PERFORMANCE OF THE G3-PLC COMMUNICATION LINKS

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ABSTRACT

G3-PLC is a transmission system using the power line channel. As it is a difficult medium, G3-PLC is designed to perform correctly on such harsh conditions. The first goal of this paper is to describe the performance of the modulation scheme. In the second part of this paper we will present our experimental setup that can monitor and analyze a G3-PLC communication. Our setup can be used to monitor the time variant feature of power line channel and therefore, correlate the communication performance with the various modulation parameters (bandwidth, modulation, gain, packet size) and also with the external parameters such as the variation of the network load, the weather, etc. In order to present the potential features and applications of our tool, some lab results will be presented in the last section of this paper.

1. INTRODUCTION

The development of the smart grid requires efficient transmission systems [1]. Amongst the different potential candidates, Power Line Communication (PLC) technologies offer the advantages for utilities to use their own infrastructure (the cable plant) for the communication purpose [2]. However, power lines are very hostile transmission media since its characteristics vary with frequency, location and the connected load [3]. Thus PLC have to be correctly conceived to achieve efficient communications especially in an outdoor context [4]. This paper is focused on the performance of G3-PLC, a recent narrowband PLC standard developed for the smart metering purpose [5]. To cope with several typical problems of PLC channels, the G3-PLC standard integrates different advanced transmission techniques inherited from the wireless transmissions world. Because it is important to know the potential and the limitations of this transmission system, the aim of this paper is to describe the main features of the G3-PLC standard and to present the expected performance of G3-PLC transmissions. In particular, we will describe the tradeoff between the achievable data rate and the robustness against noises and impairments. We will then detail the experimental setup we have developed to measure the G3-PLC transmission performance as a function of time. For that purpose, this paper is divided into 4 sections. Section 2 describes the building blocks of a G3-PLC modem. In section 3, the G3-PLC theoretical performance and an evaluation of the tradeoff between data rate and robustness based on laboratory experiments are presented. Finally, in Section 4, we present our tool developed to determine G3-PLC communication performance on the packet level over time.

2. G3-PLC STANDARD

Figure 1 shows the block diagram of a G3-PLC modem.

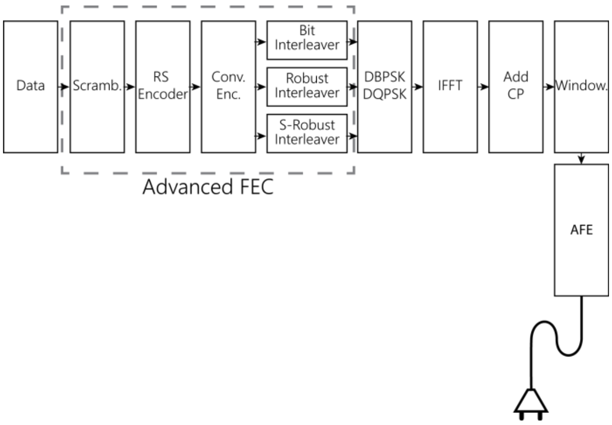

Figure 1: Block diagram of a G3-PLC transceiver

The scrambler ensures a random distribution of data. This function is realized by multiplying the data stream with a pseudorandom bit sequence derived from the following generator polynomial: $S(x) = x^7 \oplus x^4 \oplus 1$. A Forward Error Correction (FEC) block including an interleaver and correction codes (Reed-Solomon and convolutional codes) has also been integrated to deal with the channel frequency fading and the burstly nature of noises. The interleaver is not by itself a way to correct errors. It is rather a way to improve the performance of the real correction codes. The interleaver distributes the adjacent bits such that in the transmission, those same bits are not contiguous anymore. The G3-PLC interleaver not only distributes the contiguous bits on different symbols (temporal distribution) but also on different subcarriers (frequential distribution). This allows the modulation scheme to be able to better cope with burst noise and frequency fading. Reed-Solomon codes are used to correct errors by adding redundancy to the original data [6]. They are especially efficient against burst noise due to the fact that they correct entire erroneous Bytes and not just bits as the classical cyclic block codes do. This redundancy reduces the achievable bitrate of the transmission but makes the data payload more resilient against the various disturbances. The Reed-Solomon coding of G3-PLC, RS(239,255), can correct up to 8 Bytes by adding 16 Bytes of redundancy. Convolutional codes are another type of correction codes that can correct errors by adding redundancy to the datastream. The Convolutional encoder of G3-PLC has a ½ rate and a constraint length K=7. The concatenated code composed of the RS-code and the Convolutional code is used to achieve better overall performance compared to the codes considered separately. Orthogonal Frequency Division Multiplexing (OFDM) is a modulation that uses a large number of orthogonal subchannels to transmit data. OFDM is not a modulation per se, it is used to split the information into several subchannels (36 or 72 respectively for CEN-A and FCC) allowing an optimal use of the available spectrum due to an overlapping of the spectrum of each subchannel. The goal of this process is to increase the symbol duration. By doing this, the perturbations that take place in the channel have less effect on the transmission. This is particularly interesting in a bursty environment. Another interesting characteristic of the OFDM is that it is efficient in a multipath channel due to the use of a cyclic prefix that can reduce the Inter Symbol Interference (ISI).

3. G3-PLC PERFOMANCES

Based on the different potential configurations of these different blocks, G3-PLC defines four transmission modes (ROBO, DBPSK, DQPSK and D8PSK) characterized by different performance in terms of data rate and transmission robustness.
These transmission performance are also related to the bandwidth used. There are several frequency bands reserved for smart grid applications including:

- The CENELEC-A band (3-95 kHz), exclusively reserved for utilities.
- The CENELEC-B (95-125 kHz), C (125-140 kHz), D (140-148.5 kHz) bands, opened for end users applications.
- The FCC band (10-490 kHz), not yet regulated in Europe.

Table 1 shows the maximum theoretical data rates of G3-PLC transmission depending on the frequency band and on the type of applied modulation. Table 1 shows that different modulations yield different performance in terms of datarate. Those datarates may seem low for instance for the ROBO mode but the communication is much more robust than in D8PSK. This is why it is important to analyze the real achievable performance on a PLC link. Another aspect presented in this table is that higher bitrates can be attained by using the FCC band as it offers more bandwidth. Finally, the possible datarates range from 4 to 42 kbps in CENELEC-A and from 14 to 180 kbps for FCC.

Modulation	Band	Data rate [bit/s]
D8PSK	CENELEC-A	42 619
	FCC	180 451
DQPSK	CENELEC-A	34 792
	FCC	155 488
DBPSK	CENELEC-A	20 224
	FCC	72 190
ROBO	CENELEC-A	4 647
	FCC	14 577

Table 1: G3-PLC theoretical datarates [2]

In order to test the robustness of these different modulations, we developed the setup presented in figure 2.

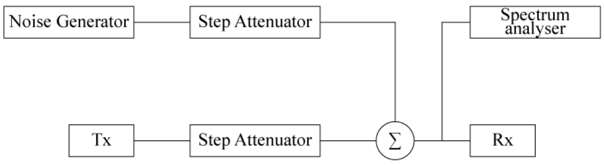

Figure 2: Experimental G3-PLC robustness setup

Two G3-PLC transceivers modules were used representing two devices of the smart grid network. A fixed attenuator was used to simulate the loss in the transmission channel. To monitor the reception of signal on a spectrum analyser, a power splitter was used. The goal of this setup is to obtain the packet error rate over the signal to noise ratio at the reception. To do this, 10.000 packets of 100 bytes each were used. The results of this experiment are shown in figure 3. Those results do not present the performance of the D8PSK because the tests we made showed that this modulation is too sensitive to the perturbations on the channel and cannot be reliably used on real channels.

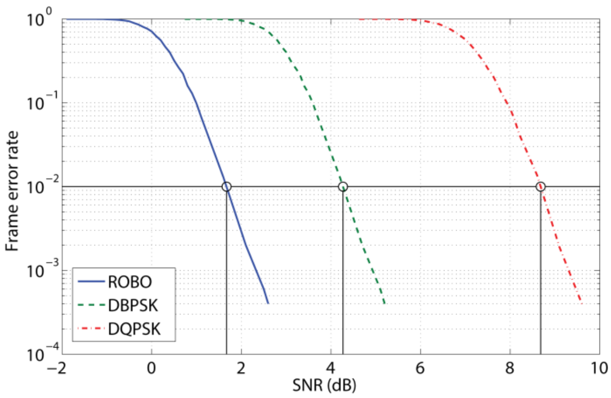

Figure 3: Experimental curves of FER in function of SNR in Gaussian Noise (CENELEC-A, 100Bytes)

For a target frame error rate, different modulations achieve different performance relating to the SNR. For example, a frame error rate of 10^{-2} is achieved with a SNR of 1.8dB in ROBO mode but with a SNR around

9dB in DQPSK mode.

4. THE DEVELOPPED ANALYSIS TOOL

Analysis tools provided by G3-PLC systems manufacturers currently allow only mean packet error determination over a G3-PLC communication [7]. To be able to correlate communication performance with the environmental parameters, we developed a hardware platform programmed to precisely control every aspect of the PHY layer (modulations, power, frame size, frequency band) and a software capable of analyzing the transmission log of the hardware platform. This allows us to monitor the channel link quality. The hardware platform allows the G3-PLC transceivers to be completely set remotely by properly configuring the communications parameters such as the transmission gain, modulation, packet size, data rate, the packet number and by defining the data payload. This payload is important for the second part of our analysis and contains various informations (packet numbering, time stamps, etc.) allowing us to properly analyze the transmission. By controlling the PHY layer, we are also able to monitor a bidirectional communication thus giving us information about the two transmissions simultaneously.
Power grids were designed to carry only the mains frequency (50 Hz or 60 Hz) from energy providers to consumers. As the frequency used by the G3-PLC transmission are in the kHz domain, the channel transfer function in this part of the spectrum is harsh and time and location dependent [3]. To be able to cope with such a medium, we need a way to better comprehend and monitor the characteristics of the communication channel. This is the goal of our second tool: the analysis software. It is able to monitor the link quality between the transceivers. This is achieved by analyzing the time stamps and the packet numbering information provided by our hardware platform.

Several analyses can be made from our tools:

- Evolution of the cumulative error;
- Delay or number of errors between two correctly received packets over time;
- Distribution of the delay or number of errors between two correctly received packets;
- Number of errors by programmable time interval;
- Evolution of the FER by programmable time interval;
- Automatic comparison between the two directions of a bidirectional transmission, as transmission channels are not symmetric due to the load.

To test our platform, we consider an arbitrarily disturbed communication (figure 4).

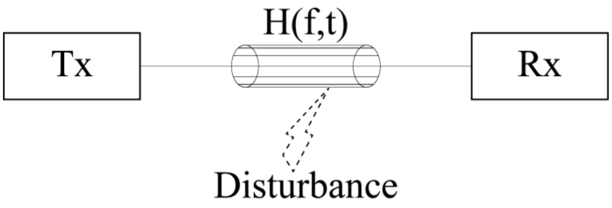

Figure 4: Analysis tool setup

The introduction of the perturbations to produce the following figures (5 to 7) has been made by changing the attenuation of the PLC signal thanks to a step attenuator at known times. The introduction of perturbations defines 5 zones in which the rhythm of the occurrence of errors is different. In the first zone, from 10:45 to 11:00, we did not introduce any perturbation. In the second zone, from 11:00 to 11:10, we attenuated the signal 2dB below the threshold introducing a FER of 10^{-3}, resulting in a zone with an average of 645 errors/min. The third zone, from 11:10 to 11:15 results from the same parameters as the first zone. The fourth zone from 11:15 to 13:30 was obtained by attenuating the signal 1dB below the threshold introducing a FER of 10^{-3} resulting in a zone with 135 errors/min. Finally, the fifth zone was obtained with the same parameters than in zone one.

Figure 5 represents the cumulated errors as a function of time. This figure clearly shows the non-uniform performance evolution versus time. As explained previously, the perturbations were introduced arbitrarily at given times but we show that our setup can detect errors and compute meaningful results. An advantage of our system compared to the tools provided by the modem manufacturers is that we can give the evolution of the important parameters with the elapsed time. For instance figure 5 gives the evolution of the total amount of errors during the transmission and figure 6 shows the evolution of the FER by intervals of 5 minutes.

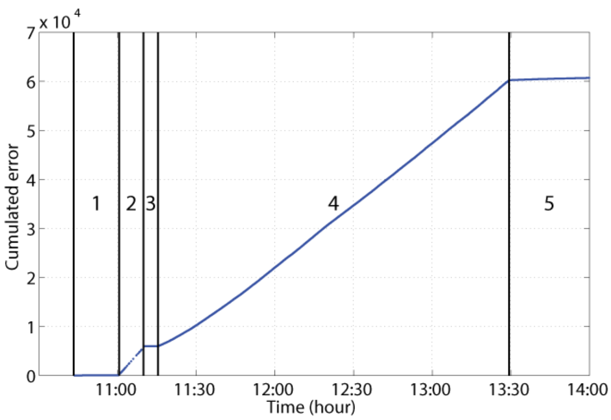

Figure 5: cumulated errors of a G3-PLC transmission over time (DQPSK, FCC band, packets of 231Bytes)

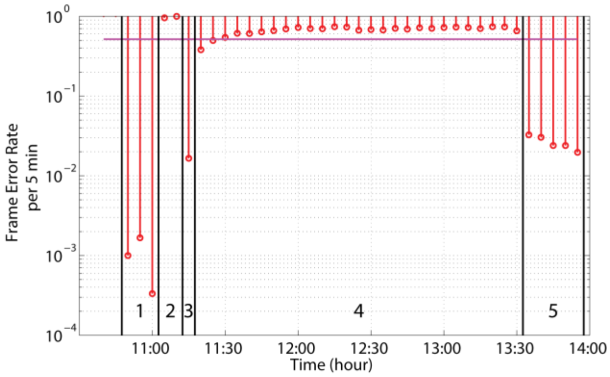

Figure 6: evolution of the FER by intervals of 5 minutes (DQPSK, FCC band, packets of 231Bytes) with mean FER=0.5

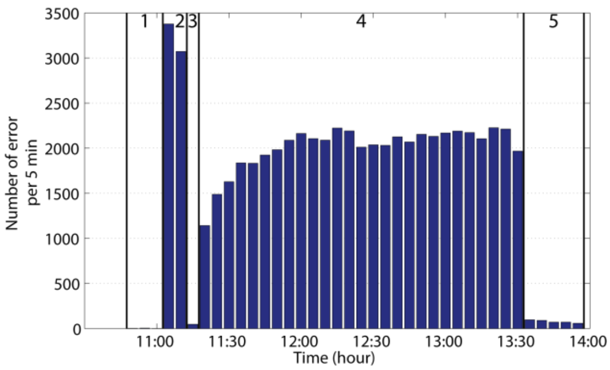

Figure 7: evolution of the number of errors by intervals of 5 minutes (DQPSK, FCC band, packets of 231Bytes)

In the communication presented in figures 5, 6 and 7, one packet over two is lost in average. Our analysis tool allows us to isolate the area displaying the best performance (from 10:45 to 11:00) from the ineffective ones which can become preferential time slots for system updates in a smart-grid case. It is also possible to consider the number of errors per time slot. Figure 7 shows the obtained result for, in this case, a considered timeslot of 5 minutes.

In the test case presented by the previous figures 5, 6 and 7, we introduce ourselves the channel perturbations.This is clearly a limitation, but we consider in the future a transmission over a field deployed power line. The goal of our experimentation is to identify the influence of various noises, perturbations and the impact of external factors on the G3-PLC transmission. The tools developed will be able to correlate a particular event with the communication performance. Such a study can be interesting for smart metering utilities by better understanding and optimizing the deployment and the operation of a PLC network. For example, the tools developed can be used to provide network simulators occurrences of erroneous packets for a fixed topology, thus providing guidelines to operators.

CONCLUSION

Analysis capabilities offered by PLC modem manufacturers only allow computation of the mean FER for a data communication. As channels characteristics are variable in time, such an analysis is not sufficient. In this paper we bring a solution to this shortcoming by developing tools for temporal analysis of G3-PLC communication performance. We demonstrated by a lab experiment that our tools are capable of performing those temporal analysis. By taking the test bench on a real network, it will then be possible to do the same kind of measurement and correlate the communication performance to various external factors.

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