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LDPC coded DFT/DCT-spread SC-FDMA for image communication: A compressed sensing approach

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Abstract

A compressed sensing (CS)-based detector is proposed for the low-density parity-check (LDPC) coded single carrier frequency division multiple access (SC-FDMA) scheme. The proposed CS-based detector can be employed at the receiver of LDPC-coded SC-FDMA systems for efficient image communications over vehicular channels. The proposed detector employs a suitable sparse recovery algorithm. We have considered both the discrete Fourier transform (DFT)-based and the discrete cosine transform (DCT)-based SC-FDMA for mitigating the channel-induced dispersion at a low peak to average power ratio (PAPR). Additionally, both the linear equalizer (LE) and the decision feedback equalizer (DFE)-based SC-FDMA have been considered for image communication. The performance of the proposed technique is investigated using a number of image quality metrics. The qualities of the received images are also compared visually. The complexity of the proposed detector and that of the benchmark detectors are quantified. Furthermore, the performance and the complexity of the proposed system using some of the sparse recovery techniques are investigated and compared. Our simulations demonstrate that LDPC coded SC-FDMA using the compressed sampling matching pursuit (CoSaMP)-based CS detector can significantly improve the performance of image communication over vehicular channels.

Keywords

Single carrier frequency division multiple access (SC-FDMA); Compressed sensing (CS); Low-density parity-check (LDPC) code; Decision feedback equalizer; Image communication; Extended vehicular A channel

Article preview

Abstract

Introduction

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Introduction

Digital image transmission over the wireless channel has been widely used in environmental monitoring, in medical and military applications and so on. The explosive growth of the Internet and of the demand for multimedia services necessitate high-speed image transmission at a significantly low bit error rate (BER)[1], [2], [3], [4]. The performance of the image communication system is degraded by multipath fading channels. However, this performance degradation may be effectively mitigated by employing a suitable multicarrier modulation. Specifically, orthogonal frequency division multiple access (OFDMA) and single carrier frequency division multiple access (SC-FDMA)[5], [6] were proposed in the downlink (DL) and the uplink (UL), respectively, of the fourth-generation (4G) long-term evolution advanced (LTE-A) standard for high-rate multimedia transmissions. OFDMA is the multiuser counterpart of orthogonal frequency division multiplexing (OFDM), whereas SC-FDMA supports multiple users by employing discrete Fourier transform (DFT) spreading of the time-domain (TD) transmit symbols[6].

OFDMA provides an improved spectral efficiency with the intersymbol interference (ISI) significantly reduced by using cyclic prefix (CP). On the other hand, SC-FDMA symbols are DFT-spread in the frequency domain (FD) before being mapped to the subcarriers. SC-FDMA transmit symbols have a low peak-to-average power ratio (PAPR). The transmit symbols may also be spread by using a discrete cosine transform (DCT)[7] in a DCT-based SC-FDMA system. DCT is widely used in signal processing as well as data compression. DCT-based multicarrier systems employ real arithmetic only and require only half of the subcarrier spacing as opposed to DFT-based systems[8]. DCT has the capability of eliminating inter-block and inter-carrier interferences without the requirement of additional guard sequences[9], [10]. However, inter-symbol interference (ISI) imposed by dispersive wireless channels is a crucial problem in wireless communications systems[11], [12]. To compensate for the signal distortion due to the frequency selectivity of wireless channels, equalization is carried out at the receiver of the communication system. Although equalization had been traditionally carried out in the TD, FD equalizers attracted considerable interest due to the simplicity of their design[13], [14]. In addition to the zero-forcing (ZF) and minimum mean-squared error (MMSE) linear equalizers (LEs), decision feedback equalizers (DFEs) were also proposed[13], [15]. Furthermore, a constraint-based block recursive least-squares (CRLS) for an adaptive frequency-domain decision feedback equalizer (AFD-DFE) is proposed for SC-FDMA systems in[16]. In order to address the adverse effects of the feedback symbols reliability, the feedback correlation metric, and the phase noise, a robust iterative block decision feedback equalization (DFE) algorithm is developed in[17] for SC-FDMA uplink systems.

Wireless image transmission using turbo codes with unequal error protection was proposed in[18]. The performance of image transmission with the aid of OFDMA and DCT-based SC-FDMA were investigated in[19], [20]. However, these studies mainly considered either an additive white Gaussian noise (AWGN) or a flat-fading channel. An SC-FDMA scheme relying on low-density parity-check (LDPC)[21], [22] code and on both the wavelet transform and the discrete cosine transform was proposed in[23] for image communication. The major contributions on OFDMA, SC-FDMA, and the relevant image communication techniques are outlined in Table 1.

On the other hand, compressed sensing (CS) has emerged as a beneficial signal processing technique of recovering sparse signals[26], [27], [28], [29], [30]. CS can recover signals sampled below the Nyquist sampling rate[31], [32] and has got widespread applications in recovering undersampled signals, especially magnetic resonance image (MRI) signals and various other signals. A wide range of studies has been carried out on the advancement of CS algorithms and on CS applications. A number of CS-based research problems exist on sparse wireless channel estimation[33]. CS-aided modulation classification[34] and CS-aided single-user and multi-user signal detection[35], [36] are also emerging research

directions in the field of wireless communications[37], [38]. The main contributions on CS applications in wireless communications are listed in Table2.

The design guidelines for the CS-based wireless communication systems are detailed in[38], [43]. Generalized frameworks for wireless signal detection are provided in[42], [43], [45]. There are lots of sparse recovery algorithms employed for CS-based signal recovery and detection. Some of the sparse recovery techniques are basis pursuit denoising[46], orthogonal matching pursuit (OMP)[47], compressed sampling matching pursuit (CoSaMP)[40], and iterative hard thresholding (IHT)[41]. These sparse recovery techniques can be employed for sparse signal detection. However, CS-based signal detection of OFDM or SC-FDMA systems still remains an open problem.

Against this background, we propose a CS-assisted detector for the SC-FDMA scheme in this article. An error-resilient LDPC-coded DFT-based or DCT-based SC-FDMA scheme is considered for image transmission over the ITU extended vehicular A (EVA) channel[48]. The proposed scheme employs Gallager's near-capacity LDPC code[21] in conjunction with the LE/DFE-based SC-FDMA. The mean-squared error (MSE), the peak signal-to-noise ratio (PSNR), and the structural similarity index measure (SSIM)[49], [50] of the received image and the BER of the system are evaluated and compared to those of the benchmark schemes. The contributions of this paper are:

1. A low-complexity improved-performance sparse recovery aided detector is proposed for the LDPC coded SC-FDMA scheme for image communications over dispersive wireless channels.
2. The DFT-based, as well as the DCT-based SC-FDMA, is considered and the performance of the scheme is investigated and compared to benchmark schemes.
3. The DFE has been designed for the LDPC coded SC-FDMA system using insights from[13], [15].
4. The BER performance of the scheme, the MSE, the PSNR, and the SSIM of the images is compared to those of the OFDMA based system. The CS-aided sparse SC-FDMA detector can be effectively used in conjunction with the LDPC encoder and decoder for image communications over ITU vehicular channels.
5. The complexity of the proposed scheme has been quantified and compared to that of the benchmark schemes. The proposed scheme can provide improved performance for image communication over vehicular channels at low complexity and low signal-to-noise ratio (SNR).

The remainder of this paper is organized as follows. Section2 provides an overview of the proposed scheme. Section3 details the proposed CS-based detector for the scheme. The computational complexity is analyzed in Section4, and the different performance metrics are described in Section5. The simulated performance results are presented in Section6. Finally, we conclude in Section7.

Section snippets

System overview

In this section, we provide a brief overview of the proposed LDPC coded SC-FDMA transceiver. The schematic diagram of the transmitter is portrayed in Fig.1. The receiver schematics with the linear equalizer and with the DFE are shown in Fig. 2, Fig. 3, respectively.

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Proposed compressed sensing aided detector for the scheme

In this section, we propose a CS-based detector for the proposed SC-FDMA system. The schematic diagram of Fig.4 illustrates the receiver architecture of the proposed scheme using the CS-based detector. The proposed CS-aided detector uses insights from[42], [43], and is designed specifically for the SC-FDMA system considered here, The output of the proposed system of Fig.2 is not sparse. However, in Fig.4, we employ an arrangement such that the output signal of the LE-based system is …

Computational complexity

In this section, we discuss the computational complexity of the proposed system. We consider the system comprising of an LDPC encoder/decoder and using either a linear ZF or MMSE or a decision feedback equalizer. We also propose an SC-FDMA scheme in conjunction with a sparse recovery algorithm. The complexity of the schemes is expressed here in terms of the required number of real multiplications. We consider a single complex multiplication operation to be equivalent to four real …

Performance metrics

The performance of the proposed system is evaluated in terms of the BER, the MSE, and the PSNR of the received image.

As a very well-known metric, the BER is the ratio of the number of incorrectly detected bits to that of the input bits. The MSE represents the cumulative squared error between the transmitted image and the received image. The MSE is defined by:

$$\mathrm{MSE} = \frac{\sum_{k=0}^{K-1} \sum_{k^{'}=0}^{K^{'}-1} I_0\left(k, k^{'}\right) - I_1\left(k, k^{'}\right)}{K.K^{'}},$$

where I_0 represents the transmitted (reference) image, I_1 represents the received (modified) …

Numerical results

In this section, the performance of the proposed LDPC coded SC-FDMA scheme has been evaluated for image communication by numerical simulations. The main simulation parameters are listed in Table6. The ‘peppers’, the ‘cameraman’ and the ‘apple’ images are taken into consideration. We consider the ITU extended vehicular A (EVA) channel for this study. As shown in Table6, we have employed a $r = \frac{1}{2}$ rate LDPC code, a total of $M = 64$ subcarriers with $N = 16$-point DFT or DCT spreading and localized …

Conclusion

In this paper, a CS-aided detector has been proposed for the LDPC coded SC-FDMA system for image communication over dispersive channels. A DFT-spread, as well as DCT-spread SC-FDMA, has been considered. The proposed CS-based detector exploits the sparsity of the estimated signal by a conventional LE-aided detector and employs a sparse recovery method. The performance of the scheme has been evaluated by the BER of the system, and the MSE, the PSNR, and the SSIM of the received images. The …

CRediT authorship contribution statement

Mohammad Ismat Kadir: Conceptualization, Methodology, Software, Writing – original draft, Review and editing, Supervision. **Rafiul Kadir:** Methodology, Software. **Ritu Saha:**

Analysis, Writing – original draft. …

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

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