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Guideline for the Implementation of Coexistence for Low Frequency Narrowband Power Line Communication Standards in the Smart Grid

Smart Grid Interoperability Panel, Priority Action Plan 15
Power Line Communications

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1. Overview

Power Line Communication (PLC) systems provide a bidirectional communication platform capable of addressing a variety of Smart Grid applications, such as home energy management and intelligent meter reading and control. One benefit of using power line communication on the power grid is that it makes use of the intrinsic electrical infrastructure rather than using other wired or wireless alternatives. Home appliances and home energy management systems can communicate with no additional wiring and minimal configuration by the homeowners.

PLC Technology could be classified into two general categories: Narrowband (NB) and Broadband (BB). The NB-PLC considered here, operates in frequency bands below 500 kilo-Hertz (kHz) and supports rates of tens to hundreds of kilobits per second (Kbps). BB-PLC operates in frequency bands above over 1.8 Mega-Hertz (MHz) and can have a data rate ranging from several megabits per second (Mbps) to a few hundred Mbps. For a more detailed discussion of the PLC technology and its use in the Smart Grid, see [1].

2. Purpose of Document

The Smart Grid Interoperability Panel (SGIP) established the Priority Action Plan 15 (PAP 15) in 2009 to address the harmonization of new PLC standards and their coexistence specifications. This NISTIR presents PAP15's recommendation on the implementation of coexistence mechanisms for NB-PLC standards. The document also gives a short introduction of NB-PLC standards and their coexistence mechanisms. A similar guideline on BB-PLC is presented in [2].

3. Why Coexistence is Important

Power line electrical wiring is a *shared* medium. It does not provide a conductor that is dedicated exclusively to a particular subscriber or application. More specifically, power line wiring may distribute energy to a set of individual homes or set of multiple dwelling units (aka "neighbors"). The signals that are generated by one set of users have the potential of interfering with signals generated by other users who share the wiring.

Low frequency NB-PLC operates in the frequency band below 500 kHz. The available frequencies differ in various geographical regions. For example, in the U.S, the Federal Communication Commission (FCC) defines frequencies between 10 and 490 kHz for NB-PLC; however, it does not specify how it is to be used. In Europe, the EN 50065-1 standard defines a set of frequencies in the range 3 kHz to 148.5 kHz for transmission of information on low voltage electrical systems, either on the public supply system or within installations in consumer's premises. It consists of four bands, commonly referred to as the CENELEC bands. CENELEC A band, from 3 kHz to 95 kHz, is restricted to electricity suppliers and their licensees; CENELEC band B from 95 kHz to 125 kHz, CENELEC band C from 125 kHz to 140 kHz, and CENELEC band D from 140kHZ to 148.5 kHz are restricted to consumer use. Japan's Association of Radio Industries and Businesses (ARIB) defines a frequency range similar to the FCC's.

Because the medium and frequency bands are shared, and because existing and emerging standards exist, it is necessary to devise a coexistence mechanism(s) that can be used to limit the harmful interference caused by non-interoperable neighboring devices. Because Smart Grid applications are expected to last much longer than In-Home applications which tend to change rapidly, it is important to enable coexistence in such a way that it is useful for current and emerging technologies over a long time horizon.

4. PAP15 Requirements on Narrowband Power Line Communication

To ensure the new standards being developed meet the Smart Grid requirements, PAP15 members developed and agreed to NB-PLC requirements for smart appliances [3] and the NB coexistence mechanism requirements [4]. These documents were delivered to the Institute of Electrical and Electronics Engineers (IEEE) and International Telecommunication Union – Telecommunication Sector (ITU-T) in 2011.

The Smart Appliance Low-Frequency Narrowband PLC Requirements document [3] lists the users, device vendors, application vendors and the utility industry functional and application requirements.

The NB Coexistence Mechanism Requirements document [4] details the general agreements for the coexistence between existing and developing protocols that use the same low frequency bands. It provides a foundation for what needs to be accomplished, which standards need to be included and how different interests will coordinate.

5. Recent NB-PLC Standards

There has been a long history of using narrowband PLC technologies for control and management. Existing standards use single-carrier or double-carrier modulation technologies, which provide limited bandwidth in tens or hundreds of bits per second (bps). Examples of such standards include LonWorks (International Organization for Standardization/International Electrotechnical Commission ISO/IEC 14908-3), KNX (ISO/IEC 14543-3-5), CEBus (CEA-600.31), and IEC 61334-5-1/61334-5-2.

A new generation of standards that uses multi-carrier orthogonal frequency division multiplexing (OFDM) technology has been developed by the P1901 group of IEEE and the G.hnem group of ITU-T. The OFDM technology enables a higher bit rate in hundreds of kbps. These standards include IEEE 1901.2, ITU-T documents G.9901, G.9902 (G.hnem), G.9903 (G3-PLC), and G.9904 (PRIME) [6-10]. They could be used for many smart grid applications including advanced metering infrastructure, home energy management, distributed energy resource management, and demand response management. PAP15 coordinated the work between these SDOs. Table 1 presents a summary of major features of these protocols. The major difference is the mechanisms by which a NB-PLC network is established and managed, and how data are routed. There are differences in the choice of frequency bands, modulation methods, and error correction codes used, resulting differences in the available bandwidth. Even though each protocol has an intended use, there is no intrinsic limitation on whether each could be used for Home Area Network or Access Area Network (including utility or metering network) applications.

Table 1: Summary of Protocol Features for G.hnem, IEEE 1901.2, G3-PLC, and PRIME

Features	G.9902 (G.hnem)	1901.2	G.9903(G3-PLC)	G.9904(PRIME)
Packet layer support	IPv6, IPv4, and other	IPv6/UDP/TCP and other	IPv6/UDP	IPv6, IPv4, IEC 61334-4-32
Routing	A network is preconfigured for either L2 (one hop, relay) or L3 routing. Mechanism for relay routing (source routing) is for further study. L3 routing protocol not selected.	A network is reconfigurable for either L2 or L3 routing.	Routing on hop-by-hop (mesh) basis, nodes uses route discovery procedure in LOADng protocol (RFC 6550, ROLL) to manage its routing table.	Switching nodes are assigned as tree branches are added. Routing table in each node is maintained by Beacons from switches. Routing to other networks always through the root.
Security	AES-128 key and CCM encryption	AES-128 key and CCM* encryption	EAP-PSK, RADIUS AES-128 key and CCM* encryption	Two profiles - no encryption and AES-128 key encryption.
PLC Network Formation/ Management	A Domain Master manages the formation and resources of a G.hnem network (called domain). Node joins a domain with the Domain Master. Nodes within a domain may communicate with each other directly, or indirectly through a relay or a domain access point. Nodes not in the same domain must communicate through Inter Domain Bridges.	The network is formed and managed by a PAN coordinator. Channel access is supported by slotted CSMA/CA and unslotted CSMA/CA for non-beacon PANs.	Use 6LoWPAN Boot Strapping Protocol for devices to discover neighbors and connect. A PAN Coordinator performs initialization/ management of a G3 network	A Prime network consists of a logical tree. The root node (Base Node) manages the network resources and connections. A new node (Service Node) attaches to the tree on a neighboring node visible to the new node. Specify procedure for firmware update.
Network Topology	Star, tree, or mesh	Star, tree, or mesh	Mesh	Tree
Convergent Layer (above MAC)	Use 6LoWPAN for IPv6 service convergence, support of IPv6 required	Provides service convergence procedures for IPv6	Use 6LoWPAN for IPv6 service convergence	Provide service convergence procedures for IPv6, IPv4, and IEC 61334-4-32. Use 6LoWPAN for IPv6 header compression
Frequency Bands (in kHz)	CENELEC-A(35.9375-90.625), CENELEC-B (98.4375-120.3125), CENELEC-CD(125-143.75), FCC(34.375-478.125), FCC-1 (34.375-137.5), FCC-2(150.0-478.125)	CENELEC-A(35.9375-90.625), CENELEC-B (98.4375-121.875), ARIB (154.6875-403.125), FCC(154.6875-487.5),	CENELEC-A(35.9375-90.625), CENELEC-B (98.4375-121.875), ARIB(154.6875-403.125),FCC(154.6875-487.5)	CENELEC A (42-89).
Modulations	(Coherent) M-PSK, M=2,4,8,16 16-QAM	(Differential) M-DPSK, M=2,4,8 (Coherent) BPSK (Coherent - optional) QPSK, 8PSK, 16-QAM	(Differential) M-DPSK, M=2,4,8 (Coherent - optional) M-PSK,M=2,4,8 16-QAM	(Differential) M-DPSK, M=2,4,8

6. Coexistence of NB-PLC

6.1 NB-PLC Coexistence Mechanisms

In 2010 PAP15 established a Coexistence Sub-Group to coordinate standardization work on coexistence mechanisms. It produced a report examining alternatives for coexistence of NB-PLC protocols [5], including use of frequency division, frequency notching, and pilot tones. Subsequently, in response to the PAP15 requirements cited above, both IEEE P1901.2 and ITU-T Q15/15 groups standardize mechanisms to allow coexistence of multiple PLC technologies. The resulting two mechanisms are described below. These two mechanisms are in addition to required CSMA coexistence mechanism detailed in EN50065-1 for CENELEC C devices.

Frequency separation and notching mechanism – The mechanism avoids frequencies used by other networks by adhering to specific band plans and by limiting the out-of-band signal level for a certain frequencies. Furthermore tone notching on one or more subcarriers within the frequency range overlapping other technologies may also be used. This mechanism is mainly to be used for coexistence with systems complying with existing SDO standards and operating below 150 kHz.

Preamble-based CSMA mechanism – The preamble-based CSMA mechanism is used to fairly share the communications medium when the devices operate in the same or overlapping frequency band. This mechanism requires a sequence of neutral coexistence preamble symbols be transmitted by the device before the “native” preamble to provide coexistence signaling. The “native” preamble is the original preamble defined by the protocol of the device that is using this coexistence mechanism. The coexistence preamble symbols are transmitted only on sub-carrier frequencies that are common to the various protocols, and only for the band being used. This mechanism is to be used for coexistence with systems complying with standards referenced in this document and future standards.

The specification for the first mechanism appears in all standards listed in Table 1 above. The preamble-based mechanism is being specified in the IEEE P1901.2 Group and is to be adopted by others when the specification is completed [11] and satisfies the PAP15 Coexistence Requirements [4]. In particular, if the coexistence mechanism is defined as a part of a PHY/MAC specification, this part shall be stand-alone, i.e., implementation of only this part shall be allowed under the same IPR policy as for the incorporating its PHY/MAC specification.

6.2 Coexistence Behavior/Fairness

Coexistence mechanisms also require a sense of fairness with respect to its effect on the network and access to the medium (channel). The following sections address this issue.

6.2.1 CSMA procedure

A system will search and detect coexistence preamble while not transmitting or receiving frames.

When a system detects a coexistence preamble and is not followed by a native preamble, the system must wait for a predefined back-off time interval before attempting transmission of a frame.

6.2.2 Fairness procedure

Once multiple systems detect the need to coexist they need to be able to fairly share the medium by following two procedures:

- Long coexistence preamble sequence
- Duty cycle

A long coexistence preamble sequence consists of repeated coexistence preambles. The transmission of the long coexistence preamble sequence is a way of “requesting” channel access from devices of different technologies. If a system attempts to access the channel but has backed off for a predefined maximum duration then it may transmit a long coexistence preamble sequence. After the transmission of a long coexistence preamble sequence, it shall immediately transmit the data frame.

Duty cycle is another means to broker fairness among coexisting networks. The Standard [11] defines the maximum allowed duration for nodes of the same network to occupy the channel. After this duration, nodes will back-off the channel for a specified amount of time before transmitting again.

A node may be capable of performing both the above mentioned solutions in order to get an optimized solution, and avoid inefficiencies.

7. PAP15 Recommendation

The following recommendation was approved by PAP15 at its meeting on December 4, 2012:

In order to ensure that NB-PLC devices deployed in proximity do not interfere with each other causing performance degradation or service disruption, PAP15 recommends that all Smart Grid devices using frequency below 500kHz NB-PLC technologies must implement and activate preamble-based coexistence mechanism as specified in IEEE 1901.2, in addition to the frequency band plans and frequency notching mechanisms defined in standards for specific NB-PLC technology.

8. References and Bibliography

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[6] Recommendation ITU-T G.9901, *Narrowband orthogonal frequency division multiplexing power line communication transceivers – power spectral density specification*, 2012

[7] Recommendation ITU-T G.9902, *Narrowband orthogonal frequency division multiplexing power line communication transceivers for ITU-T G.hnem networks*,2012

[8] Recommendation ITU-T G.9903, *Narrowband orthogonal frequency division multiplexing power line communication transceivers for G3-PLC networks*,2012

[9] Recommendation ITU-T G.9904, *Narrowband orthogonal frequency division multiplexing power line communication transceivers for PRIME networks*, 2012

[10] IEEE Standard 1901.2-2013, *Standard for Low Frequency (less than 500 kHz) Narrow Band Power Line Communications for Smart Grid Applications*, 2013. http://grouper.ieee.org/groups/1901/2/

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