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IPv6 over BLUETOOTH(R) Low Energy Mesh Networks
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Abstract

draft-ietf-6lo-btle 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 defines how IPv6 is transported over Bluetooth low energy mesh networks.

Status of This Memo

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Table of Contents

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), and draft-ietf-6lo-btle, respectively. Bluetooth 4.0 only supports Bluetooth LE networks that follow the star topology. In consequence, draft-ietf-6lo-btle was specifically developed and optimized for that type of network topology. However, subsequent Bluetooth specifications allow the formation of extended topologies, such as the mesh topology. The functionality described in draft-ietf-6lo-btle is not sufficient and would fail to enable IPv6 over Bluetooth LE mesh networks. This document specifies the mechanisms needed to enable IPv6 over Bluetooth LE mesh networks. This specification also allows to run IPv6 over Bluetooth LE star topology networks, albeit without all the topology-specific optimizations contained in draft-ietf-6lo-btle.

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 Mesh Networks

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 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, a device may implement both roles simultaneously.

This document assumes a Bluetooth LE mesh network whereby link layer connections have been established between neighboring IPv6-enabled devices. In an IPv6-enabled Bluetooth LE mesh network, 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.

3. Specification of IPv6 over Bluetooth LE mesh networks

3.1. Protocol stack

Figure 1 illustrates the protocol stack for IPv6-enabled Bluetooth LE mesh networks. There are two main differences with the IPv6 over Bluetooth LE stack in draft-ietf-6lo-btle: a) the adaptation layer below IPv6 (labelled as "6Lo for Bluetooth LE mesh") is now adapted for Bluetooth LE mesh networks, and b) the protocol stack for IPv6 over Bluetooth LE mesh networks includes IPv6 routing functionality.

```
                      +----------------------------+
                      |        Application         |
         +---------+  +----------------------------+
         |  IPSS   |  |       UDP/TCP/other        |
         +---------+  +----------------------------+
         |  GATT   |  |       IPv6  |routing|      |
         +---------+  +----------------------------+
         |  ATT    |  |  6Lo for Bluetooth LE Mesh |
         +---------+--+----------------------------+
         |          Bluetooth LE L2CAP             |
    -  - +-----------------------------------------+- - - HCI
         |        Bluetooth LE Link Layer          |
         +-----------------------------------------+
         |         Bluetooth LE Physical           |
         +-----------------------------------------+
```

Figure 1: Protocol stack for IPv6-enabled Bluetooth LE mesh networks

3.2. Subnet model

For IPv6-based Bluetooth LE mesh networks, a multilink model has been chosen, as further illustrated in Figure 2. As IPv6 over Bluetooth LE is intended for constrained nodes, and for Internet of Things use cases and environments, the complexity of implementing a separate subnet on each peripheral-central link and routing between the subnets appears to be excessive. In this specification, the benefits of treating the collection of point-to-point links between a central and its connected peripherals as a single multilink subnet rather than a multiplicity of separate subnets are considered to outweigh the multilink model's drawbacks as described in [RFC4903].

```
                                                          /
       .--------------------------------.                /
      /     6LR           6LN       6LN \               /
     /         \             \          \ \            /
    |           \             \          \ |          /
    |  6LN ----- 6LR --------- 6LR ------ 6LBR ----- |  Internet
    |   <--Link--> <---Link--->/<--Link->/ |         |
     \                        /         / /           \
      \           6LN ---- 6LR ----- 6LR /             \
       '--------------------------------'               \
                                                         \

     <------------ Subnet ----------------->&lt;---- IPv6 connection -->
                                                  to the Internet
```

Figure 2: Example of an IPv6-based Bluetooth LE mesh network connected to the Internet

One or more 6LBRs are connected to the Internet. 6LNs are connected to the network through a 6LR or a 6LBR. A prefix is used on the whole subnet.

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

3.3. Link model

3.3.1. Stateless address autoconfiguration

6LN, 6LR and 6LBR IPv6 addresses of a Bluetooth LE mesh network are configured as per section 3.2.2 of draft-ietf-6lo-btle.

Multihop DAD functionality as defined in section 8.2 of RFC 6775, or some substitute mechanism (see section 3.3.2), MUST be supported.

3.3.2. Neighbor Discovery

'Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)' [RFC6775] describes the neighbor discovery approach as adapted for use in several 6LoWPAN topologies, including the mesh topology. The route-over functionality of RFC 6775 MUST be supported.

The following aspects of the Neighbor Discovery optimizations [RFC6775] are applicable to Bluetooth LE 6LNs:

1. A Bluetooth LE 6LN MUST NOT register its link-local address. A Bluetooth LE 6LN MUST register its non-link-local addresses with its routers by sending a Neighbor Solicitation (NS) message with the Address Registration Option (ARO) and process the Neighbor Advertisement (NA) accordingly. The NS with the ARO option MUST be sent irrespective of the method used to generate the IID. The ARO option requires use of an EUI-64 identifier [RFC6775]. In the case of Bluetooth LE, the field SHALL be filled with the 48-bit device address used by the Bluetooth LE node converted into 64-bit Modified EUI-64 format [RFC4291].

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 (see the next subsection).

2. For sending Router Solicitations and processing Router Advertisements the Bluetooth LE 6LNs MUST, respectively, follow Sections 5.3 and 5.4 of the [RFC6775].

6LR TBD

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). Implementations of this specification MUST support the features described in sections 8.1 and 8.2 of RFC 6775 unless some alternative ("substitute") from some other specification is supported.

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 MUST 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.

The specific optimizations of draft-ietf-6lo-btle for header compression, which exploit the star topology and ARO, cannot be generalized in a Bluetooth LE mesh network. Still, a subset of those optimizations can be applied in some cases in a Bluetooth LE mesh network. In particular, the latter comprise link-local interactions,

non-link-local packet transmissions originated and performed by a 6LN, and non-link-local packet transmissions originated by a 6LN neighbor and sent to a 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 ARO 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 ARO 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

TBD

4. IANA Considerations

There are no IANA considerations related to this document.

5. Security Considerations

The security considerations in draft-ietf-6lo-btle apply.

Further security considerations on additional threats due to ad-hoc routing. TBD.

6. Acknowledgements

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

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