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Adaptive IIR Notch Filter Design For Cancellation of Periodic Impulsive Noise in OFDM Based Power Line Communications

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ABSTRACT: This paper presents a simple and cost effective method to remove the periodic impulsive noise in power-line communications (PLC) system. In the real PLC environment, some electrical appliances will produce impulsive noise at a fixed frequency with the power spectral density (PSD) usually exceeding that of the received signals. This type of impulsive noise is the periodic impulsive noise, and it usually remains stationary over periods of minutes or even for hours. This paper deals with a simple and effective approach to remove the periodic impulsive noise before the synchronization of PLC receiver. The proposed algorithm is employed to detect the periodic impulsive noise and then suppresses the periodic impulsive noise with an adaptive infinite impulse response (IIR) notch filter before the synchronization of the system.

KEYWORDS: Adaptive infinite impulse response (IIR) notch filter, Orthogonal Frequency Division Multiplexing (OFDM), Periodic impulsive noise, power-line communications.

I. INTRODUCTION

Unlike traditional electric grids that carry one-way flow of power from generators to customers, smart grids use two-way flows of information to create an intelligent energy delivery network. Various technologies have emerged to facilitate data communications throughout the grid, especially in two scenarios: outdoor communications between local utilities and customers, and indoor communications for home area networks [3]. Power line communications (PLC) have been attractive as a solution for smart grid communications. Power lines differ significantly in their structure and physical characteristics from usual communication mediums such as fibre optic and coaxial cables . Understanding those properties is essential for the design of PLC systems. Due to the existing power-line network infrastructure, transmitting signals over the power line will cost less than other communication approaches. The power-line network is not originally designed to transmit signals, but to supply power for all kinds of electrical appliances. So the PLC environment is full of noise which is mostly produced by the electrical appliances in the power-line networks. The noise in the PLC environment has been categorized into five general classes: colored background noise; narrowband noise; periodic impulsive noise asynchronous to the mains frequency; periodic impulsive noise synchronous to the mains frequency; and asynchronous impulsive noise.

A number of modulation techniques, including single-carrier, multi-carrier and spread spectrum are of interest for PLC. 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

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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 sub-channels through the discrete Fourier transform (DFT) operation in the receiver. OFDM offers robustness as well as simple implementation which make this technique a favoured candidate [12] for PLC. Noise in communication systems is typically modelled as a Gaussian random process. Various power electronic devices, especially those with switching circuitry, inject random or periodic emissions of noise into the connected power lines. The resulting noise deviates from the Gaussian model and is impulsive in nature. In the real PLC environment, some electrical appliances will produce impulsive noise at a fixed frequency with the power spectral density (PSD) usually greatly exceeding that of the received signals. This type of impulsive noise is the periodic impulsive noise asynchronous to the mains frequency (periodic impulsive noise) since its shape is similar to the damped sinusoid, and it is usually found remaining stationary over periods of minutes or even for hours. Periodic impulsive noise asynchronous to the mains frequency is a periodic interference that occurs with repetition rates in the range of 50 to 200 KHz. Impulses of this kind occur due to the switching of power supplies. 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 [16] may work incorrectly or fail to work. The bit-error rate (BER) of the PLC system will greatly increase, and it will lead to the significant degradation or corruption of the PLC system. The periodic impulsive noise is impulse in the frequency domain. 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. This paper deals with a simple and effective approach [1] to remove periodic impulsive noise, so that the synchronization module of PLC system can work normally and the adverse effect on the subcarriers can be reduced when the system is interfered by periodic impulsive noise. The proposed algorithm is divided into three steps: first, to detect the periodic impulsive noise in frequency domain by sharing the FFT module with the OFDM demodulation of the system, then locate the interfered subcarrier position to represent the periodic impulsive noise frequency. Then, suppress the periodic impulsive noise with the adaptive IIR notch filter. The PLC system is a narrowband OFDM system in the low-frequency band, so we should mitigate the periodic impulsive noise with maximum strength.

There were many earlier methods for noise mitigation in power line communications. These methods include time domain methods, frequency domain methods and joint time/frequency domain methods [8]. The nonlinearity technique includes clipping nonlinearity, Blanking nonlinearity and combined blanking-clipping nonlinearity. The performance of OFDM receivers with the nonlinearity impulsive noise mitigation techniques of blanking, clipping, and combined blanking-clipping has been compared in [14]. The results show that each of the three nonlinearities can have good performance under a certain signal-to-noise ratio (SNR) condition. Receiver windowing[4] is a technique which exploits redundant information in the cyclic prefix to improve the SNR of the equalized signal. It is well suited to cases where the time span of the channel impulse response is shorter than the prefix, and there is a strong correlation in the noise. Another method is an iterative interference cancellation[18] scheme for OFDM signals with blanking nonlinearity in impulsive noise channels. Traditional methods for impulsive noise suppression in multicarrier receivers are based on time domain signal processing before conventional OFDM demodulator.

II . OVERVIEW OF PROPOSED APPROACH

The PLC system in this paper is a narrowband OFDM system in the low-frequency band, so the periodic impulsive noise with maximum strength is to be cancelled. The mitigation of the periodic impulsive noise with the maximum strength will significantly improve the system performance in most cases. OFDM is a multicarrier communication system, which modulates with IFFT and demodulates with FFT. In the PLC system, the FFT demodulation module of the receiver is idle most of the time. Only when the transmitted data are received, the synchronization module of the PLC receiver will synchronize well. And then the FFT module is enabled to demodulate the received data else it is idle. Since the periodic

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impulsive noise is usually stable in a long period, the periodic impulsive noise in frequency domain can be periodically detected. When the PLC receivers receive signals, the periodic impulsive noise has already been detected, and then periodic impulsive noise can be cancelled from the received signals.

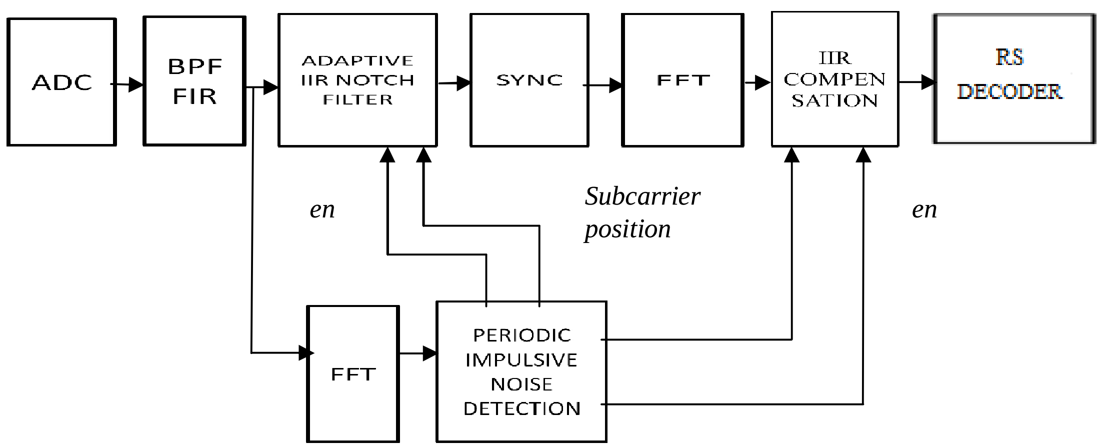

Figure 2.1: Block Diagram of PLC receiver

The ADC part is an Analog to Digital converter. The BPF FIR part is a finite impulse response (FIR) bandpass filter (BPF).The adaptive IIR notch part is an adaptive IIR notch filter which is to suppress the periodic impulsive noise. The Sync part is the synchronization module of the PLC receiver. IIR compensation part is designed to compensate the distortion of received signals brought about by the IIR notch filter. The periodic impulsive noise detection part is designed to detect the periodic impulsive noise and locate the periodic impulsive noise in the frequency domain. The FEC decoder used is a Reed Solomon(RS) decoder. The output from the power line is coupled to ADC through a power line coupler. The ADC output data are filtered by the FIR BPF. Then, the output data of the BPF are sent to the FFT module if the periodic impulsive noise detection module begins to work. The *en* means whether periodic impulsive noise exists or not. The *subcarrier position* means the frequency of periodic impulsive noise. If it is confirmed that periodic impulsive noise exists at the period, the frequency of periodic impulsive noise will be located, and the output data of the BPF will be filtered by the adaptive IIR notch filter, and then the output data of the IIR notch filter will be sent to the synchronization module of the system. If periodic impulsive noise does not exist, the output data of BPF will be sent to the synchronization module directly with the IIR notch filter bypassed. The IIR compensation module will work if the periodic impulsive noise exists, or else, it stops working. FEC is always working to decrease the BER of the system. The periodic impulsive noise detection module works periodically by sharing the FFT module with OFDM demodulation. The adaptive IIR notch filter will be enabled to suppress the periodic impulsive noise if periodic impulsive noise is confirmed and located. Due to the use of the IIR notch filter, nonlinear phase distortion and magnitude distortion are brought into the OFDM-based PLC system, and compensation for the signal distortion is needed.

III. PERIODIC IMPULSIVE NOISE CANCELLATION

The time realization of the periodic impulsive noise PIN(t)can be modeled as,

$$PIN(t)=Ae^{-\tau t}\cos(2\pi f_0 t)$$

Where, A is the peak value of the amplitude of the periodic impulsive noise, τ is the damping factor, and *f*_0 is the frequency of periodic impulsive noise. Then, the received data can be represented as,

$$r(t) = s(t) + \eta\_background + imp(t)$$

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where, s(t) is transmitted data from the transmitter, η_background is the background noise which can be modelled as white Gaussian noise (WGN), imp(t) is impulsive noise, and the periodic impulsive noise is the dominant impulsive noise. When the periodic impulsive noise detection module begins to work, only N OFDM symbols are sent to the detection module to detect the periodic impulsive noise. If most of the OFDM symbols are interfered by periodic impulsive noise and the frequency of periodic impulsive noise in every symbol are almost the same, it can be concluded that there is periodic impulsive noise in the PLC environment at that period. At the same time, the detection module calculates the frequency of the periodic impulsive noise. Since the band of the OFDM-based PLC system is divided into number of subcarriers, and the PSD of periodic impulsive noise greatly exceeds that of the signals, it is easy to find out which subcarrier is interfered by the periodic impulsive noise. Then the position of the interfered subcarrier is calculated to represent the periodic impulsive noise frequency. In this way, the complexity of the periodic impulsive noise detection can be significantly reduced. After the detection module has received OFDM symbols, whether the periodic impulsive noise exists or not will be confirmed, and the position of the interfered subcarrier can be located if there is periodic impulsive noise. The detection module will stop working until it next wakes up. So the periodic impulsive noise detection module will work periodically and work for only a short duration every time. When the detection module begins to work, every OFDM symbol sent into this part will be demodulated by FFT. Then the value of the 73 subcarriers in the symbol will be obtained. Next the power of every subcarrier is calculated and then find out the maximum power value *Pmax* and mean power value *Pmean* of the 73 subcarriers, the scale factor α is determined by repetitious experiments. If below condition is satisfied, it is confirmed that the OFDM symbol is interfered by periodic impulsive noise; otherwise, periodic impulsive noise is not in the symbol.

$$Pmax > Pth$$
$$Pth = \alpha * Pmean$$

A. Adaptive IIR Notch Filter

A band reject (band stop) filter is a filter that passes the most part of frequencies unchanged but attenuates other frequencies to very low levels in a certain range. A notch filter actually can also be perceived as a band stop filter with a high Q factor. The digital notch filter can also be classified according to the number of frequencies the filter can reject: (1) Fixed notch filters (2) Tunable notch filters (3) Adaptive notch filters. Generally, Adaptive IIR notch filters remove interference using a reference signal. If it is encountered with signals which have variable frequency and depend on events over time, i.e. the notch frequency is unknown, then adaptive notch filters (ANFs) are utilized in this kind of situation. They can automatically adjust their frequency response depending upon circumstances. This filtering method leaves source signal undistorted. Once the periodic impulsive noise is detected and located, an effective technique is needed to mitigate the periodic impulsive noise before the synchronization of the PLC receiver. The periodic impulsive noise can be cancelled in the frequency domain and then transform the signals to time domain before the synchronization of the PLC system. Since the OFDM-based PLC system is divided into 73 subcarriers and every subcarrier may be interfered by periodic impulsive noise, an adaptive IIR notch filter is designed to mitigate the periodic impulsive noise in the time domain before synchronization of the PLC receiver. If the periodic impulsive noise is located, the adaptive IIR notch filter is enabled to suppress the noise, else it is bypassed.

IV. SIMULATION RESULTS

The proposed method is simulated by using Matlab as shown in figure.2.1. In the PLC system, the signal is modulated by QPSK. In the Matlab simulation, the periodic impulsive noise is simulated as a damped sinusoid which lasts for the same time as one OFDM symbol. Since the periodic impulsive noise usually remains stationary over periods of minutes or even for hours, every OFDM symbol of the transmitted signals will be added by the same periodic impulsive noise in a simulation. To simulate the real PLC environment, WGN is also added to the transmitted signals transmitted by the PLC transmitter.

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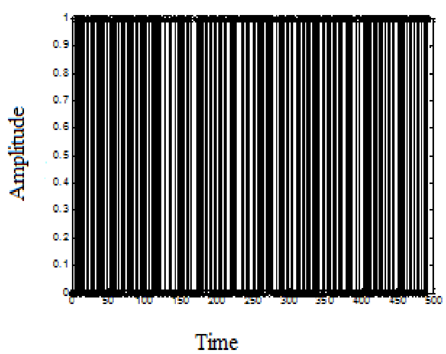


Figure 4.1 : Transmitted Signal

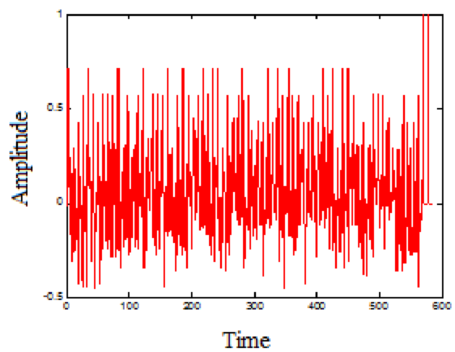
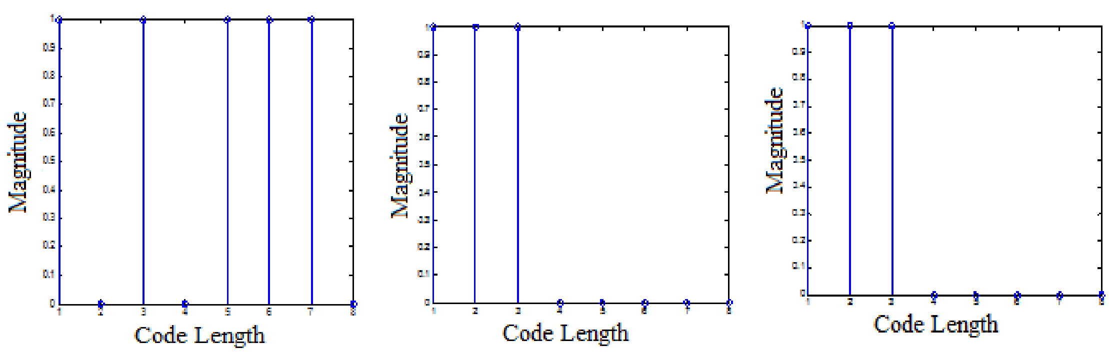


Figure 4.2: Uncorrupted OFDM

The figure 4.1 shows the transmitted data. 493 data points are transmitted. Then Reed Solomon encoder is used for encoding data. Then cyclic prefix is added and the transmitted data is modulated using quadrature phase shift keying. Here 73 subcarriers are used. The figure.4.2 shows uncorrupted OFDM, that is without anyNoise neither periodic impulsive noise nor gaussian noise.



(a) (b) (c)

Figure 4.3: (a) PN sequence (b)Channel(c) Estimated channel

After transmitting OFDM symbol channel has to be modeled. Then a complex multipath channel (figure.4.3(b)) is designed which is estimated at the receiver side for channel state informations by deconvolving pn sequence output and the complex multipath channel. When the OFDM symbol is transmitted through the communication link or channel the noise will be added to the uncorrupted data .Since Gaussian noise is an inbuilt noise in the multipath channel, it is eliminated by deconvolving the noisy transmitted signal and the estimated channel thus obtaining noise free signal.

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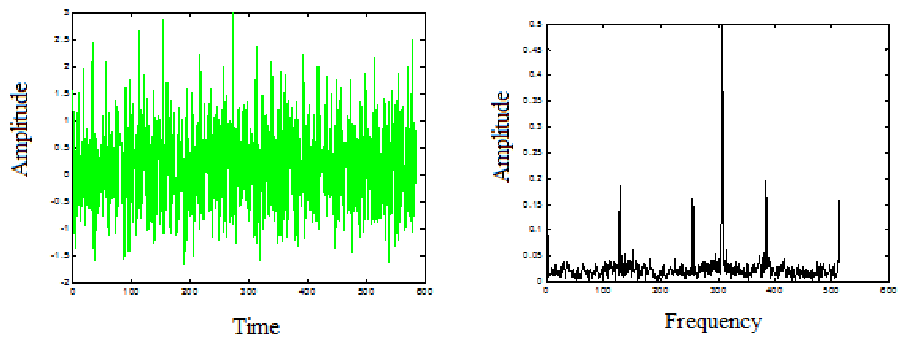
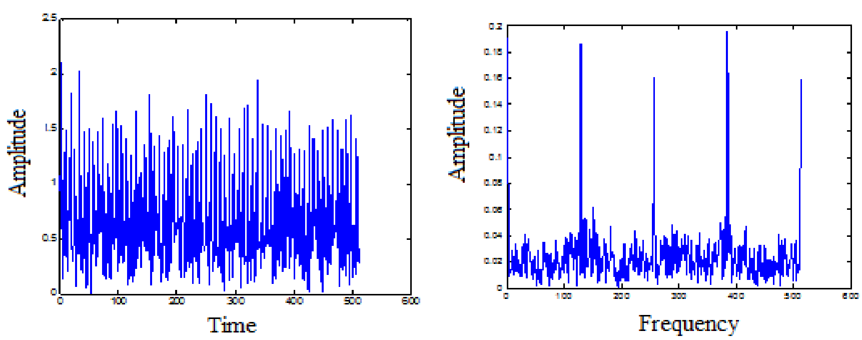


(a) (b)

Figure 4.4:(a) Corrupted OFDM(b) Frequency spectrum of corrupted OFDM

Then a 300Hz periodic impulsive noise is added to the signal. This corrupted OFDM with periodic impulsive noise is plotted in figure. 4.4(a). Since noise cannot be detected in its time domain, inorder to detect and locate the periodic impulsive noise fast fourier transform of the symbol has to be obtained. Thus the frequency spectrum of the noisy OFDM is plotted which is shown in figure 4.4(b).Then the frequency and amplitude of noise can be detected. The noise peaks can be clearly seen at 300Hz in the frequency spectrum. Once the location or frequency of the noise is detected this noise has to be removed. Inorder to remove this periodic impulsive noise an adaptive IIR notch filter is designed which removes the noise at frequency tone of 300Hz.This filtered OFDM is plotted in figure 4.5(a) which is a time domain plot.



(a) (b)

Figure 4.5: (a) Filtered OFDM (b) Frequency spectrum of filtered OFDM

The fast fourier transform of the filtered OFDM is done to obtain the frequency spectrum of this filtered OFDM which is shown in figure 4.5(b).Thus can be seen that the noise at 300Hz of frequency is filtered out. Figure 4.6 shows received signal after demodulation and RS decoding.

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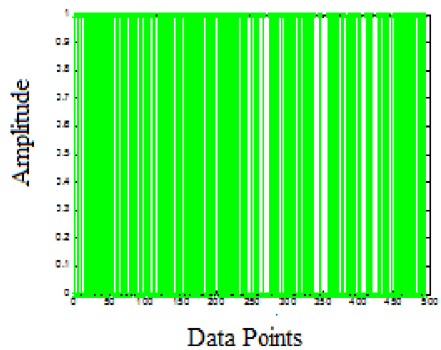

Figure 4.6: Received Signal

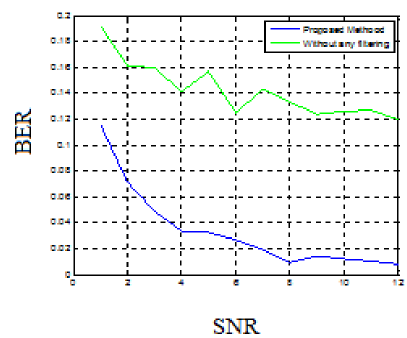

Figure 4.7: Comparison of proposed method and that without filtering

To evaluate the efficiency of the proposed algorithm, the periodic impulsive noise is added to the transmitted signals with the SINR increasing step by step. Then, the BER of the PLC system with the proposed impulsive noise mitigation technique and the BER of the PLC system without impulsive noise mitigation algorithm is calculated. Figure. 4.7 shows the results of the simulation when the PLC system is interfered with the periodic impulsive noise and without any noise. As shown in figure. 4.7, with the proposed algorithm, the BER of the PLC system will be significantly decreased when the system is interfered by the periodic impulsive noise. The Matlab simulation shows that the proposed algorithm is effective for the periodic impulsive noise cancellation

V. CONCLUSION

In this paper, an effective filtering is done for periodic impulsive noise removal. The transmitted signal when passed through power line channels it will get interrupted with periodic impulsive noise. This noise is detected in the receiver side and the detected noise is removed using an adaptive IIR notch filter. Inorder to cancel periodic impulsive noise first of all the periodic impulsive noise in frequency domain has been detected by using periodic impulsive noise detection module, and locate the interfered subcarrier position to represent the periodic impulsive noise frequency. Then, suppress the periodic impulsive noise with the adaptive IIR notch filter. Once the noise is removed the receiver decodes the signal using an RS decoder. Using this method BER can be reduced when compared to that without using filter.

As a future task the RS decoder can be replaced with a Turbo decoder. Since the turbo decoder can reduce Bit Error Rate even at low SNR values and thus can lead to better performance. Turbo encoding uses Recursive Systematic Convolutional (RSC) encoders. Turbo Codes are well suited for long distance and low power wireless communications because it achieve a very low bit error rate (BER) at very low SNR. This means that data is still transmitted nearly error-free with a low energy signal. After replacing with turbo decoder PAPR reduction of the turbo coded OFDM system can also be done.

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