Broadband Analysis and Characterization of Noise for In-door Power-line Communication Channels

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Abstract— Powerline communication (PLC) has emerged as an alternative solution for connectivity at home and offices in recent times [1]. Its development for multimedia broadband applications thus requires an extensive knowledge of the major peculiarities which influences communication over this channel. PLC channels are susceptible to noise inherent in power networks, leading to performance degradation. In this work, we have set-up a measurement system designed to capture the noise both in frequency and time domain for real power networks. The main observable components of the indoor PLC noise are: background noise, impulsive noise, and narrowband interferences. The impulsive components of PLC noise are observed to be time variant, random in nature, have high power spectral density (PSD) and lasts for very small time durations. A greater portion of the impulsive noise has cyclostationary behaviour, though with different amplitudes and widths. The repetition rates of these impulses are synchronous with the mains harmonics of 50 Hz and 100 Hz, the supply frequency in South Africa. Others have irregular occurrences and much higher repetition rates; hence they are unpredictable in nature. This noise is referred to as asynchronous impulsive noise [2].

These noise terms are key design parameters for modulation schemes in broadband PLC, popularly orthogonal frequency division multiplexing (OFDM), with its conventional receivers assuming additive white Gaussian noise (AWGN) [3]. The time variability of PLC noise is presented alongside its statistical analysis based on a series of measurements performed on numerous powerline scenarios. The relevance of this time variance is evaluated in actual channels. The significant difference in amplitudes of the impulsive noise is observed and characterized statistically. The PSD for both the background and impulsive noise is presented. Finally, we present the results of the noise PSD captured with a parametric model and compare our results with findings from other parts of the world.

1. INTRODUCTION

The universal existence of power-line networks in buildings and residential areas present a convenient and inexpensive communication media. However, developing PLC systems turns out to be a massive challenge for the communication engineer having to deal with harsh channels [4]. The difference between power line network and other conventional media such as twisted pair and coaxial is significant in terms of topology, structure and physical properties. The transfer characteristics of PLC channels are time-varying and frequency dependent with deep fades as high as 60 dB [5]. Additionally, PLC noise cannot be described as additive white Gaussian noise (AWGN) as is the case for conventional communication Channels. With high data rates (∼1 Gbps) in demand nowadays, the PLC band is expanded [6]. These goals can be achieved by improving the resource allocation efficiency [7], with regards to the transfer function [8, 9] and the stochastic noise detail [10]. Thus, obtaining realistic power line channel noise models remain a key goal for the PLC community worldwide. Practical modems' performance fluctuates widely and these variations are a consequence of the presence of different appliances connected to the network [11], electromagnetic interference (EMI) [12], power supplies and switching loads [13].

2. NOISE MEASUREMENTS

In this section we describe the measurement procedure and instrumentation employed throughout the measurement process. PLC noise from actual indoor channels was measured both in time and frequency domain using Tektronix TDS 2024B digital oscilloscope and Rhode & Schwartz spectrum analyser respectively. A coupling circuit is used as an interface between the PLC channel and measurement devices. The broadband coupler not only facilitates reception of the noise signals, but also provides galvanic isolation between mains and measurement equipment. The coupler as shown in Figure 1 employs a broadband 1 : 1 transformer in combination with a capacitor yielding a high pass (LC) filter. On either side of the transformer are placed transient voltage surge suppressors (TVSS) with a metal oxide varistor (MOV) on the primary and back-to-back zeners on

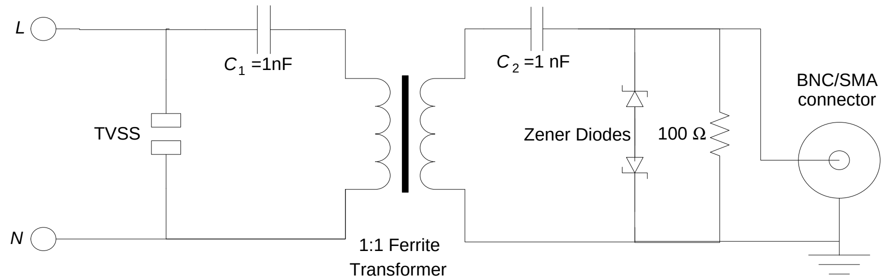

Figure 1: Coupling circuit.

the secondary. Their purpose is to suppress any voltage spikes large enough to damage the sensitive measuring equipment. The coupler transfer characteristics exhibit a reasonably flat response in the 1–30 MHz band, with the worst case loss of 1.59 dB within this band. Nonetheless, a calibration is performed prior to measurements.

PLC network noise as reported in [14] is very complex. It is resultant from electrical appliances connected to the network and external noise coupled to the network either by radiation or conduction. This noise can be classified in terms of its periodicity, randomness and cyclic nature [15].

3. IMPULSIVE NOISE

Impulsive noise can be either synchronous or asynchronous with the mains frequency. It is usually a result of switching transients peculiar with some electrical appliances in the electrical distribution network. Typical durations of impulses range from some microseconds up to a few milliseconds [16]. Typical synchronous impulsive noise is as shown in Figure 2(a) while Figure 2(b) depicts asynchronous impulsive noise. These are samples from a multitude of measurements performed in our University premises. In either case, the amplitude variability of the impulsive noise is observable. In actual PLC channels, components of both cases are present most of the time, hence in this paper; we present the behavioural statistics of impulsive noise in terms of its amplitude, duration of occurrence and time-interval between impulses. We compare our results to that of E. Liu et al. [16] which considered only the asynchronous impulsive noise. In our work, we have considered impulsive noise as that which has magnitude above a certain threshold (background noise) without cyclic classification. The results are presented in Table 1. Similar work has been done by T. Esmailian et al. [17] which presented their parameters in terms of their probability distributions.

In comparison, the disparity concerning the inter-arrival times is quite significant. This can be attributed to varied environments under study. From Table 1, the average inter-arrival time of 0.667 ms correspond to 15 impulses per half-cycle of 50 Hz mains. In our measurements, roughly 180 impulses are recorded on average every half-cycle of the mains. This is expected considering that most of our measurements are taken in laboratories running numerous electrical equipments such as electrical machines, drills, measuring equipment etc..

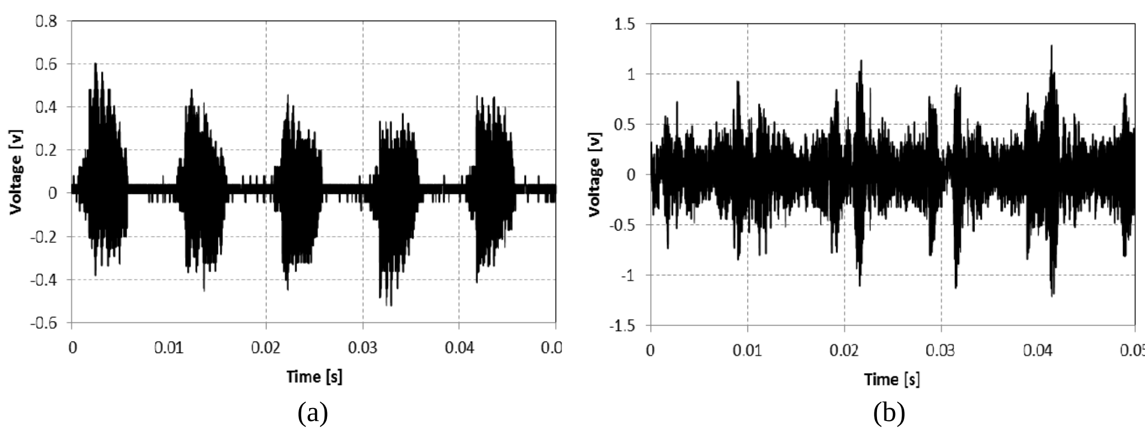

Figure 2: (a) Synchronous impulsive noise and (b) asynchronous impulsive noise.

Table 1: Statistical parameters of impulsive noise.

		Mean	Standard Deviation
Amplitude (mV)	Our Measurements	391	198
	E. Liu et al. [16]	229	121
Duration (μs)	Our Measurements	152	139
	E. Liu et al. [16]	205	157
Interval time (ms)	Our measurements	0.0558	0.0458
	E. Liu et al. [16]	0.667	0.445

4. BACKGROUND NOISE

A power spectral density (PSD) model has been proposed by Esmalian et al. [17] for background noise as shown below:

$$\mathrm{PSD}_{\mathrm{noise}}(f) = A + B \cdot f^{C}\ [\mathrm{dBm/Hz}] \tag{1}$$

Based on the results of [17], the background noise has variability in frequency and colored. The parameter C, being less than zero, results in the background noise heavily present in lower frequencies than in higher frequencies. Guillet et al. [18] applied the same model to their measurements and obtained parameters in the same order of magnitude as that of [17]. However, [18] proposed a different approach aimed at modifying the actual description of background noise to accommodate the fact that the noise decreases as the frequency goes higher. The motivation comes from the fact that the estimated parameters are influenced by narrowband interferences and frequency located jammers inherent with the unshielded and unscreened indoor power lines [18]. They proposed an algorithm that performs a frequency sweep from low to high in order to find the minimum noise spectrum. Since their PSD is estimated from time domain data, this algorithm is embedded in their post-processing of the data. In this paper, though we still use the model of [17] to describe the PSD of background noise, we consider the proposal in [18] by tracking the minimum noise spectrum during measurements in the frequency domain. In our measurements, the new spectral magnitudes are compared to the previous data and if the new data is smaller, the new data is stored. The minimum spectral noise recorded is shown in Figure 3(b) with its mathematical model. Clearly the influence of narrowband interference and other effects are minimised, thus the background noise is not overestimated.

It is also equally important to describe the worst case scenario of the PLC channel noise. In-band spurious signals are unlikely to be intercepted even with spectrum analyzers of highest dynamic range and fast sweep capability. We apply the same algorithm to determine the minimum spectral noise, only this time the result is updated only when the new data is larger than the previous data. The maximum spectral noise recorded is shown in Figure 3(a) with its mathematical model. The model is not in good agreement with the measured results but rather presents a macroscopic capture of the measured data. The results are compared with those of Esmalian et al. [17] in Table 2 which also consider both the best and the worst case noise scenario.

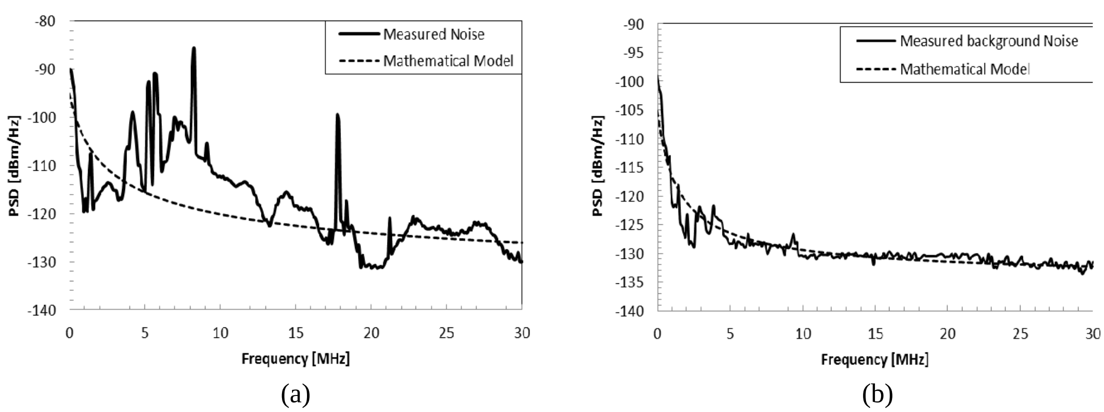

Figure 3: (a) Maximum spectral noise. (b) Minimum spectral noise.

Table 2: Parameters estimated for background noise.

		Background Parameters		
Statistics		A	B	C
Best Case	Our Measurement	−135	30.71	−0.721
	Esmailian et al.	−140	38.75	−0.72
Worst case	Our Measurement	−140	45.26	−0.341
	Esmailian et al.	−145	53.23	−0.337

5. CONCLUSIONS

In this paper, based on the measurements carried out in real indoor power line channels, the noise characteristics were investigated. The noise studies were summarised by finding the parameters of the noise statistics in terms of its amplitude, duration and interval time in time domain. Further studies were carried out in the frequency domain with a simple three parameter model used to capture its behaviour. The parameters of this model are presented. For both time and frequency domain, the parameters are compared with those of other campaigns elsewhere, a general agreement is observable, thus this statistical information can be used to aid the on-going efforts for PLC modem design and optimisation.

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