Broadband OFDM PLC solution for Medium Voltage lines based on IEEE 802.15.4 and LOADng

Asier Llano(1), David Gil(2), José Antonio Moreno(2), Txetxu Arzuaga(1) and Elsa Herbrich(3)

(1) ZIV Metering, Parque Tecnológico 210, 48170 Zamudio, Spain,
e-mails: asier.llano@cgglobal.com, txetxu.arzuaga@cgglobal.com

(2) ZIV Communications, Calle Antonio Machado, 78 Edificio Australia, 08840 Viladecans, Barcelona, Spain
e-mails: david.gil@cgglobal.com, joseantonio.moreno@cgglobal.com

(3) ZIV France, 84-88 Boulevard de la Mission Marchand, 92400 Courbevoie, France
e-mails: elsa.herbrich@cgglobal.com

Abstract

Broadband Medium Voltage Power Line Communication (PLC) has different properties than Narrow Band Low Voltage PLC and Broadband in-home PLC. The nature of its interferences, the throughput and redundancy requirements and network topology are particular and a PLC stack designed for this application introduces important advantages for this application.

Index Terms

Broadband, Medium Voltage, LOADng, IEEE 802.15.4, OFDM, PLC, Bridging.

I. INTRODUCTION

POWER Line Communication (PLC) through Medium Voltage (MV) lines are attractive as they avoid the expenses of maintaining communication services with third parties, and let Utilities control their own communications system in a fully owned existing infrastructure. They have the potential to become a technology of choice for smartgrid communication access network for the provision of several services (AMI system backbone links, LV & MV monitoring, DER integration, etc).

Broadband (BB) MV PLC is different from Narrow Band (NB) Low Voltage (LV) PLC in many aspects. From the application point of view, MV PLC requires greater communication throughput, shorter latency, longer distances, equipment redundancy and direct integration with the backbone communication network. On the contrary, it doesn't require supporting so many communication nodes per subnetwork. From the communication medium perspective, an extended frequency bandwidth is available, higher voltage levels can be coupled, the line impedance is much higher and even if the background noise is relatively lower, it has powerful selective noise interference due to the sometimes strong coupling of radiocommunication signals in MV aerial lines. Models of the medium voltage lines are described in articles [1-6].

Comparing MV PLC with the in-home PLC technologies, many of these differences still apply, like the longer distance requirement, equipment redundancy, medium propagation and disturbances particularities.

In some environments, the same technology used for NB LV PLC or in-home PLC has been implemented for MV, relaxing the requirements in terms of throughput, latency, redundancy or distance. But a PLC technology design with state of the art technology with these requires in mind has demonstrated to be of great benefit for this application.

This paper describes a new technology designed to fulfill these requirements, specifically tailored for the MV environment application. It does also describe implementation details, field tests and results.

II. SOLUTION DESCRIPTION

A. Physical (PHY) Layer

The PHY layer is based on Orthogonal Frequency Division Multiplexing (OFDM) technology with turbocoding and repetition mechanisms. The PHY Packet Data Unit (PPDU) is composed of a preamble, frame control and data payload. The frame control is encoded in a single OFDM symbol with the most robust configuration, while the payload data is of variable length and variable robustness, by configuring the repetition mechanism, the turbocode rate and the subcarrier mapping. Figures 1 and 2 depict the structure of the PHY transmitter and receiver.

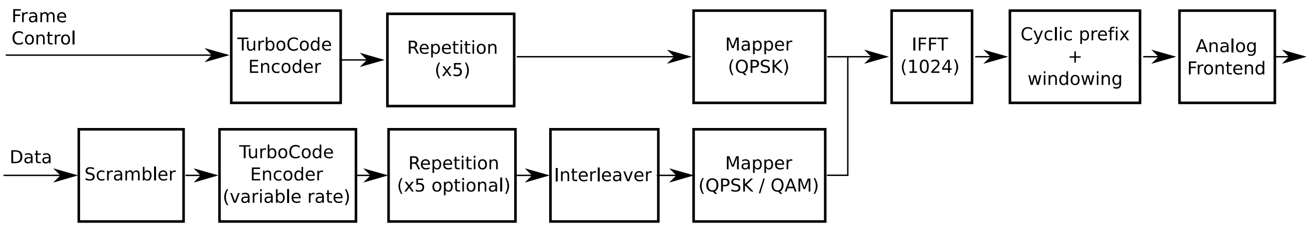

Figure 1. PHY layer transmission structure

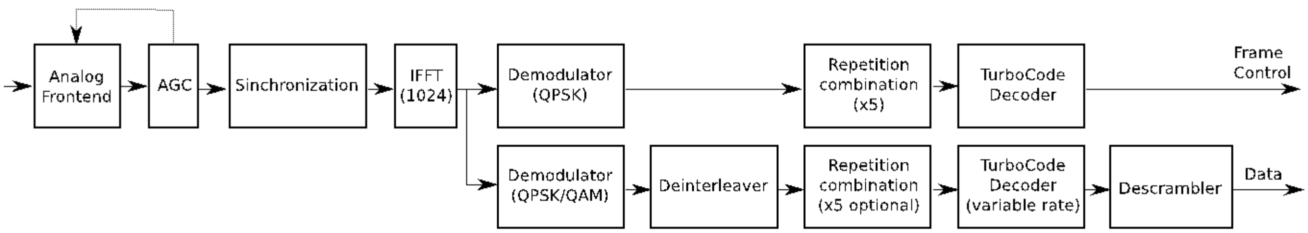

Figure 2. PHY layer reception structure

This PHY layer is configured in order to use two frequency subbands: from 2 to 8 MHz and from 8 to 14 MHz. Each band is able to provide variable throughput up to 19.2 Mb/s. The frequency subbands have been defined out of real field experience with propagation and range tests. It's also possible to configure the PHY layer in wide band adding the two subbands providing a throughput up to 38.4 Mb/s. The different configurable parameters are depicted in Table 1.

Tabla 1. PHY configuration parameters

PHY Parameter	***Options***
Bandwidth	Normal: 6 MHz, Reduced: 1.5 MHz, Doubled: 12 MHz
Constellation	QPSK, 16QAM
Turbocode	Disabled: rate=1; Enabled: rate=1/3
Repetition	Disabled: repetition=x1, Enabled: repetition=x5

B. Medium Access Control (MAC) and dynamic routing layers

Medium Access Control (MAC) layer is based on IEEE 802.15.4 (specified in [7]) providing shared medium access, security and automatic packet recovery. The PLC subnetwork routing resolution protocol used is LOADng (specified in [7]), due to its reactive nature and its integration with IEEE 802.15.4. These technologies make the MV PLC subnetwork plug-and-play and dynamic, allowing MV PLC devices intercommunicate at IP level transparently, accessible each other in the same subnetwork. The equipment redundancy is based on the fact that LOADng is a dynamic routing mechanism that will adapt to topology changes, using the path redundancy provided by the PHY communications overreaching.

The plug and play system used by the MV PLC equipment searches the neighbors and adapts the power and carriers of each hop. The MAC layer uses the LOADng mechanism to search the routes for each device. This mechanism uses short messages called RREQ (request) and RREP (response) to find the equipment that owns a particular address. The equipment will use this optimal route while it is valid. The route is be refreshed with each packet reception and when the route expires or fails the mechanism begins another route searching procedure again.

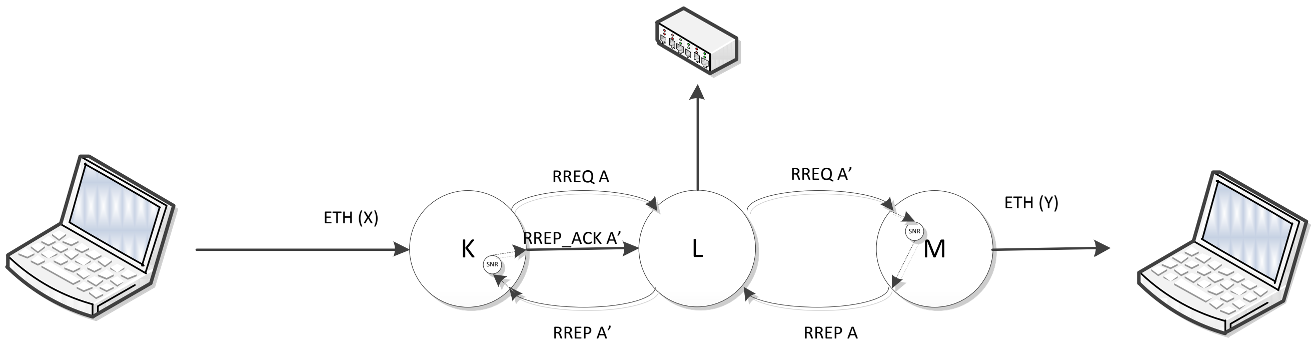

Figure 3. LOADng interchange example

III. FIELD TESTS AND RESULTS

Two different real field test campaigns have been performed using the described technology, one to test the PHY layer and one to test complete system, including MAC and dynamic routing algorithms.

A. PHY layer tests and results

The PHY layer test campaign was executed in 5 different rural locations, some of them with aerial lines and some underground. Physical links were up to 8 km long in a single hop. Being a PHY layer test campaign it was performed with the routing mechanism disabled and transmission mode negotiation disabled, in order to test direct connectivity quality performance and its dependency with the transmission mode.

For this test campaign 4 different transmission modes were configured. The details of the configuration are depicted in Table 2. For each transmission mode the Frame Error Rate (FER) of the link was tested and the obtained results are presented in Table 3.

Table 2. Field test modes tested for each link

Parameters	***Mode 1***	***Mode 2***	***Mode 3***	***Mode 4***
Throughput	9.6 Mbps	3.2 Mbps	0.64 Mbps	0.16 Mbps
Bandwidth	Normal (6 MHz)	Normal (6 MHz)	Normal (6 MHz)	Reduced (1.5 MHz)
Constellation	QPSK	QPSK	QPSK	QPSK
Turbocoding	Disabled (rate=1)	Enabled (rate=1/3)	Enabled (rate=1/3)	Enabled (rate=1/3)
Repetition	Disabled (x1)	Disabled (x1)	Enabled (x5)	Enabled (x5)

Table 3. Field test results

			FER			
Link #	***Distance***	***Link type***	***Mode 1***	***Mode 2***	***Mode 3***	***Mode 4***
Link 1	80 m	rural - underground	0.05	0.00	0.00	0.00
Link 2	152 m	rural - underground	0.09	0.00	0.00	0.00
Link 3	1282 m	rural - underground	0.34	0.00	0.00	0.00
Link 4	243 m	rural - underground	0.08	0.00	0.00	0.00
Link 5	506 m	rural - underground	0.00	0.00	0.00	0.00
Link 6	739 m	rural - aerial	1.00	0.85	0.00	0.00
Link 7	1404 m	rural - aerial	1.00	0.20	0.00	0.00
Link 8	2704 m	rural - aerial	1.00	1.00	0.00	0.00
Link 9	8000 m	rural - aerial	1.00	1.00	1.00	0.05

B. MAC layer and LOADng resolution tests and results

For the MAC layer and LOADng tests, four devices were installed in an underground environment with real application data traffic. Dynamic routing resolution and transmission mode autodetection mechanisms were enabled and tested during this campaign. The test started with all the devices connected and with a point to point connectivity test in order to check that all the possible routes were automatically resolved and an appropriate transmission mode was selected. The routing mechanism was tested up to 3 hops and equipment failure was simulated powering down devices in order to check that dynamic routing resolution procedures managed the situation to find a new route for the required traffic. Along this test campaign no route resolution error was found and the IP connectivity was successful.

IV. CONCLUSION

The results were successful in general, but they showed that the modes with turbocoding disabled were not practical, presenting an unacceptable FER even for some good quality links. This study has suggested introducing new transmission modes with puncturing for the turbocoding with effective coding rates of 8/9 and 3/4, achieving comparable throughput to the modes that had turbocoding disabled but with an important FER reduction.

A new measurement campaign with the additional PHY functionalities: QAM constellation, 8/9 and 3/4 coding and 12 MHz channels, oriented for high throughput links is currently ongoing with promising results.

This technology shows that OFDM properly configured for the MV PLC requirements can achieve high throughput transmissions and successfully communicate in long lines. The same technology can automatically adapt its transmission mode to achieve up to 38.4 Mbps and communicate in lines up to 8 km long in a single hop at 160Kbps. It does also demonstrate that using LOADng as a dynamic routing protocol can serve the double purpose of discovering the routes for enabling communication in multi-hop configurations, but also serve as redundancy mechanism detecting broken links and updating its communication routes to adapt to new network conditions.

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