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Analysis of the Use of Different Decoding Schemes in LDPC Coded OFDM Systems over Indoor PLC Channels

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[1]***Abstract*—Power line communication (PLC) method is a developing technology that is intended to provide a communication platform by using conventional power lines. In this study, bit error rate (BER) performances of low-density parity-check (LDPC) coded orthogonal frequency-division multiplexing (OFDM) systems have been examined over indoor PLC channels. Performances of different LDPC decoder schemes such as belief propagation (BP), weighted bit flipping (WBF) and implementation-efficient reliability ratio based weighted bit flipping (IRRWBF) decoders were investigated in the modelled system. Different indoor channel scenarios that were generated by using new and more realistic PLC channel model proposal were also employed to evaluate the BER performance analyses. The performed simulations in the PLC channels showed that the LDPC codes can provide significant improvement with a remarkable encoding complexity when the BP or IRRWBF decoder is utilized on the receiver unit.**

***Index Terms*—Power line communications (PLC), low-density parity-check (LDPC) codes, orthogonal frequency-division multiplexing (OFDM), bit error rate (BER).**

I. INTRODUCTION

Nowadays, power line communication (PLC) systems have attracted much interest in the field of communication and smart grid systems since they do not require to establish any new communication medium [1]–[4]. The main applications of the PLC systems can be classified into two categories as indoor and outdoor applications. The smart grid (SG) and advanced meter reading (AMR) systems are the most popular outdoor applications of these systems and they generally use narrowband PLC channel under the 500 KHz frequency band [2], [3]. The indoor applications of the PLC systems that aim to ensure high data rates for homes and offices use higher frequencies than the narrow band such as in the range of megahertz.

The power lines act as a destructive and noisy channel when they are employed as a communication medium since they were essentially designed for electrical energy delivery. Performances of the PLC systems extremely depend on the channel characteristics of the connected network. Hence, the PLC channel characteristics are intensively being investigated and researchers reported several channel models. Hensen described the first channel model in [5] where the channel attenuation was simply increased with frequency. Later the Hensen's model, another model that takes into account multipath effects, was proposed by Phillips [6]. An extended PLC channel model was also described by Zimmerman, in which they have considered effects of cable length in the frequency domain [7]. Later on, a novel and more realistic PLC channel model was proposed by Canete [8]. Moreover, in the literature, there are several PLC channel models that were based on statistical rules [9]-[11]. Also, the reported contributions in [12] showed that the indoor PLC channel conditions could be defined more accurately by using Canete's channel model proposal, which will also be utilized in this study.

The purpose of this paper is to employ a novel and more realistic model [8] as indoor PLC channels to evaluate bit error rate (BER) performance results of low-density parity-check (LDPC) coded orthogonal frequency-division multiplexing (OFDM) system. The effects of soft and hard LDPC decoder schemes such as belief propagation (BP), weighted bit flipping (WBF) and implementation-efficient reliability ratio based weighted bit flipping (IRRWBF) decoders are also examined in the modelled system regarding to the system performance. Moreover, three different PLC channel scenarios are considered in the performed simulations. The BER performance of an adopted PLC channel model that is based on the LDPC coded OFDM system with various decoder schemes has not ever been proposed and analysed, that is the main contribution of this paper.

The remainder of this paper is organized as follows: The LDPC coded OFDM scheme is presented in Section II. The third section describes the indoor PLC channel model and simulation results are drawn in fourth section in detail, while conclusions are given in Section V.

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II. LDPC CODED OFDM SYSTEM IN PLC CHANNEL

The destructive effects of the PLC channel can be reduced by using LDPC coded OFDM system that is a robust and effective method to cope influences of frequency selective channels. The LDPC codes are a class of linear block codes and are one of the most important forward error-correction (FEC) codes for channel coding. These codes were introduced by Gallager [13]. After it has been showed that the LDPC codes could reach Shannon limit error performance, they were rediscovered in the late 1990s [14]. The LDPC codes are widely preferred in modern communication systems for channel coding. The DVB-S/-T/-C, 802.11n (Wi-Fi), 802.16e (WiMAX), IEEE802.3an (10Gbit Ethernet) and G.hn/G.9960 standards are presently employed these codes due to their high performance.

Figure 1 shows block diagram of the LDPC coded OFDM system with soft and hard decision decoders employed over the indoor PLC channels. The transmitter part of the communication system is shown at the top of the Fig. 1, where the random data are firstly generated as an input message and then are applied to LDPC encoder block to perform channel-coding process. After the channel coding process performed by using LDPC codes, the mapping is applied to data in the constellation mapper block. The pilot symbols are inserted to the coded and modulated data to achieve exact estimation on the receiver. Afterwards, the data are arranged to add cyclic prefix (CP) to prevent intersymbol interference (ISI) and then data are passed through the indoor PLC channels.

The data applied to the PLC channels are exposed to various destructive effects of the channel such as attenuation and various noises that are caused by the power lines and loads connected to the grid. The mentioned noise contains background noise, impulsive noise and narrowband interferences. The lower part of the block diagram illustrates the receiver structure of the system. The input data of the receiver unit are primarily transformed to parallel data type and then the guard interval of the parallel data streams are removed to apply the data to fast Fourier transform (FFT) in OFDM receiver block. By following the FFT process, the data are converted to serial type and channel estimation, pilot symbols removal and demodulation processes are implemented to data stream where the decoding process is the final step of the receiver unit. The LDPC decoding process can be performed by using soft or hard decision decoder schemes. While the most commonly used hard decision decoders in the literature are WBF [15] and IRRWBF decoders [16], the most popular soft decision decoder is BP decoder [17]. In this study, these soft and hard decision LDPC decoder schemes are employed to analyse and to compare the performances over the indoor PLC channels.

III. POWER LINE CHANNEL MODEL

The PLC channel model proposed by Canete [8] is adopted in this study, which can generate more realistic indoor channel scenarios since it considers the practical network structure of home and offices to create the channel scenarios. The simplified network topology used to describe the PLC channel model is shown in Fig. 2.

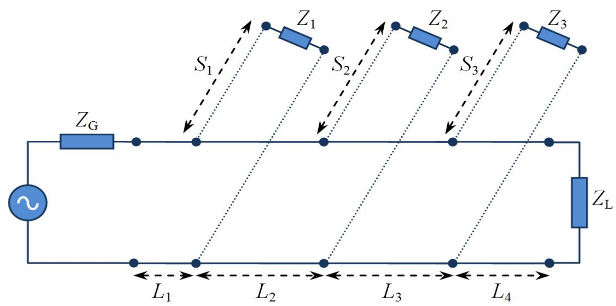

Fig. 2. Network topology of Canete's PLC channel model [8].

This model consists of line lengths $\left(L_i\left(i \in \{1,2,3,4\}\right), S_i\left(i \in \{1,2,3\}\right)\right)$ and terminal units $\left(Z_i\left(i \in \{1,2,3\}\right), Z_G \text{ and } Z_L\right)$ as shown in the Fig. 2. The outlets of the indoor network are modelled as terminal units in Canete's model. While the load impedances connected to the grid are illustrated with Z_1, Z_2 and Z_3, the transmitter and receiver units are shown with Z_G and Z_L, respectively.

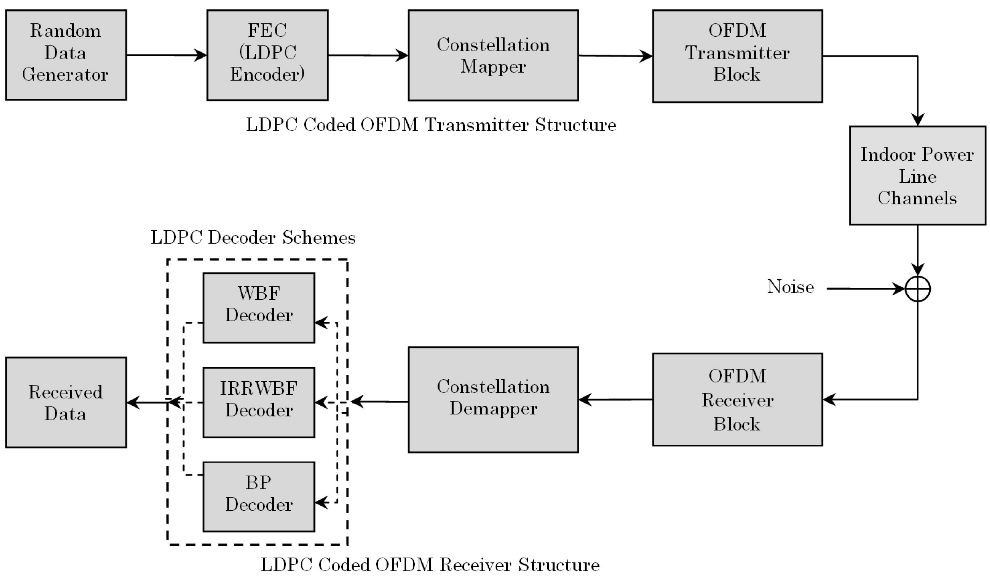

Fig. 1. The block diagram of LDPC coded OFDM system with various decoder schemes over indoor PLC channels.

The mathematical expressions between the transmitter and receiver can be obtained by using two-port network and ABCD matrix theory. In order to achieve this, characteristic impedance (Z_C) and propagation constant (¥) are firstly calculated with respect to used electrical cable parameters as follows:

$$Z_C = \sqrt{\frac{R + j\mu L}{G + j\mu C}}, \tag{1}$$

$$\text{¥} = \sqrt{(R + j\mu L)(G + j\mu C)}, \tag{2}$$

where ω is angular frequency, R, L, G, and C show resistance, inductance, conductance, and capacitance of the electrical cable, respectively. Later, ABCD matrix of the PLC model can be derived by using (1) and (2) as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cosh(\text{¥} l) & Z_C \sinh(\text{¥} l) \\ \frac{1}{Z_C}\sinh(\text{¥} l) & \cosh(\text{¥} l) \end{bmatrix}, \tag{3}$$

Finally, transfer function of the power line network with respect to the ABCD parameters is given as

$$H = \frac{Z_C}{AZ_C + B + CZ_C Z_G + DZ_G}. \tag{4}$$

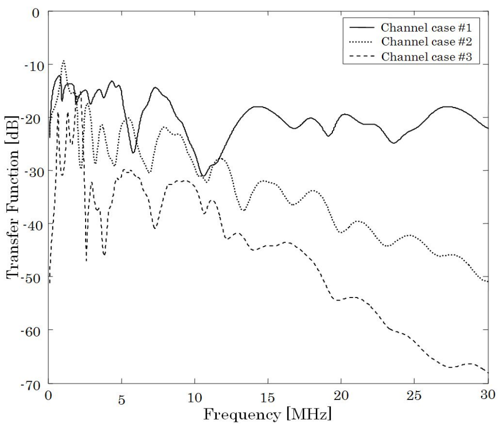

Fig. 3. Amplitude responses of the indoor PLC channel scenarios [8].

The size of the line parts and values of the impedances can be changed to obtain various channel conditions. Using the model in [8], three different channel scenarios between 0 Hz to 30 MHz is generated as can be seen from the Fig. 3. The created channel scenarios can be regarded as: Channel case #1 is the best, Channel case #2 is medium and Channel case #3 is the worst communication environment for the PLC applications according to attenuation values.

IV. Simulation Results

The computer simulations by using Matlab are carried out over the indoor PLC channels and two different LDPC codes that have $(96, 48)$ and $(1080, 540)$ code lengths are used to evaluate the BER performances of the LDPC coded OFDM system. The soft and hard decision decoders are employed in the simulations and the maximum decoding number is set to 50 for all decoder types. The subcarrier space and cyclic prefix of the OFDM system are also set as 468.75 kHz and 0.53 μs, respectively.

Figure 4 depicts both uncoded and LDPC coded BER results of the OFDM system in terms of signal to noise ratio (SNR) over indoor PLC channel case #1. When the BP decoder result is considered for $(96, 48)$ LDPC coded system, it is observed that it provides nearly 9.5 dB improvements in the BER level of 10^{-3}. The BER of $(1080, 540)$ LDPC coded system shows 0.7 dB better performance by comparing to $(96, 48)$ LDPC coded system with BP decoder. When the performances of the hard decision decoders are examined, it is seen that the IRRWBF decoder outperforms nearly 0.5 dB than that of the WBF decoder for both LDPC codes. Also it is noted that the hard decision decoders represent up to 7.5 dB improvements for BER of 10^{-3} according to the uncoded OFDM system.

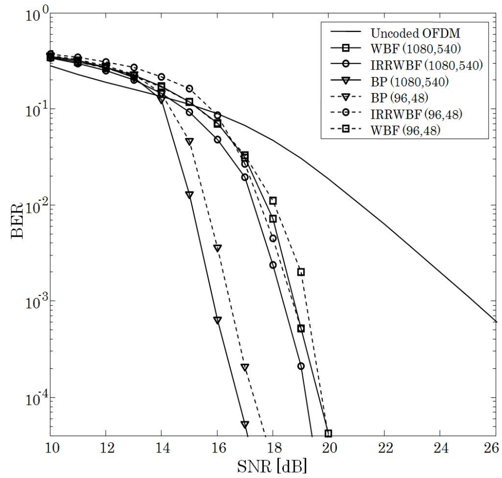

Fig. 4. BER performances of OFDM systems in the PLC channel case #1.

Figure 5 indicates the performance results obtained for the coded and uncoded OFDM systems in the PLC channel case #2. As expected from the increased channel attenuation, the BER levels of 10^{-3} are achieved at very high SNR values of the uncoded OFDM system. The coded OFDM system by $(96, 48)$ code provides up to 11.5 dB improvements in the BER level of 10^{-2} with thanks to the BP decoder than the uncoded system. If the long LDPC code is considered for the same conditions, $(1080, 540)$ LDPC coded system provides an improvement of nearly 0.85 dB than that of the other LDPC code at a BER level of 10^{-4}. When the results shown in the Fig. 5 are analysed, it is also shown that the IRRWBF decoder outperforms slightly better than the BP decoder after 28 dB value of the SNR for both LDPC codes. However, the WBF decoder is the worst one, and its improvement is about 10 dB in the BER level of 10^{-3} according to uncoded case.

The last BER results that are illustrated in the Fig. 6 are performed for the PLC channel case #3. If the BP decoder result for short LDPC code and uncoded case are compared, the LDPC code attains 13.5 dB gain in the BER level of 10^{-1}.

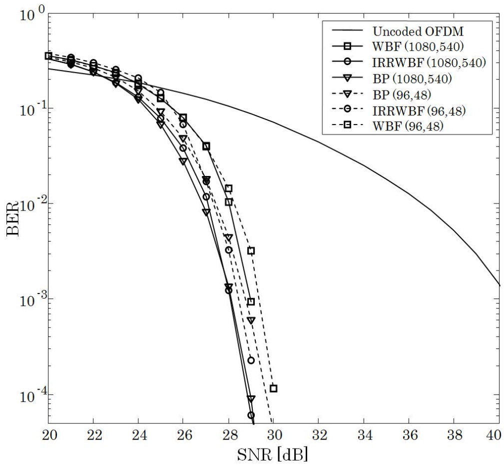

Fig. 5. Performances of the OFDM systems for the PLC channel case #2.

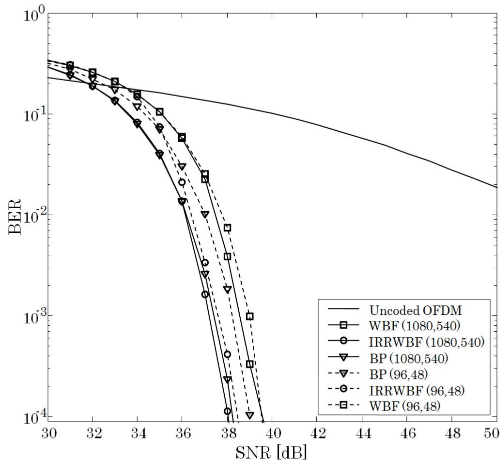

Fig. 6. BER performance comparison of OFDM systems over the PLC channel case #3.

In addition, the long LDPC code outperforms 0.75 dB gain for BER of 10^{-4} than $(96,48)$ code for the same decoder type. When the results of LDPC coded OFDM system with $(1080,540)$ code are considered, it is observed that the IRRWBF decoder outperforms nearly 0.1 dB better than the BP decoder after 37 dB SNR value. Furthermore, the IRRWBF decoder is approximately 0.5 dB better than that of the BP decoder after the 36 dB SNR for short LDPC codes. As a final remark, it is important to note that the improvements of the WBF decoder are about 13 dB for BER of 10^{-1} for both LDPC codes.

V. CONCLUSIONS

This paper focused on the BER performances of the coded and uncoded OFDM systems employed over the indoor PLC channels. Unlike the previous studies, a new and more realistic PLC channel model was utilized to evaluate the performances of the OFDM systems in this study. The computer simulations were performed for uncoded and LDPC coded OFDM systems that utilize $(96,48)$ and $(1080,540)$ LDPC codes. In addition to this, the performances of soft and hard decision LDPC decoders were also investigated regarding to the three different PLC channel scenarios. The performed simulations in the PLC channels showed that the LDPC codes can provide significant improvement with an acceptable encoding complexity when the BP or IRRWBF decoder is utilized on the receiver unit.

REFERENCES

[1] Y.J. Lin, H.A. Latchman, M. Lee, *et al.*, "A power line communication network infrastructure for the smart home", *IEEE Wireless Commun.*, vol. 9, no. 6, pp. 104–111, 2002. [Online]. Available: http://dx.doi.org/10.1109/MWC.2002.1160088

[2] S. Galli, A. Scaglione, W. Zhifang, "For the grid and through the grid: the role of power line communications in the smart grid", *IEEE Proc.*, vol. 99, no. 6, pp. 998–1027, 2011.

[3] E. Kabalci, Y. Kabalci, I. Develi, "Modelling and analysis of a power line communication system with QPSK modem for renewable smart grids", *Int. J. Electr. Power Energy Syst.*, vol. 34, no. 1, pp. 19–28, 2012. [Online]. Available: http://dx.doi.org/10.1016/j.ijepes.2011.08.021

[4] Y. Kabalci, I. Develi, E. Kabalci, "LDPC coded OFDM systems over broadband indoor power line channels: a performance analysis", in *4th IEEE Int. Conf. on Power Engineering, Energy and Electrical Drives*, pp. 1581–1585, 2013. [Online]. Available: http://dx.doi.org/10.1109/PowerEng.2013.6635852

[5] C. Hensen, W. Schulz, "Time dependence of the channel characteristics of low voltage power-lines and its effects on hardware implementation", *AEU Int. J. Electron. Commun.*, vol. 54, no. 1, pp. 23–32, 2000.

[6] H. Philipps, "Modelling of powerline communication channels", in *Conf. IEEE Int. Symp. on Power Line Communications and Its Applications*, 1999, pp. 14–21.

[7] M. Zimmermann, C. Dostert, "A multipath model for the powerline channel", *IEEE Trans. Commun.*, vol. 50, no. 4, pp. 553–559, 2002. [Online]. Available: http://dx.doi.org/10.1109/26.996069

[8] F. J. Canete, J. A. Cortes, L. Diez, J. T. Entrambasaguas, "A channel model proposal for indoor power line communications", *IEEE Commun. Mag.*, vol. 49, no. 12, pp. 166–174, 2011. [Online]. Available: http://dx.doi.org/10.1109/MCOM.2011.6094022

[9] A. M. Tonello, Z. Tao, "Bottom-up transfer function generator for broadband PLC statistical channel modeling", in *Conf. IEEE Int. Symp. on Power Line Communications and Its Applications*, 2009, pp. 7–12.

[10] S. Galli, "A simple two-tap statistical model for the power line channel", in *Conf. IEEE Int. Symposium on Power Line Communications and Its Applications*, 2010, pp. 242–248.

[11] A. M. Tonello, F. Versolatto, "Bottom-up statistical PLC channel modeling-Part I: random topology model and efficient transfer function computation", *IEEE Trans. on Power Delivery*, vol. 26, no. 2, pp. 891–898, 2011. [Online]. Available: http://dx.doi.org/10.1109/TPWRD.2010.2096518

[12] J. A. Cortes, F. J. Canete, L. Diez, J. L. G. Moreno, "On the statistical properties of indoor power line channels: measurements and models", in *Conf. IEEE Int. Symp. on Power Line Communications and Its Applications*, 2011, pp. 271–276.

[13] R. G. Gallager, "Low-density parity-check codes", MIT Press, Cambridge, MA, 1963.

[14] D. J. C. MacKay, R. M. Neal, "Near Shannon limit performance of low density parity check codes", *Electron. Lett.*, vol. 33, no. 6, pp. 457–458, 1997. [Online]. Available: http://dx.doi.org/10.1049/el:19970362

[15] Y. Kou, S. Lin, M. P. C. Fossorier, "Low-density parity-check codes based on finite geometries: a rediscovery and new results", *IEEE Trans. Inf. Theory*, vol. 47, pp. 2711–2736, 2001. [Online]. Available: http://dx.doi.org/10.1109/18.959255

[16] C. H. Lee, W. Wolf, "Implementation-efficient reliability ratio based weighted bit-flipping decoding for LDPC codes", *Electron. Lett.*, vol. 41, no. 13, pp. 755–757, 2005. [Online]. Available: http://dx.doi.org/10.1049/el:20051060

[17] M. P. C. Fossorier, M. Mihaljevic, H. Imai, "Reduced complexity iterative decoding of low-density parity check codes based on belief propagation", *IEEE Trans. Commun.*, vol. 47, no. 5, pp. 673–680, 1999. [Online]. Available: http://dx.doi.org/10.1109/26.768759