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# Transmission of IPv6 Packets over LoRa
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Abstract

This document describes how IPv6 is transmitted over LoRa using 6LowPAN techniques. LoRa is a wireless communication system for long-range low-power low-data-rate applications. LoRa networks typically are laid out in a star topology in the field with gateways relaying messages between end-devices and a central network server in the backend, the complete system referred to as star of stars network.

Table of Contents



## 1. Introduction

LoRa is a wireless modulation for long-range low-power low-data-rate applications developed by Semtech. LoRa networks typically are organized in a star-of-stars topology in which gateways relay messages between end-devices and a central network server in the backend. Gateways are connected to the network server via IP links while end-devices use single-hop LoRa communication to one or many gateways. All communication is generally bi-directional, although uplink communication from end-devices to the network server are strongly favoured.

Communication between end-devices and gateways is spread out among different frequency channels and so-called spreading factors. Selecting a spreading factor is a trade-off between communication range and data rate. Spreading factors create virtual and orthogonal non-interfering communication channels that enable simultaneous transmissions. Depending on the used spreading factor, LoRa data rates range from 0.3 kbps to 50 kbps. To maximize both battery life of end-devices and overall network capacity, the LoRa network infrastructure manages the data rate and RF output for each end-

device individually by means of an adaptive data rate (ADR) scheme. End-devices may transmit on any channel available at any time, using any available data rate.

The consolidation of that technology and its important impact in the M2M market, is triggering the need for end to end IP connectivity from end devices to the backend server without the need of proxying roles taken at LoRa Managers or Gateways. Due to the constrained nature of LoRa devices, the compression techniques developed by 6LowPAN become mandatory. The present document specifies how IPv6 and the 6LowPAN architecture run on top of the LoRa MAC layer.

## 2. 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].

## 3. Overview of LoRa Technology

TODO briefly describe the technology. Phy layer and modulation. MAC operation and frame formats.

Figure 1: LoRa Class A transmission and reception window.

```
|----------------------------|         |--------|     |--------|
|             Tx             |         |   Rx   |     |   Rx   |
|----------------------------|         |--------|     |--------|
                             |---------|
                              Rx delay 1
                             |------------------------|
                              Rx delay 2
```

## 4. Specification of IPv6 over LoRa

The LoRa technology enables low power wide area network coverage at the cost of reduced data rate and to obey to strict spectrum occupancy regulations. This imposes strict communication limitations that make applications using LoRa to contain the amount of data that is transmitted. 6LoWPAN standards RFC4944, RFC6775, and RFC6282 enable IP connectivity while leverage the overhead of fully IPv6 headers. They also provides standard Internet connectivity by enabling IPv6 adressing and stateless IPv6 address auto-configuration, Neighbour Discovery and most importantly Header Compression. The main difference between IEEE 802.15.4 and LoRa is that LoRa builds stars and star of stars networks not requiring a routing protocol nor multi-hop operation. At the same time LoRa is subject to bandwidth, data rate, radio duty-cycle regulations and

frame size constraints that impose strict limitation in the protocol overhead that is supported when compared to IEEE 802.15.4.

## 4.1. Protocol stack

Figure 2: Protocol Stack for IPv6 over LoRa

```
+----------------------------------------+ ------------------
|                                        |    Transport and
|         Upper Layer Protocols          |  Application Layer
+----------------------------------------+ ------------------
|                                        |         |
|                 IPv6                   |         |
|                                        |      Network
+----------------------------------------+       Layer
|   Adaptation Layer for IPv6 over LoRa  |         |
+----------------------------------------+ ------------------
|                                        |
|      IPv6-LOR Addressing Binding       |   LoRa Link Layer
|                                        |         |
+----------------------------------------+ ------------------
|                                        |         |
|               Activities               |        LoRa
|            Digital Protocol            |   Physical Layer
|               RF Analog                |         |
|                                        |         |
+----------------------------------------+ ------------------
```

Adaptation layer for IPv6 over LoRa SHALL support neighbour discovery, address auto-configuration, header compression, and fragmentation and reassembly.

## 4.2. Link Model

According to RFC 4861 [RFC4861] a link is "a communication facility or medium over which nodes can communicate at the link layer, i.e., the layer immediately below IPv6."

In LoRa the IPv6 layer is designed to enable transmission of IPv6 packets over LoRa links.  The LoRa protocol is in charge of establishing the pairwise communication between the LoRa gateway and the LoRa device.  The IPv6 adaptation layer however is in charge of managing header compression and packet fragmentation in order to deal with different spreading factors and allowed packet payload at the underlying MAC layer.

Per this specification, the IPv6 header compression format specified in RFC 6282 MUST be used [RFC6282] but more drastic compression based on provisioning an extended context in the NS is expected in the upcoming revision. The IPv6 payload length can be derived from the LoRa MAC header length and the possibly elided IPv6 address can be reconstructed from the link-layer address, used at the time of LoRa connection establishment. As described in Section 4.5 context information or more aggressive compression formats such as RoHC [RFC3095] SHOULD be used at the 6LBR in order to compress well-known network prefixes and indicated at the specific field of the IPHC header. This compression will be defined in the upcomming revisions.

LoRa networks form star topologies or star of stars, having a point-to-point nature. Address assignment is managed by the 6LBR that ensures that collisions do not occur. Broadcast features are used mainly by the 6LBR. 6LN to 6LN communications are always carried out through the 6LBR and hence it is in charge of relaying link local packets.

After the LoRa node and the LoRa gateway have established the LoRa connection, the link is enabled and IPv6 address configuration and subsequent transmission are able to start.

### 4.3. Stateless Address Auto-configuration

Nodes (both hosts and routers) in a LoRa network MAY use the address auto-configuration process. This process relies in the ability for a node to generate a link-local address for the communication interface. A link-local address is formed by appending an identifier of the interface to the well-known link-local prefix [RFC4291]. Before the link-local address can be assigned to an interface and used, a node must attempt to verify that this "tentative" address is not already in use by another node on the link. This section describes how LoRa nodes determine the address to be used and how this address is bound to the 6LBR node (or LoRa Manager or Gateway).

#### 4.3.1. LoRa Addressing

LoRa device addressing can be conducted in two ways. Over the air activation (OTAA) and Activation by personalization (ABP). The former requires 2 MAC layer messages to establish the network address and security keys. The latter assumes that device address and security keys are pre-programmed at the nodes. In the case of OTAA the joining negotiation establishes a unique 4 Bytes DevAddr. When ABP is used the DevAddr is pre-configured at the node.

The LoRa device address uses 32 bits and identifies the end-device within the current network. The most significant 7 bits are used as

network identifier (NetworkID) to separate addresses of territorially overlapping networks or networks managed by different network operators. The least significant 25 bits are referred to as the network address (NetworkAddress) of the end-device and can be arbitrarily assigned by the network manager.

Figure 3: End Device Address

```
+------------+---------------+---------------+
|  Bit#      |    [31..25]   |     [24..0]   |
+------------+---------------+---------------+
| DevAddr    |   NetworkID   |    End Device |
|            |               | NetworkAddress|
+------------+---------------+---------------+
```

### 4.3.2. Address Auto-Configuration

A LoRa end device performs stateless address auto-configuration as per [RFC4862]. A 64-bit Interface identifier (IID) for a LoRa interface MAY be formed by utilizing the 32-bit LoRa DevAddr. That IID MAY guarantee a stable IPv6 address and MUST be used along the lifetime of the network.

According to [RFC7136], interface IIDs of all unicast addresses for LoRa-enabled devices MUST be formed on the basis of 64 bits long and constructed using the EUI-64 format. LoRa End Device Addresses MUST follow a stateless address auto-configuration that requires 32 zeros and 32 bit DevAddr.

[RFC4291] indicates the use of a "Universal/Local" scope bit that identifies the network device to be locally accessible or globally accessible. The former SHOULD be followed and LoRa end-devices SHOULD set to 0 the "Universal/Local" bit. In the case that a Universally accessible IPv6 address needs to be used a Neighbor Discovery mechanism and a network commissioning procedure is required. This procedure is described in Section 4.4.

LoRa IPv6 Network Prefix is build using the link-local prefix FE80::/64. The IPv6 link-local address for a LoRa-enabled device is formed by appending the IID, to the prefix, as depicted in Figure 4.

Duplicate address detection for link-local addresses is performed by the 6LBR.

Once a 6LN has established its own link-local address, it starts sending Router Solicitation messages as described in [RFC4861] Section 6.3.7.

For non-link-local addresses a 64-bit IID MAY be formed by utilizing the 32-bit LoRa DevAddr as described in Section TODO.  A 6LN can also use a the EUI-64 generated IID from the MAC Layer.  The non-link-local addresses generated by the 6LN MUST be registered with the 6LBR.

The mechanism by which the 6LBR obtains an IPv6 prefix is out of scope of this document but can for example be accomplished by using Unique Local IPv6 Unicast Addresses (ULA) [RFC4193].  As 6LNs MUST always communicate to the 6LBR, the "on-link" flag (L) MUST be set to zero in the Prefix Information Option [RFC4861].  This will always happen even when the destination is another 6LN using the same prefix.

Figure 4: IPv6 link-local address in LoRa

```
  0          0                 0               0                1
  0          1                 6               9                2
  0          0                 4               6                7
  +----------+-----------------+---------------+----------------+
  |1111111010|      zeros      |     zeros     |    DevAddr     |
  +----------+-----------------+---------------+----------------+
  |                                                             |
  | /------------------------- 128 bits ---------------------/|
  |                                                             |
```

## 4.4.  Neighbour Discovery

Neighbour Discovery is addressed following the classical ND approach as defined by [RFC4861] , [RFC4862] and [RFC6775].  As LoRa networks can be organized in star topologies or star of stars topologies the LoRa manager can take two differentiated roles.  For single star topologies the LoRa manager will act as a 6LBR and MUST keep track of the nodes addresses within the link, otherwise it acts as 6LR and forwards Node Solicitation and ARO requests to the 6LBR in the network.

Figure 5: ND Procedure for a single star topology

```
  LoRa node                          LoRa 6LR/6LBR
      |    Router Solicitation (RS)     |
      |-------------------------------->|
      |                                 |
      |    Router Advertisement (RA)    |
      |<--------------------------------|
      |                                 |
      |    Neighbour Solicitation (NS)  |
      |-------------------------------->|
      |                                 |
      |    Neighbour Advertisement (NA) |
      |<--------------------------------|
      |                                 |
```

When a LoRa node joins a network, it sends an RS to the 6LR containing its IID as described in Section 4.3.2. The 6LBR router answers with a RA containing its IIDs and prefixes. Hosts receive Router Advertisement messages containing the Authoritative Border Router Option (ABRO), the IIDs of the 6LR or 6LBR and MAY optionally contain one or more 6LoWPAN Context Options (6COs). They also contain the existing Prefix Information Options (PIOs) as described in [RFC4861].

When a host has configured a non-link-local IPv6 address, it registers that address with one or more of its default routers using the Address Registration Option (ARO) in an RS message. The host chooses a lifetime of the registration and repeats the ARO periodically (before the lifetime runs out) to maintain the registration. The host needs to refresh its prefix and context information by sending a new unicast RS. As LoRa might use very low data rates it is recommended to use large Lifetime configurations assuming that LoRa devices are not mobile. According to [RFC6775] the maximum Router Lifetime is about 18 hours, whereas the maximum Registration Lifetime is about 45.5 days.

The ND Procedure for star of stars follows the multi-hop ND approach described by [RFC6775]. The multihop distribution relies on RS messages and RA messages sent between routers, and using the ABRO version number to control the propagation of the information (prefixes and context information) that is being sent in the RAs.

Figure 6: ND Procedure for star of stars in LoRa.

```
  LoRa node                         LoRa 6LR                          LoRa 6LBR
      |    Router Solicitation (RS)     |                                  |
      |-------------------------------->|                               |
      |                                 |                                  |
      |    Router Advertisement (RA)    |                                  |
      |<--------------------------------|                               |
      |                                 |                                  |
      |    Node Registration (NR)       |                                  |
      |-------------------------------->|                               |
      |                                 |  Neighbour Solicitation (NS)     |
      |                                 |-------------------------------->|
      |                                 |                                  |
      |                                 |   Neighbour Advertisement (NA)   |
      |                                 |<--------------------------------|
      |    Node Confirmation (NC)       |                                  |
      |<-------------------------------|                               |
      |                                 |                                  |
```

## 4.5. Header Compression in LoRa

TODO.

## 4.6. Fragmentation in LoRa

TODO.

# 5. Internet Connectivity Scenarios

TODO.

# 6. Security Considerations

The transmission of IPv6 over LoRa links has similar requirements and concerns for security as for IEEE 802.15.4. LoRa Link Layer security considerations are covered by the LoRa Specification [LoRaSpec].

# 7. IANA Considerations

There are no IANA considerations related to this document.

## 8. Acknowledgements

The authors would like to acknowledge the guidance and input provided by Pascal Thubert.

## 9. References

### 9.1. Normative References

[RFC7136] Carpenter, B. and S. Jiang, "Significance of IPv6 Interface Identifiers", RFC 7136, DOI 10.17487/RFC7136, February 2014, <http://www.rfc-editor.org/info/rfc7136>.

[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, <http://www.rfc-editor.org/info/rfc6775>.

[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, <http://www.rfc-editor.org/info/rfc6282>.

[RFC4944] Montenegro, G., Kushalnagar, N., Hui, J., and D. Culler, "Transmission of IPv6 Packets over IEEE 802.15.4 Networks", RFC 4944, DOI 10.17487/RFC4944, September 2007, <http://www.rfc-editor.org/info/rfc4944>.

[RFC4862] Thomson, S., Narten, T., and T. Jinmei, "IPv6 Stateless Address Autoconfiguration", RFC 4862, DOI 10.17487/RFC4862, September 2007, <http://www.rfc-editor.org/info/rfc4862>.

[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>.

[RFC4291] Hinden, R. and S. Deering, "IP Version 6 Addressing Architecture", RFC 4291, DOI 10.17487/RFC4291, February 2006, <http://www.rfc-editor.org/info/rfc4291>.

[RFC4193] Hinden, R. and B. Haberman, "Unique Local IPv6 Unicast Addresses", RFC 4193, DOI 10.17487/RFC4193, October 2005, <http://www.rfc-editor.org/info/rfc4193>.

[RFC3095] Bormann, C., Burmeister, C., Degermark, M., Fukushima, H., Hannu, H., Jonsson, L-E., Hakenberg, R., Koren, T., Le, K., Liu, Z., Martensson, A., Miyazaki, A., Svanbro, K., Wiebke, T., Yoshimura, T., and H. Zheng, "RObust Header Compression (ROHC): Framework and four profiles: RTP, UDP, ESP, and uncompressed", RFC 3095, DOI 10.17487/RFC3095, July 2001, <http://www.rfc-editor.org/info/rfc3095>.

[RFC2460] Deering, S. and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", RFC 2460, DOI 10.17487/RFC2460, December 1998, <http://www.rfc-editor.org/info/rfc2460>.

[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>.

## 9.2. External Informative References

[LoRaSpec]
LoRa Alliance, "LoRa Specification Rev.3", April 2014.

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