Time Domain Synchronous OFDM Based on Simultaneous Multi-Channel Reconstruction

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***Abstract*—Time domain synchronous OFDM (TDS-OFDM) can achieve a higher spectrum efficiency than standard cyclic prefix OFDM (CP-OFDM). Currently, it can support constellations up to 64QAM, but cannot support higher-order constellations like 256QAM due to the residual mutual interferences between the pseudorandom noise (PN) guard interval and the OFDM data block. To solve this problem, we break the traditional approach of iterative interference cancellation and propose the idea of using multiple inter-block-interference (IBI)-free regions of very small size to realize simultaneous multi-channel reconstruction under the framework of structured compressive sensing, whereby the sparsity nature of wireless channels as well as the characteristic that path delays vary much slower than path gains are jointly exploited. In this way, the mutually conditional time-domain channel estimation and frequency-domain data demodulation in TDS-OFDM can be decoupled without the use of IBI removal. We then propose the adaptive simultaneous orthogonal matching pursuit (A-SOMP) algorithm with low complexity to realize accurate multi-channel reconstruction, whose performance is close to the Cramér-Rao lower bound (CRLB). Simulation results confirm that the proposed scheme can support 256QAM without changing the current signal structure, so the spectrum efficiency can be increased by about 30%.**

I. Introduction

OFDM has been widely recognized as a prominent physical layer technique for future wireless communications [1], [2]. There are basically three types of OFDM [3]: cyclic prefix OFDM (CP-OFDM), zero padding OFDM (ZP-OFDM), and time domain synchronous OFDM (TDS-OFDM). The most widely used CP-OFDM utilizes a CP as the guard interval in between successive OFDM data blocks to alleviate inter-block-interference (IBI) [4]. The CP is replaced by a zero padding in ZP-OFDM [4]. Unlike CP-OFDM or ZP-OFDM, TDS-OFDM adopts a known pseudorandom noise (PN) sequence as the guard interval as well as the training sequence (TS) for time-domain synchronization and channel estimation. Hence, a higher spectrum efficiency can be achieved due to the avoidance of frequency-domain pilots for channel estimation as adopted by CP-OFDM and ZP-OFDM [5]. TDS-OFDM is the key technology of the international digital television broadcasting standard called digital television/terrestrial multimedia broadcasting (DTMB), which bas been proposed by China, and has been successfully deployed in China, Cuba, Cambodia, etc [5].

However, the mutual interferences between the PN sequence and the OFDM data block in TDS-OFDM make time-domain channel estimation and frequency-domain data demodulation mutually conditional, so an iterative interference cancellation algorithm [6] has to be implemented, which unfortunately cannot remove the interferences completely. Due to this, it is difficult for TDS-OFDM to support interference-sensitive high-order constellations like 256QAM in multipath channels with large delay spread [5]. Currently, the highest modulation order that can be supported by TDS-OFDM is 64QAM, while CP-OFDM in the recently announced next-generation digital television broadcasting standard called DVB-T2 [7] can support 256QAM to achieve higher spectrum efficiency. One attractive solution is the dual PN padding OFDM (DPN-OFDM) scheme [8], whereby two repeated PN sequences are inserted in every TDS-OFDM symbol to avoid the interference from the OFDM data block into the second PN sequence. However, the extra PN sequence decreases the spectrum efficiency, especially when the original guard interval length is long such as in wireless broadcasting systems.

In this paper, without changing the current signal structure, we propose a TDS-OFDM transmission scheme based on simultaneous multi-path reconstruction. To enable this, two channel properties are jointly exploited, namely the channel sparsity and the fact that path delays vary much slower than path gains, which are usually not considered in conventional OFDM systems. We break the traditional approach where the interference imposed on the received PN sequence is cancelled, and propose the idea of using multiple IBI-free regions of very small size to realize simultaneous multi-channel reconstruction by utilizing the newly emerging theory of structured compressive sensing (CS) [9]. This mechanism requires no iterative interference cancellation to decouple the mutually conditional time-domain channel estimation and frequency-domain data detection. Furthermore, by jointly utilizing the classical signal recovery algorithm called simultaneous orthogonal matching pursuit (SOMP) [9] and the specific time-frequency features of TDS-OFDM, we propose the adaptive SOMP (A-SOMP) algorithm to realize simultaneous multi-channel reconstruction with reduced complexity. In addition, we also provide the theoretical Cramér-Rao lower bound (CRLB) of the simultaneous multi-channel reconstruction method, which is closely approached as demonstrated by the simulation results.

The rest of this paper is organized as follows. Section II

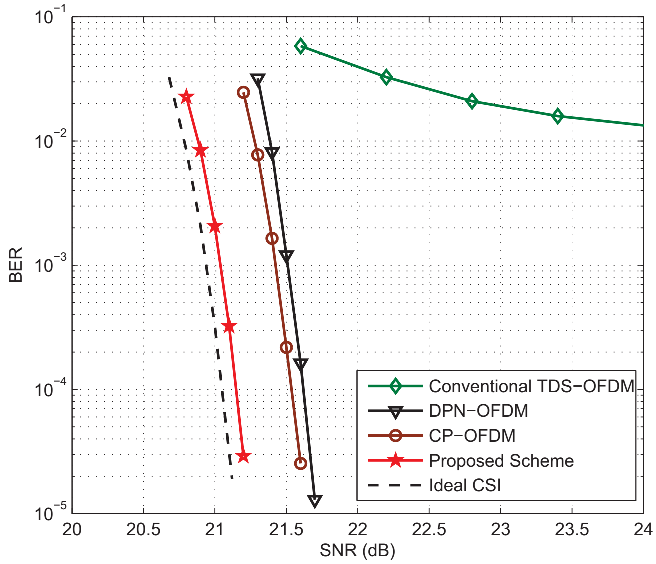

Fig. 7. Coded BER performance comparison when 256QAM is adopted in the Vehicular B channel.

prior is mainly used to reduce the complexity of SOMP as discussed in Section III-B. Moreover, it is clear that the signal reconstruction quality approaches the theoretical CRLB when the number of observations becomes large.

Fig. 7 compares the LDPC coded BER performance when 256QAM is adopted in the Vehicular B channel. The BER performance with the ideal channel state information (CSI) is also included as the benchmark for comparison. We observe that the conventional TDS-OFDM system can not support 256QAM because the residual interferences can not be removed well, while the proposed TDS-OFDM scheme can support 256QAM reliably, which leads to the improved spectrum efficiency of about 30%. Moreover, owing to the decoupling of the time-domain channel estimation and frequency-domain data detection, as well as the improved channel estimation accuracy, the proposed scheme also has superior BER performance to DPN-OFDM and CP-OFDM with an SNR gain of about 0.5 dB and 0.4 dB at a BER of 1×10^{-4}, respectively. In addition, the actual BER curve is only about 0.1 dB away from the ideal CSI case, which indicates the excellent BER performance of the proposed scheme.

V. Conclusions

In this paper, we have presented a TDS-OFDM scheme with an improved spectrum efficiency of about 30% compared with the conventional system. The sparsity nature and inter-channel correlation of wireless channels are jointly exploited, and multiple IBI-free regions of very small size within consecutive received TDS-OFDM symbols are utilized to realize a simultaneous multi-channel reconstruction with high accuracy under the framework of structured compressive sensing. In this way, not only an obviously improved channel reconstruction accuracy can be achieved, but also the mutually conditional time-domain channel estimation and frequency-domain data detection in conventional TDS-OFDM can be decoupled without the use of iterative interference cancellation. It has been shown that the proposed scheme can support 256QAM with a LDPC coded BER performance close to the ideal CSI case. Finally, it is noted that although the initial motivation of this paper is to enable TDS-OFDM to support 256QAM for higher spectrum efficiency, the proposed methods can complement TDS-OFDM as well as the so-called unique word single carrier (UW-SC) systems in any context (e.g., QPSK, 16QAM, 64QAM, etc) for BER performance enhancement.

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