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Abstract

Faculty of Engineering and Built Environment
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Doctor of Philosophy

CLASSIFICATION AND MODELING OF POWER LINE NOISE USING MACHINE LEARNING TECHNIQUES

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The realization of robust, reliable and efficient data transmission have been the theme of recent research, most importantly in real channel such as the noisy, fading prone power line communication (PLC) channel. The focus is to exploit old techniques or create new techniques capable of improving the transmission reliability and also increasing the transmission capacity of the real communication channels. Multi-carrier modulation scheme such as Orthogonal Frequency Division Multiplexing (OFDM) utilizing conventional single-carrier modulation is developed to facilitate a robust data transmission, increasing transmission capacity (efficient bandwidth usage) and further reducing design complexity in PLC systems.

On the contrary, the reliability of data transmission is subjected to several inhibiting factors as a result of the varying nature of the PLC channel. These inhibiting factors include noise, perturbation and disturbances. Contrary to the Additive White Gaussian noise (AWGN) model often assumed in several communication systems, this noise model fails to capture the attributes of noise encountered on the PLC channel. This is because periodic noise or random noise pulses injected by power electronic appliances on the network is a deviation from the AWGN. The nature of the noise is categorized as non-white non-Gaussian and unstable due to its impulsive attributes, thus, it is labeled as Non-additive White Gaussian Noise (NAWGN). These noise and disturbances results into long burst errors that corrupts signals being transmitted, thus, the PLC is labeled as a horrible or burst error channel.

The efficient and optimal performance of a conventional linear receiver in the white Gaussian noise environment can therefore be made to drastically degrade in this NAWGN environment. Therefore, transmission reliability in such environment can be greatly enhanced if we know and exploit the knowledge of the channel's statistical attributes, thus, the need for developing statistical channel model based on empirical data. In this thesis, attention is focused on developing a reconfigurable software defined un-coded single-carrier and multi-carrier PLC transceiver as a tool for realizing an optimized channel model for the narrowband PLC (NB-PLC) channel.

First, a novel reconfigurable software defined un-coded single-carrier and multi-carrier PLC transceiver is developed for real-time NB-PLC transmission. The transceivers can be adapted to implement different waveforms for several real-time scenarios and performance evaluation. Due to the varying noise parameters obtained from country to country as a result of the dependence of noise impairment on mains voltages, topology of power line, place and time, the developed transceivers is capable of facilitating constant measurement campaigns to capture these varying noise parameters before statistical and mathematically inclined channel models are derived.

Furthermore, the single-carrier (Binary Phase Shift Keying (BPSK), Differential BPSK (DBPSK), Quadrature Phase Shift Keying (QPSK) and Differential QPSK (DQPSK)) PLC transceiver system developed is used to facilitate a First-Order semi-hidden Fritchman Markov modeling (SHFMM) of the NB-PLC channel utilizing the efficient iterative Baum-Welch algorithm (BWA) for parameter estimation. The performance of each modulation scheme is evaluated in a mildly and heavily disturbed scenarios for both residential and laboratory site considered. The First-Order estimated error statistics of the realized First-Order SHFMM have been analytically validated in terms of performance metrics such as: log-likelihood ratio (LLR), error-free run distribution (EFRD), error probabilities, mean square error (MSE) and Chi-square (χ^2) test. The reliability of the model results is also confirmed by an excellent match between the empirically obtained error sequence and the SHFMM regenerated error sequence as shown by the error-free run distribution plot.

This thesis also reports a novel development of a low cost, low complexity Frequency-shift keying (FSK) - On-off keying (OOK) in-house hybrid PLC and VLC system. The functionality of this hybrid PLC-VLC transceiver system was ascertained at both residential and laboratory site at three different times of the day: morning, afternoon and evening. A First and Second-Order SHFMM of the hybrid system is realized. The error statistics of the realized First and Second-Order SHFMMs have been analytically validated in terms of LLR, EFRD, error probabilities, MSE and Chi-square (χ^2). The Second-Order SHFMMs have also been analytically validated to be superior to the First-Order SHFMMs although at the expense of added computational complexity. The reliability of both First and Second-Order

SHFMM results is confirmed by an excellent match between the empirical error sequences and SHFMM re-generated error sequences as shown by the EFRD plot.

In addition, the multi-carrier (QPSK-OFDM, Differential QPSK (DQPSK)-OFDM) and Differential 8-PSK (D8PSK)-OFDM) PLC transceiver system developed is used to facilitate a First and Second-Order modeling of the NB-PLC system using the SHFMM and BWA for parameter estimation. The performance of each OFDM modulation scheme in evaluated and compared taking into consideration the mildly and heavily disturbed noise scenarios for the two measurement sites considered. The estimated error statistics of the realized SHFMMs have been analytically validated in terms of LLR, EFRD, error probabilities, MSE and Chi-square (χ^2) test. The estimated Second-Order SHFMMs have been analytically validated to be outperform the First-Order SHFMMs although with added computational complexity. The reliability of the models is confirmed by an excellent match between the empirical data and SHFMM generated data as shown by the EFRD plot.

The statistical models obtained using Baum-Welch to adjust the parameters of the adopted SHFMM are often locally maximized. To solve this problem, a novel Metropolis-Hastings algorithm, a Bayesian inference approach based on Markov Chain Monte Carlo (MCMC) is developed to optimize the parameters of the adopted SHFMM. The algorithm is used to optimize the model results obtained from the single-carrier and multi-carrier PLC systems as well as that of the hybrid PLC-VLC system. Consequently, as deduced from the results, the models obtained utilizing the novel Metropolis-Hastings algorithm are more precise, near optimal model with parameter sets that are closer to the global maxima.

Generally, the model results obtained in this thesis are relevant in enhancing transmission reliability on the PLC channel through the use of the models to improve the adopted modulation schemes, create adaptive modulation techniques, develop and evaluate forward error correction (FEC) codes such as a concatenation of Reed-Solomon and Permutation codes and other robust codes suitable for exploiting and mitigating noise impairments encountered on the low voltage NB-PLC channel. Furthermore, the reconfigurable software defined NB-PLC transceiver test-bed developed can be utilized for future measurement campaign as well as adapted for multiple-input and multiple-output (MIMO) PLC applications.