Performance Evaluation of an OFDM-based BPSK PLC System in an Impulsive Noise Environment

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Abstract— Power line carrier (PLC) communication provides a ready medium for broadband internet connectivity and as well as monitoring, control and automation functions for both industries and homes. In fact, the power line network is the most expansive network in the world reaching every room in every facility connected to the power grid. Thus, PLC technology is the most economical way to provide internet connectivity and home networking in rural/remote areas. However, the original design of power lines was not for communication purposes but electrical power transmission. Thus, PLC technology provides a readily available channel that is hostile when used for communication purposes. This hostility is due to the many problematic characteristics of the power line network from a communications perspective. They include reflections due to impedance mismatch, frequency varying attenuation, multipath due to the cable joints, as well as the different types of noise inherent in the channel. In this paper, we investigate the impact of impulse noise on the performance of an OFDM based BPSK PLC channel. This is motivated by the fact that the very characteristics of the impulse noise, namely; pulse width, amplitude and interarrival time, have not been studied at an elementary level in terms of their influence on the performance of the PLC channel. The mathematics behind the impulse function is utilized in an attempt to fully characterize the impulse noise for the PLC channel. The performance of the PLC system is compared in terms of the bit error rate (BER) characteristics for given signal to noise ratio (SNR) values for different impulsive noise parameters.

1. INTRODUCTION

PLC technology entails the utilization of the power grid for the transfer of information from the transmitter to the receiver. This technology is attractive due to the fact that no additional network layout is required to be able to send information; apart from terminal devices. PLC technologies are mainly classified into two; narrowband and broadband depending on the frequency band of operation. Broadband PLC operates in the frequency range between 1 MHz to 300 MHz. Narrowband PLC operates in the frequency range between 3 kHz to 500 kHz. Power lines terminate at almost every home and this enables the use of the low voltage network as a last mile and last inch access solution for communication purposes. PLC is useful in automation of meter reading services, pre-paid billing services, automation of fault detection, load management, high data rate internet access and home Television carrier services. PLC networks also form part of local area networking solutions [1, 2].

However, the PLC channel is a hostile environment for use as a communications media. This is primarily so because, the channel characteristics are highly varying with frequency, time, loads and topology. The channel is also plagued with different sources of noise which are difficult to effectively describe parametrically. The main noise types in PLC include background noise, narrowband interference and impulse noise. Also the signal is attenuated as it traverses the channel from the transmitter to the receiver. This attenuation is mainly dominated by frequency selective fading. The proper choice of modulation techniques, coding schemes, access techniques and error correction methods for the PLC channel is a thorny issue. This is primarily so because of the many characteristics of the PLC channel that have to be catered for. These would range from the different types of noise mentioned above, frequency selective fading, uncertainty of the channel transfer function, channel capacity constraints, bandwidth limitations, and the threshold bit error rate requirements [1–7]. The biggest threat to PLC performance is noise; and impulsive noise is the most dominant. This noise and its impact on the performance of an Orthogonal Frequency Division Multiplexing (OFDM) based Binary Phase Shift Keying (BPSK) system is the main focus of this paper.

2. IMPULSIVE NOISE

Impulsive noise is the most severe form of noise in PLC channels. It is mainly caused by the switching ON/OFF of electrical appliances or faults in the network. It is classified into three main categories [1, 8–10]:

1. Impulsive noise that is synchronous with the mains frequency and is periodic: This type of impulsive noise is cyclostationary and is synchronous with the mains frequency. It is generated by silicon controlled rectifiers in different power supplies.
2. Impulsive noise that is periodic but asynchronous with the mains frequency: This category of impulsive noise is generated by periodic impulses whose repetition rates are between 50 to 200 kHz.
3. Asynchronous impulsive noise: This kind of impulsive noise is very unpredictable and is the most dominant. It exhibits no regular occurrence and mainly arises from transients that originate from the connection or disconnection of electrical appliances from the power line network. The impulses can last for between some microseconds and a few milliseconds with a random occurrence. The power spectral density for this kind of noise can go as high as 50 dB above the background noise. It is also sometimes referred to as sporadic impulsive noise.

The four basic parameters that describe impulsive noise are the impulse width t_w, arrival time t_{arr}, interarrival time t_{IAT} or the impulse distance t_d and the impulse amplitude, A. The impulse width is the time duration that an impulse event lasts. The interarrival time is defined as the time difference between the start of two consecutive impulse events. The impulse distance is the time between the end of an impulsive event and the beginning of another. Thus, it defines the frequency of occurrence of the impulsive noise. The three basic impulsive event time parameters are related by the following expression [8, 10]:

$$t_{IAT} = t_w + t_d = t_{arr,i+1} - t_{arr,i} \tag{1}$$

And, using a general impulse function $imp(t)$ with unit amplitude and unit width, a train of impulses can be described by [10]:

$$n_{imptrain}(t) = \sum_{t=1}^{N} A_i \cdot imp\left(\frac{t - t_{arr,i}}{t_{w,i}}\right) \tag{2}$$

where $n_{imptrain}(t)$ is the train of impulses. The parameters A, t_w and t_{arr}, can be used to derive secondary parameters that are crucial in analysis of impulse noise and studying its behavioural characteristics over time. One of these secondary parameters is the impulse rate, given by [8]:

$$r_{imp} = \frac{N_{imp}}{T_{win}} \tag{3}$$

where N_{imp} is the number of impulses that occur within a given window of observation T_{win}. Another key aspect would be the actually disturbed time, which can be determined from the "disturbance ratio"; which by definition is the ratio of the sum of the widths of all impulses generated within a window of observation, and the length of the window, that is [8]:

$$disturbance\ ratio = \frac{\sum_{i=1}^{N_{imp}} t_{w,i}}{T_{win}} \tag{4}$$

3. OFDM BASED BPSK SYSTEM

OFDM modulation technique divides the coded information into blocks that are then transmitted using N subcarriers. These subcarriers are orthogonal to each other and this eliminates any interference between them. Thus, in practice some of the subcarriers are not affected by the impulsive noise. This is dependent on the moment at which the impulse occurs, and whether or not a particular subcarrier is negatively affected. Thus, OFDM, like many other multicarrier modulation schemes spreads the impulsive noise across all the subcarriers [11].

For an OFDM based BPSK system with N subcarriers, the symbol stream after the BPSK modulator is passed through a serial-to-parallel converter, whose output will be a set of N BPSK symbols denoted by $\{S_0, S_1, \ldots, S_{N-1}\}$ corresponding to the symbols transmitted over each carrier. For the generation of the transmitted signal, the inverse discrete Fourier transform (IDFT) is performed on the N symbols. N is chosen to be a power of 2 and the IDFT in this case is implemented using the inverse fast Fourier transform (IFFT) algorithm. The OFDM symbol that is produced by the IFFT is a sequence given by $\{S_0, S_1, \ldots, S_{N-1}\}$, whose length is N, where [12]:

$$s_k = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} S_i^{j2\pi ki/N}, \quad 0 \le k \le N-1 \tag{5}$$

The symbols received after the filtering and sampling process, assuming that perfect synchronization and timing takes place, are expressed as follows:

$$r_k = s_k + n_k \quad 0 \leq k \leq N-1 \tag{6}$$

where n_k is the impulsive noise. At the receiver's side, an N-point fast Fourier transform (FFT) is performed on the received N sequence symbols $\{r_0, r_1, \ldots, r_{N-1}\}$ yielding:

$$R_k = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} r_i^{-j2\pi ki}, \quad 0 \leq k \leq N-1 \tag{7}$$

4. SYSTEM PERFORMANCE EVALUATION

In this presentation, the amplitude of the noise impulses is assumed to be constant for ease of comparison. A constant impulse width of 50 µs is used while the interarrival time is varied between 100 µs and 10000 µs according to Equation (1). The channel gain is assumed to be random. The performance of the system as the interarrival time is varied is then determined in terms of the bit error rate and signal to noise ratio. The results for the three different values of the interarrival time considered are shown in Figure 1. From this graph, the performance of the system is best when $IAT = 10000$ µs while the worst performance is obtained when the $IAT = 100$ µs. This means that the impact of the impulsive noise on the system is least when the interarrival time is greatest at a constant pulse duration and constant pulse amplitude. The reverse is also true. For example, at a BER value of 10^{-3}, the SNR values for $IAT = 10000$ µs, 1000 µs and 100 µs are 15 dB, 19.5 dB and 21.5 dB respectively. Thus, a smaller value of interarrival time would translate to more frequent impulses and deteriorated system performance, and vice versa.

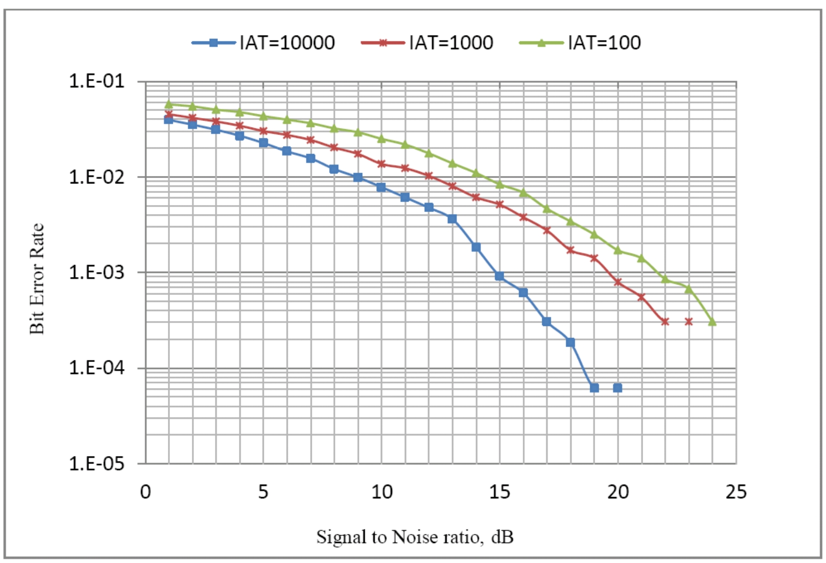

Figure 1: Performance characteristics for different noise interarrival time values.

5. CONCLUSION AND FUTURE WORK

In this paper, a simplistic approach has been presented that assesses the impact of impulsive noise on an OFDM based BPSK PLC system. The statistical properties of the impulsive noise have been utilized in their most basic form. The error statistics obtained show that the performance of the system is highly limited in the presence of the impulsive noise in the channel. We observe that a lower value of the IAT translates to more frequent impulses and this deteriorates the error performance of the system. This is explained by the fact the IAT and the impulse distance are directly related. Thus to improve on the system performance, modern digital signal processing techniques should be implemented on the channel. These techniques will be able to correct both bit and burst errors that occur due to the corruption of the signal by noise. The results presented here are based on hypothetical parameters of the impulsive noise and therefore our focus in future is to conduct extensive noise measurements that can then be used to model the noise and determine its actual impact on a real-time PLC channel.

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