

6Lo Working Group  
Internet-Draft  
Intended status: Standards Track  
Expires: June 16, 2020

C. Gomez  
S. Darroudi  
Universitat Politecnica de Catalunya  
T. Savolainen  
DarkMatter  
M. Spoerk  
Graz University of Technology  
December 14, 2019

**IPv6 Mesh over BLUETOOTH(R) Low Energy using IPSP  
draft-ietf-6lo-blemesh-07**

**Abstract**

[RFC 7668](#) describes the adaptation of 6LoWPAN techniques to enable IPv6 over Bluetooth low energy networks that follow the star topology. However, recent Bluetooth specifications allow the formation of extended topologies as well. This document specifies mechanisms that are needed to enable IPv6 mesh over Bluetooth Low Energy links established by using the Bluetooth Internet Protocol Support Profile. This document does not specify the routing protocol to be used in an IPv6 mesh over Bluetooth LE links.

**Status of This Memo**

This Internet-Draft is submitted in full conformance with the provisions of [BCP 78](#) and [BCP 79](#).

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at <https://datatracker.ietf.org/drafts/current/>.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on June 16, 2020.

**Copyright Notice**

Copyright (c) 2019 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to [BCP 78](#) and the IETF Trust's Legal Provisions Relating to IETF Documents

(<https://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

## Table of Contents

<a href="#">1.</a>	<a href="#">Introduction</a>	<a href="#">2</a>
<a href="#">1.1.</a>	<a href="#">Terminology and Requirements Language</a>	<a href="#">3</a>
<a href="#">2.</a>	<a href="#">Bluetooth LE Networks and the IPSP</a>	<a href="#">3</a>
<a href="#">3.</a>	<a href="#">Specification of IPv6 mesh over Bluetooth LE links</a>	<a href="#">4</a>
<a href="#">3.1.</a>	<a href="#">Protocol stack</a>	<a href="#">4</a>
<a href="#">3.2.</a>	<a href="#">Subnet model</a>	<a href="#">5</a>
<a href="#">3.3.</a>	<a href="#">Link model</a>	<a href="#">6</a>
<a href="#">3.3.1.</a>	<a href="#">Stateless address autoconfiguration</a>	<a href="#">6</a>
<a href="#">3.3.2.</a>	<a href="#">Neighbor Discovery</a>	<a href="#">6</a>
<a href="#">3.3.3.</a>	<a href="#">Header compression</a>	<a href="#">7</a>
<a href="#">3.3.4.</a>	<a href="#">Unicast and multicast mapping</a>	<a href="#">8</a>
<a href="#">4.</a>	<a href="#">IANA Considerations</a>	<a href="#">8</a>
<a href="#">5.</a>	<a href="#">Security Considerations</a>	<a href="#">9</a>
<a href="#">6.</a>	<a href="#">Contributors</a>	<a href="#">9</a>
<a href="#">7.</a>	<a href="#">Acknowledgements</a>	<a href="#">9</a>
<a href="#">8.</a>	<a href="#">Appendix A: Bluetooth LE connection establishment example</a>	<a href="#">10</a>
<a href="#">9.</a>	<a href="#">Appendix B: Node joining procedure</a>	<a href="#">12</a>
<a href="#">10.</a>	<a href="#">References</a>	<a href="#">13</a>
<a href="#">10.1.</a>	<a href="#">Normative References</a>	<a href="#">13</a>
<a href="#">10.2.</a>	<a href="#">Informative References</a>	<a href="#">14</a>
	<a href="#">Authors' Addresses</a>	<a href="#">15</a>

## 1. Introduction

Bluetooth Low Energy (hereinafter, Bluetooth LE) was first introduced in the Bluetooth 4.0 specification. Bluetooth LE (which has been marketed as Bluetooth Smart) is a low-power wireless technology designed for short-range control and monitoring applications. Bluetooth LE is currently implemented in a wide range of consumer electronics devices, such as smartphones and wearable devices. Given the high potential of this technology for the Internet of Things, the Bluetooth Special Interest Group (Bluetooth SIG) and the IETF have produced specifications in order to enable IPv6 over Bluetooth LE, such as the Internet Protocol Support Profile (IPSP) [[IPSP](#)], and [RFC 7668](#), respectively. Bluetooth 4.0 only supports Bluetooth LE networks that follow the star topology. In consequence, [RFC 7668](#) was specifically developed and optimized for that type of network topology. However, the functionality described in [RFC 7668](#) is not



sufficient and would fail to enable an IPv6 mesh over Bluetooth LE links. This document specifies mechanisms that are needed to enable IPv6 mesh over Bluetooth LE links. This document does not specify the routing protocol to be used in an IPv6 mesh over Bluetooth LE links.

### **1.1. Terminology and Requirements Language**

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 [RFC 2119](#) [[RFC2119](#)].

The terms 6LoWPAN Node (6LN), 6LoWPAN Router (6LR) and 6LoWPAN Border Router (6LBR) are defined as in [[RFC6775](#)], with an addition that Bluetooth LE central and Bluetooth LE peripheral (see [Section 2](#)) can both be adopted by a 6LN, a 6LR or a 6LBR.

## **2. Bluetooth LE Networks and the IPSP**

Bluetooth LE defines two Generic Access Profile (GAP) roles of relevance herein: the Bluetooth LE central role and the Bluetooth LE peripheral role. A device in the central role, which is called central from now on, has traditionally been able to manage multiple simultaneous connections with a number of devices in the peripheral role, called peripherals hereinafter. Bluetooth 4.1 (now deprecated) introduced the possibility for a peripheral to be connected to more than one central simultaneously, therefore allowing extended topologies beyond the star topology for a Bluetooth LE network. In addition, a device may simultaneously be a central in a set of link layer connections, as well as a peripheral in others. On the other hand, the IPSP enables discovery of IP-enabled devices and the establishment of a link layer connection for transporting IPv6 packets. The IPSP defines the Node and Router roles for devices that consume/originate IPv6 packets and for devices that can route IPv6 packets, respectively. Consistently with Bluetooth 4.1 and subsequent Bluetooth versions (e.g. Bluetooth 4.2 [[BTCorev4.2](#)] or subsequent), a device may implement both roles simultaneously.

This document assumes a mesh network composed of Bluetooth LE links, where link layer connections are established between neighboring IPv6-enabled devices (see [Section 3.3.2](#), item 3.b)). The IPv6 forwarding devices of the mesh have to implement both IPSP Node and Router roles, while simpler leaf-only nodes can implement only the Node role. In an IPv6 mesh over Bluetooth LE links, a node is a neighbor of another node, and vice versa, if a link layer connection has been established between both by using the IPSP functionality for discovery and link layer connection establishment for IPv6 packet transport.



Note that this specification allows using different MTUs in different links. If an implementation requires use of the same MTU on every one of its links, and a new node with a smaller MTU is added to the network, a renegotiation of one or more links can occur. In the



IPv6 mesh over Bluetooth LE links MUST follow a route-over approach. This document does not specify the routing protocol to be used in an IPv6 mesh over Bluetooth LE links.





### **3.3. Link model**

#### **3.3.1. Stateless address autoconfiguration**

6LN, 6LR and 6LBR IPv6 addresses in an IPv6 mesh over Bluetooth LE links are configured as per [section 3.2.2 of RFC 7668](#).

Multihop DAD functionality as defined in [section 8.2 of RFC 6775](#) and updated by [RFC 8505](#), or some substitute mechanism (see [section 3.3.2](#)), MAY be supported.

#### **3.3.2. Neighbor Discovery**

'Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks' [[RFC6775](#)], subsequently updated by 'Registration Extensions for IPv6 over Low-Power Wireless Personal Area Network (6LoWPAN) Neighbor Discovery' [[RFC8505](#)], describes the neighbor discovery functionality adapted for use in several 6LoWPAN topologies, including the mesh topology. The route-over functionality of [RFC 6775](#) and [RFC 8505](#) MUST be supported.

The following aspects of the Neighbor Discovery optimizations for 6LoWPAN [[RFC6775](#)], [[RFC8505](#)] are applicable to Bluetooth LE 6LNs:

1. A Bluetooth LE 6LN SHOULD register its non-link-local addresses with its routers by sending a Neighbor Solicitation (NS) message with the Extended Address Registration Option (EARO) and process the Neighbor Advertisement (NA) accordingly. Note that in some cases (e.g. very short-lived connections) it may not be worthwhile for a 6LN to send an NS with EARO for registering its address. The EARO option includes a Registration Ownership Verifier (ROVR) field [[RFC8505](#)]. In the case of Bluetooth LE, by default the ROVR field is filled with the 48-bit device address used by the Bluetooth LE node converted into 64-bit Modified EUI-64 format [[RFC4291](#)]. Optionally, a cryptographic ID (see [[I-D.ietf-6lo-ap-nd](#)]) MAY be placed in the ROVR field. If a cryptographic ID is used, address registration and multihop DAD formats and procedures defined in [[I-D.ietf-6lo-ap-nd](#)] MUST be used, unless an alternative mechanism offering equivalent protection is used. As per [RFC 8505](#), a 6LN MUST NOT register its link-local address.

If the 6LN registers for a same compression context multiple addresses that are not based on Bluetooth device address, the header compression efficiency will decrease.

2. For sending Router Solicitations and processing Router Advertisements the Bluetooth LE hosts MUST, respectively, follow Sections [5.3](#) and [5.4](#) of [[RFC6775](#)], and [Section 5.6 of \[RFC8505\]](#).



3. The router behavior for 6LRs and 6LBRs is described in [Section 6 of RFC 6775](#), and updated by [RFC 8505](#). However, as per this specification: a) Routers SHALL NOT use multicast NSs to discover other routers' link layer addresses. b) As per section 6.2 of [RFC 6775](#), in a dynamic configuration scenario, a 6LR comes up as a non-router and waits to receive a Router Advertisement for configuring its own interface address first, before setting its interfaces to be advertising interfaces and turning into a router. In order to support such operation in an IPv6 mesh over Bluetooth LE links, a 6LR first uses the IPSP Node role only. Once the 6LR has established a connection with another node previously running as a router, and receives a Router Advertisement from that router, the 6LR configures its own interface address, it turns into a router, and it runs as an IPSP Router. A 6LBR uses the IPSP Router role since the 6LBR is initialized. See an example in the Appendix.

4. Border router behavior is described in [Section 7 of RFC 6775](#), and updated by [RFC 8505](#).

[RFC 6775](#) defines substitutable mechanisms for distributing prefixes and context information ([section 8.1 of RFC 6775](#)), as well as for Duplicate Address Detection across a route-over 6LoWPAN ([section 8.2 of RFC 6775](#)). [RFC 8505](#) updates those mechanisms and the related message formats. Implementations of this specification MAY support the features described in sections [8.1](#) and [8.2](#) of [RFC 6775](#), as updated by [RFC 8505](#), unless some alternative ("substitute") from some other specification is supported by the implementation.

### **3.3.3. Header compression**

Header compression as defined in [RFC 6282](#) [[RFC6282](#)], which specifies the compression format for IPv6 datagrams on top of IEEE 802.15.4, is REQUIRED as the basis for IPv6 header compression on top of Bluetooth LE. All headers MUST be compressed according to [RFC 6282](#) [[RFC6282](#)] encoding formats.

To enable efficient header compression, when the 6LBR sends a Router Advertisement it MAY include a 6LoWPAN Context Option (6CO) [[RFC6775](#)] matching each address prefix advertised via a Prefix Information Option (PIO) [[RFC4861](#)] for use in stateless address autoconfiguration. Note that 6CO is not needed for context-based compression when a single prefix is used in the network.

The specific optimizations of [RFC 7668](#) for header compression, which exploited the star topology and ARO (note that the latter has been updated by EARO as per [RFC 8505](#)), cannot be generalized in an IPv6 mesh over Bluetooth LE links. Still, a subset of those optimizations can be applied in some cases in such a network. These cases comprise



link-local interactions, non-link-local packet transmissions originated by a 6LN, and non-link-local packets intended for a 6LN that are originated or forwarded by a neighbor of that 6LN. For the rest of packet transmissions, context-based compression MAY be used.

When a device transmits a packet to a neighbor, the sender MUST fully elide the source IID if the source IPv6 address is the link-local address based on the sender's Bluetooth device address (SAC=0, SAM=11). The sender also MUST fully elide the destination IPv6 address if it is the link-local address based on the neighbor's Bluetooth device address (DAC=0, DAM=11).

When a 6LN transmits a packet, with a non-link-local source address that the 6LN has registered with EARO in the next-hop router for the indicated prefix, the source address MUST be fully elided if it is the latest address that the 6LN has registered for the indicated prefix (SAC=1, SAM=11). If the source non-link-local address is not the latest registered by the 6LN, then the 64 bits of the IID SHALL be fully carried in-line (SAC=1, SAM=01) or if the first 48 bits of the IID match with the latest address registered by the 6LN, then the last 16 bits of the IID SHALL be carried in-line (SAC=1, SAM=10).

When a router transmits a packet to a neighboring 6LN, with a non-link-local destination address, the router MUST fully elide the destination IPv6 address if the destination address is the latest registered by the 6LN with EARO for the indicated context (DAC=1, DAM=11). If the destination address is a non-link-local address and not the latest registered, then the 6LN MUST either include the IID part fully in-line (DAM=01) or, if the first 48 bits of the IID match to the latest registered address, then elide those 48 bits (DAM=10).

#### **3.3.4. Unicast and multicast mapping**

The Bluetooth LE Link Layer does not support multicast. Hence, traffic is always unicast between two Bluetooth LE neighboring nodes. If a node needs to send a multicast packet to several neighbors, it has to replicate the packet and unicast it on each link. However, this may not be energy efficient, and particular care must be taken if the node is battery powered. A router (i.e. a 6LR or a 6LBR) MUST keep track of neighboring multicast listeners, and it MUST NOT forward multicast packets to neighbors that have not registered as listeners for multicast groups the packets belong to.

## **4. IANA Considerations**

There are no IANA considerations related to this document.



## **5. Security Considerations**

The security considerations in [RFC 7668](#) apply.

IPv6 mesh over Bluetooth LE links requires a routing protocol to find end-to-end paths. Unfortunately, the routing protocol may generate additional opportunities for threats and attacks to the network.

[RFC 7416](#) [[RFC 7416](#)] provides a systematic overview of threats and attacks on the IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL), as well as countermeasures. In that document, described threats and attacks comprise threats due to failures to authenticate, threats due to failure to keep routing information, threats and attacks on integrity, and threats and attacks on availability. Reported countermeasures comprise confidentiality attack, integrity attack, and availability attack countermeasures.

While this specification does not state the routing protocol to be used in IPv6 mesh over Bluetooth LE links, the guidance of [RFC 7416](#) is useful when RPL is used in such scenarios. Furthermore, such guidance may partly apply for other routing protocols as well.

The ROVR can be derived from the Bluetooth device address. However, such a ROVR can be spoofed, and therefore, any node connected to the subnet and aware of a registered-address-to-ROVR mapping could perform address theft and impersonation attacks. Use of Address Protected Neighbor Discovery [[I-D.ietf-6lo-ap-nd](#)] provides protection against such attacks.

## **6. Contributors**

Carlo Alberto Boano (Graz University of Technology) contributed to the design and validation of this document.

## **7. Acknowledgements**

The Bluetooth, Bluetooth Smart and Bluetooth Smart Ready marks are registered trademarks owned by Bluetooth SIG, Inc.

The authors of this document are grateful to all [RFC 7668](#) authors, since this document borrows many concepts (albeit, with necessary extensions) from [RFC 7668](#).

The authors also thank Alain Michaud, Mark Powell, Martin Turon, Bilhanan Silverajan, Rahul Jadhav and Pascal Thubert for their comments, which helped improve the document.





Carles Gomez has been supported in part by the Spanish Government Ministerio de Economia y Competitividad through projects TEC2012-32531, TEC2016-79988-P and FEDER.

## 8. [Appendix A](#): Bluetooth LE connection establishment example

This appendix provides an example of Bluetooth LE connection establishment and use of IPSP roles in an IPv6 mesh over Bluetooth LE links that uses dynamic configuration. The example follows text in [Section 3.3.2](#), item 3.b).

The example assumes a network with one 6LBR, two 6LRs and three 6LNs, as shown in Figure 3. Connectivity between the 6LNs and the 6LBR is only possible via the 6LRs.

The following text describes the different steps as time evolves, in the example. Note that other sequences of events that may lead to the same final scenario are also possible.

At the beginning, the 6LBR starts running as an IPSP Router, whereas the rest of devices are not yet initialized (Step 1). Next, the 6LRs start running as IPSP Nodes, i.e., they use Bluetooth LE advertisement packets to announce their presence and support of IPv6 capabilities (Step 2). The 6LBR (already running as an IPSP Router) discovers the presence of the 6LRs and establishes one Bluetooth LE connection with each 6LR (Step 3). After establishment of those link layer connections (and after reception of Router Advertisements from the 6LBR), Step 4, the 6LRs start operating as routers, and also initiate the IPSP Router role (note: whether the IPSP Node role is kept running simultaneously is an implementation decision). Then, 6LNs start running the IPSP Node role (Step 5). Finally, the 6LRs discover presence of the 6LNs and establish connections with the latter (Step 6).

### Step 1

\*\*\*\*\*

6LBR  
(IPSP: Router)

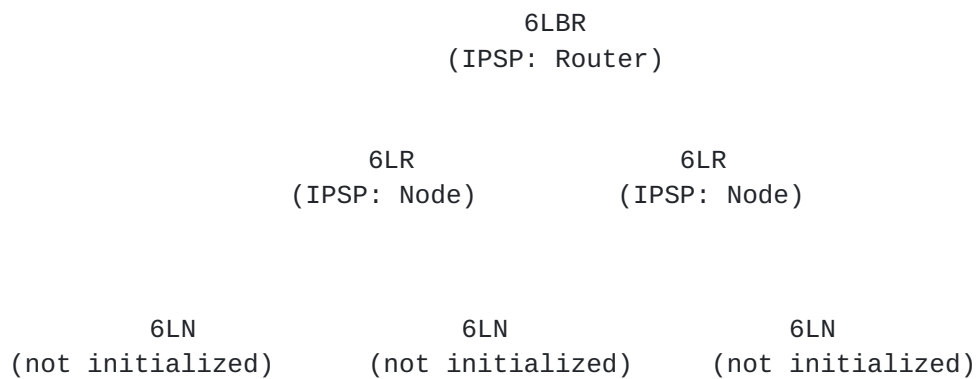
6LR                      6LR  
(not initialized)      (not initialized)

6LN                      6LN                      6LN  
(not initialized)      (not initialized)      (not initialized)



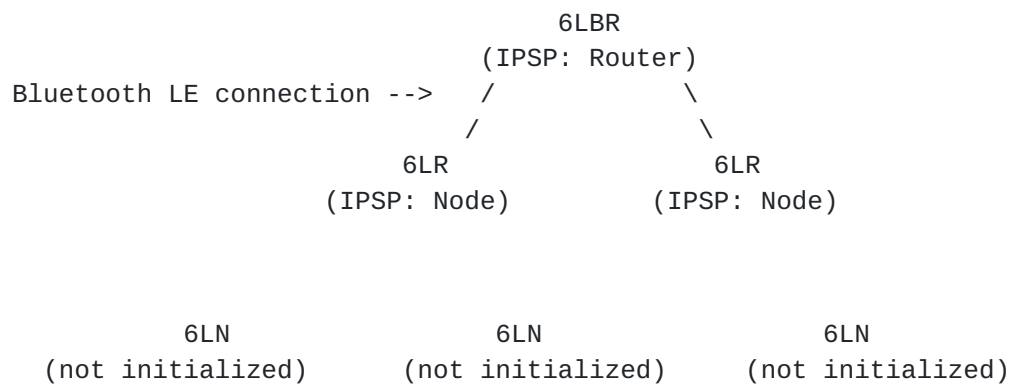
## Step 2

\*\*\*\*\*



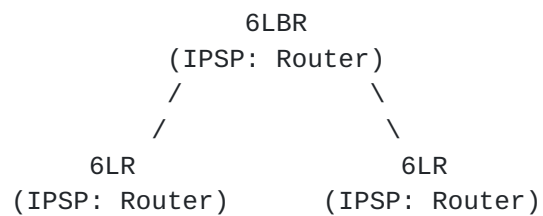
## Step 3

\*\*\*\*\*



## Step 4

\*\*\*\*\*

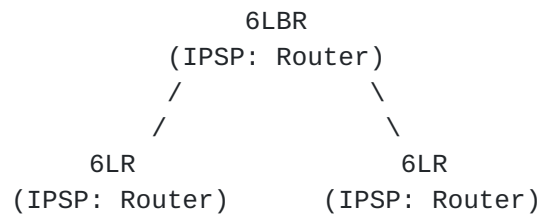




6LN (not initialized)      6LN (not initialized)      6LN (not initialized)

Step 5

\*\*\*\*\*



6LN (IPSP: Node)      6LN (IPSP: Node)      6LN (IPSP: Node)

Step 6

\*\*\*\*\*

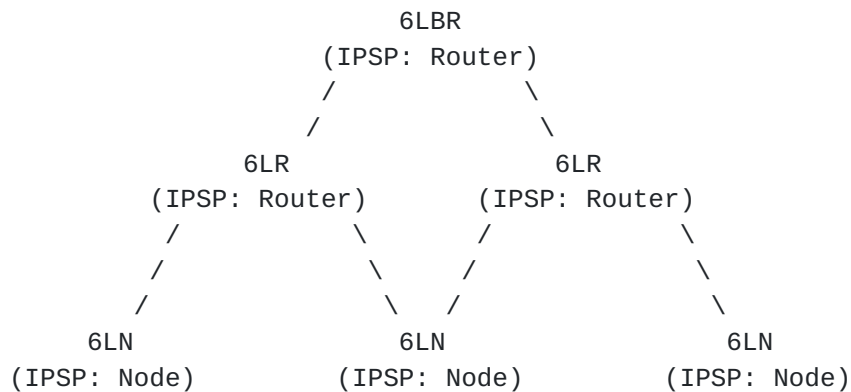


Figure 3: An example of connection establishment and use of IPSP roles in an IPv6 mesh over Bluetooth LE links.

## 9. [Appendix B](#): Node joining procedure

This appendix provides a diagram that illustrates the node joining procedure. First of all, the joining node advertises its presence in order to allow establishing Bluetooth LE connections with neighbors that already belong to a network. The latter typically run as a 6LR



or as a 6LBR. After Bluetooth LE connection establishment, the joining node starts acting as a 6LN.

Figure 4 shows the sequence of messages that are exchanged by the 6LN and a neighboring 6LR that already belongs to the network, after the establishment of a Bluetooth LE connection between both devices. Initially, the 6LN sends an RS message (1). Then, the 6LR replies with an RA, which includes the PIO (2). After discovering the non-link-local prefix in use in the network, the 6LN creates its non-link-local address, registers that address with EARO (3) in the 6LR, and multihop DAD is performed (4). The next step is the transmission of the NA message sent by the 6LR in response to the NS previously sent by the 6LN (5). If the non-link-local address of the 6LN has been successfully validated, the 6LN can operate as a member of the network it has joined.

```

(1)          6LN -----(RS)-----> 6LR
(2)          6LN <---(RA-PIO)---- 6LR
(3)          6LN -----(NS-EARO)--> 6LR
(4)          [Multihop DAD procedure]
(5)          6LN <---(NA)----- 6LR

```

Figure 4: Message exchange diagram for a joining node

## 10. References

### 10.1. Normative References

- [BTCorev4.2] Bluetooth Special Interest Group, "Bluetooth Core Specification Version 4.2", December 2014, <<https://www.bluetooth.com/specifications/archived-specifications>>.
- [IPSP] Bluetooth Special Interest Group, "Bluetooth Internet Protocol Support Profile Specification Version 1.0.0", December 2014, <<https://www.bluetooth.org/en-us/specification/adopted-specifications>>.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", [BCP 14](#), [RFC 2119](#), DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.





- [RFC4291] Hinden, R. and S. Deering, "IP Version 6 Addressing Architecture", [RFC 4291](#), DOI 10.17487/RFC4291, February 2006, <<https://www.rfc-editor.org/info/rfc4291>>.
- [RFC4861] Narten, T., Nordmark, E., Simpson, W., and H. Soliman, "Neighbor Discovery for IP version 6 (IPv6)", [RFC 4861](#), DOI 10.17487/RFC4861, September 2007, <<https://www.rfc-editor.org/info/rfc4861>>.
- [RFC6282] Hui, J., Ed. and P. Thubert, "Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks", [RFC 6282](#), DOI 10.17487/RFC6282, September 2011, <<https://www.rfc-editor.org/info/rfc6282>>.
- [RFC6775] Shelby, Z., Ed., Chakrabarti, S., Nordmark, E., and C. Bormann, "Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)", [RFC 6775](#), DOI 10.17487/RFC6775, November 2012, <<https://www.rfc-editor.org/info/rfc6775>>.
- [RFC7668] Nieminen, J., Savolainen, T., Isomaki, M., Patil, B., Shelby, Z., and C. Gomez, "IPv6 over BLUETOOTH(R) Low Energy", [RFC 7668](#), DOI 10.17487/RFC7668, October 2015, <<https://www.rfc-editor.org/info/rfc7668>>.
- [RFC8505] Thubert, P., Ed., Nordmark, E., Chakrabarti, S., and C. Perkins, "Registration Extensions for IPv6 over Low-Power Wireless Personal Area Network (6LoWPAN) Neighbor Discovery", [RFC 8505](#), DOI 10.17487/RFC8505, November 2018, <<https://www.rfc-editor.org/info/rfc8505>>.

## **10.2. Informative References**

- [BTCorev4.1] Bluetooth Special Interest Group, "Bluetooth Core Specification Version 4.1", December 2013, <<https://www.bluetooth.org/en-us/specification/adopted-specifications>>.
- [I-D.ietf-6lo-ap-nd] Thubert, P., Sarikaya, B., Sethi, M., and R. Struik, "Address Protected Neighbor Discovery for Low-power and Lossy Networks", [draft-ietf-6lo-ap-nd-12](#) (work in progress), April 2019.
- [RFC4903] Thaler, D., "Multi-Link Subnet Issues", [RFC 4903](#), DOI 10.17487/RFC4903, June 2007, <<https://www.rfc-editor.org/info/rfc4903>>.



[RFC7416] Tsao, T., Alexander, R., Dohler, M., Daza, V., Lozano, A., and M. Richardson, Ed., "A Security Threat Analysis for the Routing Protocol for Low-Power and Lossy Networks (RPLs)", [RFC 7416](https://www.rfc-editor.org/info/rfc7416), DOI 10.17487/RFC7416, January 2015, <<https://www.rfc-editor.org/info/rfc7416>>.

#### Authors' Addresses

Carles Gomez  
Universitat Politecnica de Catalunya  
C/Esteve Terradas, 7  
Castelldefels 08860  
Spain

Email: carlesgo@entel.upc.edu

Seyed Mahdi Darroudi  
Universitat Politecnica de Catalunya  
C/Esteve Terradas, 7  
Castelldefels 08860  
Spain

Email: sm.darroudi@entel.upc.edu

Teemu Savolainen  
DarkMatter LLC

Email: teemu.savolainen@darkmatter.ae

Michael Spoerk  
Graz University of Technology  
Inffeldgasse 16/I  
Graz 8010  
Austria

Email: michael.spoerk@tugraz.at

