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Performance evaluation of two narrowband PLC systems: PRIME and G3

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ABSTRACT

The present work analyzes and compares two popular standards for data transmission over power line networks: PRIME and G3.
A complete and detailed description of both standards is presented together with simulation results of their performance in a power line environment. In order to create an accurate analogy of the transmission channel, background and asynchronous impulsive noises are included using previous results from literature. Simulation results show how PRIME and G3 behave in several noisy environments.
Finally, with respect to PRIME, a proposal is made to increase its performance in a hardly impulsive noise channel.

1. Introduction

Utility companies around the world have recently started looking at their power line networks and have been trying to transform them into communications networks. A valuable application of this infrastructure is its capability to, automatically, retrieve each user's independent electricity consumption, something which, until recently, had been done manually. This is commonly referred to as Automated Metering Infrastructure (AMI).

Some other alternatives for reaching the entire customer community have been studied [1], but PLC (Power Line Communication) has a major advantage: it has already been deployed.

This paper focuses on analyzing and evaluating two of the major alternatives for the implementation of AMI applications: G3 [2], powered by Maxim company, and PRIME [3], developed by the PRIME Alliance. It extends the comparison made in other studies [4] by including simulations with different impulsive noise environments taken from real measurements [5].

Due to the severe channel disturbances, both PRIME and G3 provide source coding techniques to correct as many errors as possible at the receiver side. G3, however, makes a bigger effort by using an outer encoder/decoder. The properties of source coding are enhanced by the use of an interleaver, which shuffles the bits within a symbol (in the case of PRIME) or among several of them (in the case of G3). Finally, data is modulated using Orthogonal Frequency Division Multiplexing (OFDM) over the CENELEC-A band. Thanks to the orthogonality, OFDM makes a more efficient usage of the available spectrum. OFDM has proven to be very efficient in frequency fading mediums since each one of the sub-bands is treated as very narrow and independent channels, allowing an easier equalization. Due to this advantage, this technique has become a popular method for transmitting information over different types of noisy channels ranging from wireless transceivers [6] to communications between train vehicles [7].

The paper is organized as follows. Section 2 provides a detailed description of all elements present in a G3 and PRIME transceiver. Section 3 contains a description of the channel model used in order to evaluate both systems. In Section 4, simulations of packet transmission and receptions are described. In addition, the use of different types of noisy environments to evaluate the designs under several cases is discussed. In Section 5, an improvement proposal is made for PRIME for the context of a channel with a *heavily* impulsive noise. The final section presents the authors' conclusions.

2. Standards discussion

This section describes both the G3 and PRIME specifications that are used to transmit information over a PLC Network. In addition, Section 2.3 offers a more detailed comparison of the main G3 and PRIME characteristics.

2.1. PRIME specification

A scheme for a PRIME transmitter is shown in Fig. 1a. The standard makes use of the spectrum between 42 and 89 kHz to insert OFDM symbols. Each one of these symbols consists of 97 sub-carriers placed in the mentioned bandwidth as is depicted in Fig. 2. One of these carriers is a pilot with the mission of giving a phase reference for the receiver. Additionally, carriers present in negative and positive frequencies are conjugated to each other so that the output of the

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IFFT block is a pure real signal. To build up such a spectrum, a clock frequency of 250 kHz and a 512-length IFFT are used, giving a sub-carrier spacing of $\Delta f = 250$ kHz/512 = 488.28125 Hz. Before the parallel to serial conversion, a cyclic prefix extension of 48 samples (192 μs) is performed to avoid Inter Symbol Interference (ISI). The whole transmission scheme is represented in Fig. 1a and Table 2 details all OFDM parameters regarding PRIME. More information about their physical meaning can be found in [8].

A PRIME's signal is composed of a preamble, followed by some PHY information placed in the header, and of the payload encapsulating data from the MAC layer. Fig. 3 shows this structure with lengths in OFDM symbols. A linear chirp (Eq. (1)) is used as preamble for synchronization and channel estimation. As can be seen in Fig. 4, the signal sweeps all frequencies where OFDM sub-carriers will be placed (from $f_0 = 41992$ Hz to $f_f = 88867$ Hz) during $T = 2048$ μs.

$$s(t) = \cos\left(2\pi t\left(f_0 + t\frac{f_f - f_0}{2T}\right)\right), \quad 0 < t < T. \tag{1}$$

Prior to entering the OFDM block (Fig. 1a), data is modulated with a Differential Phase Shift Keying (DPSK) modulation and, optionally, redundancy is added. The payload might be modulated with a DBPSK, DQPSK or D8PSK (Differential Binary/Quadrature/8 Phase Shift Keying respectively) constellation with or without FEC, depending on how noisy the channel is; whereas the header will always be DBPSK modulated by using FEC. The reason for this more robust mode is that the information encapsulated in the header is vital for decoding the rest of the frame. This information includes, for instance, the type of constellation used for the payload.

The FEC mechanism consists of a convolutional encoder together with an interleaver. The convolutional encoder is a 1/2 rate encoder with a binary generator polynomial $g_{encoder} = [001111001, 001011011]$. The interleaver's function is to shuffle the input bits. The features of the encoder are enhanced by the use of the interleaver which provides protection against burst errors that might corrupt several consecutive symbols. However, since the shuffling is done over an entire OFDM symbol (96, 192 or 288 bits depending on the digital modulation), if the burst event lasts at least the duration of that symbol, the shuffling mechanism will be helpless. Burst errors are produced, as will be detailed in Section 3.3, by aperiodic impulsive noise.

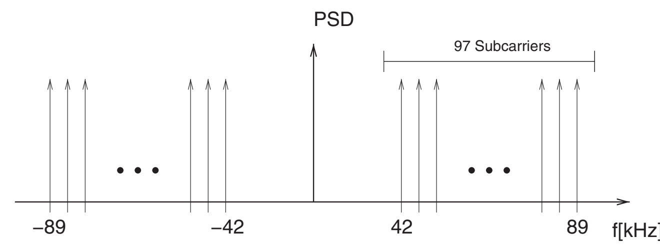

Fig. 2. PRIME spectrum. Frequencies are approximated.

Finally, the scrambler block is used to randomize the incoming data from the encoder. This guarantees that the Power Spectrum Density (PSD) of the signal does not depend on the transmitted information. The binary representation of the generator polynomial is $g_{scrambler} = [10001001]$.

2.2. G3 specification

As in PRIME, the final proposed modulation method for the G3 specification [2] is also based on OFDM. In this case, 36 subcarriers are used to create a symbol between 34 and 90 kHz. As can be seen in Fig. 5, only positive frequencies are used. Once the spectrum has been transformed to time domain, only the real part is transmitted.

The OFDM modulation is computed with a sampling frequency of 400 kHz and a FFT of 256 samples. In this case, the frequency separation to achieve orthogonality is $\Delta f = 400$ kHz/256 = 1562.5 Hz. The first subcarrier is mapped to the position 23 (35.938 kHz) in the IFFT and the last one to the position 58 (90.625 kHz).

A G3 frame is shown in Fig. 6. As in PRIME, it starts with a preamble, used for channel estimation purposes, is followed by a header, which encapsulates data regarding the PHY layer, and ends with the payload, which carries the data for the higher layer. In this case, the preamble is composed of 8 P symbols and 1.5 M symbols. P symbols are 36 tones whose phase follows a pseudo-random sequence. These tones are mapped in the same frequencies that will be used by the data carriers later on. An IFFT of 256 samples is applied to transform them to the time domain. M symbols are a copy of P but each of the carriers has a phase change of π radians. The payload is composed of groups of

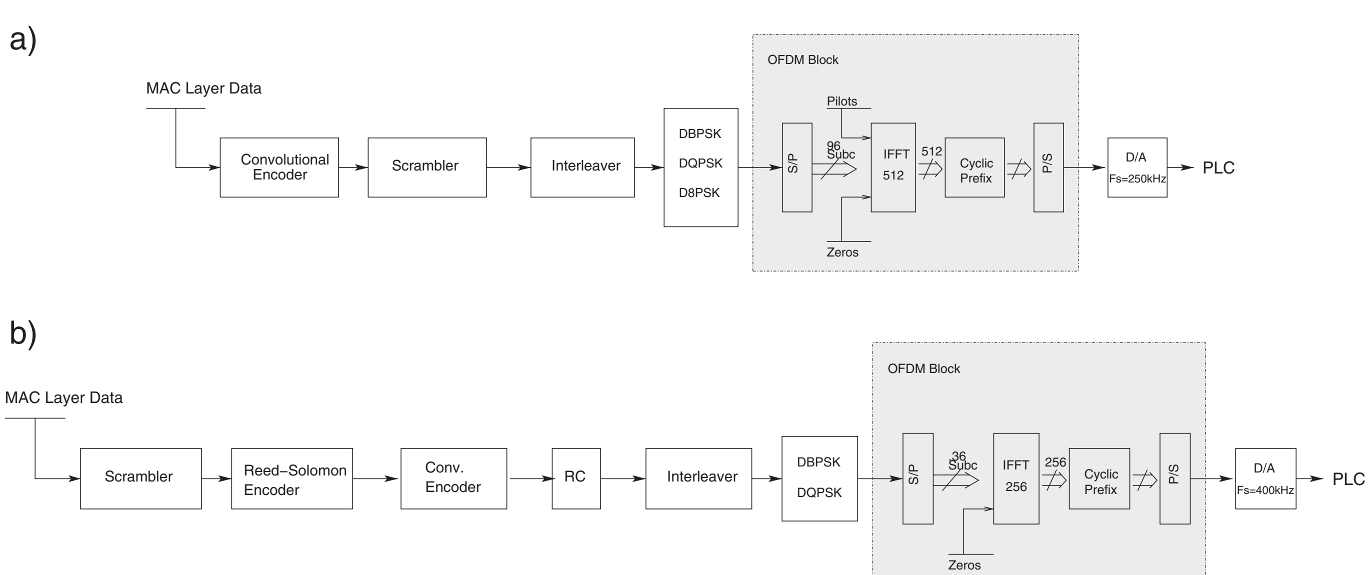

Fig. 1. Transmitter schemes: (a) PRIME, (b) G3.