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Original

# Proposal of an experimental data and image transmission system and its possible application for remote monitoring smart grids

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**Abstract**

This paper investigates the bit error rate (BER) and the peak signal-to-noise ratio (PSNR) performances of quasi-cyclic low-density parity-check (QC-LDPC) coded orthogonal frequency-division multiplexing (OFDM) systems over an actual power line communication (PLC) channel that are acquired by performing very long-term experimental measurements from the grid. The examined system is tested by changing system parameters such as code length, iteration number, coding rate and message type in detail. The results of this study show that the QC-LDPC coded OFDM system can be a possible solution for communication and remote monitoring purposes in smart grids.



*Keywords:* Smart grids; Remote monitoring; Power line communication (PLC); Quasi-cyclic low-density parity-check (QC-LDPC) codes; Orthogonal frequency-division multiplexing (OFDM)

## 1. Introduction

The rapidly decreasing reserves of fossil fuels and environmental considerations are currently compelling researchers to discover efficient alternative energy sources. The renewable energy source (RES) is a widespread concept covering wind energy, solar energy, biomass, geothermal, and tidal wave energies which are believed to have the ability to tackle our dependency on fossil fuels. Extensive studies about electrical energy generation by using RESs have been performed by numerous research laboratories and scientists (Fu et al., 2014; Jain & Agarwal, 2008; Kabalci, Kabalci, & Develi, 2012; Liserre, Sauter, & Hung, 2010; Nehrir et al., 2011; Spagnuolo et al., 2010; Yu, Zhang, Xiao, & Choudhury, 2011). At present, RESs are assumed as alternative energy sources to fuels, and they can be easily integrated into currently used grid infrastructures. Since an energy plant that is based on RES needs to permanently supply the electrical loads as well as the conventional grid, standalone renewable energy plants are assisted with battery and energy storage systems.

Distributed energy sources (DES) are suggested as a solution to energy demands by interconnecting several different energy sources together. A robust microgrid structure that is constituted from various energy sources should be able to be easily connected to and disconnected from the conventional grid; this requirement means the integration capability of any additional source connection to the existing distributed generation system without requiring any system configuration (Spagnuolo et al., 2010; Yu et al., 2011). The monitoring and metering requirements of microgrid networks should be met as well as conducted in conventional grids. Although several measuring methods have been proposed such as wired or wireless, all the solutions are related to the smart grid concept that has been extensively researched (Gungor et al., 2011; Matanza, Alexandres, & Rodríguez-Morcillo, 2014; Sung & Hsu, 2013; Wen, Wang, Zhu, Li, & Zhou, 2013; Yan, Qian, Sharif, & Tipper, 2013). The smart grid should meet the remote sensing, communication, controlling, monitoring and analysis demands in a sustainable, secure and efficient way to manage the entire infrastructure. Smart grid applications are widely used in the phase measurement, advanced metering and remote monitoring

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of source and load amplitudes (Galli, Scaglione, & Wang, 2010; Gungor et al., 2011; Kabalci et al., 2012; Matanza et al., 2014; Sung & Hsu, 2013; Yan et al., 2013; Yu et al., 2011).

The type of communication medium preferred in smart grids is wired or wireless because of environmental and substructural factors. Wireless communication systems are standardized to wireless home area networks (HAN) and wireless wide area networks (WAN). Besides these standard networks, business area networks (BANs) and neighborhood area networks (NANs) have also been proposed by several researchers and alliances. The HAN standards are implemented and operated by ZigBee alliance and Wi-Fi alliance which include the global system for mobile communications (GSM), ZigBee, Wi-Fi, and the general packet radio service (GPRS), while the WAN standards cover WiMax that is based on IEEE 802.16 standard (Gungor et al., 2011; Yan et al., 2013; Yu et al., 2011). Although wireless communication seems to be the most convenient method to transfer information and control data, the required infrastructure greatly increases the installation costs. Furthermore, the destructive effects of the communication medium decrease the sustainability and security of data transfer in wireless communication. An alternative method to transmit measured data is to use electrical power lines as a transmission medium; this concept is defined as power line communication (PLC). PLC is considered as a promising technology in smart grids because of its eliminating the additional costs of wireless and other wire line communication methods (Galli et al., 2010), and owing to its high-speed data rates of up to 200 Megabits per second (Mbps). Moreover, PLC can be used in industrial, indoor, and outdoor applications thanks to its various communication bands that are called broadband (BB) and narrowband (NB) (Galli et al., 2010; Gungor et al., 2011; Yan et al., 2013). NB PLC systems operate below 500 kHz band according to CENELEC, FCC or ARIB standards and generally utilize single carrier systems. On the other hand, BB PLC systems run between the band range of 1–30 MHz and exploit multi carrier systems such as orthogonal frequency-division multiplexing (OFDM), and especially coded OFDM. Recently reported studies in the literature showed that the low-density parity-check (LDPC) code is the best solution for the channel coding process in PLC systems (Andreadou & Pavlidou, 2010; Andreadou, Assimakopoulos, & Pavlidou, 2007; Nakagawa, Umehara, Denno, & Morihiro, 2005; Spencer, 2005; Wada, 2004). The authors in (Andreadou et al., 2007) aimed to compare LDPC code performance with Reed-Solomon and Convolutional codes over the PLC channels and they showed that LDPC codes perform better than other codes. In Nakagawa et al. (2005), the authors searched for a way to improve the decoding process of LDPC codes over PLC channels with impulsive noise. The performance of high rate and short-block LDPC codes in low bandwidth PLC systems is considered in Spencer (2005). The authors in Wada (2004) showed that the performance of LDPC codes is also better than that of Turbo codes in PLC channels. The performance of irregular quasi-cyclic (QC) LDPC codes over a statistical PLC channel model with highly impulsive noise is examined in Andreadou and Pavlidou (2010).

In previous studies (Develi & Kabalci, 2014a; Kabalci, Develi, & Kabalci, 2013), we have examined bit error rate (BER) performances of LDPC coded OFDM systems over Canete's PLC channel model and aimed to show superiority of LDPC codes among others in PLC channels. In Develi and Kabalci (2014b), effect of using different decoding schemes on the LDPC coded OFDM systems over indoor PLC channels was analyzed. In addition to these works, an image transmission system for smart grids was also proposed in (Develi, Kabalci, & Basturk, 2014). Furthermore, a PLC channel model proposal that is based on practical channel measurements acquired from electrical networks in Turkey was reported in Develi, Kabalci, and Basturk (2015).

This paper presents investigation of the QC-LDPC coded OFDM system performances over a practical PLC channel in contrast to previous studies reported in the literature. To obtain a realistic PLC channel medium, long-term measurements were carried out in Nigde Vocational College of Technical Sciences, Turkey. The simulation results were obtained by varying the code rate, block length and iteration numbers of the QC-LDPC codes over the generated PLC channel. Furthermore, the simulations were not only completed by transmitting randomly generated data, but were also carried out for the transmission of different images such as *lenna*, *cameraman* and *baboon* which are widely used for performance evaluation and comparison in the literature. As a result, it was confirmed that the QC-LDPC coded OFDM system, in which performance was analyzed in a real PLC channel, can be utilized in smart grids for communication and remote monitoring purposes in a reliable way.

The rest of this paper is organized as follows: Section 2 describes the QC-LDPC codes, the OFDM system principles and system model. The PLC channel measurement system is explained in Section 3. Finally, the simulation results and conclusions are given in Sections 4 and 5, respectively.

## 2. System model

### 2.1. LDPC and QC-LDPC codes

LDPC codes are robust error correcting codes and are a special type of linear block code (Gallager, 1963). A sparse matrix, called parity-check matrix **H**, is exploited to define these codes. When an $(n, k)$ LDPC code is considered, $k$ denotes information bits and $n$ represents coded bits with an $r = k/n$ code rate. In addition, the dimensions of the parity-check matrix **H** are shown by $(n - k) \times n$. LDPC codes have some advantages, such as a simple coding process, parallel and iterative decoding operations and good performance when they are compared with Reed-Solomon, Convolutional or Turbo codes. Because of their high performance and low decoding complexity compared to other channel coding schemes, LDPC codes have been exploited in most modern communication systems such as DVB-S2/-T2/-C2, 802.11n (Wi-Fi), 802.16e (WiMAX), IEEE802.3an (10Gbit Ethernet) and G.hn/G.9960.

QC-LDPC codes, which are a special type of LDPC code, offer a simple encoding process and better error correcting performance. These codes utilize the shifting method to decrease