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Periodic Impulsive Noise Suppression in OFDM-Based Power-Line Communications through Filtering Technique

[1] Sree Lekshmi.K, [2] Suby Varghese
[1] M.Tech Scholar, [2] Asst. Professor ECE Department
TKM Institute of Technology, Kollam, Kerala, India

Abstract;- **Power line communication (PLC) approach is in demand owing to its high data rate and low cost. PLC has a number of application areas ranging from home automation to internet access. Since the power grid is designed optimally for power delivery (not the data), the power transmission line generally appears as a harsh environment for the low-power high-frequency communication signals. The electrical appliances in the power-line network produce different types of noises, leading to performance degradation. In this paper, an algorithm is used to detect the presence of periodic impulsive noise in the orthogonal frequency division multiplexing (OFDM) based PLC system and then suppress it with an adaptive infinite impulse response (IIR) notch filter. The simulation results show that the periodic impulsive noise mitigation technique is simple and effective for the OFDM- based PLC system.**

Index terms **: adaptive IIR notch filter, bit error rate (BER), detection, OFDM, periodic impulsive noise, PLC.**

I. INTRODUCTION

Communication is the process of transmission of information from one point to another through a guided or unguided medium. Wired communication refers to the transmission of data through a wired medium of communication technology. Examples include telephone networks, cable television or internet access and fibre-optic communication. In general, wired communications are considered to be the most stable of all types of communications services. They are relatively impervious to adverse weather conditions when compared to wireless solutions. These characteristics have allowed wired communications to remain popular, even as wireless solutions have continued to advance.

Power Line Communication (PLC) is a technology where power lines or transmission lines are being used for communication purposes along with transmitting electrical energy. PLC systems include a transmitter unit competent of sending (transmitting) communication signals over the power line signal and also have a receiver unit at the receiving end which separates the communication signal and the power signal. Because the power grid is already in place, the PLC has the obvious advantage of reducing communication infrastructure cost. Power line networks, however, present a hostile channel for communication signals, since their fundamental purpose is the transmission of electric power at super-low frequencies (i.e. 50 Hz or 60 Hz) [2]. Signals propagating along the power line are subjected to very large amounts of noise, attenuation, multipath, selective fading and distortion that make them erratic and frequently variable over time, hindering the performance of PLC systems. Many noise sources on power lines result in interference, cross-chatter, and signal distortion. Electrical devices connected to the power mains can inject significant noise back onto the network [3]. The noise in the PLC environment has been categorized into five general classes: 1) colored back- ground noise, 2) narrowband noise, 3) periodic impulsive noise asynchronous to the mains frequency, 4) periodic impulsive noise synchronous to the mains frequency and 5) asynchronous impulsive noise. Periodic impulsive noise asynchronous to the mains frequency, consists of impulses of longer duration that occur periodically in time. They have significant spectral components in the band used by broadband power-line communication systems. Because of its high repetition rate i.e. between 50 and 200 KHz, it occupies frequencies that are too close to each other and therefore frequency bundles that are usually approximated by frequency bands [4].

Modern PLC networks utilize Orthogonal Frequency Division Multiplexing (OFDM) modulation techniques to increase data throughput rates and reliability in inherently noisy environments such as electric grids. OFDM combines two communication concepts: multi-carrier modulation (MCM); and orthogonal frequency shift keying (FSK). MCM attains wideband data-rates by dividing a wideband data stream into parallel, lower rate data streams and transmitting them over multiple narrowband carriers. The benefits of this strategy are longer symbol intervals and narrowband channel characteristics. Orthogonal FSK enables each OFDM carrier to be orthogonal to all other carriers transmitted. This orthogonality is achieved by separating the carriers by an integer multiple of the symbol duration of the narrowband data stream. The effects of inter-symbol-interference (ISI) are mitigated via the use of longer symbol duration, as well as the use of a cyclic prefix (CP). The cyclic prefix is a copy of the tail of the symbol period that is appended to the start of the message as a guard interval [4]. Generally, OFDM systems are inherently robust to impulsive noise interference. Indeed, the longer OFDM symbol duration provides an advantage, since the impulse noise energy is spread among simultaneously transmitted OFDM subcarriers. However, this advantage may turn into a disadvantage if impulse noise energy exceeds a certain threshold [1]. Once the signals received by the OFDM-based PLC receiver are interfered by the periodic impulsive noise, the bit-error rate (BER) of the PLC system will greatly increase, and it will lead to significant degradation of the throughput. So there arises the need for periodic impulsive noise mitigation [2].

II. RELATED WORKS

Different methods are in use for removing the periodic impulsive noise from the PLC channel [6], of which some of them are discussed in the following section :

A.Time-domain methods

The effect of impulsive noise in multicarrier signals can be reduced by preprocessing the time-domain signal at the front end of the receiver using a memoryless nonlinearity [5], [6], [7], [10]. Nonlinear techniques include clipping, blanking and clipping/blanking [8].

B. Frequency-domain methods

Such techniques are employed at the OFDM receiver after the signal demodulation and channel equalization of the received signal based on preliminary estimates of the transmitted signal that are then used to estimate the noise in the received signal. The obtained estimation of the impulsive noise term is subtracted from the original received signal prior to final demodulation using the DFT operation [9].

C. Joint time-domain/frequency-domain method

The technique combines the time-domain nonlinearities with the frequency-domain suppression technique. The impulsive noise in the received OFDM symbols is first reduced using combined clipping/blanking nonlinear preprocessors [7]. Next, in order to further improve the impulsive noise mitigation, the frequency-domain suppression techniques applied to the OFDM signal after channel equalization and DFT demodulation.

D. Error Correction Codes

Forward error correction (FEC) is implemented by adding redundancy bits to the useful data bits. The receiver can then use these redundancy bits to detect and possibly correct errors occurring during data transmission at the cost of lowering the useful data rate. Different coding methods can be suitable for PLC systems such as Hamming codes, block codes etc. [10].

E. Spread spectrum techniques

In SST, a single carrier with frequency f0 is first modulated with the information using conventional modulation methods producing a bandwidth that is approximately double the message bandwidth. Then a second stage of modulation is performed using a high-speed pseudo-random sequence. After this modulation, a bandwidth of about twice the clock frequency of the pseudo-random sequence is obtained. At the receiver side, the same sequence used in the transmitter must be known and synchronized with the received signal. After that, the resulting signal is demodulated conventionally to obtain the message signal [8].

III. SYSTEM MODEL

Fig.1. shows the block diagram for detection and mitigation of the periodic impulsive noise in the PLC channel. The encoder part is the FEC (Forward Error Correction) encoder consisting of RS (Reed Solomon) encoder, convolutional encoder (RSCC) and interleaver [10]. 16 QAM (Quadrature Amplitude Modulation) technique is adopted in the PLC system. The coded OFDM technology uses 96 subcarriers for data transmission. The FFT size is 512 points. While passing through the channel, the data gets corrupted with impulsive and background noises. At the receiver side, the initial step is noise detection.

A. Noise Detection

The periodic impulsive noise is modeled as a damped sinusoid.

$$x(t) = Ae^{-\tau t}\cos(2\pi f_0 t) \qquad (1)$$

where 'A' is the peak value of the amplitude of the periodic impulsive noise, 'τ' is the damping factor, '

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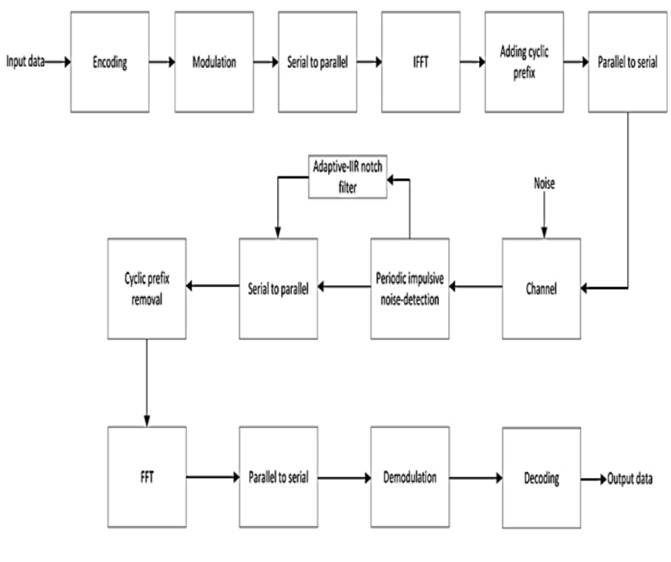

Fig. 1. Block diagram of periodic impulsive noise mitigation algorithm

f_0' is the frequency of the periodic impulsive noise. Therefore, the received signal is the sum of transmitted signal, background noise modeled as white Gaussian noise (WGN) and periodic impulsive noise [3], [4].

$$r(t)=s(t)+\eta_{background}(t)+imp(t)$$

Here, the band of the OFDM – based PLC system is divided into 96 subcarriers. For noise detection, initially the power value of each subcarrier is calculated and the maximum power value ‘P_{max}’ is found out. Then a threshold value P_{th} is set. If ‘P_{max}’ is greater than ‘P_{th}’ the presence of periodic impulsive noise can be confirmed. Since the power spectral density (PSD) of the periodic impulsive noise is much greater than the information signals, it is easy to find out the position of the interfered subcarrier. The position of the interfered subcarrier represents the frequency of periodic impulsive noise. Thus, the noise detection algorithm is simplified.Once the noise is detected and located, an adaptive IIR notch filter is designed to mitigate the periodic impulsive noise since every subcarrier may be affected by the noise.

B. Adaptive IIR Notch Filter

The main application of a notch filter is to remove narrowband or sinusoidal interferences from a desired broadband signal. Adaptive IIR notch filters are used to estimate/track frequencies of sinusoidal components in noise to cancel a periodic interference [11]. The transfer function of a single second order IIR filter is shown as :

$$H(Z)=\frac{b_0+b_1Z^{-1}+b_2Z^{-2}}{1+a_1Z^{-1}+a_2Z^{-2}} \qquad (3)$$

The band of the system is divided into 96 subcarriers, therefore 96 notch filters are designed, each of whose notch centre frequencies is the centre frequency of the interfered subcarrier. The coefficients of the filters are calculated according to (3). Assuming that the ‘ith’ IIR notch filter’s transfer function is,

$$H_i(Z)=\frac{b_0(i)+b_1(i)Z^{-1}+b_2(i)Z^{-2}}{a_0(i)+a_1(i)Z^{-1}+a_2(i)Z^{-2}} \qquad (4)$$

with $b_0(i)=$ $b_2(i)=$ $a_0(i)=1$, $a_2(i)=$ ρ^2, $b_1(i)=$ $-2\cos\omega_0$, $a_1(i)=$ $-2\rho\cos(\omega_0)$, where ‘ρ’ is the rejection bandwidth of the filter and $\omega_0=(2\pi f_i)/f_s$. ‘f_s’ is the Nyquist sampling frequency and ‘f_i’ is the notch centre frequency of the IIR notch filter [1].

So, once the position of the interfered subcarrier is located and the frequency of the periodic impulsive noise is confirmed, the notch filter whose notch centre frequency is the interfered subcarriers centre frequency, is chosen to mitigate the noise.

After filtering, the operations carried out at the transmitter are reversed i.e., removing cyclic prefix, performing FFT, demodulation and decoding to obtain the output data.

IV. SIMULATION RESULTS AND DISCUSSIONS

The parameters used for simulation are described in Table 1

TABLE 1. SIMULATION PARAMETERS

Encoder	RS-CC
Modulation Technique	16 QAM
No. of subcarriers	96
Size of cyclic prefix	16
FFT length	512

Following are the simulation results :

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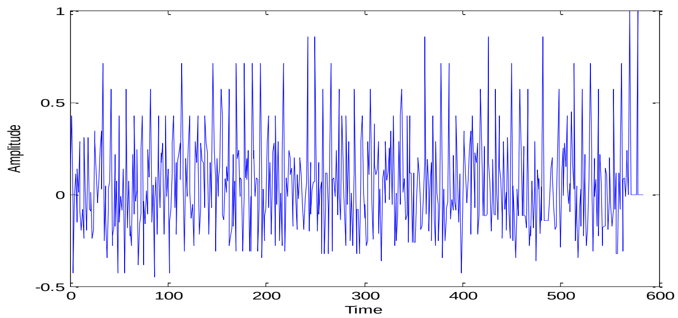

Fig. 2. Pure OFDM

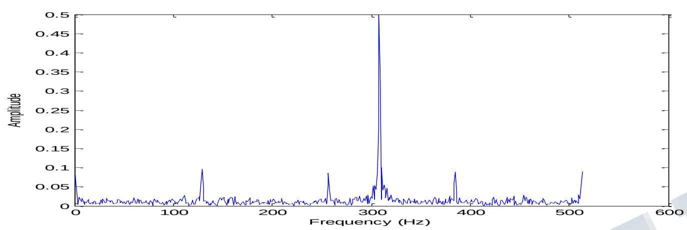

Fig. 3. Frequency spectrum of noisy OFDM

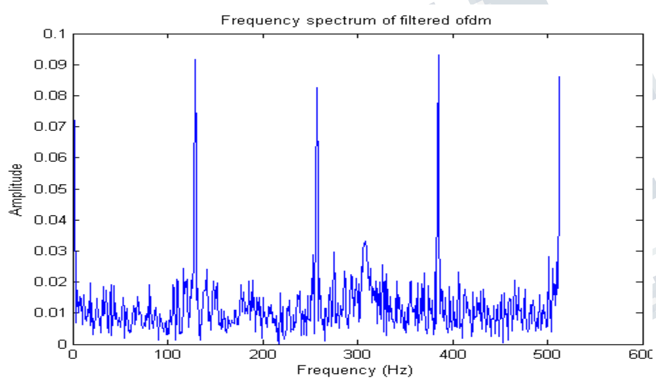

Fig. 4. Frequency spectrum of filtered OFDM

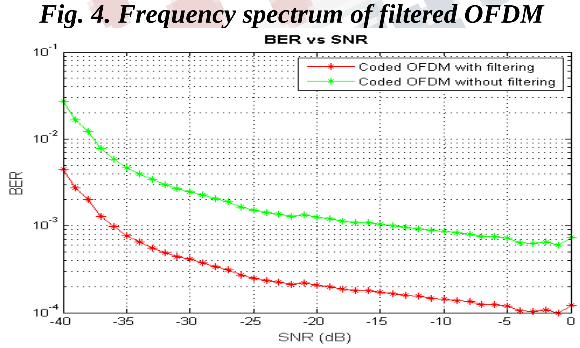

Fig. 5. BER Vs SNR

The simulation result shows that the BER of the PLC system is less when the adaptive IIR notch filter is used, compared to the BER of the system when no such filtering is done. This proves that the algorithm is effective in mitigating the periodic impulsive noise in the PLC channel.

V. CONCLUSION

High data rate and low cost makes PLC an attractive communication technique. But its performance is severely degraded by the presence of periodic impulsive noise in the channel. An adaptive IIR notch filter is used to mitigate the periodic impulsive noise. First, the noise is detected in the frequency domain. Then it is suppressed using an adaptive IIR notch filter. To find out the effectiveness of the algorithm, BER Vs SNR plot for both the filtered and the unfiltered cases were simulated. The Matlab simulation proves that the periodic impulsive noise mitigation algorithm has good performance in the OFDM-based PLC system.

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