A Novel Technique For High Speed PLC Systems

Sreenath K P, Dharmalingam R and Anandi G

Abstract— Power line communications (PLC) use the existing electrical power line networks for telecommunication purposes. It exploits the widespread electric power infrastructure to provide high-speed broadband multimedia services to and within the home or office. However Characteristics of electrical power grids present some technical challenges for high-speed data communications. Noise at a power outlet is the sum of noises produced by different appliances connected to the line producing impulsive noise and other narrow-band interference. Communication over power lines was restricted to low-speed functions such as remote metering and operations management that serve the needs of power supply utilities. Performance of OFDM in an appropriate power line channel model with the addition of a properly modeled noise environment investigated. A novel approach to mitigate the periodic impulsive noise of the orthogonal frequency-division multiplexing (OFDM) -based power-line communications (PLC) system is introduced. To improve the receiver's ability to reduce the effect of impulsive noise, a technique that combines time domain nonlinearities with a frequency-domain approach has been proposed.The results show that the proposed periodic impulsive noise mitigation technique is simple and effective for the OFDM-based PLC system.

Index Terms— High-speed broadband multimedia services, OFDM, Periodic impulsive noise mitigation technique, PLC

I. INTRODUCTION

It is generally agreed that smart grid communications will be supported by a heterogeneous set of communication technologies, ranging from wireless to power line and to fiber-optic, since no single solution fits all scenarios.Power line communications (PLC) have been attractive as a solution for smart grid communications and a promising way of information exchange.

Due to the high penetration of power line infrastructures and hence low deployment costs, power line communications (PLC) plays a prominent role in enabling a variety of smart grid applications. The main advantage when implementing power-line communications (PLC) is that there is no need for extra infrastructure, which can be both expensive and time consuming. On the other hand, the main drawback is that the power-line network was originally not designed for supporting the communication signal's transmission. There is continuous altered load, due to the number of appliances connected to the network, which changes with time. As a result, the telecommunication signal undergoes severe degradation caused by interference and impulsive noise.

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A persistent impairment for PLC systems is the noise generated by internal and external sources that are either connected or in close proximity to the PLC transmission medium. The noise at any power outlet is the sum of noises produced by different appliances connected to the line plus the background noise on the line. Five types of noise are often found in PL channels [15]: coloured background noise, narrowband noise, and periodic impulsive noise asynchronous to the mains frequency, periodic impulsive noise synchronous to the mains frequency and asynchronous impulsive noise. The first three types are almost stationary and are classified as background noise. The last two types have a time-varying random behavior and are often classified as impulsive noise. Typical impulses of this type have short durations ranging from some microseconds up to a few milliseconds and are characterized with very high amplitudes. During the occurrence of impulsive noise, the power spectral density (PSD) of this type of noise can be up to 50 dB higher than the background noise [15].

Due to the presence of impulsive noise and other undesirable characteristics of PL grids, it is crucial for high-speed PLC to select a modulation technique that can stand against such peculiarities. A number of modulation techniques, including single-carrier, multi-carrier and spread spectrum are of interest for PLC engineers and researchers [6], [17]. Among those, orthogonal frequency division multiplexing (OFDM) stands as an excellent candidate for PLC. The basic principle of OFDM is to split high-speed data symbols into slow data streams which then modulate multiple narrowband orthogonal subcarriers simultaneously. This reduces the effect of multipath by enlarging the symbol duration so that, depending on the channel delay spread, only a small portion of the symbol is affected. With the addition of a cyclic time guard, the problem of multipath can be completely eliminated in OFDM. Besides, the effect of impulsive noise is minimized because the received OFDM signal in addition to the added noise is divided by the number of subchannels through the discrete Fourier transform (DFT) operation in the receiver. OFDM offers robustness as well as simple implementation which make this technique a favored candidate for PLC.

Unlike many other communication channels, noise in power line channels cannot be described by Additive white Gaussian Noise (AWGN) due to the presence of impulsive noise. This type of noise has a random time-varying behaviour and its duration varies from a few microseconds to milliseconds. Practical experiments in power lines [15] show that, during the occurence of an impulse, the power spectral density (PSD) of impulsive noise exceeds the PSD of background noise by a minimum of 10-15 dB and may sometimes reach 50 dB. It is, therefore, necessary to employ mitigation techniques in order to combat its effect on data transmission.

Once the signals received by the OFDM-based PLC receiver are interfered by the periodic impulsive noise, it is equivalent to adding damped sinusoids to the received signals. For this reason, the correlation result of the synchronization of the OFDM-based PLC system will greatly change, then the synchronization module of PLC receiver may work incorrectly or even fail to work, the bit-error rate (BER) of the PLC system will greatly increase, and it will lead to the significant degradation of the through put or even corruption of the PLC system. In addition, OFDM systems are more sensitive to synchronization errors than single carrier systems. So the periodic impulsive noise should be mitigated before the synchronization of the PLC receiver to ensure the correct synchronization result, then the PLC system can work normally. In the OFDM-based system, the cyclic prefix removal and the segmentation of the received data (serial to parallel) are equivalent to multiplying the received signal by a rectangular window in time domain. This time-domain windowing is equivalent to convoluting with a sinc-like function in the frequency domain. The periodic impulsive noise is impulse in the frequency domain. So when the OFDM based PLC system is interfered by the periodic impulsive noise, the information of the interfered subcarrier is totally corrupted and the information of the adjacent subcarriers is affected by the periodic impulsive noise.

The mitigation of periodic impulsive noise before the synchronization of the PLC receiver will not only ensure the correct synchronization result, but also reduce the adverse effect of periodic impulsive noise on the subcarriers. In addition, the periodic impulsive noise has an adverse effect on the estimation of the OFDM-based PLC channel. In a word, the periodic impulsive noise has an adverse effect on the performance of the PLC system that should be suppressed before the synchronization of the PLC receiver.

II. PREVIOUS STUDIES

The literatures consider the performance of nonlinear techniques for impulsive noise mitigation in OFDM under practical PLC channel characteristics. The effect of impulsive noise with different magnitudes and occurrence rates in OFDM-based PLC were noted. Simulation results were obtained for three noise environments: "heavily-disturbed", "medium disturbed" and "weakly-disturbed". The severe effect of impulsive noise in PLC systems was clearly demonstrated by the drastic changes in BER curves. Furthermore, time-domain nonlinearities including clipping, blanking and the combined clipping/blanking [3] were employed in the OFDM receiver to combat impulsive noise and the issue of threshold selection was investigated. As a treatment to the threshold selection dilemma, a BER based adaptive threshold selection technique has been proposed and the performance was verified by simulations [18], [19].

III. PROPOSED SYSTEM

3.1 JOINT TD/FD IMPULSIVE NOISE SUPPRESSION

For high data rate communications over PLC mediums, mitigation of the effect of impulsive noise is inevitable, due to the high power and random behavior of this type of noise. This part of the chapter introduces a joint time-domain/frequency-domain (TD/FD) technique for impulsive noise reduction in OFDM-based PLC systems [2].

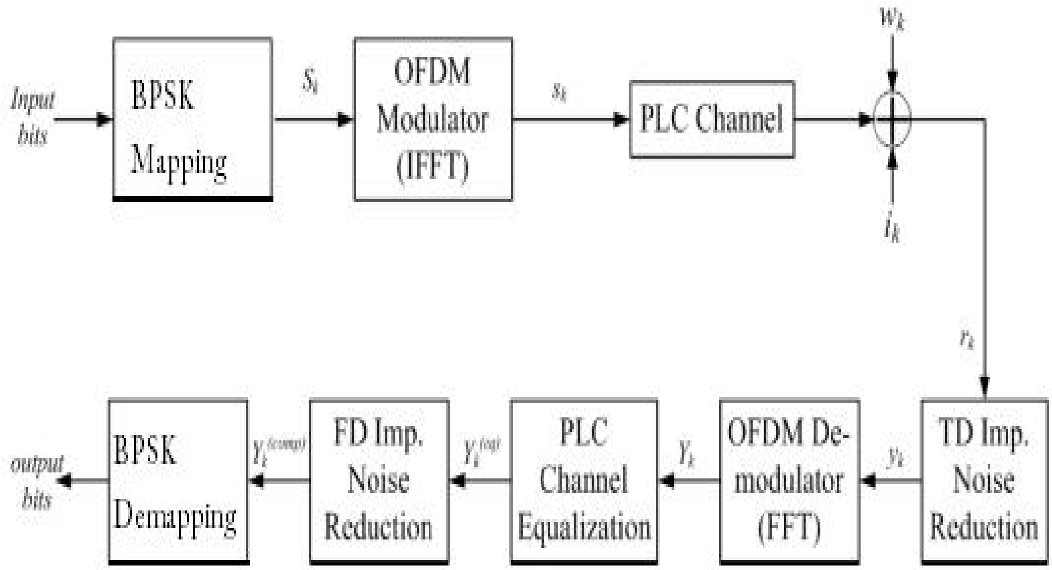

Fig 3.1 Block diagram of the OFDM-based PLC system with Joint TD/FD impulsive noise reduction

3.2 System Description

The joint time-domain/frequency-domain technique for impulsive noise reduction in OFDM-based PLC system, technique combines the time-domain nonlinearities with the frequency-domain suppression. Fig. 3.1 shows how this technique is implemented in OFDM systems. The impulsive noise in the received OFDM symbols r_k is first reduced using combined clipping/blanking nonlinear preprocessors. Clipping/blanking nonlinearity, in particular, is known to perform better than the individual clipping and blanking nonlinearities [9]. Next and in order to further improve the impulsive noise mitigation, the frequency-domain suppression technique is applied to the OFDM signal after channel equalization and DFT demodulation. The technique is tested under power line conditions with impulsive noise. It achieves a significant improvement in Bit Error Rate as compared to conventional OFDM systems and also OFDM-systems with nonlinearity based impulsive noise reduction.

IV. Results

MATLAB software was utilized to study the performance of the proposed joint time-domain/frequency-domain impulsive noise mitigation technique. A random bit stream is mapped into QPSK symbols and modulated using OFDM with 128 subcarriers and passed through a PLC multipath channel with 15 paths. Noise, including background as well as impulsive noise, is then added to the OFDM signal. The background noise is modelled as an AWGN noise, whereas the impulsive noise is modelled according to the Poisson-Gaussian noise model. In this model, impulses with Gaussian amplitudes arrive according to a Poisson distribution. The simulation is run 100 times and in every iteration 200; 000 bytes of data are transmitted and received.

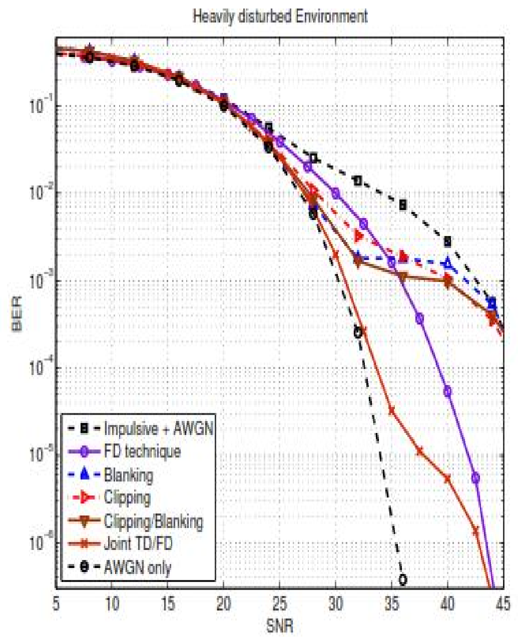

***Fig 4.1** Performance comparison of time-domain techniques, frequency domain technique and the Joint TD/FD technique for OFDM-Based PLC in a heavily-disturbed environment*

The superior performance of the proposed joint TD/FD impulsive noise suppression technique over the frequency-domain technique and the three time-domain nonlinear techniques can be observed from Fig. 4.1. It is the result of simulation in a multipath power line channel with 15 propagation paths. The channel is heavily disturbed with impulsive noise. In this noise scenario, the frequency-domain suppression method provides significant improvements over time-domain nonlinearities only at high SNR values. The proposed TD/FD technique, however, outperforms all the other techniques including the FD technique at all SNR values.

For example, at BER of 10^{-4} the joint TD/FD provides an improvement of more than 5 dB over all the other methods. In a heavily-disturbed environment and with SNR values below 35 dB, the proposed technique achieves a BER performance close to that of the signal with only AWGN, which means that the effect of impulsive noise is almost eliminated.

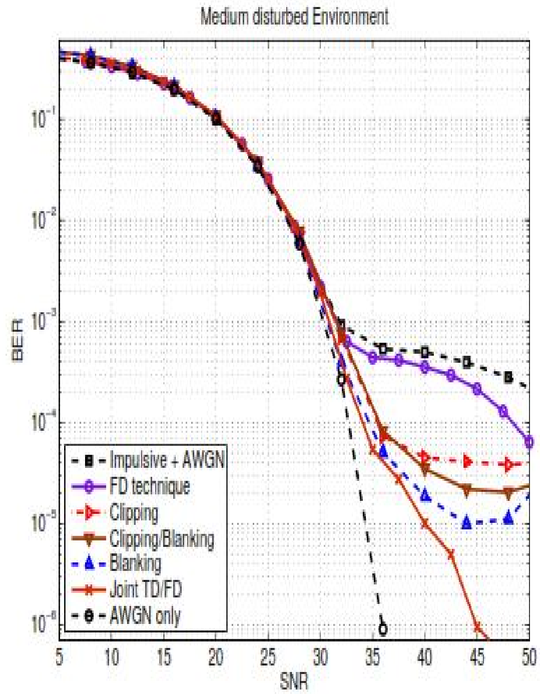

***Fig 4.2** Performance comparison of time-domain techniques, frequency domain technique and the Joint TD/FD technique for OFDM-Based PLC in a medium-disturbed environment*

Fig. 4.2 depicts the BER performance of all the studied noise reduction techniques in a power line channel that is moderately affected with impulsive noise. In this noise environment, the FD noise reduction method does not provide any advantage over TD techniques with properly selected thresholds. The curve for the joint TD/FD technique in Fig. 4.2 shows that this technique reduces the effect of impulsive noise significantly and outperforms the other studied techniques.

The performance of the joint TD/FD technique in a power line channel that is weakly affected with impulsive noise is illustrated in Fig. 4.3 The FD technique performs worse than the simple TD nonlinearities, due to the high peaks impulsive noise. On the other hand, the joint TD/FD performs the best in reducing the effect of impulsive noise among all the studied methods.

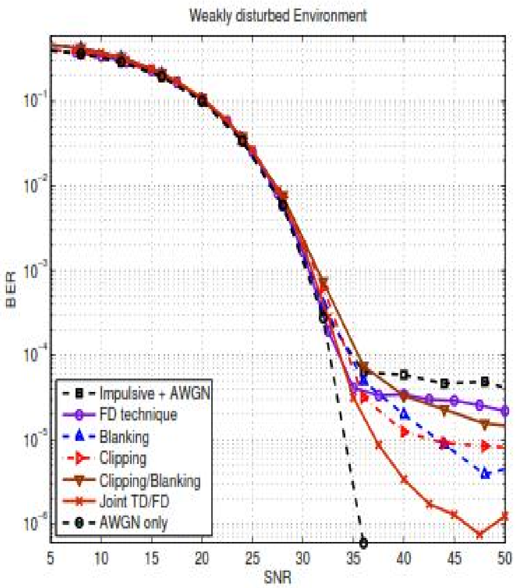

Fig 4.3 Performance comparison of time-domain techniques, frequencydomain technique and the Joint TD/FD technique for OFDM-Based PLC in a weakly-disturbed environment

V. CONCLUSION

Power line communication systems employing orthogonal frequency division multiplexing and the effect of impulsive noise have been considered in this dissertation.

The joint Time-domain/Frequency-domain im pulsive noise suppression technique was introduced. The performance of this technique is studied against well known time-domain nonlinearities by means of computer simulations. The obtained results show that the Combined TD/FD technique performs better than practically used nonlinearities and can reduce the adverse effect of impulsive noise significantly. Using the TD/FD technique and at SNR values below 35, the effect of impulsive noise can be approximately eliminated in a channel that is heavily-disturbed with impulsive noise.

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