not have multicast support, but supports broadcast. Broadcast messages could be used in some cases to represent all-node multicast messages, but periodic broadcast messages should be minimized in LoWPANs in order to conserve energy. Moreover, LoWPAN nodes are transient in nature; they are not always considered to be in a fixed network nor they are bounded by our standard definition of a wired-link. The link is often defined by reachability and radio strength. The standard IPv6 neighbor discovery [RFC4861] control messages and their default frequency also attribute to unnecessary loss of power in the 6lowpan network.

The goal of this document is to minimize/remove periodic multicast signals used by IPv6 Neighbor Discovery [RFC4861] while enabling the LoWPAN to work as efficiently and optimally as possible and reducing the complexity of LoWPAN node implementations.

Neighbor discovery for 6LoWPAN provides for basic bootstrapping, and network operation, along with advanced features such as address assignment and ND Proxy, while avoiding the use of multicast and providing both mesh under and route over support. Unlike standard IPv6 ND [RFC4861], this document takes the lossy characteristics of wireless networks into account.

The concept of a LoWPAN Whiteboard located at Edge Routers is introduced, which allows for duplicate address detection and address assignment for the entire LoWPAN. Address resolution simplifications are made to make LoWPAN operation efficient and reduce LoWPAN Nodes complexity. A new registration/confirmation message sequence is specified, allowing nodes to register their IPv6 addresses with an Edge Router, and to request global unique address assignment.

The ND for 6LoWPAN whiteboard makes use of soft bindings, thus nodes send periodic registration messages in order to maintain their binding and address assignments. Changes in network topology, and mobility between ERs and subnets are supported. The dissemination of RA information throughout multihop route over networks is also discussed.

This paper also specifies an extension to ND Proxy and its use by

Edge Routers, allowing for the seamless integration of an extended LoWPAN and multiple Edge Routers on a shared backbone link (e.g. Ethernet) to form a single IPv6 subnet. This allows hosts to keep the same IPv6 address throughout a large network, and allows for easy communications with backbone link IPv6 hosts.

This paper defines two new ICMPv6 message sets: Router Registration/ Confirmation and Relay RR/RC messages. In addition a new 6LOWPAN_ER anycast address is introduced, allowing for nodes to send register without knowing the specific Edge Router's or Router's unicast address.

1.1. Goals & Assumptions

This document has the following main goals and makes several assumptions.

Goals:

- o Avoid the use of multicast for ND messages inside the LoWPANs.
- o Disseminate prefix and context information throughout the LoWPAN.
- o Minimize the complexity of LoWPAN nodes.
- o Interconnect LoWPANs with backbone links seamlessly.
- o Provide a mechanism for address assignment.

Assumptions:

- o Either [RFC4944] or [draft-ietf-6lowpan-hc-01] 6LoWPAN header compression.
- o Link layer technology may be IEEE 802.15.4 as in [RFC4944], or any other suitable link-layer.
- o Link-local addresses are derived from an EUI-64 identifier.
- o The use of optimistic DAD.
- o Mesh-under nodes know the edge router link-layer addresses of their mesh network from some L2 mechanism.
- o A subnet covers all the LoWPANs and their backbone link with the same IPv6 global or local prefix.

1.2. Why not standard IPv6 ND?

IPv6 Neighbor Discovery [RFC4861] provides several important functions such as Router Discovery, Address Resolution, Duplicate Address Detection, Redirect, Prefix and Parameter Discovery.

Following power-on and initialisation of the network in IPv6 ethernet networks, a node joins the solicited-node multicast address on the interface and then it performs duplicate address detection (DAD) for the acquired link-local address by sending solicited-node multicast message to the link. After that it sends multicast messages to all-router address to solicit router advertisements. Once the host receives a valid router advertisement with the "A" flag, it autoconfigures the IPv6 address with the advertised prefix in the rotuer advertisement (RA). Besides this, the IPv6 routers usually send router advertisements periodically on the network. It sends the RA to all-node multicast address. Nodes send Neighbor Solicitation/ Neighbor Advertisement messages to resolve the IPv6 address of the destination on the link. These NS/NA messages are also often multicast messages and it assumes that the node is on the same link and relies on the fact that the destination node is always powered and generally reliable.

A LoWPAN network typically uses two types of L2 addresses - 16-bit short addresses and 64-bit unique addresses as defined in [RFC4944]. Moreover, the link bandwidth is often on the order of less than 100 bytes where we often might need to use header compression and use a minimum payload. The network is lossy and low-powered, and it does not provide multicast capability at the link-layer, thus simulating multicast behavior by both using broadcast or sending a number of unicast messages, both expensive for the low-powered network and the low-processing capable nodes. Besides often these low-powered nodes conserve energy by using sleep schedules; waking them up to receive IPv6 signaling messages such as multicast messages for NS, and periodic RA is not practical. Nor they are capable of processing address-resolution for its neighbors effectively. Besides due to radio strength of its neighboring router or its own strength, a node may often move between one subnet to another without physically moving from one place to another. Considering the above characteristics in a LoWPAN, and IPv6 Neighbor Discovery [RFC4861] base protocol requirements, it was concluded that standard Neighbor Discovery is not suitable as it is and a 6lowpan-specific ND protocol would be useful and efficient for wide deployment of IPv6 over low-powered wireless networks of embedded devices.

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] and "Transmission of IPv6 Packets over IEEE 802.15.4 Networks" [RFC4944].

Readers would benefit from reading "Mobility Support in IPv6" [RFC3775], "Neighbor Discovery Proxies (ND Proxy)" [RFC4389] and "Optimistic Duplicate Address Detection" [RFC4429] prior to this specification for a clear understanding of state of the art in ND proxy and binding.

This document defines additional terms:

LoWPAN Host

A node that only sources or sinks IPv6 datagrams. Referred to as a Host in this document. The term Node is used when the the differentiation between Host and Router is not important.

LoWPAN Edge Router

An IPv6 router that interconnects the LoWPAN to another network. Referred to as an Edge Router in this document.

LoWPAN Router

A node that forwards datagrams between arbitrary source-destination pairs using a single 6LoWPAN/802.15.4 interface. A LoWPAN Router may also serve as a LoWPAN Host - both sourcing and sinking IPv6 datagrams. Refered to as a Router in this document. All LoWPAN Routers perform ND message relay on behalf of other nodes.

Mesh Under

A LoWPAN configuration where the link-local scope is defined by the boundaries of the LoWPAN and includes all nodes within. Multihop forwarding is achieved at L2 between mesh nodes.

Route Over

A LoWPAN configuration where the link-local scope is defined by those nodes reachable over a single radio transmission. Due to the time-varying characteristics of wireless communication, the neighbor set may change over time even when nodes maintain the same physical locations. Multihop is achieved using IP routing.

Backbone Link

This is an IPv6 link that interconnects 2 or more Edge Routers. It is expected to be deployed as a high speed backbone in order to federate a potentially large set of LoWPANS.

Backhaul Link

This is an IPv6 link that connects a single Edge Router to another network.

Extended LoWPAN

This is the aggregation of multiple LoWPANs as defined in [RFC4919] interconnected by a backbone link via Edge Routers and forming a single subnet.

LoWPAN Subnet

A subnet including a LoWPAN or Extended LoWPAN, together with the backbone link sharing the same prefix.

Binding

The association of the LoWPAN node IPv6 address and Interface ID with associated whiteboard and proxy states including the remaining lifetime of that association.

Registration

The process during which a LoWPAN node sends a Router Registration ND message to an Edge Router causing a binding for the LoWPAN node to be registered.

3. Protocol Overview

Neighbor discovery for 6LoWPAN provides additions and optimizations to IPv6 ND [RFC4861] supporting 6LoWPAN low-power wireless stub networks. Basic bootstrapping and network maintenenace mechanisms are provided, and the use of multicast for ND messages is avoided. Duplicate address detection and global address assignment are supported as part of bootstrapping. This is achieved using a whiteboard located on the 6LoWPAN Edge Routers of the LoWPAN network.

Multihop route-over networks are supported by relaying ND messages. Finally, advanced features include ND Proxy extensions, and secondary Edge Router registrations. ND for 6LoWPAN is designed to work with many network topologies, including isolated ad-hoc networks, single ER networks, and networks with multiple ERs interconnected by a backbone link. The use of both IEEE 802.15.4 and other suitable 6LoWPAN link-layer technologies is considered. Both the use of mesh under forwarding and route over routing are supported.

```
                    |
                    |
                    |
                 +-----+
                 |     | Edge
                 |     | router
                 +-----+
                  m  m
                m      m
              m   m  m   m     m: Mesh node
               m   m  m  m
                m   m  m

                 LoWPAN
```

Figure 1: A Mesh under LoWPAN.

In a mesh under network, shown above, multihop forwarding is dealt with below layer 3. Thus the entire LoWPAN forms a link-layer mesh. This means that the IPv6 link-local scope includes all the nodes of the LoWPAN. The implication of this on ND for 6LoWPAN, is that it can always be assumed that the ER and hosts are on the same link. Multicast with mesh under technologies most often induces flooding, and therefore it is avoided.

```
                   |
                   |
                   |
                +-----+
                |     | Edge
                |     | router
                +-----+
                 r  h
               r   r   r
             h  r   h  r h        h: Host
              h   r  r  h         r: Router
                h   h  h

                LoWPAN
```

Figure 2: A Route over LoWPAN.

A route over network performs multihop using standard layer 3 IP routing. The link-local scope is defined by those nodes reachable over a single radio transmission. The implication for ND for 6LoWPAN is that if the ER is out of radio range of a host, the ND messages require relaying by intermediate Routers. Multicast may also involve flooding in such networks, and is avoided.

```
             Infrastructure
                 Cloud
                   z
                   z
                   z  Backhaul link
                   z
                   z
                +-----+
                |     | Edge
                |     | router
                +-----+
                  o  o
               o   o    o
             o  o   o  o o        o: Any node
              o   o  o  o
                o   o o

                LoWPAN
```

Figure 3: A LoWPAN connected to a backhaul link.

The simplest topology is a LoWPAN connected by a single Edge Router to another network, over a so-called backhaul link. The Edge Router maintains a whiteboard of all hosts in the network, and assigns addresses. The Edge Router terminates 6LoWPAN framing from the LoWPAN, and forwards packets. Multiple such networks may also overlap to form an Extended LoWPAN.

```
         Infrastucture Cloud
                  |
                  |
               +-----+                 +-----+
               |     | Gateway         |     | Host
               |     |                 |     |
               +-----+                 +-----+
                  |                       |
                  |     Backbone link     |
            +--------------------+------------------+
            |                    |                  |
         +-----+             +-----+             +-----+
         |     | Edge        |     | Edge        |     | Edge
         |     | router      |     | router      |     | router
         +-----+             +-----+             +-----+
            o         o       o   o  o      o        o o
        o o   o  o  o  o  o o   o  o  o  o  o   o  o  o  o
       o  o o  o o   o    o   o  o  o  o     o   o  o  o o
       o   o  o  o     o    o    o  o     o      o  o   o
         o   o o     o          o  o      o    o       o

                       Extended LoWPAN
```

Figure 4: Backbone link and edge routers with a 6LoWPAN subnet

In the backbone link topology, a backbone link federates multiple LoWPANs as a single IP link, the Extended LoWPAN. Each LoWPAN is anchored at one or more Edge Router. The Edge Routers interconnect the LoWPANs over the backbone link. A node can move freely from a LoWPAN anchored at an Edge Router to a LoWPAN anchored at another Edge Router on the same backbone link and conserve its link local and any other IPv6 address it has formed. If ND Proxy is used, a standard IPv6 Host on the backbone link can communicate with any host in the Extended LoWPAN and vice versa.

The following sections explain the basics of how ND for 6LoWPAN works, starting with bootrapping on the network, maintenance of the network, and finally optional features such as ND Proxy.

3.1. Bootstrapping

A Host first performs stateless autoconfiguration of its link-local address for each 6LoWPAN interface from its EUI-64 as in [RFC4944]. When a LoWPAN Host wants to join a LoWPAN network, it does so by listening for Route Advertisements from Edge Routers or Routers, or by broadcasting a Router Solicitations. If a global prefix is included in the RA, the host may form an optimistic global unique address with stateless autoconfiguration.

Next the Host registers with an on-link Edge Router or Router by sending a Router Registration (RR) message to it, either unicast or using the 6LOWPAN_ER anycast address. These message exchanges are illustrated below. The RR contains the addresses the node wants to register, and a possible request for a global assigned address. An RR message is structured as follows, with nested Address Options inside an Identity Request Option.

ICMP (Router Registration (Identity Request Option (Address Options)))

The Edge Router replies either directly with a Router Confirmation (RC), or through a Router. This Confirmation includes the set of addresses now bound to the whiteboard of the ER, including assigned addresses. The RC may also include other network configuration information. The Host is now capable of using the LoWPAN, and the ER forwards on its behalf.

```
Node                                                 Edge Router
  |                                                         |
  |       ---------- Router Registration -------->          |
  |                                                         |
  |       <--------- Router Confirmation ---------          |
  |                                                         |
```

Figure 5: Basic ND registration exchange.

```
Node                    Router (relay)               Edge Router
  |                           |                             |
  |       ---- RR --->        |      ---- Relay RR --->     |
  |                           |                             |
  |      <---- RC ----        |     <---- Relay RC  ----    |
  |                           |                             |
```

Figure 6: Relay ND registration exchange.

3.2. Basic operation

The whiteboard address binding and assignment are soft, and thus must be renewed periodically as indicated by the lifetime of the identity. This is achieved by periodically sending a new RR to the ER. If a host moves, or the network topology changes, and the current ER is no longer available, the host then starts the registration process with another ER. If the host is still in the same Extended LoWPAN, its IPv6 addresses remain the same. If the host moves to a different LoWPAN, with a different global prefix, the bootstrapping process is initiated again. In route over networks, Routers that act as relays must disseminate RAs to their neighbors. The Edge Router disseminates RAs, and this information is included in the RAs of each Router.

3.3. Optional features

ND Proxy is specified in [RFC4389], and allows for two segments to be merged into a single IPv6 link. This specification extends ND Proxy for use with Extended LoWPAN networks with multiple ERs on a backbone link. This optional feature allows for the entire Extended LoWPAN and backbone links to appear as a single IPv6 link. The extended ND Proxy includes an option to uniquely identify the LoWPAN Host on the backbone, and override the claim on an address on behalf of a LoWPAN Host. Thus a Host can keep the same address, and appears the same to other Hosts on the backbone link, regardless of moving its binding from one ER to another. Forwarding is automatic regardless of which ER the host is proxied by.

4. 6LoWPAN ND messages

This section introduces message formats for all messages used in this specification. The new messages are all ICMPv6 messages and extend the capabilities of "The IPv6 Neighbor Discovery Protocol" [RFC4861].

4.1. Router Registration/Confirmation message

The Router Registration (RR) and Router Confirmation (RC) messages are used by a Host to register with an ER, and for the ER to confirm the binding. Any option that is not recognized MUST be skipped silently. The Router Registration message is sent by the LoWPAN Node to an on-link ER or Router, and may be sent unicast or to the 6LOWPAN_ER anycast address.

```
    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      |     Code      |          Checksum             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |              TID              |          Reserved             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   +                   Host Interface Identifier                   +
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |   option(s)...
   +-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 7: Router Registration/Confirmation message format (16 octets)

IP Fields:

Source Address: A Link-local IPv6 address. This address may be an optimistic address.

Destination Address: A link-local IPv6 address of an Edge Router or Edge Router Relay.

Hop Limit: 255

ICMP Fields:

Type: TBD by IANA.

Code: 0

Checksum: The ICMP checksum.

TID: A unique Transaction ID assigned by the host to match replies.

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

Host Interface Identifier: A globally unique identifier for the requesting host's interface.

Possible Options:

Identity Request Option

Future versions of this protocol may define new option types. Receivers MUST silently ignore any options they do not recognized and continue processing the message.

4.2. Relay RR/RC message

The Relay Router Registration/Confirmation message is used between Routers and Edge Routers in order to relay the content of RR/RC messages from nodes multiple IP hops from the ER. When a Host sends an RR message to a Router, the Router copies the RR message TID, HII and options to this Relay RR message format. When the ER Relay is sending a confirmation message back to the Host, it is converted to a standard RC message format.

```
 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      |     Code      |           Checksum            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             TID               |           Reserved            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                   Host Interface Identifier                   +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+          Host Link-Local Address Interface Identifier         +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
.                                                               .
.              6LoWPAN ND Options (variable length)             .
.                                                               .
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 8: Relay RR/RC message format (24 octets)

IP Fields:

Source Address: The IPv6 address of the Edge Router or Router that is originating this message.

Destination Address: The IPv6 address of the Edge Router or Router that is consuming this message.

Hop Limit: 255

ICMP Fields:

Type: TBD by IANA.

Code: 0

Checksum: The ICMP checksum.

TID: A unique Transaction ID assigned by the requesting host to match replies.

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

Host Interface Identifier: A globally unique identifier for the requesting host's interface.

Host Link-Local Address Interface Identifier: The interface identifier of the requesting hosts's link-local address used by the relay to communicate replies to the requesting client.

Possible Options:

Identity Request Option

Future versions of this protocol may define new option types. Receivers MUST silently ignore any options they do not recognized and continue processing the message.

4.3. Router Advertisement message

The RA message for 6LoWPAN is based on the [RFC4861] RA message with the addition of a new flag "E". In addition new options are identified.

```
     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      |     Code      |          Checksum             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    | Cur Hop Limit |M|O|S|E| rsv |         Router Lifetime         |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                         Reachable Time                        |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                          Retrans Timer                        |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |   Options ...
    +-+-+-+-+-+-+-+-+-+-+-+-
```

Figure 9: Router Advertisement Message Format (16 octets)

IP Fields:

Source Address: MUST be the link-local address assigned to the interface from which this message is sent.

Destination Address: Typically the Source Address of an invoking Router Solicitation or the all-nodes multicast address.

Hop Limit: 255

ICMP Fields:

Type: 134

Code: 0

Checksum: The ICMP checksum.

Cur Hop Limit: As specified in [RFC4861].

M: As specified in [RFC4861] with the exception that managed mode here refers to the address assignment mechanism specified in this paper, not DHCPv6 as in [RFC4861].

O: As specified in [RFC4861].

S: 1-bit "Router Solicitation" flag. When set, it indicates that the router is requesting neighboring routers to generate Router Advertisement messages.

E: 1-bit "Edge Router" flag. When set, it indicates that the router is an Edge Router.

Reserved: A 3-bit unused field. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.

Router Lifetime: As specified in [RFC4861].

Reachable Time: As specified in [RFC4861].

Possible Options:

6LoWPAN Prefix Information Option

Multihop Information Option

Future versions of this protocol may define new option types. Receivers MUST silently ignore any options they do not recognized and continue processing the message.

4.4. Neighbor Solicitation message

NS message employed between ERs on the backbone link when ND proxy is used. A unique identifier needs to be added to the message as an option to uniquely identify a host's interface. The NS message is used in this document is as in [RFC4861] with the addition of the Host Interface Identifier Option.

4.5. 6LoWPAN ND Message Options

This section defines the common ND for 6LoWPAN message options.

4.5.1. Identity Request Option

```
 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     |G|P|         Reserved          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Lifetime                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   option(s)...
+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 10: Identity Request Option format

Type: TBD.

Length: 8-bit unsigned integer. The length of the option (including the type and length fields) in units of 8 octets.

G: 1-bit Global Address Request flag. Set to indicate that the client is requesting global addresses.

P: 1-bit Primary flag. Set to indicate that the router is primary and MAY proxy for the node if Proxy ND is used on the backbone link. If the flag is not set then the router MUST not proxy for the node.

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

Lifetime: 32-bit unsigned integer. The amout of time in units of seconds remaining before the binding MUST be considered expired. A value of zero indicates that the Binding Cache entry for the registered node MUST be deleted.

Possible Options:

Address Option

6LoWPAN Address Option

Future versions of this protocol may define new option types. Receivers MUST silently ignore any options they do not recognized and continue processing the message.

4.5.2. Identity Reply Option

```
 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     |G|P|X|   rsv   |    Status     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Lifetime                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  option(s)...
+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 11: Identity Reply Option format

Type: TBD.

Length: 8-bit unsigned integer. The length of the option (including the type and length fields) in units of 8 octets.

G: 1-bit Global Address Request flag. Set to indicate that the client is requesting global addresses.

P: 1-bit Primary flag. Set to indicate that the router is primary and MAY proxy for the node if Proxy ND is used on the backbone link. If the flag is not set then the router MUST not proxy for the node.

X: 1-bit Proxy Flag. Indicates that the router actually proxies for all of the addresses in the options field that are being assigned to the node. This can only happen if the P flag is set as well.

Status: 8-bit unsigned integer. Values TBD. 0 means unqualified success. Any value below 128 is a positive status that means that the binding was created or is being created optimistically.

Lifetime: 32-bit unsigned integer. The amout of time in units of seconds remaining before the binding MUST be considered expired. A value of zero indicates that the Binding Cache entry for the registered node MUST be deleted.

Possible Options:

Address Option

6LoWPAN Address Option

Future versions of this protocol may define new option types. Receivers MUST silently ignore any options they do not recognized and continue processing the message.

4.5.3. Address Option

```
 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     |       P       |       S       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|D|                           Reserved                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
.                                                               .
.                  IPv6 Address (variable length)               .
.                                                               .
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 12: Address Option format

Type: TBD.

Length: 8-bit unsigned integer. The length of the option (including the type and length fields) in units of 8 octets.

P: 8-bit unsigned integer. Identifies prefix compression in use, if any.

0: Prefix is carried inline.

1: Prefix compressed and link-local (fe80:/10) is assumed.

2-255: Reserved.

S: 8-bit unsigned integer. Identifies suffix compression in use, if any.

0: Suffix carried inline.

1: Suffix compressed and assumes the same value as the Host Interface Identifier field in the RR/RC message header.

2: Suffix compressed and is derived from the 6LoWPAN PAN ID/SHORT address option as defined in RFC 4944.

3-255: Reserved.

D: 1-bit Duplicate flag. When set, indicates that duplicates are allowed for this address (to support anycast).

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

IPv6 Address:

4.5.4. 6LoWPAN Address Option

```
 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     |            Reserved           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            PAN ID             |         Short Address         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 13: 6LoWPAN Address Option format

Type: TBD.

Length: 1

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

PAN ID: PAN ID of the client node. When included in a reply, the PAN ID MUST be echoed from the request.

Short Address: Short address of the client node. A value of 0xffff indicates an unspecified short address.

4.5.5. 6LoWPAN Prefix Information Option

Note: Context Identifier field to be added in rsv for use with HC.

```
 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    | Prefix Length |L|A|  CID  | r |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Valid Lifetime                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
.                                                               .
.                            Prefix                             .
.                                                               .
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 14: 6LoWPAN Prefix Information Option format

Type: TBD.

Length: 8-bit unsigned integer. The length of the option (including the type and length fields) in units of 8 octets.

Prefix Length: 8-bit unsigned integer. The number of leading bits in the Prefix that are valid. The value ranges from 0 to 128. The prefix length field provides necessary information for on-link determination (when combined with the L flag in the prefix information option). It also assists with address autoconfiguration as specified in [ADDRCONF], for which there may be more restrictions on the prefix length.

L: 1-bit on-link flag. When set, indicates that this prefix can be used for on-link determination. When not set the advertisement makes no statement about on-link or off-link properties of the prefix. In other words, if the L flag is not set a host MUST NOT conclude that an address derived from the prefix is off-link. That is, it MUST NOT update a previous indication that the address is on-link.

A: 1-bit autonomous address-configuration flag. When set indicates that this prefix can be used for stateless address configuration as specified in [ADDRCONF].

CID: 4-bit Context Identifier for this prefix information. This is used as defined in [draft-ietf-6lowpan-hc-01].

Prefix: IPv6 Prefix.

4.5.6. Multihop Information Option

```
 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     |        Sequence Number        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|V|                          Reserved                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 15: Multihop Information Option

Type: TBD.

Length: 1

Sequence Number: 16-bit signed integer. Indicates the freshness of the information advertised by the RA.

V: 1-bit flag. Indicates if the sequence number is valid and the router is advertising information obtained from another router.

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

5. LoWPAN Subnet

In a LoWPAN, a link can be a very instable set of nodes, for instance the set of nodes that can receive a packet that is broadcast over the air. Such a set may vary from one packet to the next as the node moves or as the radio propagation conditions change. As a result, a link does not define the proper set of nodes to perform ND operations such as Duplicate Address Detection and Neighbor lookup. So in ND for 6LoWPAN, those operations are performed over a subnet. A subnet is a collection of LoWPAN links interconnected by routers that may share one or more global prefixes. In particular, DAD is performed over a subnet for all types of addresses, inclucing link local.

In the backhaul model, an Edge Router and all the LoWPAN Nodes registered to that Edge Router form a subnet. In that model, the Edge Router serves all the prefixes that are defined on its subnet and can be connected to an IP routed infrastructure.

In the backbone model, a Backbone Link federates multiple LoWPANs into a single IP subnet. Each LoWPAN is a collection of links anchored at an Edge Router. The Edge Routers interconnect the LoWPANs over the Backbone Link. A node can move freely from a LoWPAN anchored at an Edge Router to a LoWPAN anchored at another Edge Router in the same subnet and conserve its link local and any other IPv6 address it has formed.

6. LoWPAN Node Specification

Instead of relying on multicast ND messages for DAD and neighbor address resolution, LoWPAN Nodes make use of an Edge Router in the LoWPAN which keeps a whiteboard of all bound addresses from nodes attached to the same ER. In addition, ERs may perform ND proxy on a backbone link, creating an extended LoWPAN sharing the same subnet prefix. ND proxy allows nodes to change their point of attachment without changing its IPv6 addresses. This specification simplifies address resolution compared to standard IPv6 ND. Global address assignment is also specified as part of the binding process, avoiding the need for additional mechanisms such as DHCPv6.

6.1. Forming addresses

All nodes are required to autoconfigure at least one address, a link-local address that is derived from the IEEE 64-bit extended MAC address that is globally unique to the device as in [RFC4944]. Link-local addresses are described in section 2.5.6 of [RFC4291]. Appendix A of that specification explains how the node builds an interface-ID based on the IEEE 64-bit extended MAC address by inverting the "u" (universal/local) bit.

As a result, knowledge of the 64-bit address of another node on the same extended LoWPAN is enough to derive its link-local address and reach it over IP. Another consequence is that the link local address is presumably unique on the Extended LoWPAN, which enables the use of Optimistic Duplicate Address Detection (oDAD) [RFC4429] over the Transit Link and the LoWPAN. The address SHOULD be created as optimistic to enable its use in the binding process with the Edge Router.

Nodes MAY learn the address of Edge Routers or Routers using traditional means such as L2 configuration or Router Advertisement messages. This specification also introduces a new anycast address 6LOWPAN_ER that the node can use to reach any Edge Router or Router on the link. This specification tolerates movement within the LoWPAN so the node does not have to stick with a given ER and MAY keep using the 6LOWPAN_ER anycast address for all its registrations.

The node might also form Unique Local and Global Unicast addresses, for instance if it needs to be reachable from the outside of the Extended LoWPAN. If a Global Prefix is available from an RA ('A' flag is set), then a Global Unicast address can be derived from the IEEE-64-bit extended MAC address using SAA. This address is marked optimistic until confirmed by the ER.

This specification includes a method for requesting a unique assigned Global Unicast address from the Edge Router by setting the 'G' flag of the Identity Request Option during registration. This is useful in the case of e.g. short addresses and avoids the need for a separate mechanism such as DHCPv6.

To simplify address resolution it is assumed that LoWPAN nodes are assigned addresses in a homogeneous so that the unicast IPv6 addresses IID resolve directly to a corresponding link-layer address. Thus avoiding address resolution when possible.

6.2. Registration process

The binding process is very similar to that of a MIPv6 mobile node, though the messages used are new Neighbor Discovery ICMP messages. A LoWPAN Node address is tentative or optimistic as long as the binding is not confirmed by the Edge Router.

The LoWPAN node uses unicast Router Registrations to perform the binding. The destination Address is that of an on-link Edge Router or Router or the 6LOWPAN_ER anycast address. The source address is the link local address of the node. A unique Host Interface Indentifier is included in the Router Registration so the binding can be identified throughout the subnet. This is usually the EUI-64 identifier of the sending node. The RR message includes an Identity Request Option. If the node would like to be assigned a Global Unique address the Global Flag 'G' is set. For each address to be bound an Address Option is included in the Identity Request Option. Thus the message is structured as follows.

ICMP (Router Registration (Identity Request Option (Address Options)))

The acknowledgment to a Router Registration is a unicast Router Confirmation message that contains the status of the binding. The source of the packet is the link-local address of the Edge Router or Router. The destination address is the link local address of the node. An Address Option for each confirmed or assigned address is included in the Identity Reply Option. Upon successful completion in the Router Confirmation message, the LoWPAN Node sets the address from optimistic or tentative to preferred.

The 'X' flag in the Router Confirmation Indentity Reply Option indicates that the Edge Router has completed DAD and now owns the Binding Address over the Transit Link.

This specification also introduces the concept of a secondary binding. For redundancy, a node might place a secondary binding with one or more other Edge Routers over a same or different LoWPANs. The 'P' flag in the Router Registration Indentity Request Option indicates whether the binding is primary.

ER bindings have a timeout associated with them, therefore nodes must periodically send a new Router Registration message to renew the bindings. If a node no longer receives RCs from any ER in the current subnet (with the same network prefix), the registration process begins from the beginning.

6.3. Next-hop determination

Next-hop determination is performed as in Section 5.2 of [RFC4861] with the following exceptions. Global and Local prefix are assumed to be off-link as the LoWPAN subnet with that prefix may be much larger than the link in route over topologies, unless the destination address exists in the neighbor cache. Link-layer information should be used to maintain the neighbor cahce whenever possible rather than using ND traffic. The ERs and Routers used for registration are kept in the Default Router List. Multihop addresses resolve to a broadcast as specified in [RFC4944].

6.4. Address lookup

A LoWPAN node does not use multicast for its Neighbor Solicitation as prescribed by the ND protocol [RFC4861] and oDAD [RFC4429]. When lookup is necessary, all NS messages are sent in unicast to the Edge Router, that answers in unicast as well. The message is a standard Neighbor Solicitation but for the destination is set to the Edge Router address or the well known 6LOWPAN_ER anycast address as opposed to the solicited-node multicast address for the destination address. A LoWPAN Node SHOULD retain a small queue for packets to neighbors awaiting to be delivered while address lookup is being performed. The size of the queue should be suitable to the available RAM of the node, and is not required to be a minimum of one buffer per neighbor as in [RFC4861].

The Target link-layer address in the response is either that of the destination if a short cut is possible over the LoWPAN, or that of the Edge Router if the destination is reachable over the Transit Link, in which case the Edge Router will terminate 6LoWPAN and relay the packet.

A LoWPAN Node does not need to join the solicited-node multicast address for its own addresses and SHOULD NOT have to answer a multicast Neighbor Solicitation. It MAY be configured to answer a unicast NS but that is not required by this specification.

Care must be used with the 6LOWPAN_ER and other anycast addresses, as anycast resolution is normally performed with a multicast NS/NA exchange. As nodes are not required to answer NS messages, the next hop determination process SHOULD map the anycast address to the link layer address of a neighbor using available L2 or other ND information.

7. LoWPAN Router Specification

LoWPAN Routers are used in a route-over configuration where the network is composed of overlapping link-local scopes. As a result, we must extend ND as specified in [RFC4861] to operate over an entire subnet, specifically the subnet controlled by Edge Routers, rather than a single IP link.

Network configuration parameters carried in Router Advertisements originate at Edge Routers and must disseminate to all Routers and Hosts within the LoWPAN. The Multihop Information option is used to support information dissemination from one or more Edge Routers to all other nodes in the LoWPAN. The option includes a "V" flag that indicates that the information contained in the Router Advertisement is valid. The option also includes a sequence number to ensure that all nodes converge on the same settings.

Because Router Registration/Confirmation exchanges only occur over link-local scope, such messages must be relayed between Hosts and Edge Routers when separated by multiple IP hops. Every LoWPAN Router MUST also serve as a Relay to ensure that any neighboring node can successfully participate in the LoWPAN.

7.1. Router Configuration Variables

A router MUST allow the following conceptual variables to be configured by system management. The specific variable names are used for demonstration purposes only, and an implementation is not required to have them, so long as its external behavior is consistent with that described in this document. The meaning of these variables are as defined in Section 6.2.1 of [RFC 4861]. Default values are specified to simplify configuration in common cases.

- IsRouter

- MaxRtrAdvInterval

- MinRtrAdvInterval

- AdvDefaultLifetime

A router MUST allow the following conceptual variables to be configured by information received in Router Advertisement messages. The specific variable names are used for demonstration purposes only, and an implementation is not required to have them, so long as its external behavior is consistent with that described in this document. The meaning of these variables are as defined in Section 6.2.1 of [RFC 4861]. However, default values are not relevant as a router should not be advertising such values until they have been received from other neighboring routers.

- AdvManagedFlag

- AdvOtherConfigFlag

- AdvReachableTime

- AdvRetransTimer

- AdvCurHopLimit

- AdvPrefixList

7.2. Becoming an Advertising Interface

An interface may become an advertising interace as specified in Section 6.2.2 of [RFC 4861].

A LoWPAN Router's interface MAY become an advertising interface before all of its router variables have been initializes. The router MUST learn these variables (e.g. AdvCurHopLimit, AdvReachableTime, prefix information, etc.) from neighboring routers. While the variables are not initialized, the router MAY send Router Advertisement with the "Solicit" flag set to solicit Router Advertisements from neighboring routers. However, the router MUST set the Router Lifetime field to zero while one or more of its variables are uninitialized.

7.3. Router Advertisement Message Content

A router sends periodic as well as solicited Router Advertisements out its advertising interface. Outgoing Router Advertisements are filled with the following values constistent with the message format given in [ramess].

- In the Router Lifetime field: if the router has a default route, the interface's configured AdvDefaultLifetime. If the router does not have a default route, zero.

- In the M and O flags: the current value of AdvManagedFlag and AdvOtherConfigFlag, respectively.

- The E flag is not set.

- In the S flag: One if the router is soliciting Router Advertisements from neighboring nodes. Zero if the router is not soliciting Router Advertisements from neighboring nodes.

- In the Cur Hop Limit field: the current value of CurHopLimit.

- In the Reachable Time field: the current value of AdvReachableTime.

- In the Retrans Timer field: the current value of AdvRetransTimer.

- In the options:

  - Multihop Information option: to indicate if the information contained in the Router Advertisement is valid and, if so, the freshness of the information contained in the Router Advertisement message. The option fields are set as follows:

    - In the "valid" flag: the current value of AdvInformationValid.

    - In the Sequence Number field: the current value of AdvInformationSequence.

  - Prefix Information options: one Prefix Information option for each prefix listed in AdvPrefixList with the option fields set from the information in the AdvPrefxList entry as follows:

    - In the "on-link" flag: the entry's AdvOnLinkFlag.

    - In the "Autonomous address configuration" flag: the entry's AdvAutonomousFlag.

    - In the Valid Lifetime field: the entry's AdvValidLifetime.

7.4. Sending Unsolicited Router Advertisements

As specified in Section 6.2.4 of [RFC 4861].

7.5. Ceasing To Be an Advertising Interface

As specified in Section 6.2.5 of [RFC 4861].

7.6. Processing Router Solicitations

As specified in Section 6.2.6 of [RFC 4861].

7.7. Router Advertisement Consistency

TBD

7.8. Relaying a Router Registration Message

When a router receives a Router Registration message from a LoWPAN Node, the router copies the information from the Router Registration message into the Relay Router Registration message. The Host Link-Local Address Interface Identifier is the only differing field from the Router Registration message, and the router copies the value from the IID of the Router Registration's IP Source Address.

By default, the router relays Router Registration messages to the 6LOWPAN_ER anycast address. However, the router MAY be configured to use a list of destination addresses, which MAY include unicast addresses, the 6LOWPAN_ER anycast address, or other addresses selected by the network administrator.

7.9. Relaying a Router Confirmation Message

When the router receives a Relay Router Confirmation message from an Edge Router, the router copies the information from the Relay message into a Router Confirmation message. The Host Link-Local Address Interface Identifier is used to form the IPv6 Destination Address for the Router Confirmation message. The Hop Limit of the Router Confirmation message is set to 255.

8. LoWPAN Edge Router Specification

Edge Routers are introduced to scale the Neighbor Discovery Operations by reducing the amount of costly multicast ND messages over a subnet that may cover hundreds or thousands of nodes.

Instead of multicasting ND messages, a LoWPAN Node performs unicast exchanges to its Edge Router to claim and lookup addresses using unicast and anycast addresses, and the Edge Router proxies the ND requests over the Backbone Link when necessary.

This specification documents the extensions to IPv6 Neighbor Discovery that enables a LoWPAN Node to claim and lookup addresses using a Edge Router as an intermediate proxy. The draft also documents the use of EUI-64 based link-local addresses and the way they are claimed by the Edge Routers over the Backbone link.

For the purpose of Neighbor Discovery proxying, this specification documents the LoWPAN registration table, a conceptual data structure that is similar to the MIPv6 binding cache.

Another function of the Edge Router is to perform 6LowPAN compression and uncompression between the LoWPAN and the Backbone Link and ensure MTU compatibility. Packets flow uncompressed over the Backbone Link and are routed normally towards a Gateway or an Application sitting on the Backbone link or on a different link that is reachable via IP.

8.1. Registration process

Upon a new registration for a link-local address based on an IEEE 64-bit extended MAC address, the Edge Router MAY use Optimistic DAD on the Transit Link. A positive acknowledgement can be sent to the 6LoWPAN node right away if oDAD is used on the Transit Link.

A LoWPAN Node should be able to join a different Edge Router at any time without the complexities of terminating a current registration and renumber. To enable this, the ND proxy operation upon a Router Registration/Confirmation flow wins the address ownership over a ND proxy operation that is done asynchronously, on behalf of the same LoWPAN Node, upon a prior registration. So an Edge Router that would happen to have a binding for that same address for the same LoWPAN Node identified by its EUI-64 address will yield and deprecate its binding.

A new option in NS/NA messages that carries the node EUI-64 address enables to differentiate an address collision from a movement of a node from one Edge Router to the next. Upon a registration flow, a node doing DAD SHOULD ignore NA without the the override (O) bit, and set the override (O) bit in its own NA messages. Asynchronously to the registration, a node SHOULD NOT set the override (O) bit in its NA messages and should yield to an NA message with the override (O) bit set.

So the Edge Router operation on the transit link is similar to that of a Home Agent as specified in "Mobility Support for IPv6" [RFC3775] yet different. In particular, the Neighbor Advertisement message is used as specified in section "10.4.1. Intercepting Packets for a Mobile Node" with the exception that the override (O) bit is not set, indicating that this Edge Router acts as a proxy for the LoWPAN and will yield should another Edge Router claim that address on the Backbone Link.

This specification also introduces the concept of secondary binding. Upon a secondary binding, the Edge Router will not announce or defend the address on the backbone link, but will be able to forward packets to the node over its LoWPAN interface.

The Edge Router responds to a Router Registration with a Router Confirmation. The source address is a link local address of the router and the destination is the optimistic address of the node. The ER responds to Relay RR messages with a Relay RC message, where the destination address is the address of the Router which sent the Relay RR message.

If the Edge Router is primary for a registration as indicated by the 'P' flag in the Identity Request Option and it is connected to a Backbone, then it SHOULD perform proxy ND operations on the backbone and indicate so in the Router Confirmation message using the 'X' flag of the Identity Reply Option. In particular the Egde Router SHOULD reject the registration if DAD fails on the backbone. When oDAD is used over the backbone the Edge Router MAY issue the Router Confirmation right away with a positive code, but if a collision is finally detected, it cancels the registration with an asynchronous Router Confirmation and a negative completion code on the same TID.

8.2. Exposing the Edge Router

The Backbone link is used as reference for Neighbor Discovery operations. When an Edge Router does not have an entry in its registration table for a target node, it looks it up over the backbone using ND operation in place for that medium. Edge Routers also perform ND proxying for the LoWPAN Nodes that are proactively registered to them. That way, a lookup over the backbone is not propagated over the LoWPANs, but answered by the proxy that has the registration for the target, if any.

To enable proxying over the backbone Link, an Edge Router must join the solicited-node multicast address on that link for all the registered addresses of the nodes in its LoWPANs. The Edge Router answers the Neighbor Solicitation with a Neighbor Advertisement that indicates its own link-layer address in the Target link-layer address option.

An Edge Router expects and answers unicast Neighbor Solicitations for all nodes in its LoWPANs. It answers as a proxy for the real target. The target link-layer address in the response is either that of the destination if a short cut is possible over the LoWPAN, or that of the Backbone Router if the destination is reachable over the Transit Link, in which case the Backbone Router will terminate 6LoWPAN and relay the packet.

The Edge Router forms a link-local address in exactly the same way as any other node on the LoWPAN. It uses the same link local address for the Backbone Link and for all the associated LoWPAN(s) connected to that Edge Router.

The Edge Router configures the well known 6LOWPAN_ER anycast address on the LoWPAN interfaces where it serves as Edge Router. Note that the Edge Router will accept registration packets with a hop limit that is lower than 255 on that specific address.

The Edge Router announces itself using Router Advertisement (RA) messages that are broadcasted periodically over the LOWPAN and the backbone link.

A new (E) bit in the RA indicates the Edge Router capability. In this way a node can learn the PAN-ID and the 16-bit short address for the Edge Router if it was not already acquired from another process that is not covered by this specification.

The Edge Router MAY also announce any prefix that is configured on the transit link, and serve as the default gateway for any node on the Transit Link or on the attached LoWPANs.

The transit link Maximum Transmission Unit serves as base for Path MTU discovery and Transport layer Maximum Segment Size negotiation (see section 8.3 of [RFC2460]) for all nodes in the LoWPANs. To achieve this, the Edge Router announces the MTU of the transit link over the LoWPAN using the MTU option in the RA message as prescribed in section "4.6.4. MTU" of IPv6 Neighbor Discovery [RFC4861].

LoWPAN Nodes SHOULD form IPv6 packets that are smaller than that MTU. As a result, those packets should not require any fragmentation over the transit link though they might be intranet-fragmented over the LoWPAN itself as prescribed by [RFC4944]).

More information on the MTU issue with regard to ND-proxying can be found in Neighbor Discovery Proxies [RFC4389] and [I-D.van-beijnum-multi-mtu].

8.3. Forwarding packets

Upon receiving packets on one of its LoWPAN interfaces, the Edge Router checks whether it has a binding for the source address. If it does, then the Edge Router can forward the packet to another LoWPAN Node or over the Backbone link. Otherwise, the Edge Router MUST discard the packet. If the packet is to be transmitted over the Transit link, then the 6LoWPAN sublayer is terminated and the full IPv6 packet is reassembled and expanded.

When forwarding a packet from the Backbone Link towards a LoWPAN interface, the Edge Router performs the 6LoWPAN sublayer operations of compression and fragmentation and passes the packet to the lower layer for transmission.

8.4. Fault tolerance

TBD : to be provided in the next revision.

9. 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 LoWPAN MAC provides secure unicast to/from Routers and secure broadcast from the Routers in a way that prevents tempering with or replaying the RA messages. However, any future 6LoWPAN security protocol that applies to Neighbor Discovery for 6LoWPAN protocol, is out of scope of this document.

10. IANA Considerations

This specification requires four new ICMP types for binding registration. The is also a need for a new link local anycast address, 6LOWPAN_ER for the Edge Routers and Routers; used as a functional address.

11. Acknowledgments

The authors thank Carsten Bormann, Geoff Mulligan and Julien Abeille for useful discussions and comments that have helped shaped and improve this document.

12. References

12.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[RFC2460] Deering, S. and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 2460, December 1998.

[RFC3775] Johnson, D., Perkins, C., and J. Arkko, "Mobility Support in IPv6", RFC 3775, June 2004.

[RFC4291] Hinden, R. and S. Deering, "IP Version 6 Addressing Architecture", RFC 4291, February 2006.

[RFC4429] Moore, N., "Optimistic Duplicate Address Detection (DAD) for IPv6", RFC 4429, April 2006.

[RFC4443] Conta, A., Deering, S., and M. Gupta, "Internet Control Message Protocol (ICMPv6) for the Internet Protocol Version 6 (IPv6) Specification", RFC 4443, March 2006.

[RFC4861] Narten, T., Nordmark, E., Simpson, W., and H. Soliman, "Neighbor Discovery for IP version 6 (IPv6)", RFC 4861, September 2007.

[RFC4862] Thomson, S., Narten, T., and T. Jinmei, "IPv6 Stateless Address Autoconfiguration", RFC 4862, September 2007.

[RFC4944] Montenegro, G., Kushalnagar, N., Hui, J., and D. Culler, "Transmission of IPv6 Packets over IEEE 802.15.4 Networks", RFC 4944, September 2007.

12.2. Informative References

[I-D.van-beijnum-multi-mtu]
Beijnum, I., "Extensions for Multi-MTU Subnets", draft-van-beijnum-multi-mtu-02 (work in progress), February 2008.

[RFC3963] Devarapalli, V., Wakikawa, R., Petrescu, A., and P. Thubert, "Network Mobility (NEMO) Basic Support Protocol", RFC 3963, January 2005.

[RFC3971] Arkko, J., Kempf, J., Zill, B., and P. Nikander, "SEcure Neighbor Discovery (SEND)", RFC 3971, March 2005.

[RFC3972] Aura, T., "Cryptographically Generated Addresses (CGA)", RFC 3972, March 2005.

[RFC4389] Thaler, D., Talwar, M., and C. Patel, "Neighbor Discovery Proxies (ND Proxy)", RFC 4389, April 2006.

[RFC4919] Kushalnagar, N., Montenegro, G., and C. Schumacher, "IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals", RFC 4919, August 2007.

Authors' Addresses

Zach Shelby (editor)
Sensinode
Kidekuja 2
Vuokatti 88600
FINLAND

Phone: +358407796297
Email: zach@sensinode.com

Pascal Thubert
Cisco Systems
Village d'Entreprises Green Side
400, Avenue de Roumanille
Batiment T3
Biot - Sophia Antipolis 06410
FRANCE

Phone: +33 4 97 23 26 34
Email: pthubert@cisco.com

Jonathan W. Hui
Arch Rock Corporation
501 2nd St. Ste. 410
San Francisco, California 94107
USA

Phone: +415 692 0828
Email: jhui@archrock.com

Samita Chakrabarti
IP Infusion
1188 Arquest Street
Sunnyvale, California
USA

Phone:
Email: samitac@ipinfusion.com

Erik Nordmark
Sun Microsystems, Inc.
17 Network Circle
Menlo Park, California 94025
USA

Phone:
Email: Erik.Nordmark@Sun.COM

Full Copyright Statement

Intellectual Property

Acknowledgment

Funding for the RFC Editor function is provided by the IETF Administrative Support Activity (IASA).