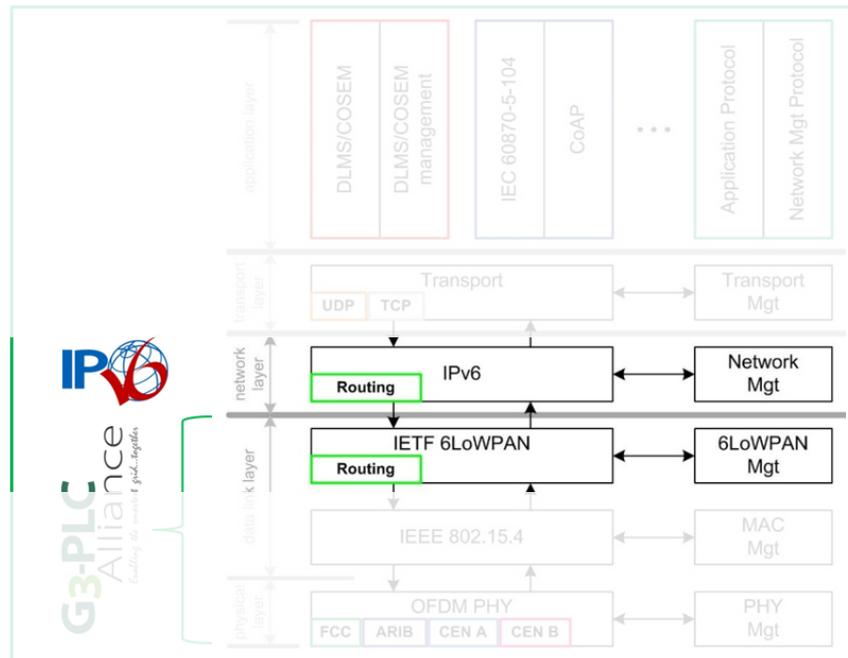


G3-PLC User Guidelines

IPv6 route establishment guidelines (version 1.0, 04/2020)

Executive Summary

By design the G3-PLC communication stack allows native support of IPv6, which grants end-user flexibility to fulfill business requirements when choosing the appropriate higher layers (ISO/OSI transport and application layers). This key feature also secures G3-PLC infrastructures in the long term, thanks to the scalability and future application compatibility provided by IPv6



This document provides guidelines on how to make G3-PLC devices directly accessible over IPv6, by having one node acting as an IPv6 border router. In this document, we will assume that the border is the PAN-Coordinator, which is representative of the typical use case. This document will focus on unicast routing.

Optimisations are also proposed, allowing to reduce message size by using the full potential of the IPv6 header-compression mechanism.

In an annex, fundamental concepts related to IPv6 are reminded to provide some technical basics to the reader.

About G3-PLC

G3-PLC facilitates high-speed, highly-reliable, long-range communication over the existing powerline grid. The features and capabilities of G3-PLC have been developed to address the difficult challenges of powerline communications. While earlier approaches were a step in the right direction, they fall short of meeting the technical and reliability requirements necessary in the hostile environment of PLC.

G3-PLC meets these requirements because of its unique features such as a mesh routing protocol to determine the best path between remote network nodes, a “robust” mode to improve communication under noisy channel conditions and channel estimation to select the optimal modulation scheme between neighbouring nodes. Furthermore, its support of IPv6, enabling easy integration of various application profiles, adds high versatility and carries G3-PLC well into the future.



G3-PLC is an open, international standard published by ITU: <https://www.itu.int/rec/T-REC-G.9903>.

To help adopters properly integrate the G3-PLC protocol stack in products and systems we have developed a set of user guidelines. All user guidelines can be found on the G3-PLC Alliance website: <http://www.g3-plc.com/what-is-g3-plc/userguidelines>

For more information: www.g3-plc.com

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1. Objectives

This document provides guidelines on how to make G3-PLC devices directly accessible over IPv6, by having one node acting as an IPv6 border router. In this document, we will assume that the border is the PAN-Coordinator, which is representative of the typical use case. This document will focus on unicast routing (i.e. exchanging messages between an external IPv6 network and one target device in the PLC network).

Optimisations are also proposed, allowing to reduce message size by using the full potential of the IPv6 header-compression mechanism.

2. Default connectivity in G3-PLC

By default, G3-PLC devices can be addressed by their link-local addresses, constituted of link-local prefix **fe80::/10** and interface identifier **"yyyy:ff:fe00:xxxx"** (where **"yyyy"** is the 16-bit PAN-ID and **"xxxx"** the 16-bit short address, see §4.1 for a general explanation on IPv6 addressing).

Link-local addresses do not require any configuration, but cannot be routed from/to outside the PLC network.

3. Full IPv6 connectivity in G3-PLC

If IPv6 addressing is required outside the PLC network, a globally accessible subnet prefix must be acquired or generated (see §4.3 for details). This prefix is then provided to the border router and propagated to all devices in the PLC network.

This propagation can be done using one of several standardized protocols.

The next chapter describes one way to implement this prefix propagation, using "IPv6 Stateless Address Autoconfiguration" as described in IETF RFC 4862 (mechanism) and RFC 4861 & 6775 (message encoding).

Additional optimisations for G3-PLC are proposed, in particular the configuration of the compression context. This allows to reduce message size by compressing IPv6 headers in exchanged messages.

3.1. Stateless Address Autoconfiguration applied to G3-PLC

First, the border router must be configured with a valid IPv6 prefix (see §4.3). In the following, a prefix set to 2001:db8:1:ab/64 will be used as an example.

In order to join a PLC network, a G3-PLC device will execute the joining procedure defined in G3-PLC specification §9.4.4. This commissioning procedure results in the attribution of a PAN-ID and a short MAC address to the device, allowing the device to compute its interface identifier (consisting in the concatenation of "PAN-ID", "0x00FFFE00", "short MAC address").

As short MAC addresses are allocated by the PAN-Coordinator, duplicate interface identifiers are not possible in a PLC network. Therefore, no duplicate detection mechanism is required. As a consequence, ICMPv6 Neighbor Solicitation and Neighbor Advertisement messages are not used.

Following the completion of the joining procedure (and of the initial route-establishment if **adpDefaultCoordRouteEnabled** is set to TRUE), the device should send an ICMPv6 Router Solicitation (RS) message to the PAN-Coordinator. This message should be sent in unicast to the PAN-Coordinator, using its link-local address (RFC 4862 defines the use of a multicast group, which is less optimal on a G3-PLC network). Router Solicitation encoding is described in RFC 4861 §4.1.

Upon reception of a Router Solicitation, the border router should reply with an ICMPv6 Router Advertisement (RA) message, typically configured as follows:

- Router Advertisement (RFC 4861 §4.2 and RFC 6775 §5.4)
 - M = 0 and O = 0 (indicate that DHCPv6 is not used)
 - Router Lifetime = 0xFFFF (in second, maximum value allowed by RFC 6775)

- Reachable Time and Retrans Timer = 0 (the neighbour unreachability detection algorithm is not used)
- Options:
 - Prefix Information option (PIO, RFC 4861 §4.6.2)
 - Prefix Length = 64
 - L = 1
 - A = 1 (this prefix can be used for stateless address configuration)
 - Valid Lifetime = Preferred Lifetime = 0xFFFFFFFF (infinity)
 - Prefix = 2001:db8:1:ab/64
 - 6LoWPAN Context Option (6CO, RFC 6775 §4.2)
 - Context Length = 64
 - C = 1 (context can be used for compression)
 - CID = 0 (context identifier)
 - Valid Lifetime = 0xFFFF (in 60s units, maximum value allowed)
 - Context Prefix = 2001:db8:1:ab/64
 - More 6LoWPAN Context Options may be present (see §3.1.1 when multiple compression contexts are used)

The RA message must be sent using link-local addresses (to avoid any issue with IPv6 header compression using context information that has not yet been received by the target device).

Upon reception of a Router Advertisement message, the G3-PLC device must update the following attributes:

- **adpPrefixTable** should be configured with the IPv6 prefix for this network
- **adpContextInformationTable** should contain one entry for each 6LoWPAN Context Option received.

Note: **adpPrefixTable** and **adpContextInformationTable** must also be updated in the border router after sending a RA message, in order for IPv6 header compression to work.

As prefix information has a limited duration (set by the “Router Lifetime” field), Router Advertisements must be sent periodically by the border router in broadcast to refresh the validity duration for all devices of the network.

When forwarding a packet, if the destination address is not part of the local network (its prefix is not present in the prefix table), it must be sent to the PAN-Coordinator’s address for routing outside the G3-PLC network.

3.1.1. Additional optimisation

To allow for further optimisation, a 6LoWPAN prefix compression context may be added to compress the address of a remote host interacting with the PLC devices (for example, a data-collection server).

In this case, an interface identifier equal to “0:ff:fe00:xxxx” should be configured on the host (with “xxxx” having a value comprised between 0x0000 and 0xFFFF). If for example this host prefix is 2001:db8:beef::/64, then its complete IPv6 address will be 2001:db8:beef::ff:fe00:xxxx.

An additional 6LoWPAN Context Option should be added to the Router Advertisement, with the following information:

- 6LoWPAN Context Option (6CO, RFC 6775 §4.2)

- Context Length = 112 (the context does not cover the last 16 bits of the host address)
- C = 1 (context can be used for compression)
- CID (context identifier) value chosen between 1 and 15. The CID must be unique.
- Valid Lifetime = 0xFFFF (in 60-second units, maximum value allowed)
- Context Prefix = "2001:db8:beef::ff:fe00"

3.1.2. Considerations on header compression deployment

As described in RFC 6775 §7.2, changes in compression contexts must be handled with care:

- When a 6LoWPAN Context Option is advertised for the first time, the corresponding "C" field shall be set to 0, such as the context is not initially used for compression (devices can only use it for decompression purpose). After several RA have been sent by the border router (to ensure that all PLC devices have received the new information), the "C" field can be set to 1, allowing the use of the context for compression purpose.
- After a 6LoWPAN Context Option is not valid anymore, the border router shall continue advertising it for a certain time with "C" set to 0 (so the context is not used for compression), then advertise it with Valid Lifetime = 0 to remove it.

3.2. Address registration

Once a PLC device has obtained a fully routable address, it is useful to publish the correspondence between a long-lived identifier of the device (for example the device extended MAC address) and the allocated IPv6 address. This allows external clients to access and query the PLC device, using the long-lived identifier to retrieve the device's IPv6 address, and then to initiate direct communication using IPv6 packets.

Several possibilities exist to achieve this, which requires to provide a mean to resolve "identifier to IPv6" and to register PLC devices following bootstrap.

For example, one possibility is to use standard DNS servers and protocols:

- Use extended MAC addresses for the long-lived device identifiers of PLC devices.
- The correspondence between extended MAC addresses and IPv6 addresses is provided by a DNS server, using extended MAC addresses as names for IPv6 AAAA records.
- After a device completes the bootstrap procedure, the EAP-PSK server updates the DNS server using RFC 2136 messages:
 - The EAP-PSK server already manages the allocation of short MAC addresses to devices identified by their extended MAC addresses, thus the correspondence between extended MAC addresses and IPv6 addresses can be retrieved easily (as IPv6 addresses are derived from short MAC addresses).
 - If needed, DNS update messages may be secured using either RFC 2845 or RFC 3007

4. Annex: overview of IPv6 unicast routing configuration

This chapter briefly introduces how IPv6 addresses are created and how IPv6 routing is configured in routers and devices.

4.1. IPv6 addressing

4.1.1. General

An IPv6 address is a 128-bit identifier (16 bytes) that allow to uniquely identify a device in a network. It is composed of 2 parts:

- The subnet prefix, which identifies the network the device belongs to.
 - The prefix must be unique in the network target scope (local, organisation or global).
 - Prefixes are variable in length, typically 64 bits or smaller and are right-padded with zeros as required.
 - For G3-PLC networks, prefixes must have a length of 64 bits (this restriction is added by RFC 4944 §6)
- The interface identifier, which identifies the device itself.
 - The identifier must be unique in a given network. By default, interface IDs are 64-bit long.
 - A device may have several interface identifiers (derived from MAC address, manually configured, privacy-preserving random IDs, cryptographic IDs, etc.).

An IPv6 address is created by the concatenation of a subnet prefix and an interface identifier.

An IPv6 device may have several IPv6 addresses, by being directly connected to several network (with a subnet prefix for each network) and/or by having several interface identifiers (having several network interfaces, manually configured interface IDs, privacy-preserving IDs, etc.).

4.1.2. IPv6 text representation

IPv6 addresses are written as 8 groups of 2 bytes, written in lower-case hexadecimal and separated by “:”.

To allow for shorter address representations, leading ‘0’ in each group are omitted. Also if two or more consecutive groups are all ‘0’, then the longest series of “:0:0: ...” may be replace by “::”.

For prefix, a “/” followed by a decimal number indicates the length of the prefix, in bits.

Examples:

- A prefix equal to “fe80:0000:0000:0000/10” is written fe80::/10
- An interface identifier equal to “01d7:00ff:fe00:0001” is written 1d7:ff:fe00:1
- The resulting IPv6 address is written fe80::1d7:ff:fe00:1

4.2. Routing configuration

For an IPv6 network to function properly, three operations are required:

- A subnet prefix must be attributed to the IPv6 router of each network.
- The router must distribute its subnet prefix to each connected device.
 - This can be achieved using ICMPv6 Router Advertisement or DHCPv6.
- Each device must generate a unique interface identifier (duplicate detection may be required to ensure the ID is unique).

- Several Interface identifier generation mechanisms are possible (derived from MAC address, set manually, random or cryptographic generation, etc.)
- Duplicate detection may be achieved using Neighbour Discovery or DHCPv6 (if needed).

In G3-PLC, interface identifier are generated following the format: “**yyyy:ff:fe00:xxxx**”, where “**yyyy**” is the 16-bit PAN-ID of the PLC network and “**xxxx**” is the 16-bit short address of the device.

As short MAC addresses are allocated by the PAN-Coordinator, duplicate interface identifiers are not possible in a PLC network. Therefore, no duplicate detection mechanism is required.

4.3. IPv6 subnet prefix types

Several types of IPv6 subnet prefixes are available for use in an IPv6 network:

- Link-local prefix: this prefix is mandatory and always available without configuration, but link-local addresses cannot be accessed from a host located outside of the local network.
 - The link-local prefix is equal to fe80::/10.
- Globally routable prefix: this prefix allows PLC devices to be accessible from the Internet.
 - A globally routable prefix will be in the 2000::/3 address space (see RFC 2373 and RFC 2373bis)
 - The current allocation scheme provides prefixes that are a subnet of 2001::/16 and are allocated by a Regional Internet Registry (RIR) or an Internet Service Provider (ISP).
- ULA (Unique Local Addresses) prefix: this prefix allows routing access to PLC devices from inside an organisation, but not from the Internet.
 - An ULA prefix is formatted as 0xFC (7 bits) + L (1 bit, = 1 if locally assigned) + Global ID (40 bits, random value) + Subnet ID (16 bits, identifies a subnet within the organisation). No registration is required.
 - It is to be noted that the use of ULA prefixes within an organization is quite similar to the use of globally routable prefixes; thus, the recommendations made in §3 remain valid.

4.4. Specification references

IPv6 main specification: IETF RFC 8200

IPv6 Addressing Architecture: IETF RFC 4291

IPv6 Stateless Address Autoconfiguration: IETF RFC 4862

Router Advertisement/solicitation message definition: IETF RFC 4861

6LoWPAN extensions for compression: IETF RFC 6775

Unique Local IPv6 Unicast Addresses: IETF RFC 4193

IPv6 Packets over IEEE 802.15.4 Networks: IETF RFC 4944

IP Version 6 Addressing Architecture: IETF RFC 2373