Noise and Interference in Power Line channels

Hernán Paz Penagos
Communications Area, Electronic Engineering Faculty
Escuela Colombiana de Ingeniería JULIO GARAVITO,
(Bogotá-Colombia)
hernan.paz@escuelaing.edu.co

Germán Castellanos Tache
Communications Area, Electronic Engineering Faculty
Escuela Colombiana de Ingeniería JULIO GARAVITO,
(Bogotá-Colombia)
german.castellanos@escuelaing.edu.co

***Abstract*—The power lines grid has been utilized for low-data-rate applications for some generations. Today, many are the challenges that this technology has presented to the Communications Engineering, when it is intended to offer high-speed data services.**

This article presents an evaluation of the noise and interference effects on an information byte transmitted over a PLC channel. The observations presented could be helpful in suitable design of the indoors PLC networks for a better data transfer and system performance.

Keywords-power transmission line; indoor network; noise; interference; multipath channels; load impedances; attenuation.

I. INTRODUCTION

In the past, the electric power lines have been used for some time for remote metering and control and presently being considered for broadband communication services. A brief summary of this history is presented in the table I.

TABLE I. SUMMARIZE OF THE INFORMATION SIGNS TRANSMISSION USING POWER LINES.

Name	Period	Services	Rates of transmission	Technical specifications	References
CTP: Carrier transmission on power line.	Decade of the 20.	Telemetry and supervision control	Lower bits rate	Frequency: 15 - 500KHz; Means: high tension lines; distance <900Km; Modulation outlines: AM, FM; Transmission powers <10W.	[1], [2], [3]
Ripple Control	Decade of the 30	Services telemetric.	Lower bits rate	Frequency: 100 - 900Hz; Means: medium and low tension lines; Way of transmission: simplex.	[4], [5]
RCS: Carrier signaling	Decade of the 70.	Administration of electric demand and energy accountants' reading.	Slight increasing of the transmission rates	Frequency: 5 - 500KHz; Means: medium and high tension lines; distance <4Km.	[6]
SCADA: Supervisory Control and Data Acquisition	Lates 80s and early 90s.	Voice transmission	Increasing of the transmission rates	Frequency: 5 - 1500KHz. distance <4Km; Way of transmission Duplex; Modulation: ASK, FSK; Power <10W.	[7]
PLC/PLT	1997.	Voice, data and Internet (alternative for solution of the last mile).	HomePlug v1: 14Mbps.	Frequency: 100 - 2000KHz; Means: lines of half tension; distance <4Km; Way of transmission Duplex; Modulation: OFDM, DSSS Power <10W.	[5], [6], [7]
PLC/PLT of wide band	2005:	Servicies triple play: Voice, Internet and video.	"HomePlug-Turbo": 85Mbps, "HomePlug-AV": 200Mbps.	Frequency: 1 - 30MHz; Means: low tension lines; distance <200m; Transmission way Half-Duplex; Modulation: BPSK, QPSK, 8, 16, 64, 256 and 4096-QAM for FF OFDM PHY, and BPSK, 4, 8, 16 and 32_PAM for Wavelet OFDM PHY.	[7], [8], [9], [10].

Two factors of interest in the technology PLC are: The information bandwidth and the nature of the electric power line, in order to not overcoming the advisable bit error rate. Claude Shannon demonstrated that you can transmit with a probability of error as low as it is wanted and a binary speed as high as it is wanted, whenever this speed is below of the channel capacity; This is in function of the bandwidth and the signal-to-noise ratio (SNR).

In this paper, we focus on describing the effects of the signal attenuation due to propagation in the local PLC network, then report a case of study based in the characterization of the PLC channels, finally proposes some recommendations to the design of local PLC systems.

II. NOISE, ATTENAUTION AND HARMONIC DISTORTION

The performance of PLC systems is determined by several parameters, such as noise, interference due to noisy loads, frequency varying and time-varying attenuation, load impedance, line length, power line network topology, branched line length and number of branches. Extensive characterization of the sources of disturbance can be found in the literature [10], [11], [12], etc.

The noise that is present in power line grid has a random behavior [13]. A typical signal layout of the noise's voltage *n(t)* is shown in the figure 1; in this figure is assumed that is a Gaussian[1] process with average equals to zero, a variance of the noise "σ^2" known (*Vrms, Irms* and *Prms* are predictable) and that its power spectral density is *No/2*.

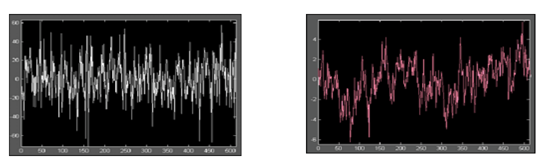

Figure 1. Voltage of noise *n(t)*: a) White noise, b) Colored noise.

Now is important to explain some types of noise that can be found in the PLC channels.

Colored noise: It is no stationary noise. It is also known as fluctuation noise because can rise to considerable levels

1 The theorem of the central limit of the probability demonstrates that, if random variables X_i are continuous, the sum of probability density function spreads to a Gaussian distribution.

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when certain appliances are switched on. The model of the colored noise is similar to the Additive White Gaussian Noise (AWGN).

Impulse noise: It is manifests in the Power Line grid in intermittent and random interferences on the AC signal. The impulse amplitude can reach hundred of volts and its occurrences are solitude events. The typical occurrence takes place when the electric appliances are switched on and off. The impulse noise can be classified in a) Periodic impulsive noise caused by switched power supplies, and b) Asynchronous impulsive noise. This last one is caused by random transients related to switching events that occur in time intervals from *μs* to *ms*. The more common sources of this type of noise are the switching sources present in the personal computers and ballasts.

Middleton proposed in 1977 a model of impulse noise that incorporates background noise and impulse noise. In this model, according to the bandwidth of the noise, three general classes differ: 'class A', 'class B' and 'class C' [14]. Middleton's Class A noise model is an appropriate model for impulsive noise environments [15].

Narrowband noise: It is caused by broadcast stations in the medium and shortwave broadcast band, and switching power supplies. Two specific representations exist to characterize this type of noise, a) It is defined in terms of two components: amplitude and phase; b) In turn, the last one is divided in two components: the first one in phase and another one in quadrature (shifted 90°).

Background noise: It is a noise component that is still remained once the impulsive and tonal components are eliminated. It can be consider stationary and its power spectral density falls with the frequency.

Fading: The spectral components of broadband signals can suffer different attenuation and dispersion rates; this causes severe distortion and produces selective dissipation in the information.

In a modeling channel as linear system, the exit signal is not distorted if it is fulfilled: 1) $Y(t) = KX(t - t_d)$ y 2) $H(f) = Ke^{-j(wt_d \pm m\pi)}$; so the magnitude is constant with the frequency and equal to *K*, and the phase has a linear behavior with the frequency and it is equal to $-(wt_d \pm m\pi)$. When the magnitude of *H(f)* is not constant, it produced amplitude distortion. When the phase of *H(f)* is not linear with the frequency, takes place distortion and phase delay. With non-linear distortion, the amplitude and phase change with the entrance voltage *Vin* in a nonlinear way.

The amplitude and phase of an electromagnetic signal that is transmitted by PLC channel can vary according to the primary electric parameters of electric power line: R, L, C and G; and the variations are directly proportional to the branched line length and number of branches. Likewise, the propagation speed of the wave depends of the *C* and *L* values of the line.

III. CHARACTERIZATION OF THE INDOOR POWER LINE CHANNEL – CASE STUDY

The characterization of the PLC channel implies to investigate the characteristics of the power network as a communication channel.

For indoor PLC, many models based on transmission line theory have been proposed. Biglieri [16], Pavlidodou *et al*. [17], Banwell and Galli [18] and Esmailian *et al.* [19] model the characteristics of the power line grid for data transmission. Other articles, based on the propagation characteristics, model the electrical medium as echo model [20], [21].

The power line grid was originally designed to distribute electrical energy; however today, its potentiality is exploited to assist high-speed data services. Some of the technical problems of these medium are specified in [14] and [21].

In order to understand the characteristics of the electric power lines grid over which was designed and implemented the local PLC networks in the Colombian School of Engineering "JULIO GARAVITO", the Colombian electric interconnection system will be described briefly. It is coordinated and controlled by the "CENTRO NACIONAL DE DESPACHO" CND[2] and has four main components: generation component, transmission lines component[3], substations and transformers stations component and medium voltage (LV)/low[4] voltage (LV) power system[5] component. The access and use of these last one is regulated by the resolution 004 of 1994 and it has biggest interest for PLC solutions because it is used in indoors electric facilities.

The primary circuits (MV) of urban distribution grid use three phases and three wires with neutral connected to earth in the sub central[6], the voltage signal is sinusoidal and its nominal values of amplitude and frequency for Bogotá are 11.4 kV y 60 Hz respectively; the frequency variation range can be between 59.8Hz and 60.2Hz under normal conditions of operation[7]. The indoor facilities use the nominal voltage which is 120V and almost all the facilities have three wires with neutral connected to earth.

In particular, the researchers implemented a PLC network in the telecommunication laboratory of the Colombian School of Engineering "JULIO GARAVITO",

2 At the present time ISA assumes the roll of this.

3 It transports extra high voltage (EHV) and high voltage (HV) whose tension levels are bigger to 300 kV. and 36 kV. respectively.

4 It transports smaller tensions to 1 kV. and secondary circuits are denominated.

5 It is also called primary circuits; they transport tensions between 1 to 36 kV.

6 The tensions in stationary state to 60Hz and their permissible variations are the established in the norm NTC 1340.

7 Resolution CREG 025 of 1995.

measuring the attenuation levels of the signals transmitted in the laboratory. This network consisted of distributed branches and arbitrary terminal load variations; also the lengths of branches were variables.

In the electric distribution network that extends to the building G of the Colombian School of engineering you may find lines of low voltage with the specifications showed in the table II. There is a general board, located in the first floor of the building G, and from there electric wires that go to the G-204 laboratory entrance, in the second floor. From this point, the electric energy is distributed through connections dedicated to each one of the five work desk.

TABLE II. PHYSICAL FEATURES OF THE POWER LINE.

Characteristic	Value
Sorts of line	Parallel pair
Wire's material	Cooper
Nominal size	12 (gauge 12)
Diameter of the wire	2.03mm
Insolated	Polyethylene
Distances among centers	10mm
Band Wide	300KHz
Antiquity of the building	10 years

The first test was made transmitting signals conformed by binary pulses. These signals were coded in NRZ-L and modulated in ASK with carrier's frequency of 40 KHz and baud rate of 200bps (See table III). These signals were sent from a node of the PLC local network to the receiver, with presence of loads that are turned on, turned off or still connected in the branches of network. In the receiver, the signal of information plus the noise was received; in some cases the noise caused errors.

In the figure 2 is observed bigger attenuation levels and distortion of the transmitted byte, under conditions of the loaded network, as consequence of the harmonic overlapping introduced by the loads. The data's attenuation is around 2.08dB more that the data average attenuation without load.

TABLE III. FIRST TEST SPECIFICATIONS.

Number of the test.	Transmitted and received Data at 8m of distance	Characteristic of the signal transmitted	State of the network with regard to the loads	Attenuation level in dB $A=20\log(V_{TX}/V_{RX})$
1	**10101000** plus Synchronization byte.	Carrier modulated digitally in ASK: Fc=40KHz, Rb=200bps. Amplitude of original signal = 8 V, Amplitude of received signal ≈ 200 mV	Without load	32.04
2	**10101000** plus Synchronization byte.		With inductive load: Motor of three phases.	34.17
3	**10101000** plus Synchronization byte.		UIT load: computer's source.	33.68
4	**10101000** plus Synchronization byte.		With inductive load: drill.	34.52

The measurement without load was contrasted with three loaded cases. The first one was the data transmitted with the simultaneous connection of a motor 3-phase on the electric network (See figure 2a). Three phenomena are observed: 1) Distortion and attenuation, 2) Presence of impulse noise with voltage levels that go from 1.2 volts to -0.8 volts, during very short times, in instants of the motor outburst and motor braked, 3) Overlapping of the impulse noise with levels of proportional voltages to the number of connected motors, with an exponential deterioration of the binary data's amplitude.

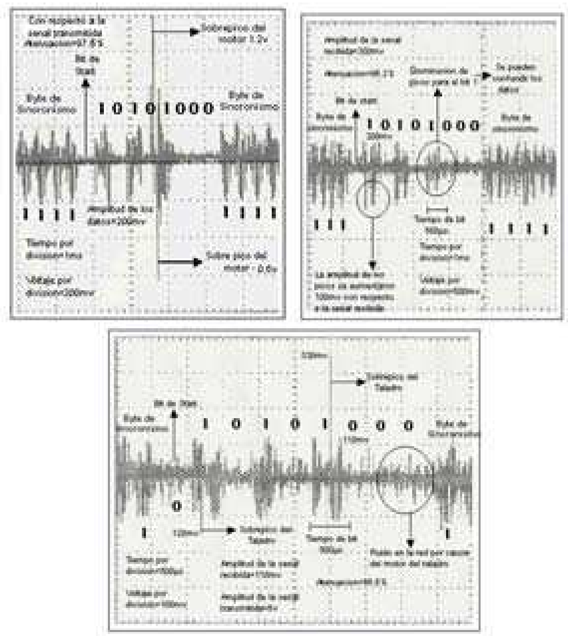

Figure 2. Effect of the non lineal loads on the transmitted information data: a) With motor 3-phases, b) With commuted source, c) With drill.

In the second case, with the simultaneous presence of a commuted source, it is showed in the figure 2b. There are not voltage picks, but whether a widespread attenuation of the information signal and the presence of noise affects mainly the frequency of the signal modulated in ASK.

For the third case (See figure 3c), when the data is transmitted simultaneously with the presence of a drill connected to the electric network, it is observed that picks are produced by the drill's motor, however the number and the magnitude from this signals are smaller regarding the signals caused by the motor 3-phases.

The data transmission without load presence in the network suffers an attenuation of the 27.6 dB and it is smaller with regard to the first test for reasons of smaller transmission distance. On the other hand, the transmission of the same data with the presence of a computer, the second case experiment, caused noise and distortion of the information signal for the presence of harmonic; this resulted in the recovery of the information data with error.

According to the figures 2 and 3, the noise's sources, in this case the presence of loads in the electric network, have shapes of waves which is not possible to predict the amplitude in a specific time, neither they are correlated or they do not have relationship of definable phase. In this case, the voltages and the currents do not added directly, but the total voltage or the total currents are determined calculating the square root of the sum of the squares of each one of the voltages or the currents.

A PLC channel of multiple trajectories can characterize for the Rayleigh's distribution, due to the statistical variable nature in the time of the amplitude signal received is described quite well according to this distribution and several examples are known in the wireless communications. The fading happens due to the reflection and dispersion of the modulated information signal. The transfer function between two points of a power line is basically determinate for five parameters: load impedance, line length, power line network topology, branched line length and number of branches.

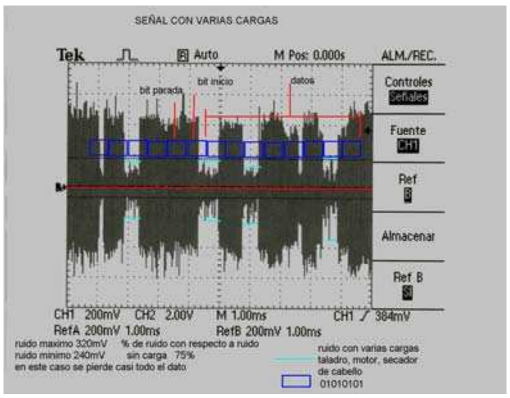

Figure 3. Electric characteristic of the received data with multiple loads connected in the network.

Fritchman presents a form of characterizing the channels of electric line of low tension, based on the Markov's chains, representation of two states that is known like Golbert-Elliot's model [22].

IV. RECOMMENDATIONS

In indoors electric networks where the ground wire is present and accessible, the transmission line-ground should be selected. For this case, the modulated information signals are coupled to the line with reference to the ground wire that is used as the return line of the communication signal. The advantage offer by this procedure is a smaller level of attenuation of the transmitted signals due to less conflict from the signal of electric supply that are transmitted among line-neuter.

Power lines are classified as a noisy, horrible and unpredictable channel for the data propagation. A strategy that was positive for the noise, distortion and interference control was the use of line filters and the correct isolation of the modules. However, the effectiveness of this solution depends on the electric distribution node localization, of the network's topology, of the connected loads and of the random impulsive noise.

On the other hand, it is important to know the quality, antiquity and state of maintenance of the electric distribution network, because these characteristics affect the throughput of the transmission system. If these characteristics are not the required one, stem will result on increasing of attenuation, noise and distortion of the signal modulated digitally.

Some strategies for elimination of noises in the sources of noise are: a) Place the noise sources in encapsulated in order to isolate them. b) Filter all the sources possible of the external noisy. c) Join the noisy sources to obtain cancellations them. d) Have good connections to ground with the purpose of suppressing radiated interference. e) Operate sources and loads balanced to ground.

Furthermore, in the receivers can be implemented: a) Use alone the necessary band width. b) Use selective filters in frequencies when they can be applied. c) Provide appropriate decoupled for the tension source. d) Isolate the noise sign. e) Make couples of impedances with the maximum transfer of power.

In the digital communications, with highly noisy channels, three aspects are important when choosing a robust modulation sketch: 1) Get a high spectral efficiency of transmission, 2) Require the smallest possible transmission power, and 3) Obtain a low bit error rate (BER).

Fourier and Wavelet Transforms-based Orthogonal Frequency Division Multiplexing (FT-OFDM, WT-OFDM) are presented as Multicarrier Modulation (MCM) scheme most suited to multipath and frecuency-selective channels [23], [24] and [25].

Recently the study of innovative channel coding schemes, such as: Accumulate Repeat Accumulate (ARA) code, Repeat Accumulate (RA) code, Irregular Repeat Accumulate (IRA) code and Low Density Parity Check (LDPC) code seeks to reach in a practical way the limits of Shannon [26], [27] y [28].

V. RESEARCH RESULTS AND CONCLUSIONS

The transmitted signal attenuation on the indoor power line channel consisted of two parts: line losses and coupling losses, which were very high (2.08dB/5m). This large attenuation caused a very low signal-to-noise ratio (SNR).

The digital byte does propagate along multipath suffers frequency-varying and time-varying attenuation due to signal reflections caused by the impedance mismatches, the line length and the presence of several branches, this phenomena leaded to inter-symbol interference (ISI) and increased the bit error rate.

The PLC channel had time-varying character-sticks, which was mainly due to the variable impedance loads connected to the power lines.

The local distribution of the terminals and the distance among transceivers electronic devices were important parameters that kept in mind the configuration of the indoors network to the Electronic engineering laboratory "G-204" from the ECI.

The information transfer rates in indoors networks that use electric wire depends on diverse factors, such as: length of the copper line, the gauge of the conductive wire (specification AWG/mm), the presence of branches in the network, the interference of crossed coupling, etc. The increase in branched line length tends to limit the available bandwidth in the medium power channel.

The noise always exists in the electric systems and its interferences limit the ability to identify correctly the signal that interest to the system.

The use of system that send data across of a hostile line, like the electric distribution network, demands the design and the develop of robust physical layer that specifies the modulation techniques, the code, the basic formats of the packages and an efficient protocol of Medium Access Control (MAC) that regulates the access to the clients.

The channel that is assumed as a low-pass lineal system shows a non-lineal behavior due to the signal reflections. The PLC channel should be examined as hostile line, multipath and with selective attenuation of frequencies. As well as the characteristics of the PLC channel changes with the frequency or due to insertion and retirement of loads from the network, it should be optimized modulation sketches and coding technical against errors, power levels, transfer rates and bands of frequency, according to the fluctuations of the relationship signal to noise in the channel and its evolution with the time.

Studies are still necessary to better understand and improve the performance of power lines for higher bit rate transmission.

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