Coded FSK and SFSK Performances Analysis under the Narrow-Band PLC Channel

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Abstract

In this paper, two decision methods for the conventional and spread frequency shift keying (FSK and SFSK) are detailed and their extension to the coded FSK using the permutation coding are proposed. The performance results of the different methods are compared under the real indoor narrowband PLC (NB PLC) channel attenuation and impulse noise. The decision schemes are mainly the probability density function PDF-based system for the SFSK and the Non-PDF-based system (select largest) for the conventional FSK. The BER performances of the different techniques prove that the coded FSK using the Select Largest method achieves good performance results in the PLC constraints while having a low complexity, in comparison with SFSK system. The coded FSK Select Largest gives an error floor equal to 6×10^{-6} under impulse noise and channel effect compared to 2×10^{-6}achieved by the coded SFSK.

Index Terms

FSK, SFSK, coded modulation, permutation codes, channel attenuation, impulse noise, BER.

I. INTRODUCTION

SPREAD frequency shift keying (SFSK) is known for its robustness to PLC channel impairments since it combines the advantages of both FSK modulation and spread spectrum techniques [1, 2]. Thus, several commercial solutions are based on SFSK to combat difficult channel constraints [3, 4]. Although FSK and the mono carrier systems have low data rates, they are characterized by their low complexity and their resistance to narrowband interference and impulse noise [5]. Thus, FSK modulation is a suitable candidate for home automation applications in home area network (HAN), which require high reliability rather than high data rates [6]. Therefore, we study the performances of FSK and SFSK under indoor narrowband PLC (NB PLC) channel constraints.

In this paper, we propose an improved coded FSK modulation scheme that can be used in the design of a low–cost NB PLC modem. The performances of this system are assessed under Gaussian channel and realistic measured PLC channel transfer function and noise conditions.

This paper is organized as follows, Section II exposes the PLC channel characteristics followed by an overview of the permutation coding principle as well as the coded and uncoded FSK and SFSK systems description. Section IV reports the performance results in terms of bit error rate (BER) calculations of the various schemes under different channel and noise conditions.

II. NARROWBAND PLC CHANNEL CHARACTERISTICS

In this study, realistic indoor NB PLC channel and noise are used. The measurements of the channel characteristics were carried out in a university campus with different configurations (time, distance, loads connected to the grid...) in the frequency band from 10 kHz to 500 kHz and hundreds of measures were obtained [7]. Fig 1 shows the used channel transfer function.

Furthermore, we study the effect of impulse noise on the signals since it is the most severe constrain of the power line. The measures of the impulse noise showed that the majority class is the single impulse with a damped sinusoid shape. Thus, a stochastic model of this class was defined and the characteristic parameters were determined [8, 9]. The time domain model of this class obeys to the equation (1):

$$b(t) = A\sin(2\pi ft)\exp(-t/\tau); t \in [0, T_d] \quad (1)$$

where A is the peak amplitude of the impulse, f is its pseudo-frequency, τ stands for the damping factor and T_d represents the duration of the pulse. To complete the definition of the impulse noise, the inter-arrival time parameter T_{it} is used, it is defined as the duration separating the end of an impulse and the beginning of the next one.

In this work, the impulse noise is generated as follows. First, the different parameters (A, f, τ, T_d and T_{it}) are uniformly picked from the intervals extracted in the modeling process [8, 9]. Next, the pulse is constructed using the equation in (1). Then, an additive white Gaussian noise (AWGN) of duration T_{it} and a power spectral density (PSD) varying from -120 dBm/Hz to -130 dBm/Hz is added to complete the generated pulse. The pseudo frequency of the impulse noise is fixed to f = 135 kHz, which is the majority frequency of the measured impulses. An example of the temporal shape of the generated impulse noise segment with 0.5 ms duration is shown in Fig 2.

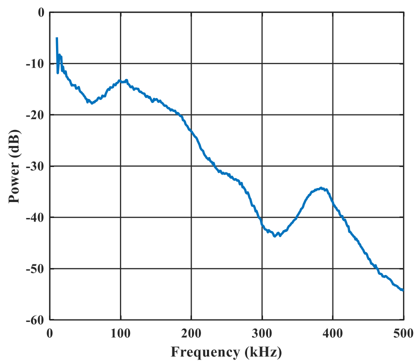

Fig. 2. Measured PLC channel transfer function.

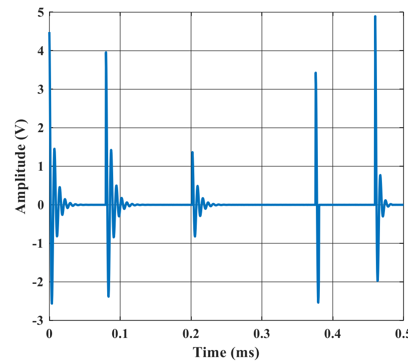

Fig. 1. Example of the generated impulse noise.

III. IMPROVED DECISION TECHNIQUES FOR UNCODED AND CODED FSK

Permutation coding has the advantage of adding time and frequency diversity to the system with the possibility of low complexity decision such as the threshold-based hard decision [10].

A permutation code C has |C| code words, each of length M, and the minimum Hamming distance between two codes is d_{min}. Every code word is represented by an $M\times M$ binary matrix to be used for the decision, where rows describe the output for the detector at frequency f_i, $i=1,.., M$ and columns represent the time interval T_j, $j=1,.., M$, in which it occurs.

In the literature, the permutation coding is mainly studied for M-ary FSK with M≥4 since it offers more frequency diversity. In this work, we aim to study the permutation coding for the binary FSK and to investigate the improvement it offers to our system. The considered systems are based on the classical non coherent binary FSK transceiver, namely the classical FSK and the spread FSK (SFSK). The decision methods are detailed below for the coded and uncoded systems. For the binary coded FSK, the used code words are $c_0 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ and $c_1 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$. Let $Y_C = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$ be the output of the demodulation process for the coded system.

A. The "Select Largest" Decoding Method

The FSK using the "Select Largest" (FSK/SL) method for the uncoded FSK is simply the classical FSK decision, which compares the outputs of the demodulator and chooses the largest as the transmitted frequency. Similarly, the coded FSK SL decision, it chooses the code that maximizes the probability in (2):

$$P(Y \mid c_k) = \sum_{i,j=1}^{2} \Pr(y_{ij} \mid c_{kij} = 1), k = 0,1 \tag{2}$$

B. The SFSK decision

The SFSK decision is based on the calculation of the PDF of the signal at the output of the non-coherent FSK demodulator [1, 2]. For that, it estimates the channel and noise parameters using a known preamble. Concerning the coded SFSK, the decoding process is applied on the output of the SFSK decision unit as expressed in (3):

$$P(Y \mid c_k) = \prod_{i,j=1}^{2} \Pr_i(y_i, y_j), k = 0,1 \tag{3}$$

where Pr is the decision metric of the uncoded SFSK calculated using the PDFs [2]. The decoding process is based on the Maximum Aposteriori Probability (MAP) demodulator [10].

IV. PERFORMANCE RESULTS ANALYSIS

Simulations of the described systems are carried out in order to analyze their performances through BER calculations. The considered bit rate is 9.6 kbps. The chosen carrier frequencies for the binary FSK and SFSK systems are f_0=100 kHz and f_l=119.2 kHz for all the channel and noise configurations. The used sampling frequency is f= 1 MHz. The simulations use up to 10^9 bits with a packet-based transmission. Each packet is modulated then exposed to the channel and/or the noise. An AWGN noise is also added with a PSD value fixed according to the needed SNR.

A. *Performance Results in the Gaussian Channel*

We start by assessing the performances of the coded and uncoded systems in the Gaussian channel for a validation purpose. Fig. 3 displays the BER performance versus the signal to noise ratio (SNR). The analytical BER curve of the non-coherent FSK in the Gaussian channel is taken as a reference.

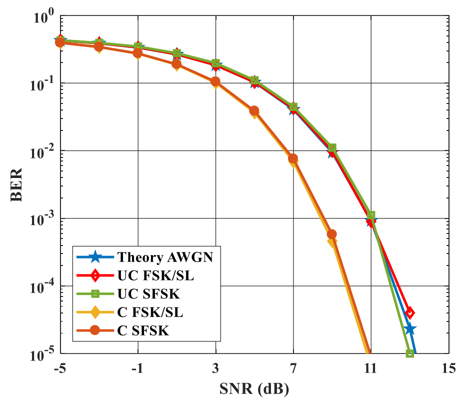

Fig. 3. BER versus SNR performance of the coded and uncoded systems in the AWGN channel.

Fig 3 shows that the uncoded FSK/SL (UC FSK/SL) and uncoded SFSK (UC SFSK) have the same performances in the Gaussian channel, compared to the theoretical FSK curve. On the other hand, the coded FSK/SL (C FSK/SL) and coded SFSK (C SFSK) introduce a gain up to 3 dB over the theoretical performance under AWGN.

B. *Performance Results under the Effect of the Impulse Noise*

Fig 3 gathers the BER versus curves for the coded and uncoded systems under the impulse noise effect only.

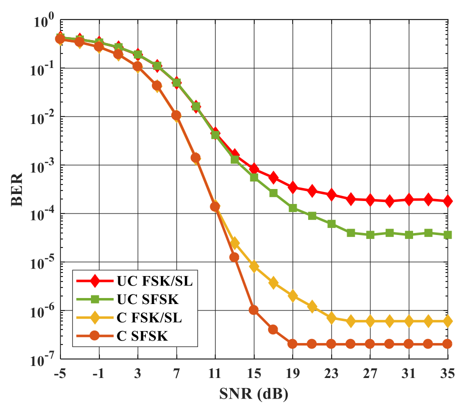

Fig. 4. BER versus SNR performance of the coded and uncoded systems under the impulse noise effect.

For SNR values up to 11 dB, both FSK and SFSK have the same performances for the coded and uncoded cases, with a gain up to 3 dB for the coded systems. As the SNR value increases, all the curves reach an error floor where the BER is almost constant. This error floor is due to the impulse noise presence with the same average power regardless of the SNR. UC SFSK outperforms UC FSK/SL by reaching an error floor equal to 4×10^{-5} for high SNR values against 2.10^{-4} for UC FSK/SL. Besides the coding gain in the low SNRs, the coded systems show their effectiveness in impulse noise mitigation, the error floor of C FSK/SL is 6×10^{-7}, while C SFSK achieves an error floor of 2×10^{-7}.

C. *Performance Results under the Effect of the PLC Channel Transfer Function*

The modulated signals are now exposed to the measured PLC channel transfer function, without the impulse noise presence. The obtained curves are depicted in Fig.5.

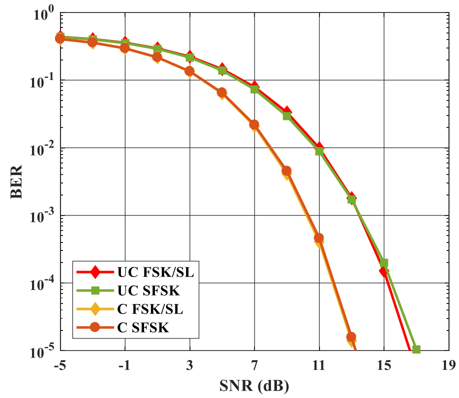

Fig. 5.BER versus SNR performance of the coded and uncoded systems under the PLC channel effect.

Under the channel effect, UC FSK/SL and UC SFSK have the same performances. At SNR = 17 dB, their BER is equal to 10^{-5}. This is due to the fact that the attenuation values of the channel for the used carrier frequencies are almost the same in the considered simulation scenario. For higher attenuation values, this performance may be degraded and UC FSK/SL may have worse BER than and UC SFSK.

When the coding is used, C FSK/SL and C SFSK have better but the same BER performances, similarly to the results obtained by the uncoded system, with an additional gain of 3 dB. The gain is nearly 4 dB at BER = 10^{-5}.

D. *Performance Results under the Effect of the PLC Channel and Noise*

We expose the modulated signals to both PLC channel and impulse noise. The obtained curves are illustrated in Fig. 6.

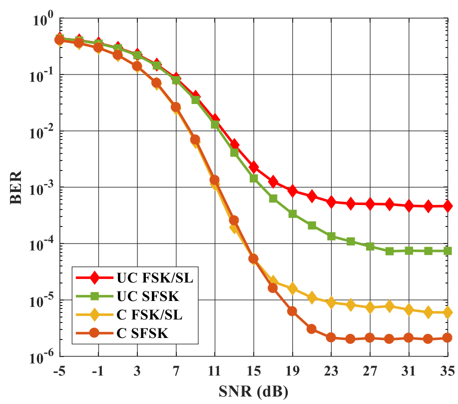

Fig. 6.BER versus SNR performance of the coded and uncoded systems under the PLC channel effect and impulse noise effect.

When the PLC channel and impulse noise effects are combined, similar shapes are obtained as those corresponding to the effect of only impulse noise (Fig. 4). The BER values are worse due to impact of the channel attenuation. UC FSK/SL has the same performance as UC SFSK for SNR values lower than 11 dB. For higher SNR values, UC FSK/SL loses 7.5 dB compared to UC SFSK at BER = 5×10^{-4}. Regarding the coded systems, C SFSK has the best performances with an error floor equal to 2×10^{-6}. C FSK/SL achieves an error floor equal to 6×10^{-6}, which is an excellent result considering its low complexity and compared to the performance of C SFSK and the amount of calculations it needs. Besides, both methods have the same performance for low SNR values up to 15 dB, which is the range of SNR values in the practical cases and the impulse noise effects appear only for high SNRs.

V. CONCLUSION

In this paper, two different decision methods for the coded FSK modulation techniques using permutation codes were exposed and their performances were compared under the indoor NB PLC channel attenuation and noise. The detailed decision schemes are SFSK and FSK/SL. The different schemes were applied to both coded and uncoded systems. The BER performances of the different techniques were assessed under Gaussian channel and indoor NB PLC channel constraints.

SFSK proved to have the best performances and to be efficient in combating the PLC channel impairments. For the uncoded systems, UC SFSK has an error floor equal to 7×10^{-5} versus 7×10^{-4} for UC FSK/SL. As for the coded systems, C SFSK gave an error floor reaching 2×10^{-6} compared to 6×10^{-6} for C FSK/SL under the NB PLC channel conditions.

Although it does not give the best error floor, C FSK/SL proved its efficiency in combating the harsh PLC channel impairments since it achieves the same performance as C SFSK for the SNR values up to 15 dB. Thus, C FSK/SL is a good choice for a low complexity decision method for the permutation coding in the power line environment.

Future works might explore the effect of using M-ary FSK coded modulations for more robustness and investigate low complexity impulse noise mitigation methods.

REFERENCES

[1] T. Schaub, "Spread frequency shift keying," in *IEEE Transactions on Communications*, vol. 42, no. 234, pp. 1056-1064, Feb/Mar/Apr 1994.

[2] D. Veronesi, L. Guerrieri and P. Bisaglia, "Improved spread frequency shift keying receiver," *International Symposium on Power Line Communications and its Applications (ISPLC2010)*, Rio de Janeiro, 2010, pp. 166-171.

[3] ST7570 S-FSK power line networking system-on-chip, STMicroelectronics, September 2012.

[4] AMIS-30585 S-FSK PLC Modem, On Semiconductor, December 2008.

[5] IEC 61334-5-1 Ed. 2.0 b:2001, Distribution automation using distribution line carrier systems - Part 5-1: Lower layer profiles – The spread frequency shift keying (S-FSK) profile.

[6] Y. Li, X. Cheng, Y. Cao, D. Wang and L. Yang, "Smart Choice for the Smart Grid: Narrowband Internet of Things (NB-IoT)," in *IEEE Internet of Things Journal*, vol. 5, no. 3, pp. 1505-1515, June 2018.

[7] H. Gassara, F. Rouissi, A.Ghazel, "Top-down random channel generator for the narrowband power line communication," in *AEU - International Journal of Electronics and Communications*, vol. 89, pp 146-152, 2018.

[8] H. Gassara, F. Rouissi, A.Ghazel, "A Novel Stochastic Model for the Impulsive Noise in the Narrowband Indoor PLC Environment," *IEEE International Instrumentation and Measurement Technology Conference (I²MTC)*, Pisa, 11-14 Mai 2015.

[9] F. Rouissi, A. J. H. Vinck, H. Gassara and A. Ghazel, "Statistical characterization and modelling of impulse noise on indoor narrowband PLC environment," *2017 IEEE International Symposium on Power Line Communications and its Applications (ISPLC)*, Madrid, 2017, pp. 1-6.

[10] A. J. H. Vinck and J. Häring "Coding and Modulation of Power-Line Communications," *International Symposium on Power-line Communications and its Applications (ISPLC2000)*, Limerick, 2000, pp. 265-272.