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Transmission of IPv6 Packets over BLUETOOTH Low Energy
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Abstract

BLUETOOTH Low Energy is a low power air interface technology defined by the BLUETOOTH Special Interest Group (BT-SIG). The standard BLUETOOTH radio has been widely implemented and available in mobile phones, notebook computers, audio headsets and many other devices. The low power version of BLUETOOTH is a new specification that enables the use of this air interface with devices such as sensors, smart meters, appliances, etc. The low power variant of BLUETOOTH is currently specified in the revision 4.0 of the BLUETOOTH specifications (BLUETOOTH 4.0). This document describes how IPv6 is transported over BLUETOOTH Low Energy using 6LoWPAN techniques.

Status of this Memo

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1. Introduction

BLUETOOTH Low Energy (BT-LE) is a radio technology targeted for devices that operate with coin cell batteries or minimalistic power sources, which means that low power consumption is essential. BT-LE is an especially attractive technology for Internet of Things applications, such as health monitors, environmental sensing, proximity applications and many others.

Considering the potential for the exponential growth in the number of sensors and Internet connected devices and things, IPv6 is an ideal protocol due to the large address space it provides. In addition, IPv6 provides tools for stateless address autoconfiguration, which is particularly suitable for sensor network applications and nodes which have very limited processing power or lack a full-fledged operating system.

RFC 4944 [RFC4944] specifies the transmission of IPv6 over IEEE 802.15.4. The BT-LE link in many respects has similar characteristics to that of IEEE 802.15.4. Many of the mechanisms defined in the RFC 4944 can be applied to the transmission of IPv6 on BT-LE links. This document specifies the details of IPv6 transmission over BT-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 6LN, 6LR and 6LBR are defined as in [RFC6775], with an addition that BT-LE master and BT-LE slave can both be either 6LN or 6LBR.

2. BLUETOOTH Low Energy

BT-LE is designed for transferring small amounts of data infrequently at modest data rates at a very low cost per bit. BLUETOOTH Special Interest Group has introduced two trademarks, BLUETOOTH Smart for single-mode devices (a device that only supports BT-LE) and BLUETOOTH Smart Ready for dual-mode devices. In the rest of the draft, the term BT-LE refers to both types of devices.

BT-LE is an integral part of the BT 4.0 specification [BTCorev4.0]. Devices such as mobile phones, notebooks, tablets and other handheld computing devices which include BT 4.0 chipsets also have the low-energy functionality of BLUETOOTH. BT-LE is also included in many

different types of accessories that collaborate with mobile devices such as phones, tablets and notebook computers. An example of a use case for a BT-LE accessory is a heart rate monitor that sends data via the mobile phone to a server on the Internet.

2.1. BLUETOOTH Low Energy stack

The lower layer of the BT-LE stack consists of the Physical (PHY) and the Link Layer (LL). The Physical Layer transmits and receives the actual packets. The Link Layer is responsible for providing medium access, connection establishment, error control and flow control. The upper layer consists of the Logical Link Control and Adaptation Protocol (L2CAP), Generic Attribute protocol (GATT) and Generic Access Profile (GAP) as shown in Figure 1. GATT and BT-LE profiles together enable the creation of applications in a standardized way without using IP. L2CAP provides multiplexing capability by multiplexing the data channels from the above layers. L2CAP also provides fragmentation and reassembly for large data packets.

```
+-----------------------------------------+------------------+
|              Applications                                  |
+-----------------------------------------+------------------+
|        Generic Attribute Profile        |  Generic Access  |
+-----------------------------------------+     Profile      |
| Attribute Protocol |Security Manager    |                  |
+--------------------+--------------------+------------------+
|              Logical Link Control and Adaptation           |
+--------------------+--------------------+------------------+
|              Host Controller Interface                     |
+--------------------+--------------------+------------------+
|           Link Layer       |      Direct Test Mode         |
+--------------------+--------------------+------------------+
|              Physical Layer                                |
+--------------------+--------------------+------------------+
```

Figure 1: BT-LE Protocol Stack

2.2. Link layer roles and topology

BT-LE defines two Link Layer roles: the BT-LE master role and the BT-LE slave role. A device in the master role, which is called master from now on, can manage multiple simultaneous connections with a number of devices in the slave role, called slaves from now on. A slave can only be connected to a single master. Hence, a BT-LE network (i.e. a BT-LE piconet) follows a star topology shown in the Figure 2. This specification primarily addresses the situation where

the slave is a 6LN but not a 6LBR at the IPv6 level.

```
[BT-LE slave]-----\                  /-----[BT-LE slave]
                   \                /
  [BT-LE slave]-----+[BT-LE Master]+-----[BT-LE slave]
                   /                \
[BT-LE slave]-----/                  \-----[BT-LE slave]
```

Figure 2: BT-LE Star Topology

A master is assumed to be less constrained than a slave. Hence, in the primary scenario master and slave will act as 6LoWPAN Border Router (6LBR) and a 6LoWPAN Node (6LN), respectively.

In BT-LE, communication only takes place between a master and a slave. Hence, in a BT-LE network using IPv6, a radio hop is equivalent to an IPv6 link and vice versa.

2.3. BT-LE device addressing

Every BT-LE device is identified by a 48-bit device address. The BLUETOOTH specification describes the device address of a BTLE device as:"Devices are identified using a device address. Device addresses may be either a public device address or a random device address." [BTCorev4.0]. The public device addresses are based on the IEEE 802-2001 standard [IEEE802-2001]. The random device addresses are generated as defined in the BLUETOOTH specification. The device addresses are always unique within a BT-LE piconet, but the random addresses are not guaranteed to be globally unique.

2.4. BT-LE packets sizes and MTU

Maximum size of the payload in the BT-LE data channel PDU is 27 bytes. Depending on the L2CAP mode in use, the amount of data available for transporting bytes in the single BT-LE data channel PDU ranges between 19 and 27 octets. For power efficient communication between two BT-LE nodes, data and its header should fit in a single BT-LE data channel PDU. However, IPv6 requires support for an MTU of 1280 bytes. An inherent function of the BT-LE L2CAP layer, called Fragmentation and Recombination (FAR), can assist in transferring IPv6 packets that do not fit in a single BT-LE data channel PDU.

The maximum IPv6 datagram size that can be transported by L2CAP depends on the L2CAP mode. The Basic L2CAP Mode allows a maximum payload size (i.e. IPv6 datagram size) of 65535 bytes per L2CAP PDU.

The rest of the L2CAP modes allow a maximum payload size that ranges between 65527 and 65533 bytes per L2CAP PDU. Appendix A describes FAR operation and five L2CAP Modes.

3. Specification of IPv6 over BLUETOOTH Low Energy

BT-LE technology sets strict requirements for low power consumption and thus limits the allowed protocol overhead. 6LoWPAN standards [RFC4944], [RFC6775], and [RFC6282] provide useful functionality for reducing overhead which can be applied to BT-LE. This functionality comprises of link-local IPv6 addresses and stateless IPv6 address autoconfiguration (see Section 3.2.1), Neighbor Discovery (see Section 3.2.2) and header compression (see Section 3.2.3).

A significant difference between IEEE 802.15.4 and BT-LE is that the former supports both star and mesh topology (and requires a routing protocol), whereas BT-LE does not currently support the formation of multihop networks at the link layer. In consequence, the mesh header defined in [RFC4944] for mesh under routing MUST NOT be used in BT-LE networks. In addition, a BT-LE node MUST NOT play the role of a 6LoWPAN Router (6LR).

3.1. Protocol stack

In order to enable transmission of IPv6 packets over BT-LE, a new fixed L2CAP Channel Identifier (Channel ID) is to be reserved for IPv6 traffic by the BT-SIG. Until the Channel ID is reserved, prototype implementations can be implemented as is described in the Appendix B.

Figure 3 illustrates IPv6 over BT-LE stack. UDP and TCP are provided as examples of transport protocols, but the stack can be used by any other upper layer protocol capable of running atop of IPv6.

```
+---------------------------+
|       UDP/TCP/other       |
+---------------------------+
|            IPv6           |
+---------------------------+
|  6LoWPAN adapted to BT-LE |
+---------------------------+
|        BT-LE L2CAP        |
+---------------------------+
|      BT-LE Link Layer     |
+---------------------------+
|       BT-LE Physical      |
+---------------------------+
```

Figure 3: IPv6 over BT-LE Stack

3.2. Link model

The concept of IPv6 link (layer 3) and the physical link (combination of PHY and MAC) needs to be clear and the relationship has to be well understood in order to specify the addressing scheme for transmitting IPv6 packets over the BT-LE link. RFC 4861 [RFC4861] defines a link as "a communication facility or medium over which nodes can communicate at the link layer, i.e., the layer immediately below IPv6."

In the case of BT-LE, L2CAP is an adaptation layer that supports the transmission of IPv6 packets. L2CAP also provides multiplexing capability in addition to FAR functionality. This specification requires that FAR functionality MUST be provided in the L2CAP layer. The L2CAP channel characteristics for the transmission of IPv6 packets on top of BT-LE are the following:

MTU: Equal to or greater than 1280 bytes

Flush Timeout: 0xFFFF (Infinite)

QoS: Best Effort

Mode: Basic Mode

Since FAR in BT-LE is a function of the L2CAP layer, fragmentation functionality as defined in RFC 4944 [RFC4944] MUST NOT be used in BT-LE networks. This specification also assumes the IPv6 header compression format specified in RFC 6282 [RFC6282]. It is also assumed that the IPv6 payload length can be inferred from the L2CAP header length and the IID value inferred, with help of Neighbor Cache, from the link-layer address.

The BT-LE link between two communicating nodes can be considered to be a point-to-point or point-to-multipoint link. When one of the communicating nodes is in the role of a master, then the link can be viewed as a point-to-multipoint link from the master point of view. However, due to BT-LE star topology, each branch of the star is considered to be an individual link and thus the slaves cannot directly hear each other and also cannot talk to each other with link-local addresses. The master ensures address collisions do not occur (see Section 3.2.2).

After the slave and master have connected at the BT-LE level, the link can be considered up and IPv6 address configuration and transmission can begin.

3.2.1. Stateless address autoconfiguration

A BT-LE 6LN performs stateless address autoconfiguration as per RFC 4862 [RFC4862]. A 64-bit Interface identifier (IID) for a BT-LE interface MAY be formed by utilizing the 48-bit BLUETOOTH device address (see Section 2.3) as defined in RFC 2464 "IPv6 over Ethernet" specification [RFC2464]. Alternatively, a randomly generated IID (see Section 3.2.2), MAY be used instead. In the case of randomly generated IID or randomly generated BLUETOOTH device address, the "Universal/Local" bit MUST be set to 0 [RFC4291]. Only if the BLUETOOTH device address is known to be a public address the "Universal/Local" bit can be set to 1.

As defined in RFC 4291 [RFC4291], the IPv6 link-local address for a BT-LE node is formed by appending the IID, to the prefix FE80::/64, as depicted in Figure 4.

```
  10 bits        54 bits             64 bits
+----------+-----------------+----------------------+
|1111111010|       zeros     | Interface Identifier |
+----------+-----------------+----------------------+
```

Figure 4: IPv6 link-local address in BT-LE

The tool for a 6LBR to obtain an IPv6 prefix for numbering the BT-LE network is out of scope of this document, but can be, for example, accomplished via DHCPv6 Prefix Delegation [RFC3633] or by using Unique Local IPv6 Unicast Addresses (ULA) [RFC4193]. Due to the link model of the BT-LE (see Section 2.2) the 6LBR MUST set the "on-link" flag (L) to zero in the Prefix Information Option [RFC4861]. This will cause 6LNs to always send packets to the 6LBR, including the case when the destination is another 6LN using the same prefix.

3.2.2. 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. BT-LE does not support mesh networks and hence only those aspects that apply to a star topology are considered.

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

1. A BT-LE 6LN MUST register its address with the 6LBR by sending a Neighbor Solicitation (NS) message with the ARO option and process the Neighbor Advertisement (NA) accordingly. The NS with the ARO option SHOULD be sent irrespective of whether the IID is derived from the unique 48 bit BT-LE device address or the IID is a random value that is generated as per the privacy extensions for stateless address autoconfiguration [RFC4941]. Although RFC 4941 [RFC4941] permits the use of deprecated addresses for old connections, in this specification we mandate that one interface MUST NOT use more than one IID at any one time.

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

3.2.3. 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 in this document as the basis for IPv6 header compression on top of BT-LE. All headers MUST be compressed according to RFC 6282 [RFC6282] encoding formats. The BT-LE's star topology structure can be exploited in order to provide a mechanism for IID compression. The following text describes the principles of IPv6 address compression on top of BT-LE.

In a link-local communication, both the IPv6 source and destination addresses MUST be elided [RFC6282], since the node knows that the packet is destined for it even if the packet does not have destination IPv6 address. On the other hand, a node SHALL learn the IID of the other endpoint of each L2CAP connection it participates in. By exploiting this information, a node that receives a data channel PDU containing an IPv6 packet (or a part of it) can infer the corresponding IPv6 source address. A node MUST maintain a Neighbor Cache, in which the entries include both the IID of the neighbor and the Device Address that identifies the neighbor. For the type of

communication considered in this paragraph, the following settings MUST be used in the IPv6 compressed header: CID=0, SAC=0, SAM=11, DAC=0, DAM=11.

When a 6LN transmits an IPv6 packet to a remote destination using global Unicast IPv6 addresses, if a context is defined for the prefix of the 6LNs global IPv6 address, the 6LN MUST indicate this context in the corresponding source fields of the compressed IPv6 header as per Section 3.1 of RFC 6282 [RFC6282], and MUST elide the IPv6 source address. For this, the 6LN MUST use the following settings in the IPv6 compressed header: CID=1, SAC=1, SAM=11. In this case, the 6LBR can infer the elided IPv6 source address since 1) the 6LBR has previously assigned the prefix to the 6LNs; and 2) the 6LBR maintains a Neighbor Cache that relates the Device Address and the IID of the corresponding slave. If a context is defined for the IPv6 destination address, the 6LN MUST also indicate this context in the corresponding destination fields of the compressed IPv6 header, and MUST elide the prefix of the destination IPv6 address. For this, the 6LN MUST set the DAM field of the compressed IPv6 header as DAM=01 (if the context covers a 64-bit prefix) or as DAM=11 (if the context covers a full, 128-bit address). CID and DAC MUST be set to CID=1 and DAC=1. Note that when a context is defined for the IPv6 destination address, the 6LBR can infer the elided destination prefix by using the context.

When a 6LBR receives an IPv6 packet sent by a remote node outside the BT-LE network, and the destination of the packet is a 6LN, if a context is defined for the prefix of the 6LN's global IPv6 address, the 6LBR MUST indicate this context in the corresponding destination fields of the compressed IPv6 header, and MUST elide the IPv6 destination address of the packet before forwarding it to the 6LN. For this, the 6LBR MUST set the DAM field of the IPv6 compressed header as DAM=11. CID and DAC MUST be set to CID=1 and DAC=1. If a context is defined for the prefix of the IPv6 source address, the 6LBR MUST indicate this context in the source fields of the compressed IPv6 header, and MUST elide that prefix as well. For this, the 6LBR MUST set the SAM field of the IPv6 compressed header as SAM=01 (if the context covers a 64-bit prefix) or SAM=11 (if the context covers a full, 128-bit address). CID and SAC MUST be set to CID=1 and SAC=1.

3.2.4. Unicast and Multicast address mapping

The BT-LE link layer does not support multicast. Hence traffic is always unicast between two BT-LE nodes. Even in the case where a master is attached to multiple slaves, the master cannot do a multicast to all the connected slaves. If the master needs to send a multicast packet to all its slaves, 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 master is battery-powered. In the opposite direction, a slave can only transmit data to a single destination (i.e. the master). Hence, when a slave needs to transmit an IPv6 multicast packet, the slave will unicast the corresponding BT-LE packet to the master. As described in the Section 3.2 the master will not forward link-local multicast messages to other slaves connected to the master.

3.3. Internet connectivity scenarios

In a typical scenario, the BT-LE network is connected to the Internet as shown in the Figure 5.

A degenerate scenario can be imagined where a slave is acting as 6LBR and providing Internet connectivity for the master. How the master could then further provide Internet connectivity to other slaves, possibly connected to the master, is out of the scope of this document.

```
                      6LN
                        \            ____________
                         \          /            \
                6LN ---- 6LBR --- |  Internet    |
                         /          \____________/
                        /
                      6LN

                <-- BT-LE -->
```

Figure 5: BT-LE network connected to the Internet

In some scenarios, the BT-LE network may transiently or permanently be an isolated network as shown in the Figure 6.

```
                     6LN      6LN
                       \      /
                        \    /
                6LN --- 6LBR --- 6LN
                        /    \
                       /      \
                     6LN      6LN

                <------ BT-LE ----->
```

Figure 6: Isolated BT-LE network

In the isolated network scenario communications between 6LN and 6LBR can use IPv6 link-local methodology, but for communications between different slaves, the master has to act as 6LBR, number the network with ULA prefix [RFC4193], and route packets between slaves.

4. IANA Considerations

There are no IANA considerations related to this document.

5. Security Considerations

The transmission of IPv6 over BT-LE links has similar requirements and concerns for security as for IEEE 802.15.4. IPv6 over BT-LE SHOULD be protected by using BT-LE Link Layer security.

BT-LE Link Layer supports encryption and authentication by using the Counter with CBC-MAC (CCM) mechanism [RFC3610] and a 128-bit AES block cipher. Upper layer security mechanisms may exploit this functionality when it is available. (Note: CCM does not consume bytes from the maximum per-packet L2CAP data size, since the link layer data unit has a specific field for them when they are used.)

Key management in BT-LE is provided by the Security Manager Protocol (SMP), as defined in [BTCorev4.0].

6. Additional contributors

Kanji Kerai, Jari Mutikainen, David Canfeng-Chen and Minjun Xi from Nokia have contributed significantly to this document.

7. Acknowledgements

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

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8.1. Normative References

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Appendix A. BLUETOOTH Low Energy fragmentation and L2CAP Modes

This section provides an overview of Fragmentation and Recombination (FAR) method and L2CAP modes in BT-LE. FAR is an L2CAP mechanism, in which an L2CAP entity can take the (large) upper layer PDU, prepend the L2CAP header (4 bytes in the Basic L2CAP mode) and break the resulting L2CAP PDU into fragments which can then be directly encapsulated into Data channel PDUs. There are bits in the Data channel PDUs which identify whether the payload is a complete L2CAP PDU or the first of a set of fragments, or one of the rest of the fragments.

There are five L2CAP modes defined in the BT 4.0 spec. These modes are: Retransmission Mode (a Go-Back-N mechanism is used), Enhanced Retransmission Mode (includes selective NAK among others), Flow Control Mode (PDUs are numbered, but there are no retransmissions), Streaming Mode (PDUs are numbered, but there are no ACKs of any kind) and Basic L2CAP Mode.

Appendix B. BLUETOOTH Low Energy L2CAP Channel ID Usage for 6LoWPAN/ IPv6

The BT-LE Logical Link Control and Adaptation Protocol (L2CAP) uses Channel Identifiers (IDs) to distinguish the upper layer protocol carried on top of it. Two devices exchanging IPv6/6LoWPAN packets need to use a common Channel ID to be able to send and receive the packets correctly over L2CAP. It is also important that they avoid using Channel ID's that conflict with other L2CAP usages. For the initial use of IPv6/6LoWPAN over BT-LE L2CAP, implementers are recommended to use Channel ID 0x3E from the BLUETOOTH Special Interest Group reserved space (BLUETOOTH 4.0 Logical Link Control and Adaptation Protocol Specification -part, table 2.1 [BTCorev4.0]). As the IPv6/6LoWPAN use becomes more widely adopted, the BT SIG may allocate 0x3E or some other Channel ID exclusively for IPv6/6LoWPAN. Any such BT SIG allocation will deprecate the recommendation given in this Appendix, and a new RFC will be published at the time of allocation that will update this RFC and specify the allocated value. The initial implementers are thus recommended to keep their Channel ID usage capability flexible to potential future changes.

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