International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682
Vol.1, No.2, June 2012 DOI:10.15693/ijaist/2012.v1i2.25-29

Combined NBI and Impulsive Noise Cancellation in OFDM System

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***Abstract*— Narrowband Interference (NBI) and Impulsive Noise (IN) jointly occur in power-line networks and underwater acoustic communications. In these applications, OFDM (Orthogonal Frequency Division Multiplexing) is used as the modulation technique for efficient communication. It is observed here that the combined effect of NBI and IN on the performance of OFDM has been highly destructive. In order to reduce the adverse effect of NBI and IN, frequency domain identification and cancellation technique and joint time-frequency domain approach are made use in OFDM respectively. In this paper, the performance of OFDM system is evaluated in terms of Bit Error Rate (BER) versus Signal to Noise Ratio (SNR) curves.**

Keywords—NBI; IN; Power Line Communication; DWT-OFDM; AWGN channel; DFT-OFDM

I. INTRODUCTION

Power Line Communication (PLC) technology is an emerging technology where power line channel is used as a multipurpose medium providing services such as voice, data, energy distribution and internet services. Power line was originally used to distribute power. But recent advances in digital communication have made it possible to access internet by simply plugging in computer to the wall socket in home [1]. However, the major drawback of this technology has been the transmission channel full of noise i.e. colored Gaussian noise, different types of narrowband interference and impulsive noise [2]. The multicarrier modulation scheme employed in PLC is OFDM.

About underwater acoustic communication one can say that it is a technique of sending and receiving messages under water. Some of the difficulties encountered in this type of communication are multi-path propagation, strong signal attenuation and susceptibility to various interferences. Mainly, external interferences/noise are divided into two categories according to time-frequency characteristics: (1) NBI with small bandwidth and long time duration; and (2) Impulsive noise with short time duration and large bandwidth [3]. The preferred modulation technique used in underwater acoustic communication is OFDM. This is because OFDM is known for its robustness against multipath effect, fading (large delay spreads) and interference.

The common factor observed in the above mentioned applications is the type of transmission technique they use i.e. OFDM. OFDM is basically a spectrally efficient modulation technique, a particular type of multicarrier transmission suitable for frequency selective channels and high data rates.

The basic principle of OFDM is to split high data rate stream into number of low-rate data streams that are transmitted simultaneously over a number of subcarriers that are orthogonal to each other [4]. By this low rate transmission, symbol duration is increaseddue to which amount of time dispersion caused by multipath delay spread is decreased. Inter-Symbol Interference (ISI) which is found when single carrier modulation is used for high bandwidth and data rate communications is eliminated in OFDM by introducing guard time in every ODFM symbol. In guard time, symbol is cyclically extended to avoid Inter-Carrier Interference (ICI). This is called cyclic prefix.

Subcarriers in OFDM are made orthogonal by using sinusoids of DFT (Discrete Fourier Transform) as orthogonal basis set. DFT and IDFT operations are effectively implemented using FFT and IFFT respectively. The IDFT and DFT transform which form the inverse and forward transforms of OFDM are flexible, i.e. they can be replaced with IDWT (Inverse Discrete Wavelet Transform) and DWT respectively instead. By doing in this way, we get DWT-OFDM or wavelet based OFDM. This DWT-OFDM is found to have several advantages over the conventional OFDM (where DFT and IDFT are made use). They are improved spectral containment as there is no need to use cyclic prefix (due to overlapping nature of wavelet properties), reduced side lobe and ICI levels.

In this paper, OFDM system with PLC channel, added impulsive noise and NBI is considered. Zimmermann's model is used to represent multipath PLC channel. Gated-Gaussian model is used to model IN. NBI is modeled as a single tone sinusoidal interference. IN mitigation is carried out using joint time-frequency domain approach and NBI suppression is done using frequency domain identification and cancellation technique. The cancellation is carried out both in DFT-OFDM and DWT-OFDM and the BER values obtained for a particular value of SNR are compared in order to evaluate the performance of OFDM system.

This paper is organized as follows. In section II, literature survey on OFDM, NBI and IN is done. Later, efficient NBI and IN suppression techniques are discussed in section III. Simulation results and its analysis are presented in section IV, and finally conclusions are given in section V.

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II. LITERATURE SURVEY

NBI is defined as the interference signal whose spectrum is far less than signal transmission bandwidth. It is most commonly found in unlicensed frequency bands e.g., Industrial Scientific Medical (ISM) band [5]. It is basically the interference which occurs when two or more communication systems share the same frequency band. NBI causes SNR degradation when present in OFDM. This is due to the spectral leakage of NBI at the receiver in DFT process. The adverse effect of NBI on OFDM can be overcome in several ways. In [5] frequency domain cancellation and excision filtering techniques are proposed. It is also shown here that wavelet based OFDM system outperforms Fourier based OFDM system in many cases. Frequency excision, frequency identification and cancellation and adaptive narrowband filtering techniques for NBI suppression are detailed in [6]. Apart from these methods, it is suggested in [7] that spread spectrum (SS) techniques which are well known for its resistance towards narrowband jamming can be used for NBI suppression. Though, ability of SS to withstand both intentional and unintentional interference is its greatest asset, it has been clarified in [8] that SS can suppress only a given amount of interference.In [9] adaptive filtering using Least Mean Square (LMS) algorithm is used for NBI cancellation. Here LMS adaptively tracks the frequency at which interference is located. Wavelet denoising which is a technique used to remove noise has been inferred to give an additional BER improvement in [10]. So among wavelet denoising, adaptive notch filtering, frequency excision, spread spectrum modulation, adaptive filtering and frequency domain identification and cancellation techniques, frequency domain identification and cancellation technique is proved to be best suited for NBI suppression in π/4-DQPSK modulated DWT-OFDM [11].

Impulsive noise (IN) is defined as a short burst of non-Gaussian additive noise that occurs randomly over a period of time. The source from which IN arises is identified to be switching electrical equipment in [12].The time domain threshold based memoryless nonlinearity schemes for IN mitigation are clipping, blanking and combined clipping/blanking. Among these methods it is shown analytically that combined clipping-blanking gives better results in [1]. Both in [1] and [13] joint TD-FD technique for IN mitigation is proposed and a significant improvement in BER is obtained for this technique as compared to conventional OFDM systems and also OFDM-systems with nonlinearity-based impulsive noise reduction. The use of frequency domain method and joint time-frequency domain approach for IN reduction is described in [13] and their performances are compared in DFT-OFDM system affected by Poisson-Gaussian modeled IN. With respect to the use of coding schemes in OFDM, convolution coding (CC) is shown to best to mitigate IN than other coding schemes in [4]. Thus using these interpretations IN mitigation in DWT-OFDM using time domain methods, frequency domain method and joint time-frequency approach is simulated and compared with DFT-OFDM. The result from [14] show that joint time-frequency approach performs better in terms of BER in IN environments than the other methods.

III. NBI AND IMPULSIVE NOISE MITIGATION IN OFDM

From the literature survey, it was found that frequency domain identification and cancellation technique effectively suppresses NBI and joint time –frequency domain approach is effectual in IN environments. In this section joint time-frequency domain IN reduction and frequency domain identification and cancellation technique are briefed.

A. Frequency domain identification and cancellation

This method is carried out after DFT operation at the receiver i.e. in frequency domain. The k^{th} complex sample at the input of OFDM receiver is given by,

$$r(k) = s_t(k) * h(k) + n(k) + i_n(k) \quad (1)$$

Where $s_t(k)$ is the complex output signal for the sample k at the transmitter, $h(k)$ is impulse response of the channel, $n(k)$ is AWGN for sample k, and $i_n(k)$ is n^{th} complex single tone NBI for sample k. The narrow band interfering signal can be modeled as a complex sinusoidal tone.In this approach, the NBI frequency is estimated by tracking the position of maximum amplitude in the signal spectrum. A matrix is used to represent the interference.

$$i_n = Mx \quad (2)$$

$$M = \begin{bmatrix} \cos\left(\frac{\hat{w}_n k_1}{T}\right) & \text{j}\sin\left(\frac{\hat{w}_n k_1}{T}\right) \\ \cos\left(\frac{\hat{w}_n k_2}{T}\right) & \text{j}\sin\left(\frac{\hat{w}_n k_2}{T}\right) \\ & \cdots \\ \cos\left(\frac{\hat{w}_n k_N}{T}\right) & \text{j}\sin\left(\frac{\hat{w}_n k_N}{T}\right) \end{bmatrix} \quad (3)$$

$$x = \begin{bmatrix} a_n \\ b_n \end{bmatrix} \quad (4)$$

The interference i_n is a column vector of size $N \times 1$. Applying maximum likelihood algorithm, the solution is given by Equation (5).

$$\hat{x} = (M^T M)^{-1} M^T r \quad (5)$$

Where r is the input signal vector, $\hat{x}$ is the estimated amplitude of n^{th} complex NBI. After estimating the amplitude, frequency and phase, NBI cancellation is carried out by subtracting the estimated signal from received signal.

$$\hat{r}(k) = r(k) - \sum_{n=1}^{M} \alpha_n e^{j\left(\frac{w_n k}{T} + \varphi_n\right)} \quad (6)$$

Where $\hat{r}(k)$ is the input signal for the OFDM demodulator after NBI cancellation.

B. Joint Time-Frequency domain approach

The impulsive noise in received OFDM symbols is first reduced using a time domain preprocessor. The preprocessor is made of a Clipping/Blanking nonlinearity circuit. This combined nonlinearity technique is known to perform better than clipping and blanking nonlinearities. In order to further improve the impulsive noise mitigation, a frequency-domain suppression technique is applied to the OFDM signal after demodulation by means of DFT. A significant improvement in BER is obtained in case of joint time-frequency domain as compared to conventional OFDM systems and also OFDM-systems with nonlinearity-based impulsive noise reduction. The procedure used in joint time-frequency domain approach [13] is illustrated in block diagram Fig. 1.

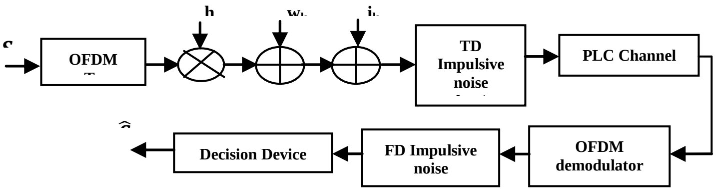

Fig. 1 Block diagram of the OFDM-based PLC system with impulsive noise reduction

IV. SIMULATION RESULTS AND DISCUSSION

For combined NBI and IN mitigation, the block diagram of DFT-OFDM and DWT-OFDM systems used are depicted in Fig. 2 and 3, the specifications employed are given in Table I. Mitigation of IN and NBI is carried out at the receiver end of OFDM system.

Table-I.OFDM System Parameters

Parameters	Specifications
Length of CP	16
Number of subcarriers/ no. of DFT or IDFT points	64
Rate of convolution encoder	1/2
Generator polynomials used in CC	[133], [171]
Modulation type	16-QAM, DQPSK
Channel model	PLC+NBI+IN
Type of wavelet used in case of DWT-OFDM	Haar
Decoding algorithm	Viterbi

The comparison of performances of NBI suppression methods namely wavelet denoising, frequency identification and cancellation, adaptive filtering and frequency excision techniques in DFT-OFDM and DWT-OFDM are shown in Fig. 4 and 5.

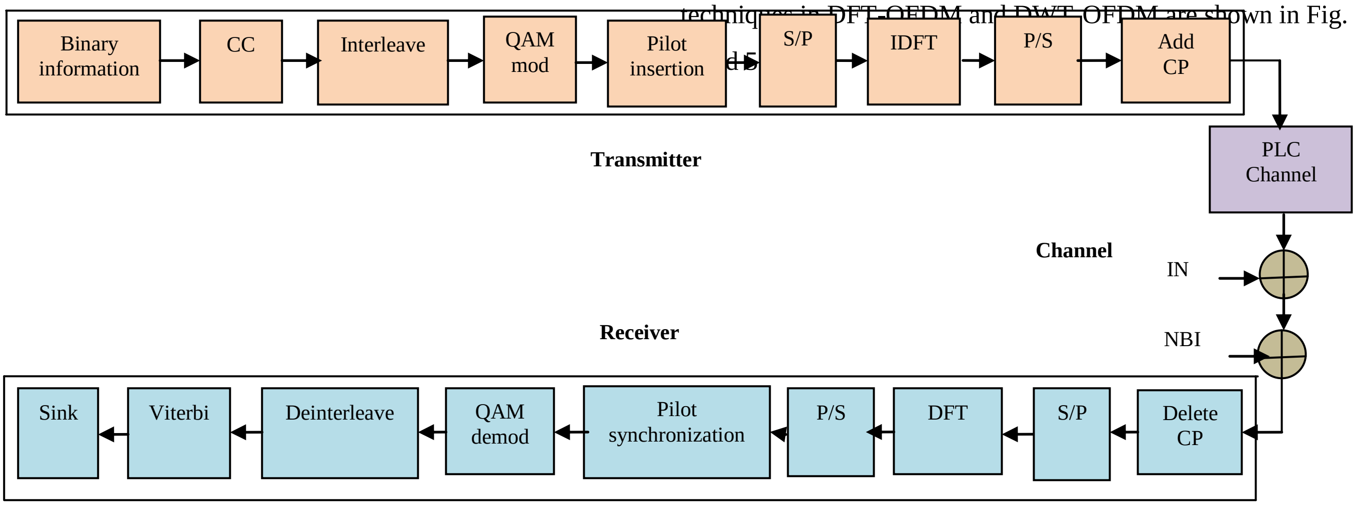

Fig. 2 Block diagram of DFT-PLC based OFDM with NBI and IN

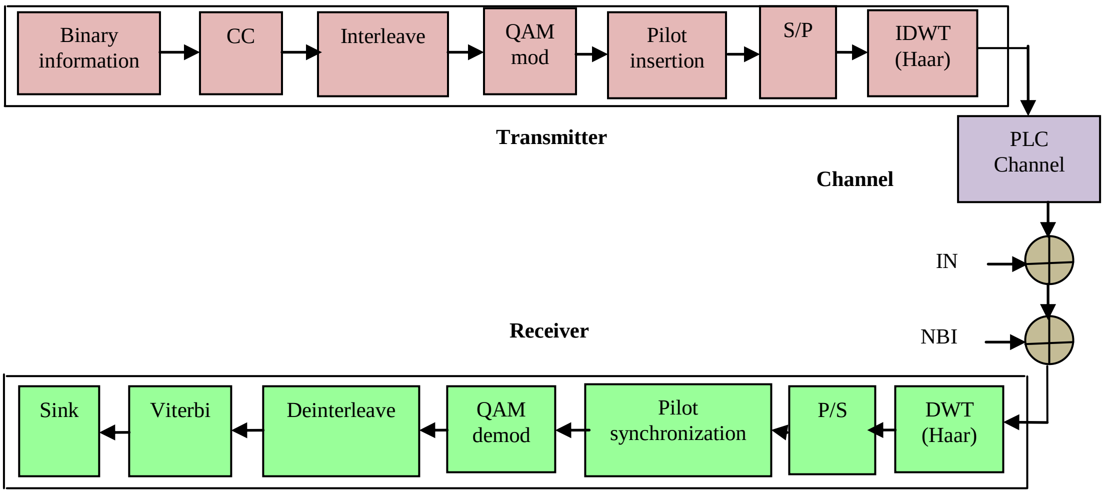

Fig. 3Block diagram of DWT-PLC based OFDM with NBI and IN

From Fig. 4, it can be observed that wavelet denoising, adaptive notch filtering, adaptive filtering, frequency excision and frequency domain identification and cancellation techniques provide BER of 0.1028, 0.1104, 0.05638, and 0.004396 respectively for an SNR of 20dB. Least value of BER is obtained for frequency identification and cancellation and highest value of BER is obtained in case of wavelet denoising. It is experimentally clear from Fig. 5 that wavelet denoising, adaptive filtering and frequency excision techniques offers

BER of 0.1717, 0.147, and 0.01235 at an SNR of 20dB respectively and frequency identification and cancellation technique provides a BER of 1E-3 at SNR 11.2 dB.

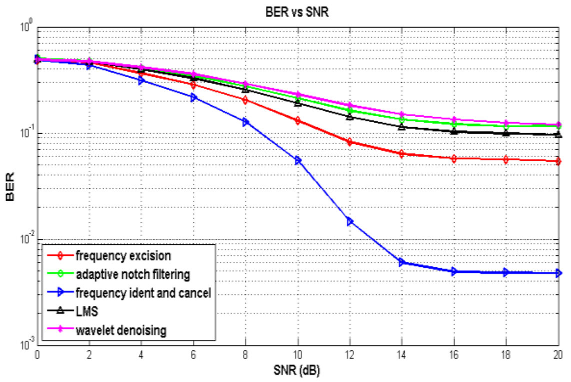

Fig. 4 Comparison of NBI suppression techniques in DQPSK-DFT-OFDM

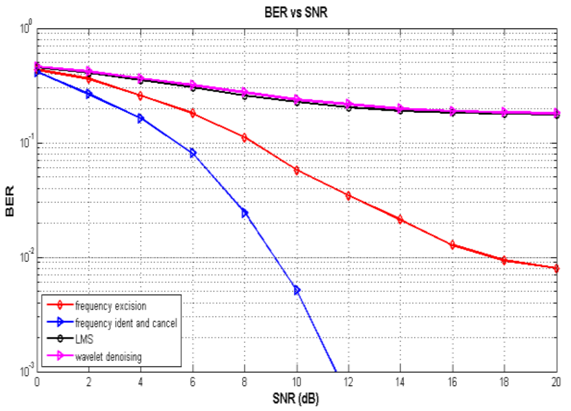

Fig. 5 Comparison of NBI suppression techniques in DQPSK-DWT-OFDM

Impulsive Noise cancellation in DFT- and DWT-OFDM systems with PLC channel and additive IN and AWGN is performed using clipping, blanking, combined clipping/blanking and joint time-frequency domain approach and their performances are compared. IN is represented using Gated-Gaussian (GG) model. The BER versus SNR comparison curves are as shown in Fig. 6 and 7. Joint time-frequency domain approach provides a least BER of 1E-4 for an SNR of 20dB as compared to 2.2E-1, 8.5E-2, 1.4E-2 and 1.1E-2 respectively attained in case of no mitigation, clipping, blanking and combined clipping/blanking. BER values of 1.4E-1, 7.7E-2, 2.5E-2, 9.77E-3 and 2.083E-005 are obtained for no mitigation case, clipping, blanking combined clipping/blanking and joint TD-FD technique respectively at SNR of 20dB. From both the plots it can be inferred that jointtime-frequency domain approach shows significant improvement in BER performance over the all other methods.

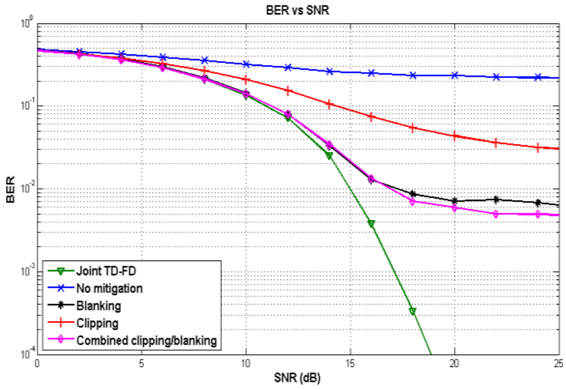

Fig. 6 Comparison of GG-IN mitigation techniques in DFT-OFDM based PLC

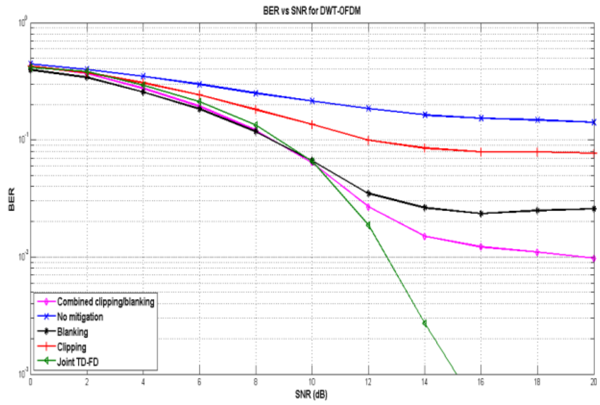

Fig. 7Comparison of GG-IN mitigation techniques in DWT-OFDM based PLC

From all the above simulations, it can be concluded that frequency domain identification and cancellation technique is suitable for NBI suppression and joint time-frequency domain approach is apt for IN mitigation. Making use of these two techniques in DFT-OFDM and DWT-OFDM systems with PLC channel, NBI and GG-IN yields performance curves which are depicted in Fig. 8. Here, BER of 6.875E-3 and 4.604E-3 is achieved at an SNR of 30dB for FFT-OFDM and DWT-OFDM respectively.It can also be unambiguously said that in all cases DWT-OFDM outperforms DFT-OFDM system.

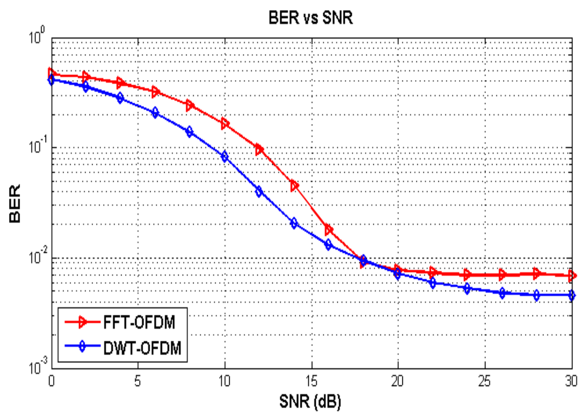

Fig. 8 Combined IN and NBI mitigation in OFDM

V. CONCLUSION

The combined effect of IN and NBI on OFDM is devastating. It causes severe degradation in the performance of OFDM. This problem can be overcome by using frequency domain identification and cancellation and joint time-frequency domain approaches. Further, the use of DWT-OFDM in PLC or in any other environment with noise and interferences proves to better than DFT-OFDM. DWT-OFDM in PLC has provided a least BER of 4.604E-3 at an SNR of 30dB. Finally, from the simulation and analysis done so far it can be concluded that DWT-OFDM with frequency domain identification and cancellation technique for the case of NBI and joint time-frequency domain approach for IN reduction gives an efficient OFDM system that can be preferred to be employed for the next generation communication systems.

ACKNOWLEDGMENT

This work has been supported as part of the project work by BMSCE, Bangalore. The authors would like to express their gratitude to Vision Group on Science & Technology, Govt of Karnataka for providing the infrastructure support to carry out this research work.

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