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Transmission of IPv6 Packets over PLC Networks
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Abstract

Power Line Communication (PLC), namely using the electric-power lines for indoor and outdoor communications, has been widely applied to support Advanced Metering Infrastructure (AMI), especially the smart meters for electricity. The inherent advantage of existing electricity infrastructure facilitates the expansion of PLC deployments, and moreover, a wide variety of accessible devices raises the potential demand of IPv6 for future applications. As part of this technology, Narrowband PLC (NBPLC) is focused on the low-bandwidth and low-power scenarios that includes current standards such as IEEE 1901.2 and ITU-T G.9903. This document describes how IPv6 packets are transported over constrained PLC networks.

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1. Introduction

The idea of using power lines for both electricity supply and communication can be traced back to the beginning of the last century. With the advantage of existing power grid, PLC is a good

candidate for supporting various service scenarios such as in houses and offices, in trains and vehicles, in smart grid and advanced metering infrastructure (AMI). Such applications cover the smart meters for electricity, gas and water that share the common features like fixed position, large quantity, low data rate, and long life time.

Although PLC technology has an evolution history of several decades, the adaptation of PLC for IPv6 based constrained networks is not fully developed. The 6lo related scenarios lie in the low voltage PLC networks with most applications in the area of Advanced Metering Infrastructure, Vehicle-to-Grid communications, in-home energy management and smart street lighting. It is of great importance to deploy IPv6 for PLC devices for its large address space and quick addressing. In addition, due to various existing PLC standards, a comparison among them is needed to facilitate the selection of the most applicable PLC standard in certain using scenarios.

The following sections provide a brief overview of PLC, then describe transmission of IPv6 packets over PLC networks. The general approach is to adapt elements of the 6LoWPAN specifications [RFC4944], [RFC6282], and [RFC6775] to constrained PLC networks. Similar 6LoPLC adaptation layer was previously proposed in [draft-popa-6lo-6loplc], however, with the same purpose, this document provides more updated, structured and instructive information for the deployment of IPv6 over PLC networks.

2. Requirements Notation and Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

Below are the terms used in this document:

6LoWPAN: IPv6 over Low-Power Wireless Personal Area Network

AMI: Advanced Metering Infrastructure

BBPLC: Broadband Power Line Communication

CID: Context ID

EV: Electric Vehicle

HDPLC: High Definition Power Line Communication

IID: Interface Identifier

IPHC: IP Header Compression

LAN: Local Area Network

LOADng: Lightweight On-demand Ad-hoc Distance-vector Routing Protocol Next Generation

MSDU: MAC Service Data Unit

MTU: Maximum Transmission Unit

NBPLC: Narrowband Power Line Communication

OFDM: Orthogonal Frequency Division Multiplexing

PCO: PAN Coordinator

PLC: Power Line Communication

PSDU: PHY Service Data Unit

RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks

RA: Router Advertisement

WAN: Wide Area Network

3. Overview of PLC

PLC technology enables convenient two-way communications for home users and utility companies to monitor and control electric plugged devices such as electricity meters and street lights. Due to the large range of communication frequencies, PLC is generally classified into two categories: Narrowband PLC (NBPLC) for automation of sensors, and Broadband PLC (BBPLC) for home and industry networking applications. Various standards have been addressed on the MAC and PHY layers for this communication technology, e.g. IEEE 1901 and ITU-T G.hn for BBPLC (1.8-250 MHz), IEEE 1901.2, ITU-T G.9902 (G.hnem), ITU-T G.9903 (G3-PLC) and ITU-T G.9904 (PRIME) for NBPLC (3-500 kHz) and the recent proposal for the IEEE 1901.1 standard aiming at the frequency band of 2-12 MHz.

Narrowband PLC is a very important branch of PLC technology due to its low frequency band and low power cost. So far the recent PLC standards, ITU-T G.9903 (G3-PLC) and IEEE 1901.2, are dominating as two of the most robust schemes available. Different networking

methods exist in different NBPLC standards. There are 2 routing algorithms used in PLC networks for AMI applications:

- o LOADng (Lightweight On-demand Ad-hoc Distance-vector Routing Protocol Next Generation) is a reactive protocol, operating in layer 2 or layer 3.

- o RPL (Routing Protocol for Low-Power and Lossy Networks) is a proactive protocol operating only in layer 3.

LOADng is supported in G.9903 and 1901.2. IEEE 1901.2 specifies additionally Information Elements (IEs) which carry metrics from PHY layer to IP layer and the IE content is user-defined. These IEs enable RPL to be used as the routing algorithm in 1901.2 networks.

The IEEE 1901.1 WG is currently working on a new PLC standard, IEEE 1901.1, which focuses on the frequency band of 2-12 MHz [IEEE 1901.1]. This promising medium-frequency PLC standard, known as PLC-IoT, is suitable for 6lo applications thus mentioned in this document. Details on this standard is to be determined.

3.1. Protocol Stack

The protocol stack for IPv6 over PLC is illustrated in Figure 1 that contains the following elements from bottom to top: PLC PHY Layer, PLC MAC Layer, Adaptation layer for IPv6 over PLC, IPv6 Layer, TCP/UDP Layer and Application Layer. The PLC MAC/PHY layer corresponds to a certain PLC standard such as IEEE 1901.2 or ITU-T G.9903. For the Broadband PLC cases, the adaptation layer for IPv6 over PLC MAY not be used unless in some certain specifications. The deployment of the 6lo adaptation layer are specified in section 4 according to different standards. Routing protocol like RPL on Network layer is optional according to the specified PLC standard, for example IEEE 1901.2 SHALL use RPL routing protocol while ITU-T G.9903 MUST NOT.


```
+----------------------------------------+
|           Application Layer            |
+----------------------------------------+
|                TCP/UDP                 |
+----------------------------------------+
|                                        |
|                  IPv6                  |
|                                        |
+----------------------------------------+
|   Adaptation layer for IPv6 over PLC   |
+----------------------------------------+
|             PLC MAC Layer              |
|   (IEEE 1901.2 MAC/ITU-T G.9903 MAC)   |
+----------------------------------------+
|             PLC PHY Layer              |
```

```
|    (IEEE 1901.2 PHY/ITU-T G.9903 PHY)    |
+------------------------------------------+
```

Figure 1: PLC Protocol Stack

3.2. Addressing Modes

Each PLC device has a globally unique 64-bit long address and a 16-bit short address. The long address is set by manufacturers according to the IEEE EUI-64 address. Each PLC device joins the network by using the long address and communicates with other devices by using the short address after joining the network.

3.3. Maximum Transmission Unit

Maximum Transmission Unit (MTU) of MAC layer is an important parameter that determines the applicability of fragmentation and reassembly at the adaptation layer of IPv6 over PLC. IPv6 requires that every link in the Internet have an MTU of 1280 octets or greater, thus for a MAC layer with MTU lower than this limit, fragmentation and reassembly at the adaptation layer are required.

The IEEE 1901.2 MAC layer supports the MTU of 1576 octets (the original value 1280 byte was updated in 2015 [IEEE 1901.2a]). The MTU for ITU-T G.9903 is 400 octets, insufficient for supporting complete IPv6 packets. For this concern, fragmentation/reassembly in [RFC4944] MUST be enabled for the G.9903-based scenarios (details can be found in section 4.2.6).

4. Specification of IPv6 over Narrowband PLC

Due to the narrow bandwidth and low data rate in NBPLC, a 6lo adaptation layer is needed to support the transmission of IPv6

packets. 6LoWPAN standards [RFC4944], [RFC6775], and [RFC6282] provides useful functionality including link-local IPv6 addresses, stateless address auto-configuration, neighbor discovery and header compression. These standards are referred in the specifications of the 6lo adaptation layer which is illustrated in the following subsections.

4.1. IEEE 1901.2

4.1.1. Stateless Address Autoconfiguration

An IEEE 1901.2 device performs stateless address autoconfiguration according to [RFC4944] so as to obtain an IPv6 Interface Identifier (IID). The 64-bit IID SHALL be derived by insert 16-bit "FFEE" into a "pseudo 48-bit address" which is formed by the 16-bit PAN ID, 16-bit zero and the 16-bit short address as follows:

```
16_bit_PAN:00FF:FE00:16_bit_short_address
```

Considering that this derived IID is not globally unique, the "Universal/Local" (U/L) bit (7th bit) SHALL be set to zero.

4.1.2. IPv6 Link Local Address

The IPv6 link-local address [RFC4291] for an IEEE 1901.2 interface is formed by appending the Interface Identifier, as defined above, to the prefix FE80::/64 (see Figure 2).

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

Figure 2: IPv6 Link Local Address in IEEE 1901.2

4.1.3. Unicast Address Mapping

The address resolution procedure for mapping IPv6 unicast addresses into IEEE 1901.2 link-layer addresses follows the general description in section 7.2 of [RFC4861], unless otherwise specified.

The Source/Target Link-layer Address option has the following form when the link layer is IEEE 1901.2 and the addresses are 16-bit short addresses.


```
                    0                   1
```

```
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |   Length=1    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     16-bit short Address      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Padding            |
+-                             -+
|          (all zeros)          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: Unicast Address Mapping in IEEE 1901.2

Option fields:

Type: 1 for Source Link-layer address and 2 for Target Link-layer address.

Length: This is the length of this option (including the type and length fields) in units of 8 octets. The value of this field is 1 for the 16-bit IEEE 1901.1 short addresses.

Multicast address mapping is not supported in IEEE 1901.2. A link-local multicast only reaches neighbors within direct physical connectivity. IEEE 1901.2 excludes the functionality of multicast either in [RFC4944] or in coexistence modes with G3-PLC and PRIME.

4.1.4. Neighbor Discovery

Neighbor Discovery Optimization for 6LoWPANs [RFC6775] describes the neighbor discovery approach in several 6LoWPAN topologies including the mesh topology. In the route-over RPL-based network, the neighbor discovery process in IEEE 1901.1 networks SHALL refers to [RFC6775] with no modifications. The IEEE 1901.1 6LNs MUST follow Sections 5.3 and 5.4 of [RFC6775] for sending Router Solicitations and processing Router Advertisements. Note that although PLC devices are electrically powered, the sleeping mode is still applicable for power saving. In addition, if DHCPv6 is used to assign addresses, Duplicate Address Detection (DAD) SHOULD not be required. However, the mesh-under LOADng-based 1901.1 network SHOULD NOT use [RFC6775] address registration. An implementation for mesh-under operation MUST use [RFC6775] mechanisms for managing IPv6 prefixes and corresponding header compression context information [RFC6282].

4.1.5. Header Compression

The IEEE 1901.2 MAC layer supports the MTU of 1576 octets which is

larger than the minimum requirement of an IPv6 packet. However, the IEEE 1901.2 PHY layer supports a maximum PSDU (PHY Service Data Unit) of 512 octets while the allowed PHY payload is smaller and can change dynamically based on channel conditions. Due to the limited PHY payload, header compression at 6lo adaptation layer is of great importance and MUST be applied. The compression of IPv6 datagrams within IEEE 1901.2 frames refers to [RFC6282], which updates [RFC4944]. Header compression as defined in [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 in IEEE 1901.2. All headers MUST be compressed according to [RFC6282] encoding formats.

4.1.6. Fragmentation and Reassembly

To cope with the mismatch between the size of the PHY frame payload and the size of the MAC Service Data Unit (MSDU), IEEE 1901.2 Data Link layer provides the functionality of segmentation and reassembly. A Segment Control Field is defined in the MAC frame header regardless of whether segmentation is required. This process segments a MAC layer datagram into multiple fragments and provides a reliable one-hop transfer of the resulting fragments. However, for the 6lo adaptation layer, since IEEE 1901.2 naturally supports a MAC payload of 1280 octets, namely the minimum MTU required by IPv6 packets, there is no need for fragmentation and reassembly for the IPv6 packet transmission. This document specifies that, in the IPv6 packet transmission over IEEE 1901.2, fragmentation and reassembly in [RFC4944] MUST NOT be used.

4.2. ITU-T G.9903

4.2.1. Stateless Address Autoconfiguration

The stateless address auto-configuration in ITU-T G.9903 is performed the same way as IEEE 1901.2, which also refers to [RFC4944] with the following selections: The 64-bit interface identifier SHALL be derived from a "pseudo 48-bit address" formed with the PAN identifier and the short address as follows:

```
16_bit_PAN:00FF:FE00:16_bit_short_address
```

Additional care shall be taken when choosing a PAN identifier so as not to interfere with I/G and U/L bits of the interface identifier. If the PAN identifiers are chosen randomly, then the U/L and I/G bits (7th and 8th bits) shall be set to zero [ITU-T G.9903].

4.2.2. IPv6 Link Local Address

In ITU-T G.9903, the formation of IPv6 link-local address follows the same process as IEEE 1901.2 (see section 4.1.2) by appending the Interface Identifier (IID) to the prefix FE80::/64.

4.2.3. Unicast Address Mapping

The address resolution procedure for mapping IPv6 unicast addresses into ITU-T G.9903 link-layer addresses follows the general description in section 7.2 of [RFC4861], unless otherwise specified. Source/Target link-layer address option field SHOULD contain the combined address with PAN ID and 16-bit short address of the source or target device as below. Note that the format of the Target Link-layer address in ITU-T G.9903 (see Figure 4) is specified according to the Annex E of [ITU-T G.9903].

```
 0                   1
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |   Length=1    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            PAN ID             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     16-bit short Address      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         (all zeros)           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4: Unicast Address Mapping in ITU-T G.9903

Option fields:

Type: 1 for Source Link-layer address and 2 for Target Link-layer address.

Length: This is the length of this option (including the type and length fields) in units of 8 octets. The value of this field is 1 for the 16-bit G.9903 short addresses.

It is worthy to note that this address resolution is performed only

on addresses for which the sender does not know the corresponding link-layer address. EUI-64 MAC address is only used by PAN Devices during the PAN bootstrapping protocol. Once the bootstrapping is completed, the short address is assigned and used for the rest of the time.

4.2.4. Neighbor Discovery

Neighbor Discovery Optimization for 6LoWPANs [RFC6775] describes the

neighbor discovery approach in several 6LoWPAN topologies including the mesh topology. The mesh-under LOADng-based ITU-T G.9903 network SHOULD NOT proceed the address registration as described in [RFC6775]. ITU-T G.9903 supports the 6LoWPAN Context Option (6CO) specified in [RFC6775] (see clause 9.4.1.1 in [ITU-T G.9903]), which can be attached in Router Advertisements (RAs) to disseminate Context IDs (CIDs) to use for compressing prefixes. An implementation for mesh-under operation MUST use [RFC6775] mechanisms for managing IPv6 prefixes and corresponding header compression context information [RFC6282].

4.2.5. Header Compression

Header compression as defined in [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 in ITU-T G.9903. All headers MUST be compressed according to [RFC6282] encoding formats.

4.2.6. Fragmentation and Reassembly

Similar to IEEE 1901.2, Segment Control Field is also defined in the ITU-T G.9903 MAC frame header, and the functionality of fragmentation and reassembly is also enabled at the G.9903 MAC layer. However, the maximum MAC payload size is fixed to 400 octets in ITU-T G.9903 recommendation, thus to cope with the required MTU of 1280 octets by IPv6, fragmentation and reassembly at 6lo adaptation layer MUST be provided referring to [RFC4944].

4.2.7. Extension at 6lo Adaptation Layer

Apart from the 6lo headers specified in [RFC4944], an additional

Command Frame Header is defined for the mesh routing procedure. Figure 5 illustrates the format of the Command Frame Header [RFC8066]: The ESC dispatch type (01000000b) indicates an ESC extension type follows (see [RFC4944] and [RFC6282]). Then this 1-octet dispatch field is used as the Command Frame Header and filled with the Command ID. The Command ID can be classified into 4 types:

- LOADng message (0x01)

- LoWPAN bootstrapping protocol message (0x02)

- Reserved by ITU-T (0x03-0x0F)

- CMSR protocol messages (0X10-0X1F)

The LOADng message is used to provide the default routing protocol

LOADng while the LoWPAN bootstrapping protocol message is for the LoWPAN bootstrap procedure. The CMSR protocol messages are specified for the Centralized metric-based source routing [ITU-T G.9905] which is out of the scope of this draft.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      ESC      |  Command ID   |      Command Payload
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5: Command Frame Header Format of ITU-T G.9903

Command Frame Header appears in the last position if more than one header is present in the 6LoWPAN frame [ITU-T G.9903]. On the other hand, this Command Frame Header MUST appear before the LoWPAN_IPHC dispatch type as per [RFC8066]. An example of the header order is illustrated in Figure 6 including the Fragmentation type, Fragmentation header, ESC dispatch type, ESC Extension Type (Command ID), ESC Dispatch Payload (Command Payload), LOWPAN_IPHC Dispatch Type, LOWPAN_IPHC header, and Payload. Since layer-2 routing protocol is used, which eliminates the need for route-over routing, this document specifies that 6LoWPAN Mesh header MUST NOT be used.

```
+-----+-----+-----+-----+-------+-------+-----------------+-------+
```

```
 |F typ|F hdr| ESC | EET |  EDP  |Disptch|LOWPAN_IPHC hdr| Payld|
 +-----+-----+-----+-----+-------+-------+---------------+-------+
```

Figure 6: A 6LoWPAN packet including the Command Frame Header

5. Internet Connectivity Scenarios and Topologies

The network model can be simplified to two kinds of network devices: PAN Coordinator (PCO) and PAN Device. PCO is the coordinator of the PLC subnet and can be seen as a master node while PAN Devices are typically PLC meters and sensors. The IPv6 over PLC networks SHOULD be built as tree, mesh or star according to the specified using scenarios. Every network requires at least one PCO to communicate with each PAN Device. Note that the PLC topologies included in this section are based on the logical connectivity, not physical links.

One common topology in the current PLC scenarios is star. In this case, the communication at the link layer only takes place between a PAN Device and a PCO. The PCO collects data (e.g. smart meter reading) from different nodes, and then concentrates and uploads the data through Ethernet or LPWAN (see Figure 7). The collected data is transmitted by the smart meters through PLC, aggregated by a concentrator, sent to the utility and then to a Meter Data Management

System for data storage, analysis and billing. Such topology has been widely applied in the deployment of smart meters, especially in the apartment buildings.

```
                 PAN Device    PAN Device
                        \        /           +---------
                         \      /           /
                          \    /           +
                           \  /            |
        PAN Device ------  PCO ==========  |  Internet
                           /  \            |
                          /    \           +
                         /      \           \
                        /        \           +---------
                 PAN Device    PAN Device

               <----------------------->
                       PLC subnet
```

```
                 (IPv6 over PLC packet)
```

Figure 7: PLC Star Network connected to the Internet

Tree topology is used when the distance between a device A and PCO is beyond the PLC allowed limit while there is another device B in between able to communicate with both sides. Device B in this case acts both as a PAN Device and a Proxy Coordinator. For this scenario, the link layer communications take place between device A and device B, and between device B and PCO. An example of PLC tree network is depicted in Figure 8. This topology can be applied in the smart street lighting, where the lights adjust the brightness to reduce energy consumption while sensors are deployed on the street lights to provide information such as light intensity, temperature, humidity. Data transmission distance in the street lighting scenario is normally above several kilometers thus the PLC tree network is required. A more sophisticated AMI network may also be constructed into the tree topology which as depicted in [RFC8036]. Tree topology is suitable for the AMI scenarios that require large coverage but low density, e.g. the deployment of smart meters in rural areas.


```
                          PAN Device
                               \                   +---------
                  PAN Device    \                 /
                       \         \               +
                        \         \              |
                    PAN Device -- PCO ========== |  Internet
                        /         /              |
                       /         /               +
      PAN Device---PAN Device   /                 \
                               /                   +---------
              PAN Device---PAN Device
```

```
            <------------------------->
                     PLC subnet
               (IPv6 over PLC packet)
```

Figure 8: PLC Tree Network connected to the Internet

Mesh networking in PLC is of great potential applications and has been studied for several years. By connecting all nodes with their neighbors in communication range (see Figure 9), mesh topology dramatically enhances the communication efficiency and thus expands the size of PLC networks. A simple use case is the smart home scenario where the ON/OFF state of air conditioning is controlled by the state of home lights (ON/OFF) and doors (OPEN/CLOSE). LOADng enables direct pan device to pan devices (without being obliged to get through the pan coordinator) which significantly improves performances in typical use cases like charging station to electric vehicle (EV) communications.

```
                PAN Device---PAN Device
                    / \        / \                   +---------
                   /   \      /   \                 /
                  /     \    /     \               +
                 /       \  /       \              |
           PAN Device--PAN Device---PCO ========== |  Internet
                 \       /  \       /              |
                  \     /    \     /               +
                   \   /      \   /                 \
                    \ /        \ /                   +---------
                PAN Device---PAN Device

        <------------------------------->
                   PLC subnet
             (IPv6 over PLC packet)
```

Figure 9: PLC Mesh Network connected to the Internet

6. IANA Considerations

There are no IANA considerations related to this document.

7. Security Consideration

Due to the high accessibility of power grid, PLC might be susceptible to eavesdropping within its communication coverage, e.g. one apartment tenant may have the chance to monitor the other smart meters in the same apartment building. For privacy consideration, a mechanism for constructing a 64-bit IID from the a 16-bit short address is RECOMMENDED. As mentioned in [RFC8065], the 64-bit IID might be generated using a one-way hash that includes the shared secret together with the Short Address. [draft-rashid-6lo-iid-assignment-03] proposed an optimized approach with high privacy and minimized potential duplication. This document also recommends [draft-ietf-6lo-ap-nd-02] that defines a address-protection mechanism for 6LoWPAN neighbor discovery.

8. Acknowledgements

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9. References

9.1. Normative References

[IEEE 1901.2] IEEE-SA Standards Board, "IEEE Standard for Low-Frequency (less than 500 kHz) Narrowband Power Line Communications for Smart Grid Applications", IEEE 1901.2, October 2013, <https://standards.ieee.org/findstds/standard/1901.2-2013.html>.

[ITU-T G.9903] International Telecommunication Union, "Narrowband orthogonal frequency division multiplexing power line communication transceivers for G3-PLC networks", ITU-T G.9903, February 2014, <https://www.itu.int/rec/T-REC-G.9903>.

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

10.17487/RFC2119, March 1997, <http://www.rfc-editor.org/info/rfc2119>.

[RFC2464] Crawford, M., "Transmission of IPv6 Packets over Ethernet Networks", RFC 2464, December 1998, <http://www.rfc-editor.org/info/rfc2464>.

[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, <http://www.rfc-editor.org/info/rfc4861>.

[RFC4944] Montenegro, G., Kushalnagar, N., Hui, J., and D. Culler, "Transmission of IPv6 Packets over IEEE 802.15.4 Networks", RFC 4944, September 2007, <http://www.rfc-editor.org/info/rfc4944>.

[RFC6282] Hui, J. and P. Thubert, "Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks", RFC 6282, September 2011, <http://www.rfc-editor.org/info/rfc6282>.

[RFC6775] Shelby, Z., Chakrabarti, S., Nordmark, E., and C. Bormann, "Neighbor Discovery Optimization for IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs)", RFC 6775, November 2012, <http://www.rfc-editor.org/info/rfc6775>.

9.2. Informative References

[draft-ietf-6lo-ap-nd-02] Sarikaya, B., Thubert, P. and M. Sethi, "Address Protected Neighbor Discovery for Low-power and Lossy Networks", draft-ietf-6lo-ap-nd-02, May 2017, <https://tools.ietf.org/html/draft-ietf-6lo-ap-nd-02>.

[draft-popa-6lo-6loplc] Popa, D. and J.H. Hui, "6LoPLC: Transmission of IPv6 Packets over IEEE 1901.2 Narrowband Powerline Communication Networks", draft-popa-6lo-6loplc-ipv6-over-ieee19012-networks-00, March 2014, <https://tools.ietf.org/html/draft-popa-6lo-6loplc-ipv6-over-ieee19012-networks-00>.

[draft-rashid-6lo-iid-assignment-03] Sangi, AR., Chen, M. and C. Perkins, "Designating 6LBR for IID Assignment", draft-rashid-6lo-iid-assignment-03, March 2017, <https://tools.ietf.org/html/draft-rashid-6lo-iid-assignment-03>.

[IEEE 1901.1] IEEE-SA Standards Board, "Standard for Medium Frequency

(less than 15 MHz) Power Line Communications for Smart Grid

Applications", IEEE 1901.1, work in progress, <http://sites.ieee.org/sagroups-1901-1>.

[IEEE 1901.2a] IEEE-SA Standards Board, "IEEE Standard for Low-Frequency (less than 500 kHz) Narrowband Power Line Communications for Smart Grid Applications - Amendment 1", IEEE 1901.2a, September 2015, <https://standards.ieee.org/findstds/standard/1901.2a-2015.html>.

[ITU-T G.9960] International Telecommunication Union, "Unified high-speed wireline-based home networking transceivers - System architecture and physical layer specification", ITU-T G.9960, December 2011, <https://www.itu.int/rec/T-REC-G.9960>.

[ITU-T G.9961] International Telecommunication Union, "Unified high-speed wireline-based home networking transceivers - Data link layer specification", ITU-T G.9961, June 2010, <https://www.itu.int/rec/T-REC-G.9961>.

[RFC8036] Cam-Winget, N., Hui, J. and D. Popa, "Applicability Statement for the Routing Protocol for Low-Power and Lossy Networks (RPL) in Advanced Metering Infrastructure (AMI) Networks", RFC 8036, January 2017, <http://www.rfc-editor.org/info/rfc8036>.

[RFC8065] D. Thaler, " Privacy Considerations for IPv6 Adaptation-Layer Mechanisms", RFC 8065, Februray 2017, <http://www.rfc-editor.org/info/rfc8065>.

[RFC8066] Chakrabarti, S., Montenegro, G., Droms, R. and J. Woodyatt, "IPv6 over Low-Power Wireless Personal Area Network (6LoWPAN) ESC Dispatch Code Points and Guidelines", RFC 8066, Februray 2017, <http://www.rfc-editor.org/info/rfc8066>.

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