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# A semi-hidden Fritchman Markov modeling of indoor CENELEC A narrowband power line noise based on signal level measurements

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ABSTRACT

To achieve error-free communication on the narrowband power line communication (NB-PLC) channel, there is need for constant measurement campaign and modeling of burst errors resulting from noise, perturbation and disturbances on the channel. This work thus reports a signal level measurement and First-Order Semi-Hidden Fritchman Markov modeling of the three major NB-PLC noise types for a typical South African residential and laboratory indoor low voltage environment. Two distinguishable disturbance scenarios: *mildly disturbed* and *heavily disturbed* were considered and Baum–Welch maximum likelihood estimation (MLE) algorithm is used to obtain the most probable model parameters that statistically depict the experimentally measured noise error sequences.



## 1. Introduction

The pervasive PLC network offers a solution to the last-mile access communication problem. Its application includes, utilization in in-house automation and inter-connection of home appliances for a smart home. The in-home NB-PLC channel makes use of the existing power line networks (PLNs), originally conceptualized for powering end-user electrical and electronics appliances for data communication purposes. Hence, considering the pervasive or ubiquitous nature of power lines, huge cost of deploying new cables in buildings can be saved. The NB-PLC make use of the frequency band between 3 and 148.5 kHz (further categorized into bands A, B, C and D) for both low speed and high speed NB-PLC applications standardized by CENELEC European committee and up to 450 kHz standardized by ARIB for Japan [1,2]. NB-PLC is highly relevant for both low and high speed NB-PLC purposes. Its importance ranges from, its historical applications for automatic meter reading (power grid control), control of street light, airport runways ground-light control to its use in street car/subway systems [3,4]. PLC technology generally operates in a hostile environment inherited from the PLN. The effect of this hostile environment is the resulting performance degradation. Hence, despite the attractive advantages PLC technology has to offer, like every other communication technology, it must overcome the challenges posed by the hostile environment to ameliorate the overall system design and performance. The low voltage indoor CENELEC A band suffers the most noise impairment amidst the CENELEC category. Noise, perturbation and disturbances caused by the inherent attribute of the PLN itself, the intrinsic electrical attributes of the numerous electrical and electronic appliances connected onto the network and external disturbances poses a hostile environment which results into signal degradation. The introduction and conduction of noise harmonics is caused by the uncoordinated "ON" and "OFF" switching of end user appliances on the network, thus resulting in burst errors and consequently data loss or signal corruption at the receiver. Thus, quantifying, characterizing and modeling of these noise impairment, perturbations and disturbances is vital in improving the overall NB-PLC system design, and performance for a reliable communication.

In this article, we thus report a signal level measurement and First-Order Semi-Hidden Fritchman Markov modeling (SHFMM) of the three major CENELEC A band NB-PLC noise captured in a typical South African residential and laboratory in-door environment. Error sequences for each noise type is obtained for two distinct scenarios: "mildly disturbed" and "heavily disturbed". A three state SHFMM is assumed for modeling the three NB-PLC noise types, with Baum–Welch, an iterative parameter estimation algorithm used to obtain the most probable parameters that statistically depict the measured error sequences. The resulting statistical models, are a class of mathematical model which captures the information about the error distribution of the originally measured sequences for the three noise types experimentally obtained. These

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statistical modeling results are thus useful in designing and evaluating of the performance of modulation techniques (robust and adaptive) and FEC codes capable of mitigating errors on the burst error prone in-door NB-PLC CENELEC A channel. Moreover, these evaluations are utilized in optimizing communications on NB-PLC channel.

The remaining part of this article is arranged as follows: Section 2 explains the three major PLC noise classifications. In Section 3, an extensive but concise description of the Fritchman model assumed in this work, it's parameters and the reason behind the choice of this model is presented. Baum–Welch algorithm, a MLE iterative algorithm aimed at estimating the SHFMM parameters for the three noise types measured is discussed in Section 4. Section 5 discusses the experimental setup and methodology for capturing and measuring the three major noise types. In Section 6, the SHFMM statistical modeling results for the measured noise types are presented and analyzed. Section 7 gives a summary and conclusion of work done in this article.

## 2. Power line communication channel noise categories

In most communication systems, Additive White Gaussian noise (AWGN) model is often assumed. While AWGN is a suitable model for some communication channels, this model does not depict the attributes of the burst errors present on the NB-PLC channels. Several power electronics appliances, particularly those having switching circuits, injects periodic or random noise pulses onto the channel. The resulting noise is non-white, non-Gaussian and transient due to its impulsive nature, hence, it is been referred to as Non-AWGN, which is a deviation from the AWGN model [5,6]. In literature, PLN noise has been classified into three major kinds namely: impulse noise, background noise and narrowband noise discussed as follows [5–8]:

### 2.1. Background noise

Background noise (BN) possess comparatively low power spectral density (PSD), and often result from the sum of various low power noise sources connected onto the channel. It is frequently identified by a constant envelope occurring over a prolonged duration [7]. This noise type includes; flickering noise, and thermal noise emanating from receivers' front end amplifier. BN also emanates from universal motors often found in but not limited to end user gadgets such as fans, drilling tools and dryers. BN is also identified due to its non-white attribute, hence it possesses a frequency-dependent power spectral density and is always present on the NB-PLC channel. The power spectral density of this noise type decays as frequency increases, possessing a slope varying between 20 and 25 dB/decade in an indoor low voltage NB-PLC environment [7,8] and is principally present in narrowband frequencies than in broadband frequencies [8].

### 2.2. Narrowband Noise

Narrowband noise (NBN) is typically limited to a certain frequency slot dependent on its source. It emanates primarily from signals (sinusoidal) having modulated amplitude and are radiated or conducted from both internal and external appliances onto the network, thus the power line acting as an antenna. In literatures, this noise has been found to originate from the horizontal retrace frequency of televisions [7]. Other NBN origins are spurious electromagnetic disturbances emanating from end user gadgets with in-built transmitters and receivers [7,8].

### 2.3. Impulse noise

Impulse noise (IN) is transient in nature and it is described as the principal cause of burst errors on the PLC channel. Unlike NBN, impulse noise covers a wider part of the spectrum in use. It possesses high power spectral density and is distinguished by its inter-arrival time, duration and amplitude. It is significant to clarify that on a low voltage NB-PLC channel, two main classification of impulse noise exist: the "*Periodic impulse noise*" and "*Aperiodic impulse noise*" [7–9].

*Aperiodic impulse noise* also regarded as *asynchronous impulsive noise*, originates from arbitrary emission events or isolated activities at both homes and industrial sites. Classic aperiodic impulse noise emanates from switching transient such as: on and off switching, plugging and unplugging of appliances and co-existence issues that often occur due to uncoordinated PLC transmissions. This impulse noise type is predominant in the high frequency band ranging from several hundred kHz to 20 MHz [10,11].

*Periodic impulse noise* also referred to as "*Cyclostationary impulsive noise*" is sub-divided into two: *Periodic synchronous impulse noise* and *Periodic asynchronous impulsive noise* as discussed as follows:

#### 2.3.1. Periodic synchronous impulse noise

This IN waveform exhibit a train of impulses synchronous to the low voltage AC mains 50/60 Hz frequency. It comprises of a series of impulses that are isolated, with fairly large amplitude and duration. They originate from non-linear power electronic gadgets like; silicon controlled rectifier operations in power supplies, thyristors operation in light dimmer, laptops, desktop computers, LCD monitors and from a brush motor commutating effects [12].

#### 2.3.2. Periodic asynchronous impulse noise

This noise type is characterized by periodic noise impulses or trains of impulses which occurs with a frequency and repetition rates independent of mains frequency [12,13]. It has repetition rates between 50 and 200 kHz and is majorly injected by transient operations such as switching of relays that occurs in switch mode power supplies connected to the network [7,12]. The noise impulses typically possess much shorter durations and much lower amplitudes than those of the periodic synchronous impulse noise [12,14].

As aperiodic impulse noise is predominant on broadband power lines, recent indoor and outdoor noise measurements on both low-voltage and medium-voltage PLNs established that "cyclostationary noise (both periodic synchronous and asynchronous to mains frequency impulse noise)" are the prevailing noise impairment present on the 3–500 kHz NB-PLC spectrum [1,2,15]. This noise kind possesses long noise bursts with periodically varying statistics and whose period is same as half the AC main's cycle. In PLC systems, a typical periodic synchronous impulse noise is composed of noise bursts having high power which spans from 10% to 30% of the period [15], which is oftentimes a lot prolonged than the standardized duration of a typical OFDM symbol [11] and amounts to 833 μs–2.5 ms in the US FCC band [15,16]. A single cyclostationary noise burst could possibly lead to corruption of multiple successive OFDM symbols. For instance, for a PLC-G3 standard functioning in the 3–95 kHz CENELEC A band [1], the OFDM symbol duration is 695μs, hence, cyclostationary noise burst that lasts 30% of a period is bound to corrupt up to four successive OFDM symbols [16]. During certain period of the bursts, the noise power at particular frequency bands could rise to 30–50 dB greater than in the remaining period [15,16].