Mitigation of Impulse Noise in Powerline Systems Using ANFIS Technique

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Abstract--- The use of OFDM channel for the transmission of data in power line communication (PLC) system has been of several importance to technology development. However, during transmission, the OFDM channel is greatly disturbed by impulse noise that causes a wrong information to be received. Several techniques such as iteration, coding, clipping and nulling methods have been used to lessen the upshot of impulse noise in OFDM channel. However, these techniques still suffer some drawbacks and require a high signal-to-noise (SNR) power for high performance. This paper presents an advanced use of artificial neuro-fuzzy inference system (ANFIS) technique in removing the complete impulse noise and some of the additive white Gaussian noise (AWGN) that were mixed with the transmitted data in an OFDM channel and using the minimum SNR power. Obtained results propose that ANFIS technique can be used to mitigate impulse noise from a powerline communication channel.

Keywords— Machine learning, Orthogonal frequency division multiplexing, additive white Gaussian noise, impulse noise, encoders, ANFIS, clipping and nulling. bit error rate, power line communication.

I. INTRODUCTION

Power-line communication (PLC) system is commonly used to transmit data and signals from the transmitter to the receiver end. PLC has also been used for several technology purposes such as home automation, smart grid metering and internet access referred to as "broadband over powerline (BPL)" [1]. Some of the merits of PLC include low cost of implementation, easy to install, serves well for distribution purposes and can work with an existing electrical wiring [2]. However, data transmission through PLC is greatly disturbed by both impulse noise and background noise [3]. Other sources of distortion in PLC include frequency-selectivity and high-channel attenuation [4]. Both impulse noise and background noise contribute majorly to the high packet rate or bit error rate (BER) in powerline systems [5]. The impulse noise varies rapidly with time and can be classified into asynchronous impulse noise (AIN), periodic impulse noise synchronous to main frequency and periodic impulse noise asynchronous to the main frequency [6, 7]. Background noise varies slowly with change in time. Background noise is classified into narrowband noise and coloured noise. A good example of coloured noise is the additive white Gaussian noise (AWGN) [8]. Several schemes of suppressing and eliminating impulse noise (IN) were studied and can be classified into two groups namely parametric and non-parametric method. The Parameter methods aim to obtain the optimal onset to process the received signal using parameter estimation with the noise model. This method is known as nonlinear methods. Parametric methods try to seek a maximum threshold that limits the power of impulse noise. Regrettably, parametric methods still interfere with the signal in the process of limiting the impulse noise. Furthermore, parametric method involves extra training overhead and once the noise model mismatches the time varying noise statistics, they suffer degradation in the performance. Non-parametric methods however can bypass the demand of previous knowledge and noise model by using the sparse arrangement of impulse noise in the time domain [9].

Recent work is done using clipping and nulling (blanking) technique, interleaves, iterative and coding techniques to reduce the effect of impulse noise from a corrupted data in PLC channel [9, 10, 11]. However, the use of clipping requires a good understanding of the corrupted signal and determining the corrupt signal magnitude in order to proffer a threshold value (T_h) and nulling (setting to zero) that tends to remove the impulse noises from the corrupted signal. Equation (1) explains the mathematical process of clipping while equation (2) presents the nulling methodology,

$$\vec{r}_k = \left\{ \begin{matrix} r_k,\ \text{for}\left|r_k\right| \le T_h \\ T_h e^{j\arg(r_k)},\ \text{for}\left|r_k\right| \ge T_h \end{matrix} \right\} \rightarrow \textit{Clipping phase} \qquad (1)$$

$$\vec{r}_k = \left\{ \begin{matrix} r_k,\ \text{for}\left|r_k\right| \le T_h \\ 0,\ \text{for}\left|r_k\right| > T_h \end{matrix} \right\} \rightarrow \textit{Nulling phase} \qquad (2)$$

Where r_k is the transmitted signal mixed with impulse noise and AWGN noise while $\vec{r}_k$ is the received sample after clipping and nulling process has been performed to remove the impulse noise from the transmitted signal (r_k) [12, 13].

Iterative technique is an estimation technique and can be implemented by subtracting an estimated value of the impulse noise (IN) from the received signal vector (r) [14]. However, this technique demands a high number of iterations for performance improvement. This method can be time consuming and does not necessarily remove the impulse noise completely [15]. While the use of error correcting codes such as convolution coding and Reed-Solomon (RS) coding are relatively easy to implement, present a better mitigation performance [16, 17]. However, some of these error-correcting techniques suffer some limitations [18, 19]. For example, RS code performance is poor with binary-phase-shift-keying (BPSK) modulator while convolution codes are suitable for linear-time invariant (LTI) systems and underperforms with non-linear LTI systems [20, 21].

The contribution of this paper is to introduce an advanced use of artificial neuro-fuzzy inference system (ANFIS) for the extenuation of corrupt impulse noise present in an orthogonal frequency division multiplexing (OFDM) channel.

The layout of this paper is organized as follows, section 2 will present a summary of the used ANFIS technique. In section 3, a report of the experiment setup and method is provided. Section 4 will present the results, and section 5 will include the conclusions.

II. ANFIS TECHNIQUES

This is a supervised machine learning technique that combines both Sugeno (a type of fuzzy logic control inference system) and artificial neural network (ANN) into a single method recognized as artificial neuro-fuzzy inference system (ANFIS) technique [22]. In an ANFIS controller, ANN is used to automatically regulate the membership functions (MFs) using backpropagation alone or combined with least square technique to lower the level of inaccuracies in the determination of rules in fuzzy logic systems. [23] Merits of ANFIS include easy implementation for both linguistic and numeric knowledge, fast and accurate learning, and does not need prior human knowledge. Applications of ANFIS include optimization of energy from a photovoltaic system, prediction of lung detection risk in humans, edge detection and Arabic alphabet detection [24]. However, a major demerit of ANFIS is the limitation to one output variable [25, 26, 27].

III. SIMULATION MODEL

To examine the practicability of the proposed noise cancellation algorithm with the use of ANFIS technique to adaptively distinguish and moderate the impulse noise present in the transmitted signal (Tx) in an OFDM system, an experiment was conducted by modelling a first-order Sugeno FIS (fuzzy inference system) using some set of rules (e.g. IF, AND, and NOT). A complete OFDM system that comprises of bernoulli signal generator for generating the transmitted signal (T_x), binary phase shift keying (BPSK) modulator and demodulator for converting the bit samples (0 and 1) into complex values and vice versa, Inverse-fast-fourier-transform (IFFT), FFT (fast fourier transform), BPSK demodulator, AWGN channnel and with random impulse noise generator were implemented to achieve the objectives of the experiment. The random impulse noise data were generated using equations (3-5),

$$F_m(n_k) = \sum_{m=0}^{\infty} p_m \quad (n_k; 0, \sigma_m^2) \tag{3}$$

$$\text{where,} \quad P_m = \frac{A^m e^{-A}}{m!} \tag{4}$$

$$\text{and} \quad \sigma_m^2 = \sigma_i^2 \frac{m}{A} + \sigma_g^2 = \sigma_g^2 \left(\frac{m}{A\Gamma} + 1 \right) \tag{5}$$

$F_m(n_k)$ is the probability density distribution (PDF) of a noisy signal (n_k), $(n_k; \mu, \sigma_m^2)$ denotes the Gaussian PDF, μ is the mean, σ^2 is the variance with k -samples, σ_i^2 is the impulse noise variance, σ_g^2 is the AWGN (background noise) and Γ denotes the ratio between Gaussian power (σ_g^2) and impulse noise power (σ_i^2) and is computed mathematically as $\frac{\sigma_g^2}{\sigma_i^2}$. The parameter (A) is the impulse density.

Figure 1 displays the magnitude of the impulse noise. It illustrates the amplitude value of the corrupt impulse noise that got mixed with the transmitted data (T_x) added for a duration of 500 seconds.

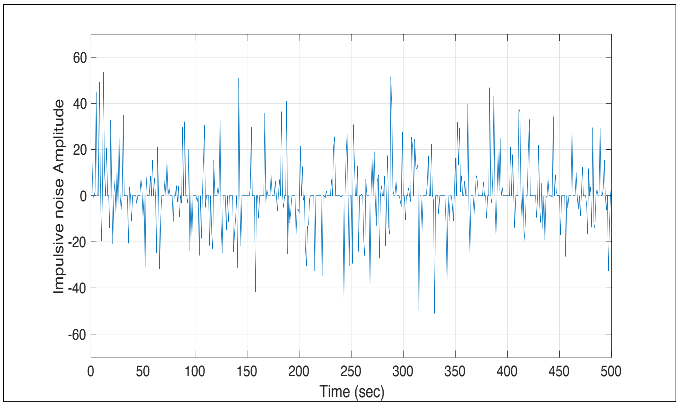

Fig. 1: Impulse signal Magnitude

Figure 2 presents the block illustration of a complete OFDM system developed using two ANFIS controllers. In the trasmitter, the generated bernoulli signal is modulated using BPSK modulator and channeled through IFFT. Then the output data from the IFFT passess through AWGN channel, through which AWGN is been added to the transmitted signal and subsequently, impulisve noise (v) is also added to the transmitted signal (t). This addition goes on to make up the corrupted transmitted signal (u) as seen in the figure. The ANFIS controllers were trained using the 10,000 input samples of signals u and v as the input variables (predictors) and signal t (output signal from the IFFT/AWGN block) as the target.

For simplicity, the complex-variable data $u = u_1 + ju_2, v = v_1 + jv_2$, and $\vec{t} = \vec{t_1} + j\vec{t_2}$ were split into real and imaginary components and both the real and imaginary parts of signals (u,v) were the ANFIS controllers inputs (u_1, u_2, v_1, v_2) while the real and imaginary component of signal t (t_1, t_2) were used as targets to predict responses $(t_1{*}, t_2^{*})$as the output from the ANFIS 1 and ANFIS 2 controller respectively. This output is then demodulated, passed through the FFT channel and compared with the transmitted signal. Figure 3 shows the flowchart algorithm of the used ANFIS error-correcting technique.

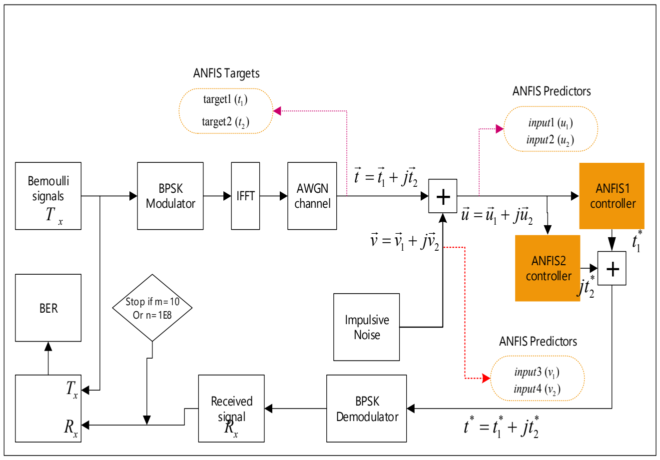

Fig. 2: Complete OFDM channel Using ANFIS Techniques

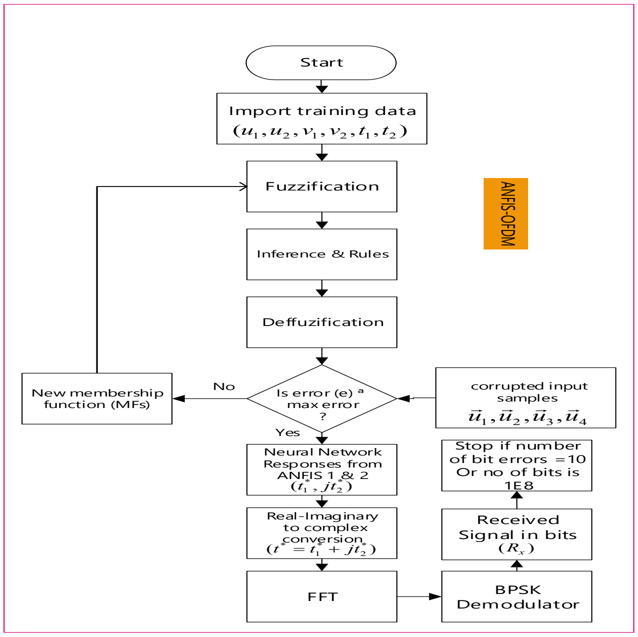

Fig. 3: ANFIS Algorithm

IV. EXPERIMENTAL RESULTS

Figure 4 gives a comparison of the ANFIS-treated OFDM, theoretical OFDM (OFDM corrupted by AWGN only), and highly corrupt OFDM channel (OFDM corrupted with AWGN and impulse noise as the uncorrected OFDM within the range of 0 dB to 40 dB noise power. The outcome of the experiment displays the high performance of the ANFIS impulse-noise error correcting technique as the bit-error-rate (BER) with ANFIS was the lowest in most of the considered signal-to-noise (SNR) levels (0 dB, 4 dB, 8 dB, 10 dB, and 12 dB) and using the lowest SNR power (dB) where the variace of the noise was set to 50 and probability of impulse noise present was 50%. After removing the entire impulse noises that were mixed with the transmitted data, it can also be observed that the ANFIS technique displays the capability of removing some of the AWGN channel noise from the OFDM channel. Similarly, the variance of the impulse noise was varied at a fixed value of probabilty of impulse noise present. The value of the variance of the impulse was also fixed while the probability was varied and the improvement of the PLC was observed, the BER perfomances for these are displayed in Figures (5-12).

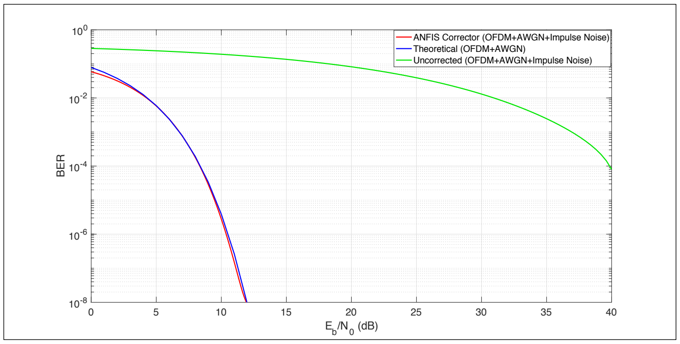

Fig. 4: Comparion of the bit rrror rate of theoretical OFDM with uncorrceted IN-corrupted OFDM and ANFIS-treated OFDM, with impulse noise of varance (V) = 0.5 and probability (P) = 0.5

Fixing the variance of the impulse noise at 50, and varying the probabilty of the impulse noise, the following graphs were obtained.

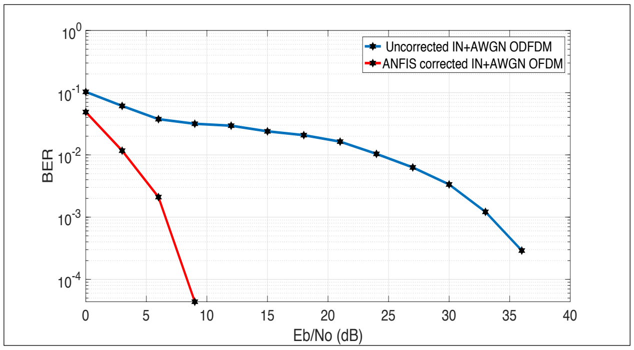

Fig. 5: BER graph with variance of IN (V) = 50 probability (P) = 10%

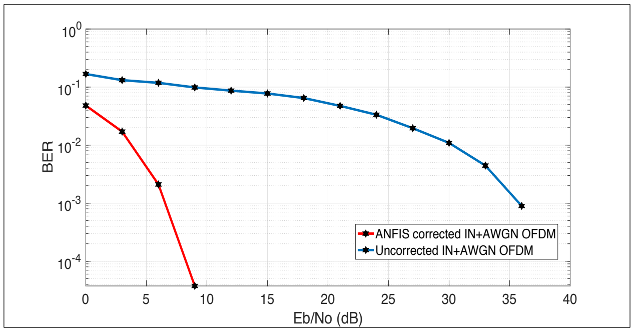

Fig. 6: BER graph with variance of IN (V) = 50 probability (P) = 30%

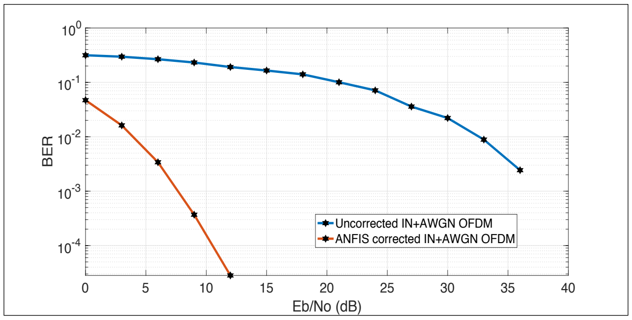

Fig. 7: BER graph with variance of IN (V) = 50 probability (P) = 70%

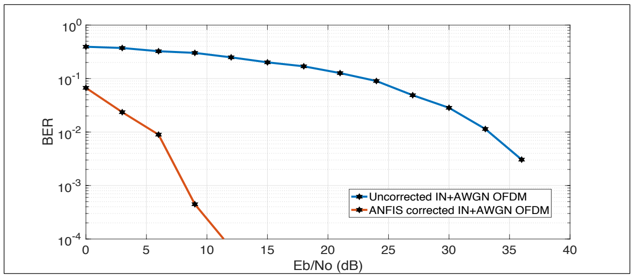

Fig. 8: BER graph with variance of IN (V) = 50 probability (P) = 90%

Fixing the probability of the impulse noise at 50%, and varying the variance of the impulse noise, the following graphs were obtained.

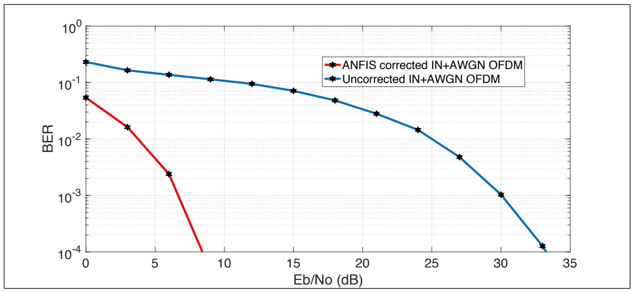

Fig. 9: BER graph with probability of IN (P) = 50% variance (V) = 10

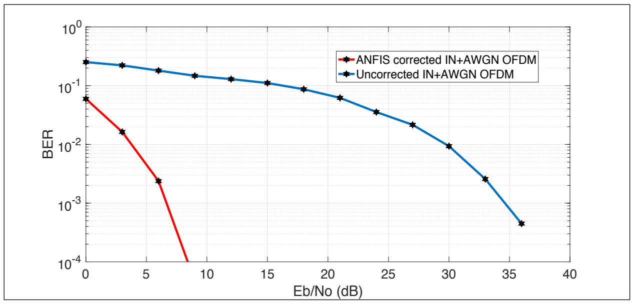

Fig. 10: BER graph with probability of IN (P) = 50% variance (V) = 30

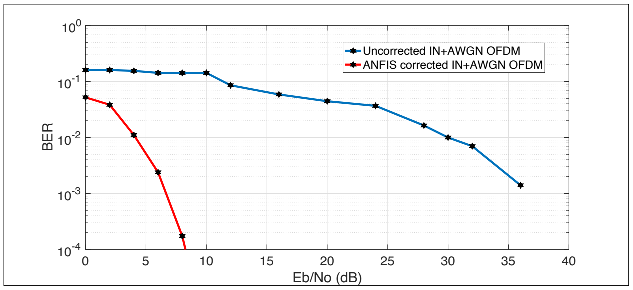

Fig. 11: BER graph with probability of IN (P) = 50% variance (V) = 50

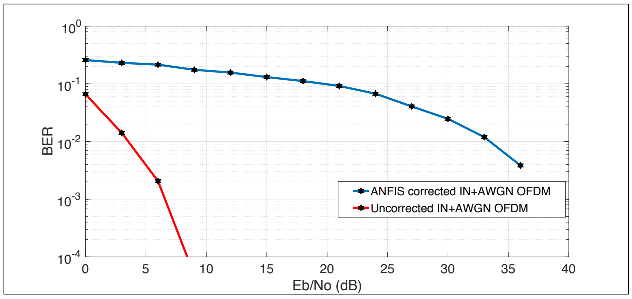

Fig. 12: BER graph with probability of IN (P) = 50% variance (V) = 70

Figures 5 to 12 illustrates the BER performance of the signal for uncorerected corrupt signal and the ANFIS corrected signal. For figures 5 to 8, the variance of the impulse noise was fixed at 50, while the probability of the noise was varied to the values of 10%, 30%, 70% and 90%. It can be observed from figures 5 to 8 that at lower probability values, the BER of the ANFIS corrected signal improved better (<10dB) unlike at higher probability (70% & 90% impulse noise) where the SNR value was slightly higher than 10dB. Also considering figures 9 to 12, where the probability of the impulse noise is fixed at 0.5, and the variance changed between 10, 30, 50 and 70, it is seen that these changes in the variance has little or no effect in the ANFIS result. In general, the efficiency of the implementation of ANFIS in eliminating impulse noise in PLC signal was confirmed.

V. CONCLUSIONS

This article presents an advanced use of ANFIS technique in removing the complete impulse noise and some of the AWGN that were mixed with the transmitted data in an OFDM channel using minimal signal-to-noise ratio (SNR) power. However, it can be observed from the graphs that the ANFIS performance is not affected by change in variance of the impulse noise (IN). However, it is slightly affected by the change in probability (P) of IN. As seen in Figures 6 and 7, when the probability of IN increased, the performane of ANFIS slightly degraded to SNR of about 12 dB at BER of 10^{-5}, compared to the SNR of about 9dB for P = 0.3. Obtained results advise that ANFIS technique can be recommended in mitigating impulse noise in a powerline communication channel.

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