BPSK-OFDM versus QFSK-OFDM in Combating the Effects of Narrowband Interference and Impulsive Noise in Power Line Communication

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***Abstract*—This work serves to demonstrate the use of hybrid QFSK-OFDM and modified BPSK-OFDM in combating the effects of Narrowband Interference (NBI) and Impulsive noise (IN) as a mixture in Power Line Communication channel. Therefore, in this paper we demonstrate the superiority of modified BPSK-OFDM over QFSK-OFDM and over conventional BPSK-OFDM. The performance analysis of the system is carried out by Matlab simulations whereby the noise models used are the Middleton Class A for IN and NBI models as found in literature. The simulations show modified BPSK-OFDM to have better performance of 5 dB in terms of SNR as compared to QFSK-OFDM and 3 dB better than the conventional BPSK-OFDM.**

I. Introduction

Power line communication (PLC) has been viewed as a promising and interesting digital communication technology. Unfortunately, it suffers from major drawbacks like attenuation, impulsive noise and narrowband interference to name but a few. PLC intends to use the existing power line infrastructure with the aim of lowering the costs of using PLC commercially [1]. The most outstanding challenge in PLC lately is the effect of noise on the transmitted data. Background noise modeled as Additive White Gaussian Noise (AWGN), Impulsive Noise (IN) and Narrowband Interference (NBI) are classified as the most prominent noise types in PLC. From reviewed literature, the scenarios of either noise type have been extensively addressed individually. This has resulted in conventional/traditional methods that serve to mitigate the noise effects. For instance, IN 's renowned mitigating methods are clipping and blanking (set to zero) [2] and for NBI there is frequency excision and cancellation [3]. These can be labelled as traditional ways since lately more sophisticated ones have been developed. For example, compressive sensing technique [4], use of Machine Learning [5], and hybrid transmission systems like MFSK-OFDM [6].

Over the years, researchers have successfully modeled the PLC channel [7] and developed the various noise mitigating methods. However, work on mitigating the joint effect of IN and NBI as a mixture has not been widely explored. Mitigating a single noise type could improve the realiabilty of the communication system if that noise type was the only noise present in the channel, however, a PLC channel is subject to various noise types, background noise, IN and NBI [8], the channel's reliability is not significantly improved by mitigating one noise type. This gives rise to the need for counteracting the noises' effect as a mixture, not individually since their probability of occurrence is independent of each other, but have a collective destructive effect on the transmitted signal. There are a very few researchers that attempt to combat all the different noise types in PLC channel. This paper attempts to do the same.

Recently, there have been some interesting developments in addressing the combination of IN and NBI [9]. The similarity in the proposed methods in the literature is to work in time domain and move to the frequency domain or vice versa. The IN sample is more visible in time domain and has large amplitude when compared to an AWGN sample. Contrary, NBI is more visible in the frequency domain. To mitigate both IN and NBI, Sanjana and Suma [10] employ Discrete Wavelet Transforms (DWT), instead of the popular Discrete Fourier Transform (DFT) in conjunction with Quadrature Amplitude Modulation (QAM) to collectively mitigate noise in a PLC channel. They demonstrated that DWT actually gives a better performance compared to DFT when used with frequency domain identification and cancellation for NBI and, joint time-frequency domain for IN. The mitigating ways presented involved previous works found in literature such as the use of thresholds to identify IN samples [11]. Further work found in literature is whereby a novel algorithm of estimating and cancelling both IN and NBI was proposed [9]. In [9] employ multiple signal characterization algorithms to find IN and NBI locations.

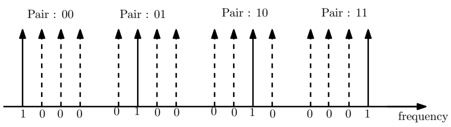

Fig. 1: A pair is mapped onto $M = 4$ sub-carriers with only one sub-carrier used for transmission which is the case of QFSK-OFDM. In the figure the used sub-carrier is indicated by a solid line.

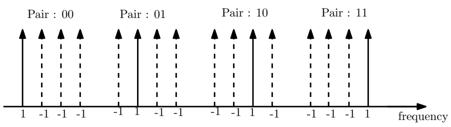

Fig. 2: A pair is mapped onto $M = 4$ sub-carriers with only one sub-carrier used for transmission which is the case of BPSK-OFDM. In the figure the used sub-carrier is indicated by a solid line.

To estimate the amplitudes and phase, minimum mean square error estimator and least square estimator are used for IN and NBI respectively. The full outline of the methods is described in the publication [9].

The work in this paper is to address the mixed noise case of IN and NBI, implementing the hybrid, non-conventional transmission methods, QFSK-OFDM and modified BPSK-OFDM. The rest of the paper is organized as follows. Section II will describe the system model used for simulation, Section III will give the simulation results and analysis based on the BER curves of BPSK-OFDM and QFSK-OFDM. Then lastly, it will be the conclusion on this work.

Wetz *et al.* have formulated a new OFDM-based hybrid transmission scheme to use in fast fading channels [6]. Their system labeled OFDM-M-ary FSK, for $M = 4$, is a non-conventional scheme in the sense that M-ary FSK modulation can be identified as an orthogonal frequency modulation scheme similar to Orthogonal Frequency Division Multiplexing (OFDM) scheme. Both OFDM and M-ary modulation methods have shown robustness against NBI and IN [12]. Wetz's method can be detected non-coherently and therefore requires no channel estimation and equalization, meaning less complex designs. This has made OFDM-MFSK a more feasible option for combating the mixture of IN and NBI, which unfortunately gave poor perfomance when tested in this paper (the results are discussed in Section III). Primarily the random bits generator output is grouped into blocks of bit size 2, thereafter apply QFSK on each group (setting only one frequency high) as shown in Figure 1. An almost similar idea is demonstrated in [13]. The proposed method is vectoring the message into vectors or blocks of different sizes. Fortunately, their system was developed for non-Gaussian PLC channel. In [13] it was concluded that Vector-OFDM (VOFDM) presents a better probability of identifying IN in the midst of AWGN, by using the threshold approach. In this paper we implement a similar method, however, our proposed method can deal with AWGN, IN and NBI, instead of just AWGN and IN only.

For the basis of this paper, the 2-state Middleton Class A model is used as derived in [14], to model IN. This model has been widely used in the literature especially in research involving the mitigation of the effect of IN on transmitted data. IN has always been thought of as more destructive when compared to other noises. On the other hand, NBI has not been given much attention therefore its model has not been studied extensively compared to IN models. Fortunately, in [14] a detailed NBI model applicable in OFDM systems is presented. This model is also used for this paper's simulations. Interestingly, the NBI model is quite similar to the IN model, which is used often in telecommunications.

II. System Model and Description

A. Brief description of used noise models

The noise models used for the simulations in this paper have been widely used in literature. To begin with is the IN model. The model used is the 2-state Middleton Class model as derived and explained in [14]. The model is a derivative of the Poisson distribution.

$$P\left(x : \mu\right) = \left(e^{-\mu}\right) \frac{\left(\mu^{x}\right)}{x!}, \tag{1}$$

where μ is the mean value of either impulse or frequency disturbers occurring within a period of time or bandwidth respectively. x, is the total number of their occurrences in the system observed.

The probability of occurrence for IN, Λ, is extensively explained in [14] whereby it is technically stated as the impulsive index. Using a 2-state Middleton Class A model, the transmitted data can take the route with Λ probability of being corrupted by IN.

Let variance (noise power) of any noise affecting a symbol by,

$$\sigma^2 = \tfrac{N_n}{2}$$

where the N_n is the noise Power Spectral Density (PSD) and the factor of 2 indicates that the PSD is two-sided [15] [16].

Therefore, for the whole system, the variance of IN and AWGN is, σ_i^2 and σ_g^2, respectively. These two are related by the power ratio, γ, whereby,

$$\gamma = \left(\frac{\sigma_g^2}{\sigma_i^2}\right)$$

The average impulsive noise affecting a single symbol is given by

$$\bar{\sigma}_i^2 = \frac{\sigma_i^2}{\Lambda} = \frac{\sigma_g^2}{\Lambda\gamma}$$

The work done in [14] gives a more detailed model for NBI. The NBI's probability is modeled using the Poisson distribution as shown in Equation (1). The mean value of occurrence, μ, is the disturbers within a specific bandwidth as explained in [17]. It can be noted that the μ, is similar to the probability of occurrence λ, of NBI as it is for Λ in IN. The average NBI power affecting each symbol is given by,

$$\bar{\sigma}_{nbi}^2 = \left(\frac{\sigma_{nbi}^2}{\lambda}\right).$$

B. Description of the modulation schemes

In this section we give a brief description of the modulation schemes used in this paper, which are the Conventional BPSK termed CB, modified BPSK-OFDM termed MB and QFSK-OFDM termed QF as already mentioned in the previous sections. We analyse the modulations expected perfomance in the presence of AWGN whereby we consider the squared Euclidean distance, d^2. This perfomance analysis is similar to that used in [18].

In MB and QF, as shown in Figures 1 and 2, only two (2) message bits are transmitted per four (4) sub carriers. This results in the transmission rate of MB being $r_{MB} = 1/2$ and that of QF to be $r_{QF} = 1/2$. For conventional BPSK, any four (4) sub-carriers carry four (4) information bits. This makes the rate of CB to be $r_{CB} = 1$ since all the sub-carriers carry information bits. One of the deciding factors on a scheme's ability to withstand AWGN's effect is the minimum Euclidean distance between the symbols. The higher the minimum d^2, the greater the ability. Even though the rate for MB is half that of CB, the d^2 of MB is maintained at $d_{MB}^2 = 2$. Despite the low rate, MB is robust to noise as compared to the other schemes. It is could be applied in systems where high data rate is not vital like in periodic load management in residential areas. Lastly is QF, which is adapted from [6]. This mechanism is similar to MB for it also have $r = 1/2$ with the main difference is in the d^2. For QF, the minimum squared Euclidean distance, $d_{QF}^2 = 1$. Between MB and QF, MB is expected to perform better in an AWGN-only characterized channel since it has a higher minimum squared Euclidean distance compared to QF.

C. System description

Following the system model in Figure 3, the generated data bits undergo the QFSK-OFDM or modified BPSK-OFDM, depending on the modulation observed. The resultant symbols denoted $S[k]$ are translated to the time domain resulting to $s[n]$. The total length of $S[k]$ is $\psi = N \times \phi$. The $s[n]$ is a vector of cascaded ϕ vectors which represent the specific transmitted data in the time domain. The signal is transmitted through a PLC channel characterized by IN, NBI and AWGN. Then the received signal, $r[n]$, is made into column vectors to form ϕ vectors of length N.

Therefore the received signal in time domain can be expressed as

$$r[n] = s[n] + \digamma[n] + \Theta[n] + \Upsilon[n], n = 0, 1, ..., N-1 \quad (2)$$

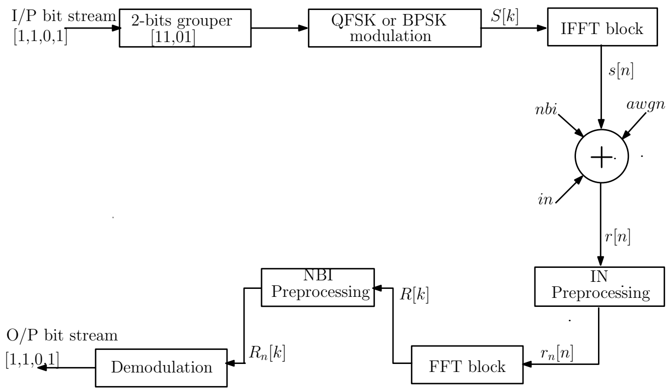

Fig. 3: The OFDM-based PLC system block diagram with nonlinear (clipping) preprocessor before the demodulator.

where $\digamma$ is the Narrowband Interference, Θ is the Impulsive noise and Υ is the AWGN in time domain.

The signal $r[n]$ goes through the preprocessing block which is meant to identify and clip/null the amplitude of $r[n]$ greater than $T_{in} = \sqrt{E_b} \times \alpha$ where α is a factor to accommodate a floor caused by σ_{nbi}^2 in time domain after IFFT transform. The IN preprocessing block is governed by

$$r_n[n] = \begin{cases} r[n] & , \quad |r[n]| \leq T_{in} \\ r[n] \times clip_{val} & , \quad |r[n]| > T_{in} \end{cases}$$

where $r_n[n]$ is the result of clipping in time domain and $clip_{val} \geq 0$. $clip_{val} = 0$ is a special case of clipping called nulling.

After the FFT block the aim is to identify and also clip/null the amplitude of NBI in frequency domain. The same procedure used for IN is used for NBI. Whatever is greater than the threshold, $T_{nbi} = \sqrt{E_b} \times \beta$, is considered corrupted by NBI therefore either clipped or nulled. $T_{nbi} = \sqrt{E_b} \times \beta$, where β is a factor to accommodate a floor caused by σ_{in}^2 in frequency domain after FFT transform.

$$R_n[k] = \begin{cases} R[k] & , \quad |R[k]| \leq T_{nbi} \\ R[k] \times clip_{val} & , \quad |R[k]| > T_{in} \end{cases}$$

where the $R_n[k]$ is the result of nulling in time domain $clip_{val} \geq 0$ and $k = 0, 1, \ldots, N-1$.

The different demodulation methods highlight the differences between the conventional BPSK and modified BPSK-OFDM which are the rate of modulation and the decision-making mechanism at the receiver. Conventional BPSK's decision-making is solely based on the phase of the received signal whilst for modified BPSK-OFDM is based on the most likely value to be $\sqrt{E_b}$ using the Maximum Likelihood (ML) idea. ML forms the basis for M-FSK modulation schemes for decision making at the receiver, whilst for M-PSK schemes it is based on phase change. Interestingly, in this work we have modified

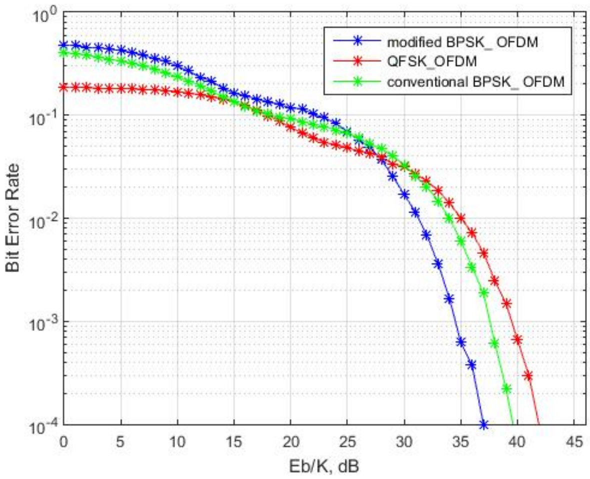

Fig. 4: Both modified and conventional BPSK-OFDM and QFSK-OFDM simulation parameters : $\lambda = 0.25$, $\Lambda = 0.25$, $\sigma^2_{nbi} = 100$, $\gamma = 0.1$.

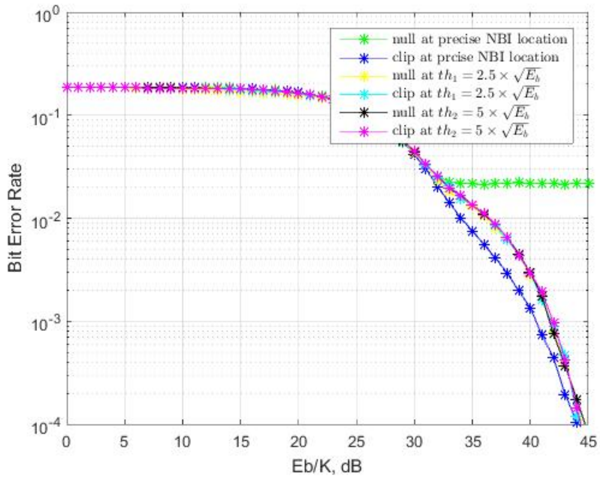

Fig. 5: The modulation scheme considered here is the QFSK-OFDM with parameters: $\lambda = 0.1$, $\Lambda = 0.1$, $\sigma^2_{nbi} = 100$, $\gamma = 0.01$. The scenarios were observed when NBI was clipped at precise locations and system located places.

the conventional BPSK-OFDM modulation to our MB scheme such that the ML can be used for decision making at the receiver as done in M-FSK.

III. Simulation and analysis

This section focuses on the performance of the QF scheme in comparison to the MB based on the BER curves. The parameters of the simulation are the probability of occurrence, variances of each noise are kept constant. The signal to noise ration in decibels denoted by SNR_{dB} is given by

$$SNR_{dB} = 10\log_{10}\left(\frac{E_b}{N_g + N_i + N_{nbi}}\right) = 10\log_{10}\left(\frac{E_b}{K}\right)$$

for $N_g = 2\sigma_g^2$, $N_i = 2\sigma_i^2$, $N_{nbi} = 2\sigma^2_{nbi}$.

The use of the MB to combat the three major noises in PLC demonstrates good improvement as shown in Figure 4 when compared to QF and CB. There is a gain of approximately 4 dB at $BER = 10^{-4}$ when compared to the CB. Unfortunately, both modulation schemes have shortcomings which hinder performance.

Figure 5 and 6 show the response of the system to precise identification of NBI in frequency domain. The MB (Figure 6) performs better than QF (Figure 5) when considering the error floor. MB gives an error floor of $BER = 0.00895$ at $SNR = 36$ dB whilst QF has $BER = 0.02099$. To add, at $BER = 10^{-4}$ MB outperforms QF by approximately 5 dB.

With regards to the probabilities of occurrence for each noise type, where the probability of IN is kept constant while varying the probability of NBI, both systems show a similar behavior, but again the MB scheme performs better when compared to the QF scheme when considering Figures 7 and 8. Worth noting is that as the λ is decreased both systems get more erroneous at higher SNR. To recall from the NBI model used, as λ decreases, $\bar{\sigma}^2_{nbi}$, average NBI power is expected to increase. Low λ values favor low SNR values. Therefore it implies that the $\lambda \propto \frac{1}{BER}$. At $SNR \geq 25$ dB for QF there is an introduction of an error floor whilst for MB scheme, the error floor is experienced from $SNR \geq 18$ dB. The overall performance presented in Figures 7 and 8 show that at $BER = 10^{-4}$, MB still outperforms QF by 5 dB. This performance is consistent with that shown in Figures 5 and 6.

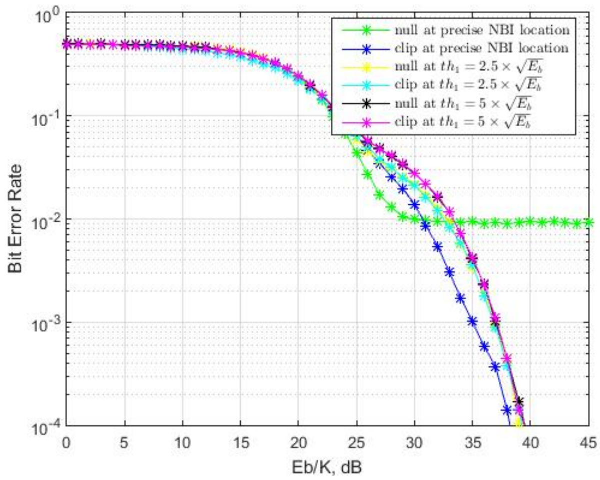

Fig. 6: The modulation scheme considered here is the modified BPSK with parameters: $\lambda = 0.1$, $\Lambda = 0.1$, $\sigma^2_{nbi} = 100$, $\gamma = 0.01$. The scenerios obsevered were the clipping of NBI is at precise locations and system located places.

Figures 10 and 11 show that the variation of Λ, probability of occurrence for IN has no effect on the performance of both the MB scheme and QF scheme. The effect of

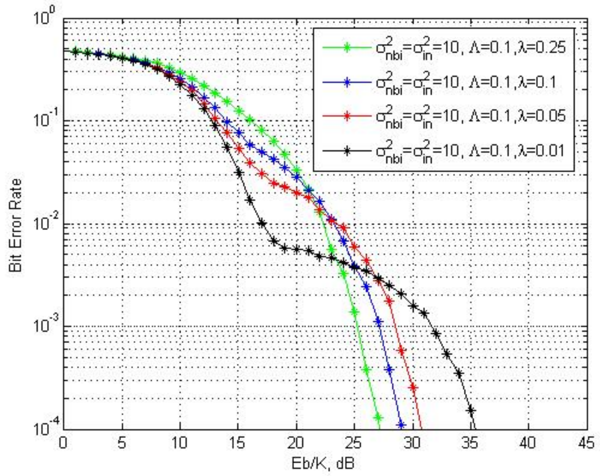

Fig. 7: The modulation scheme considered here is the modified BPSK-OFDM with parameters: $\lambda = 0.1$, $\Lambda = 0.1$, $\sigma^2_{nbi} = 100$, $\gamma = 0.01$, whereby the probability of occurence for NBI was varied.

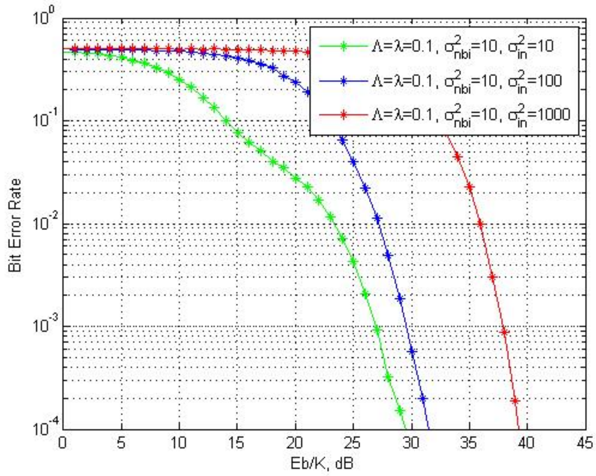

Fig. 9: The modulation scheme considered here is the modified BPSK-OFDM with parameters: $\lambda = 0.1$, $\Lambda = 0.1$, $\sigma^2_{nbi} = 10$, where there was a variation of $\bar{\sigma}^2_i$, the effective power of IN.

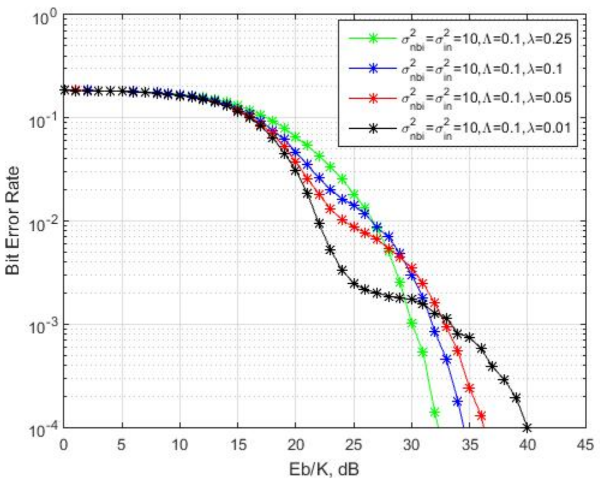

Fig. 8: The modulation scheme considered here is the QFSK-OFDM with parameters: $\Lambda = 0.1$, $\sigma^2_{nbi} = 10$, $\gamma = 0.1$ where there was a variation of λ.

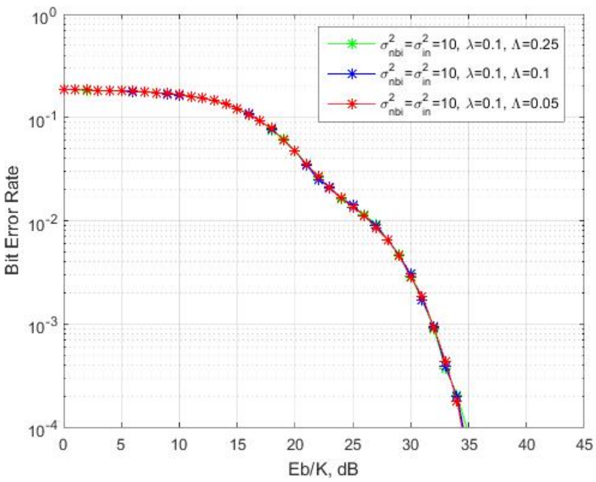

Fig. 10: The modulation scheme considered is the QFSK-OFDM with parameters: $\lambda = 0.1$, $\sigma^2_{nbi} = 10$, $\gamma = 0.1$, where there was a variation of Λ, the probability of occurence for IN.

IN probability in frequency domain is diminished by the FFT transform, but the effect of the power is maintained as demonstrated by Figures 9, 12 and13. But the 5 dB difference at $BER = 10^{-4}$ is maintained between the two systems with close reference to all the figures (Figure 4 – Figure 8 and Figure 10 – Figure 12) where the two systems can be compared.

IV. Conclusion

Noise is a challenge for any communication system and PLC is no exception. Various ways have been researched on how to mitigate the effects of IN and NBI individually. The knowledge gathered for this paper shows that not much work has been done in mitigating the combined effect of IN and NBI as a mixture in a single channel. In this paper a modified version of BPSK is presented and has shown to give better performance, in the presence of all the three noise types (AWGN, IN and NBI), when compared to QFSK-OFDM and the conventional BPSK-OFDM.

References

[1] J. Lin, M. Nassar, and B. L. Evans, "Impulsive noise mitigation in powerline communications using sparse bayesian learning," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 7, pp. 1172–1183, July 2013.

[2] S. V. Zhidkov, "Impulsive noise suppression in ofdm-based communication systems," *IEEE Transactions on Consumer Electronics*, vol. 49, no. 4, pp. 944–948, 2003.

[3] V. N. Papilaya and A. H. Vinck, "Investigation on a new combined impulsive noise mitigation scheme for OFDM transmission," in *Proceeding of the 17th IEEE International Symposium on Power Line Communications and Its Applications*, Johhanesburg, South Africa, Mar. 24-27 2013, pp. 86–91.

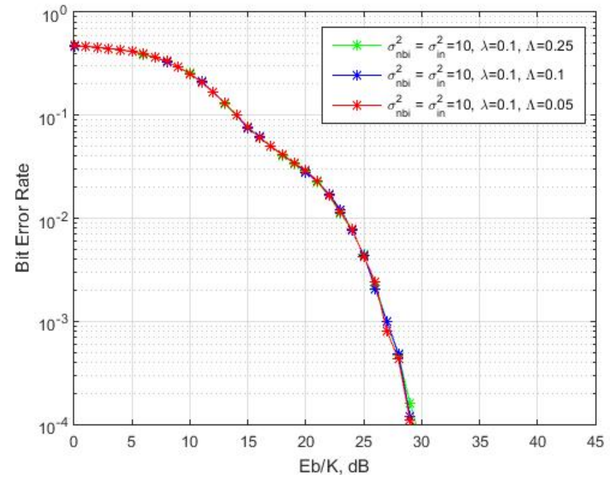

Fig. 11: The modulation scheme considered here is the modified BPSK-OFDM with parameters: $\lambda = 0.1$, $\sigma^2_{nbi} = 10$, $\gamma = 0.1$, where there was a variation of Λ.

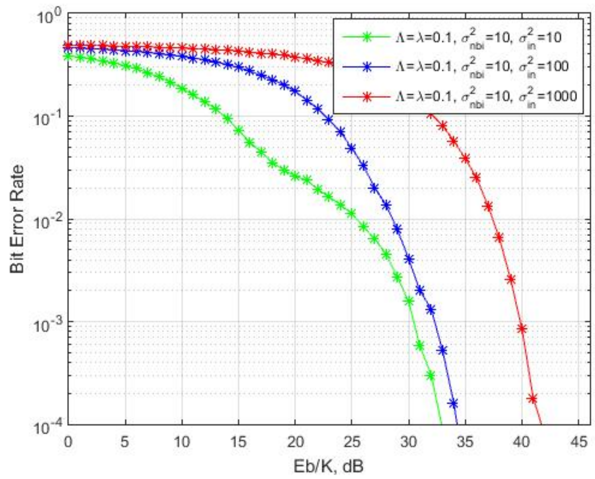

Fig. 13: The modulation scheme considered here is the conventional BPSK-OFDM with parameters: $\lambda = 0.1$, $\Lambda = 0.1$, $\sigma^2_{nbi} = 10$, where there was a variation of $\bar{\sigma}^2_i$, the effective power of IN.

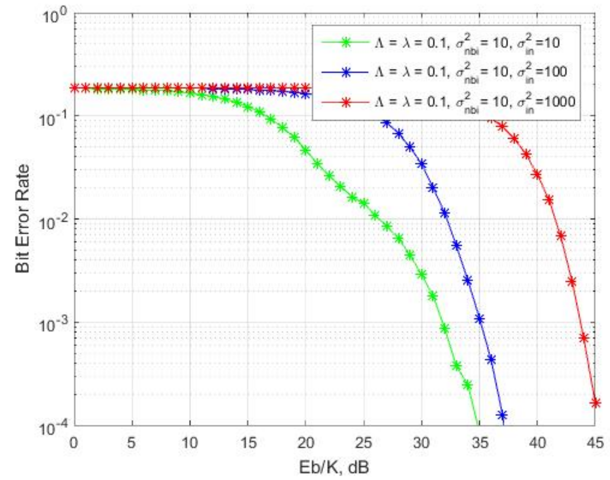

Fig. 12: The modulation scheme considered here is the QFSK-OFDM with parameters: $\lambda = 0.1$, $\Lambda = 0.1$, $\sigma^2_{nbi} = 10$, where there was a variation of $\bar{\sigma}^2_i$, the effective power of IN.

[4] S. Liu, F. Yang, W. Ding, and J. Song, "Double kill: Compressive-sensing-based narrow-band interference and impulsive noise mitigation for vehicular communications," *Proceedings of the IEEE Transactions on Vehicular Technology*, vol. 65, no. 7, pp. 5099–5109, July 2016.

[5] A. N. Hasan and T. Shongwe, "Proposed machine learning system to predict and estimate impulse noise in ofdm communication system," in *Industrial Electronics Society, IECON 2016-42nd Annual Conference of the IEEE*. IEEE, 2016, pp. 1016–1020.

[6] M. Wetz, W. G. Teich, and J. Lindner, "Ofdm-mfsk with differentially encoded phases for robust transmission over fast fading channels," in *11th International OFDM-Workshop*, August, 2006.

[7] H. C. Ferreira, L. Lampe, J. Newbury, and E. T. G. Swart, *Power Line Communications: Theory and Applications for Narrowband and Broadband Communications Over Power Lines*. Chichester, England: John Wiley and Sons, 2010.

[8] H. Chaouche, F. Gauthier, A. Zeddam, M. Tlich, and M. Machmoum, "Time domain modeling of powerline impulsive noise at its source," *Journal of Electromagnetic Analysis and Applications*, vol. 3, no. 9, p. 359, 2011.

[9] D. Shrestha, A. Tonello, X. Mestre, and M. Payaró, "Simultaneous cancellation of narrow band interference and impulsive noise in plc systems," in *Proceeding of the 2016 IEEE International Conference on Smart Grid Communications*, Sydney, NSW, Australia, Nov. 6-9, 2016, pp. 326–331.

[10] T. Sanjana and M. Suma, "Combined nbi and impulsive noise cancellation in OFDM system," *International Journal of Advanced Information Science and Technology*, vol. 1, no. 2, Jun. 2012.

[11] K. Al-Mawali, A. Z. Sadik, and Z. M. Hussain, "Joint time-domain/frequency-domain impulsive noise reduction in OFDM-based power line communications," in *Proceeding of the Telecommunication Networks and Applications Conference, Australasian*, Adelaide, SA, Australia, Dec. 7-10, 2008, pp. 138–142.

[12] K. T. Ouahada, "Coded modulation for power-line communication channel," Ph.D. dissertation, University of Johannesburg, 2009.

[13] B. Adebisi, K. M. Rabie, A. Ikpehai, C. Soltanpur, and A. Wells, "Vector OFDM transmission over non-gaussian power line communication channels," *IEEE Systems Journal*, vol. PP, no. 9, pp. 1–9, Mar. 30 2017.

[14] T. Shongwe, H. C. Ferreira, and A. Han Vinck, "Broadband and narrow-band noise modeling in powerline communications," *Wiley Encyclopedia of Electrical and Electronics Engineering*, pp. 1–18, Dec 2015.

[15] B. Sklar, *Digital Communications: Fundamentals and Applications, 2nd edition*. Prentice Hall Inc., 2001.

[16] S. V. Vaseghi, *Advanced digital signal processing and noise reduction*. John Wiley & Sons, 2008.

[17] T. Shongwe, V. N. Papilaya, and A. H. Vinck, "Narrow-band interference model for OFDM systems for powerline communications," in *Proceedings of the 17th IEEE International Symposium on Power Line Communications and Its Applications*, Johannesburg, South Africa, March. 24-27 2013, pp. 268–272.

[18] V. N. Papilaya, T. Shongwe, A. H. Vinck, and H. C. Ferreira, "Selected subcarriers QPSK-OFDM transmission schemes to combat frequency disturbances," in *Proceedings of the 16th IEEE International Symposium on Power Line Communications and Its Applications*, Beijing, China, March. 27-30 2012, pp. 200–205.