Design and Analysis of OFDM System for Powerline Based Communication

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Abstract - Research on digital communication systems has been greatly developed in the past few years and offers a high quality of transmission in both wired and wireless communication environments. Coupled with advances in new modulation techniques, Orthogonal Frequency Division Multiplexing (OFDM) is a well-known digital multicarrier communication technique and one of the best methods of digital data transmission over a limited bandwidth [1].
In this paper, design and analysis of OFDM system for powerline based communication is proposed. In doing so, MATLAB and embedded Digital Signal Processing (DSP) systems are used to simulate the operation of virtual transmitter and receiver. The performance of the system design is then analysed by adding noise (additive white Gaussian noise, Powerline coloured background noise and Middleton Class A noise) in an attempt to corrupt the signal.
In this paper results will show that performance is improved by using lower order modulation formats e.g. Binary Phase Shift Keying (BPSK), QPSK, etc. compared to the higher modulation schemes e.g. 64 Quadrature Amplitude Modulation (QAM); as they offer lower data rates but are more robust in the presence of noise. The performance study of OFDM scheme is also examined with and without presence of noise and application of forward error correction (FEC).

Keywords: Digital communication, OFDM, Powerline, DSP, PSK, QAM, FEC

1. Introduction

Multicarrier modulation has long been known as an efficient modulation scheme for band-limited channels. OFDM is considered as one of the most promising modulation methods for powerline communications [2].

The research aim of this paper is to design and implement an OFDM communication link for Powerline Communication (PLC), using MATLAB and embedded DSP systems to simulate the operation of virtual transmitter and receiver. The performance of the system design is then analysed by adding noise such as additive white Gaussian noise (AWGN), Powerline background noise and Middleton Class A noise, in an attempt to corrupt the signal.
Figure 1 depicts the block diagram of OFDM modem which is designed in this research paper.

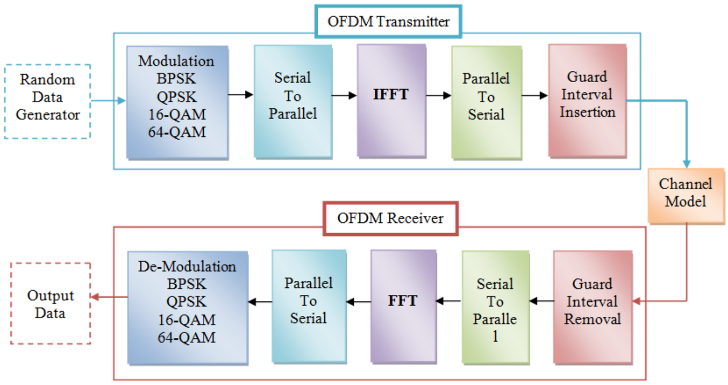

Figure 1. OFDM Block diagram

Despite wide use of the OFDM in conjunction with (or without) other techniques, there is a great potential for this technique to be employed in PLCs, and the author has therefore diverted the main focus of the current research to this goal.

In this research, a basic structure of a modem, using BPSK was initially designed and tested. Later a more comprehensive OFDM modem was designed, for which a comparative performance studies using the Bit Error Rate (BER) plots was conducted for numerous simulations scenarios. These simulation scenarios include the use of different modulation types, with and without use of encoding and use of different types of noise.
In addition to comparative studies, the functioning of communication link with respect to OFDM was also investigated by utilising guard time/cyclic prefix to assist in counteracting the effects of delay, Inter-Symbol Interference (ISI) and Inter-Channel Interference (ICI).

I. OFDM Background

OFDM systems have been widely recognised as an efficient transmission technique for wireless communications and are extensively used in the standards for digital audio/video broadcasting. OFDM is a frequency-domain approach to communications, and has important advantages when dealing with the frequency-selective nature of high data rate communication channels. As the demand for operating with higher data rates has increased, OFDM systems have emerged as an effective physical-layer solution in their environment [3].

The paper is organised as follows. Section 2 describes the classification of powerline noise and presents the mathematical algorithms and characteristics of the noises used in this paper; Section 3 describes the simulation response and noise modelling; Finally, Section 4 contains the concluding remarks.

2. Powerline Noise

It is well known that the data transmission over powerlines provide many attractive properties. However, like all other communication systems, PLC systems are also at risk of internal or external noise and disturbances. Powerline noises can be classified into 5 categories as follows [4]:

- Coloured background noise with a relatively low power spectral density (PSD), which is caused by summation of numerous noise sources of low power.
- Narrow band noise, mostly amplitude modulated sinusoidal signals caused by ingress of radio broadcasting stations.
- Periodic impulsive noise asynchronous to the mains frequency, which is mostly caused by switched-mode power supplies.
- Periodic impulsive noise synchronous to the mains frequency, which is mainly caused by switching actions of rectifier diodes found in many electrical appliances.
- Asynchronous impulsive noise, which is by switching transients in the power network.

This paper offers an insight into the influence of different types of powerline noise (e.g. Coloured background noise and Impulsive Noise) as well as AWGN.

a) Coloured background noise

A statistical analysis method is usually employed to understand the random behaviour of the noise in the time domain. In [4], an extensive study of the noise amplitude spectrums taken from the laboratory and residential house measurements, was done and it was suggested that the probability distribution of the time-domain noise amplitudes resembles the Nakagami-m distribution. The Nakagami-m probability density functions (PDF) can be written as:

$$p(r) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^{m} r^{2m-1} e^{-\frac{mr^2}{\Omega}} \qquad (1)$$

Where r is the random variable, p is the probability of the corresponding random variable, Γ(.) is the Gamma function and *m* is the ratio of the moments i.e. the closeness between the Nakagami and Rayleigh distribution. Simulation response of this research shows that the Nakagami PDF is exactly the same as the Rayleigh PDF when $m = 1$. However, when $m > 1$, the Nakagami PDF has smaller variance and larger mean than the Rayleigh PDF, and reverse is true when $m < 1$.

b) Impulsive Noise – Class A Noise

By means of statistical analysis method, the performance of OFDM system is analysed through an impulsive noise to corrupt the channel. The starting point for deriving the impulsive noise model is the assumption that a large number of statistical independent interferers contribute to the noise. According to the bandwidth of the noise emitted by each of the interferers, Middleton classifies the noise in 3 general classes of A, B and C [5]. This paper considers focusing on the Class A noise model. It is worth mentioning that the noise bandwidth is assumed to be comparable or less than the bandwidth of the disturbed communication system and so transient effects in the analogue receiver stages can be neglected.
As this paper is partly concentrated on the influence of impulsive noise on OFDM transmission, the channel modelling for the additive impulsive noise channel will be kept simple as (2).

$$\boldsymbol{r} = \boldsymbol{s} + \boldsymbol{n} \qquad (2)$$

- S = The transmitted symbol
- n = Class A distributed random variable
- r = The received value

Additionally, a Gaussian noise component is added to model the (almost) always present thermal receiver noise. The Class A noise PDF is given by (3) [6].

$$p_n(\eta) = e^{-A} \sum_{m=0}^{\infty} \frac{A^m}{m!2\pi\sigma_m^2} \, exp\left(-\frac{\eta^*\eta}{2\sigma_m^2}\right) \qquad (3)$$

With η^* denotes the complex conjugate of η.

$$\sigma_m^2 = \frac{\frac{m}{A} + T}{1 + T}$$

The parameter A is the impulsive index given by the product of the average number of impulses per unit time and the mean duration of the emitted impulses entering the receiver. For $A \rightarrow \infty$ the noise gets Gaussian distributed and small A produces more structured/impulsive noise. The parameter *T* is the ratio between the mean power of the Gaussian and the mean power of the impulsive noise component [6].

3. Simulation Response and Noise Modelling

This section concentrates on presenting the simulation response for different simulation scenarios, considering the comparison for different modulation types and orders, BER comparison curves for AWGN channel with/ without convolutional channel coding.

Figure 2 depict the different Bit Error Rate (BER) curves for different orders of PSK and QAM modulation types in an AWGN channel.

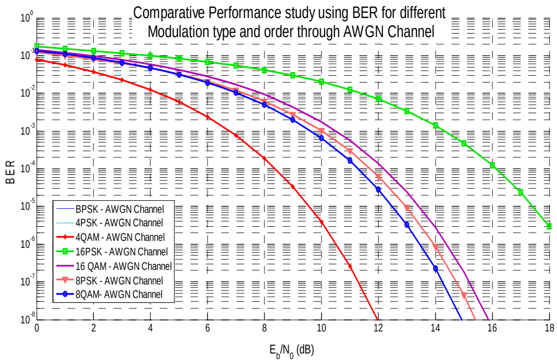

Figure 2. Comparative performance study using BER for different order of PSK and QAM through AWGN Channel

As it is shown Figures 2, the performance is improved by using lower order modulation formats e.g. BPSK, 4PSK, 4QAM etc. compared to the higher modulation schemes e.g. 64PSK, 64QAM etc; as they offer lower data rates but are more robust in the presence of noise.

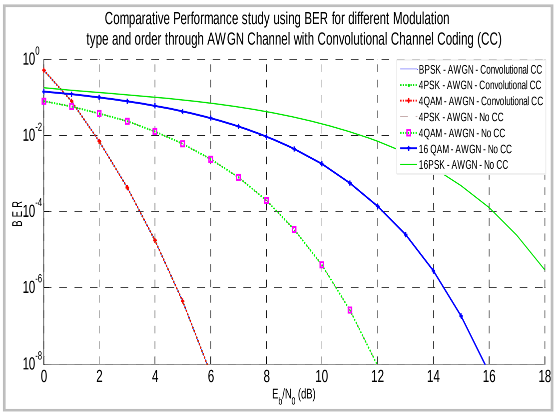

Figure 3. Comparative performance study using BER for PSK and QAM with/without convolutional channel coding

The performance study of OFDM scheme is also examined with and without presence of noise and application of forward error correction (FEC) and it can be seen that the performance of the system is greatly improved when FEC, in this case convolutional coding, is used.

Figures 4 and 5 depicts the steps and comparison of noise modelling.

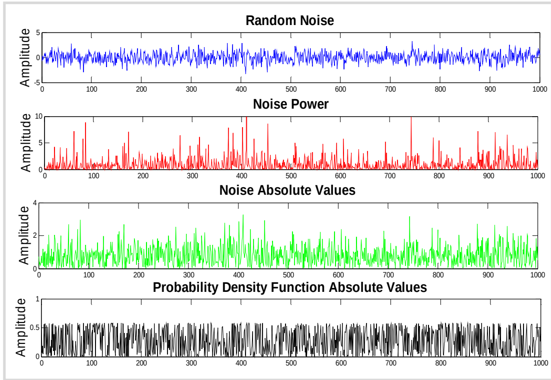

Figure 4. Graphs of random input noise, its power, absolute value and absolute value of its PDF

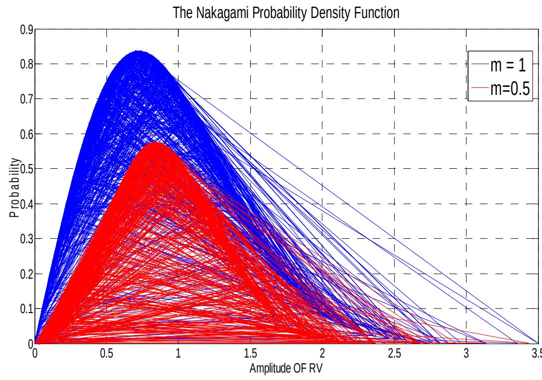

Figure 5. The Nakagami Probability Density Function for different m = 1 and m = 0.5

As illustrated in Figure 6, the modelled coloured background noise does not have rational effect on the performance of the channel and hence the system.

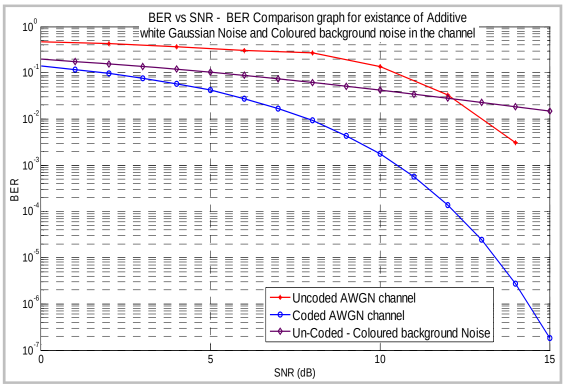

Figure 6. BER comparison graph for different channel scenarios, Un-coded AWGN, convolutionaly coded AWGN and Channel affected by the modelled coloured background noise.

4. Conclusion

In this paper, design and analysis of OFDM system for powerline based communication was presented. In doing so, MATLAB was used to simulate the operation of virtual transmitter and receiver.

The performance of the system design was then analysed by adding AWGN and powerline coloured background noise and in an attempt to corrupt the signal.

This research is currently carried out for degree of Masters by Research. More results (e.g. Image transmission through the OFDM system and Middleton Class A noise modelling, etc) will be obtained on-time for the presentation date of this workshop.

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