Temporal Correlation Based Sparse Channel Estimation for TDS-OFDM in High-Speed Scenarios

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***Abstract*—Accurate channel estimation is essential for time domain synchronous OFDM (TDS-OFDM), which is a key enabling technology in digital terrestrial multimedia broadcasting (DTMB) standard. However, conventional channel estimation schemes for TDS-OFDM systems suffer from the obvious performance loss in high-speed scenarios. In this paper, by exploiting the temporal correlation of wireless channels, we propose a sparse channel estimation scheme to improve the channel estimation performance for TDS-OFDM systems in high-speed scenarios. Specifically, we first propose an overlap-add method of the received time-domain training sequences (TSs) to acquire the rough channel estimation, whereby the temporal correlation of wireless channels is exploited to improve the estimation performance of time-varying channels. Then, a priori information aided matching pursuit (PIA-MP) algorithm is proposed to acquire the accurate channel estimation with low complexity, whereby the priori information from the rough channel estimation is utilized to further improve the channel estimation accuracy. Simulation results demonstrate that the proposed scheme is superior to the state-of-the-art schemes in high-speed scenarios, especially under severe multipath channels with long delay spread.**

I. Introduction

As a key modulation technology, OFDM has been widely adopted in digital terrestrial television broadcasting (DTTB) standards, including the second generation digital video broadcasting standard DVB-T2 and the digital terrestrial multimedia broadcasting (DTMB) standard [1]. Unlike cyclic prefix OFDM (CP-OFDM) adopted by DVB-T2, where the cyclic prefix is used to avoid inter-symbol-interferences (ISI) between two adjacent OFDM symbols, DTMB adopts time domain synchronous OFDM (TDS-OFDM), where a time-domain training sequence (TS) instead of the cyclic prefix is used to avoid ISI. Besides, the known TS can be used to achieve fast frame synchronization and estimate channels without extra overhead. Therefore, TDS-OFDM is superior to CP-OFDM in terms of fast synchronization and high spectrum efficiency [1]–[4].

In TDS-OFDM systems, TS and OFDM data block interfere with each other due to multipath channels. To effectively estimate channels and demodulate data, an iterative interference cancellation based channel estimation scheme has been proposed to decouple the TS and OFDM data block [2]. The iterative interference cancellation performs well in quasi-static channels. However, it suffers from an obvious performance loss in high-speed scenarios, since the mutual interference between the TS and OFDM data block is difficult to be perfectly eliminated over time-varying channels [3]. To overcome this problem, a dual pseudo-noise OFDM (DPN-OFDM) scheme has been proposed to achieve the accurate channel estimation even over fast time-varying channels [3]. However, this scheme suffers from an obvious reduction in spectrum efficiency due to dual PN sequences. Recently, a compressive sensing (CS) based channel estimation scheme has been proposed for TDS-OFDM [5], whereby the sparsity of time-domain channels is leveraged to estimate channels without the reduction in spectrum efficiency. However, this scheme suffers from the high computational complexity due to the required matrix inversion in channel estimation, and it works poorly when the delay spread of multipath channels is large.

To solve these problems, in this paper, we propose a low-complexity sparse channel estimation scheme, which can achieve both the improved channel estimation performance and high spectrum efficiency, when compared to state-of-the-art schemes in high-speed scenarios. Our contributions are twofold. Firstly, an overlap-add method of the received TSs is proposed to acquire the rough estimation of wireless channels, whereby the temporal correlation of wireless channels is exploited to improve the rough channel estimation performance, especially under severe multipath channels with long delay spread. Secondly, a low-complexity priori information aided matching pursuit (PIA-MP) algorithm is proposed to acquire the accurate channel estimation. Compared with conventional CS based channel estimation schemes, e.g., the modified compressive sampling matching pursuit (CoSaMP) algorithm [6], the proposed PIA-MP algorithm can reduce the computational complexity significantly. The proposed method can adaptively require the sparsity level of the channels, and this is also different from our previous work [7], which requires the priori information of the sparsity level of the channels.

The rest of the paper is organized as follows: Section II reviews the TDS-OFDM system model and several conventional channel estimation schemes for TDS-OFDM. Section III introduces the proposed channel estimation scheme. In Section IV, simulation results are provided. Finally, conclusions are drawn in Section V.

Notation: Boldface capital and lower-case letters stand for matrices and column vectors, respectively. The operators $*$

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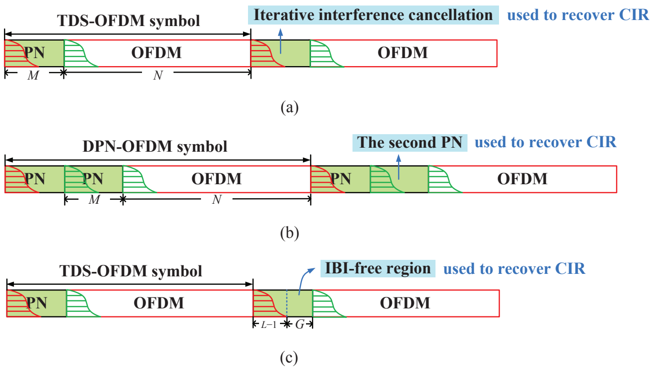

Fig. 1. Several conventional channel estimation schemes for TDS-OFDM systems: (a) Iterative interference cancellation based scheme; (b) DPN-OFDM scheme; (b) Compressive sensing based scheme.

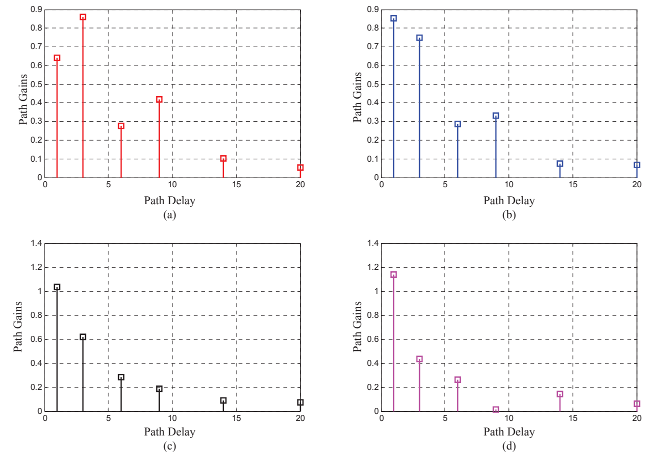

Fig. 2. Snapshot of CIRs during four adjacent TDS-OFDM symbols over ITU-VA channel with the receiver's mobile speed of 120 km/h .

and $\otimes$ represent the linear convolution and circular correlation, respectively. $|\cdot|_c$ denotes the cardinality of a set, and $\lfloor\cdot\rfloor$ denotes the integer floor operator. While the transpose, conjugate transpose, and Moore-Penrose matrix inversion are denoted by $(\cdot)^T$, $(\cdot)^H$, and $(\cdot)^\dagger$, respectively. $\text{supt}\{\mathbf{x}\}$ is a set whose elements are indices of the non-zero elements of the vector $\mathbf{x}$. The r-sparse vector of $\mathbf{x}$ is denoted by $\mathbf{x}\rangle_r$, which is generated by retaining the r largest elements of $\mathbf{x}$ and setting the rest of the elements to zero. $\mathbf{x}|_\Gamma$ denotes the entries of $\mathbf{x}$ defined in the set Γ, while $\mathbf{\Phi}|_\Gamma$ denotes the sub-matrix consists of columns of $\mathbf{\Phi}$ defined in the set Γ.

II. System Model

In the time domain, each TDS-OFDM symbol consists of a TS and the following OFDM data block. For the ith TDS-OFDM symbol, the TS is a known PN sequence $\mathbf{c} = [c_0, c_1, \cdots, c_{M-1}]^T$ of length M, and the subsequent OFDM data block is $\mathbf{x}_i = [x_{i,0}, x_{i,1}, \cdots, x_{i,N-1}]^T$ of length N. Hence, the ith TDS-OFDM symbol in the time domain can be expressed as $\mathbf{s}_i = [\mathbf{c}^T \ \mathbf{x}_i^T]^T$.

At the receiver side, the received signal can be expressed as $\mathbf{r}_i = \mathbf{s}_i * \mathbf{h}_i + \mathbf{n}_i$, where $\mathbf{n}_i$ is the zero mean additive white Gaussian noise (AWGN), and $\mathbf{h}_i$ is the time-varying channel impulse response (CIR). Since $\mathbf{h}_i$ can be considered to be quasi-static during the ith TDS-OFDM symbol, we get the vector form of CIR, i.e., $\mathbf{h}_i = [h_{i,0}, h_{i,1}, \cdots, h_{i,L-1}]^T$, where L is the delay spread. Meanwhile, due to the sparsity of wireless channels [8]–[14], we have $P = |\text{supt}(\mathbf{h}_i)|_c \ll L$, where P is the number of resolvable propagation paths.

Fig. 1 illustrates several existing channel estimation schemes for TDS-OFDM systems. As shown in Fig. 1 (a), the conventional iterative interference cancellation scheme using single PN has the high spectrum efficiency. However, the mutual interference between the PN sequence and OFDM data block cannot be perfectly removed over fast time-varying channels [2], which restricts its application in high-speed scenarios. DPN-OFDM scheme, as shown in Fig. 1 (b), can achieve good channel estimation performance even in high-speed scenarios, since an extra PN sequence is adopted to prevent the second PN sequence from being contaminated by the preceding OFDM data block. This scheme can achieve the accurate channel estimation over fast time-varying channels, however, at the cost of the obvious reduction in spectrum efficiency, especially for broadcasting systems with long delay spread.

Generally, the length of the TS in TDS-OFDM systems is designed to be longer than the maximum delay spread to ensure the reliable system performance in the worst case. However, the actual delay spread L is often less or even much less than the length of the guard interval M in the most practical scenes. Hence there is an IBI-free region of small size $G = M - L + 1$ at the end of the received PN sequence. By exploiting the IBI-free region, as shown in Fig. 1 (c), [5] proposed a modified CoSaMP algorithm based channel estimation scheme, which can reconstruct the channel of large size from the IBI-free region of small size due to the sparsity of wireless channels [10]. However, this scheme suffers from the high computational complexity due to the required matrix inversion operations in channel estimation. Moreover, when the delay spread of multipath channels is large, this scheme works poorly due to the reduced size of the IBI-free region.

Fortunately, extensive experiments show that wireless channels appear the temporal correlation, which can be leveraged to overcome the challenging channel estimation problem in TDS-OFDM. The temporal channel correlation implies that, for time-varying channels, the path delays usually vary slower than its gains [15]. Even in high-speed scenarios, although path gains of several adjacent TDS-OFDM symbols change obviously, path delays remain almost unchanged [16]. For example, Fig. 2 shows the snapshot of CIRs during four adjacent TDS-OFDM symbols over International Telecommunications Union Vehicular A (ITU-VA) channel [17] with the receiver's mobile speed of 120 km/h, where the carrier frequency $f_c = 634$ MHz and the system band $f_s = 1/T_s = 7.56$ MHz are considered. From Fig. 2, it can be observed that although path gains are different from one TDS-OFDM symbol to another, path delays are virtually unchanged. Such temporal correlation of wireless channels inspires us to jointly exploit several adjacent IBI-free regions to improve the estimation performance of time-varying channels.

III. Temporal Correlation Based Sparse Channel Estimation Scheme for TDS-OFDM Systems

In this section, we propose a low-complexity sparse channel estimation scheme for TDS-OFDM systems in high-speed scenarios, whereby the temporal correlation of wireless channels is leveraged to improve the channel estimation performance. Moreover, the computational complexity and spectrum efficiency of the proposed scheme are discussed.

A. Proposed Temporal Correlation Based Sparse Channel Estimation Scheme

The proposed channel estimation scheme consists of four steps. First, the rough estimation of delay spread and path delays are acquired. Second, the rough estimation of channel gains are obtained. Third, the proposed PIA-MP algorithm is used to acquire the accurate estimation of path delays with the aid of priori information from the first two steps. Finally, a minimum mean square error (MMSE) estimator is used to obtain the accurate estimation of path gains.

For high-speed scenarios, as discussed in Section II, the CIR in the time interval of T_c can be considered to share the same sparse pattern due to the temporal correlation of wireless channels, where T_c is mainly determined by the mobile speed of the receiver and the carrier frequency [15], [16]. Hence channel delays can be considered to remain almost unchanged during $2R_d-1$ TDS-OFDM symbols, where $R_d = \left\lfloor \frac{T_c}{2T_s(M+N)} \right\rfloor$. Meanwhile, over the time interval of T_c, channel gains can be expressed as $|\alpha_{i,p}|\exp(\phi_0+2\pi f_d t)$ [18], where $\alpha_{i,p}$ is the pth path gain in the ith OFDM symbol, ϕ_0 is the initial phase, t denotes time, f_d is doppler frequency offset, and f_d can be easily estimated at the receiver [18]. Clearly, the phase variation of the complex path gain is less than π over the time interval of $1/(2f_d)$, or equivalently during $R_g = \left\lfloor \frac{1}{2f_d T_s(M+N)} \right\rfloor$ adjacent TDS-OFDM symbols. Therefore, by averaging the CIR estimation of R_g adjacent TDS-OFDM symbols, we can improve the effective signal to noise ratio (SNR) and acquire more accurate channel estimation. Finally, channel is considered to be quasi-static during one TDS-OFDM symbol, i.e., both path delays and path gains remain unchanged during one TDS-OFDM symbol [16].

1) Step 1: Rough Estimation of Delay Spread and Path Delays: We jointly use the overlap-add results of the received TSs from the $(i-R_d+1)$th to $(i+R_d)$th TDS-OFDM symbols. Specifically, we superpose the TS tail part caused by the multipath channels on the preceding TS main part, and this process can be expressed as

$$\mathbf{r}_k = \mathbf{r}_{k,\text{main}} + \mathbf{r}_{k,\text{tail}}, i - R_d + 1 \le k \le i + R_d, \quad (1)$$

and $\mathbf{r}_{k,\text{main}}$ and $\mathbf{r}_{k,\text{tail}}$ can be expressed as

$$\mathbf{r}_{k,\text{main}} = \mathbf{\Psi}_k \mathbf{h}_k + \mathbf{n}_{k,\text{main}}, i - R_d + 1 \le k \le i + R_d, \quad (2)$$

$$\mathbf{r}_{k,\text{tail}} = \mathbf{\Theta}_k \mathbf{h}_k + \mathbf{n}_{k,\text{tail}}, i - R_d + 1 \le k \le i + R_d, \quad (3)$$

where $\mathbf{n}_{l,\text{main}}$, $\mathbf{n}_{l,\text{tail}}$ are the zero mean AWGN vectors, and

$$\mathbf{\Psi}_k = \begin{bmatrix} c_0 & x_{k-1,N-1} & x_{k-1,N-2} & \cdots & x_{k-1,N-L+1} \\ c_1 & c_0 & x_{k-1,N-1} & \cdots & x_{k-1,N-L+2} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_{L-1} & c_{L-2} & c_{L-3} & \cdots & c_0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_{M-1} & c_{M-2} & c_{M-3} & \cdots & c_{M-L} \end{bmatrix}_{M\times L},$$

$$\mathbf{\Theta}_k = \begin{bmatrix} x_{k,0} & c_{M-1} & c_{M-2} & \cdots & c_{M-L+1} \\ x_{k,1} & x_{k,0} & c_{M-1} & \cdots & c_{M-L+2} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{k,L-1} & x_{k,L-2} & x_{k,L-3} & \cdots & x_{k,0} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{k,M-1} & x_{k,M-2} & x_{k,M-3} & \cdots & x_{k,M-L} \end{bmatrix}_{M\times L}.$$

We average the overlap-add results of R_g adjacent TDS-OFDM symbols, then circularly correlate the averaged result with the known TS, whereby the good auto-correlation and circular cross-correlation property of the TS are exploited. The circular correlation can be expressed as

$$\tilde{\mathbf{h}}_q = \frac{\mathbf{c} \otimes \sum_{k=q}^{q+R_g} \mathbf{r}_k}{M(R_g+1)}, i - R_d + 1 \le q \le i + R_d - R_g, \quad (4)$$

Therefore, the rough channel estimation $\bar{\mathbf{h}}$ is

$$\bar{\mathbf{h}} = \sum_{q=i-R_d+1}^{i+R_d-R_g} \text{abs}\{\tilde{\mathbf{h}}_q\}/(2R_d - R_g). \quad (5)$$

As a result, path delays of the most significant taps $D_0 = \{\tau_1 : |\bar{h}_{\tau_1}| \ge E_{\text{th}}\}_{\tau_1=0}^{L-1}$ are retained, where $\{\bar{h}_{\tau_1}\}_{\tau_1=0}^{L-1}$ are the elements of $\bar{\mathbf{h}}$, and E_{th} is the power threshold according to [19]. Moreover, the delay spread can be estimated from the rough channel estimation, i.e., $\hat{L} = \max\{D_0\}$. Besides, according to the initial channel sparsity level $S_0 = |D_0|_c$, we consider the practical channel sparsity level $S \ge S_0$ [16].

2) Step 2: Rough Estimation of Path Gains: The received TSs of the ith and $(i+1)$th TDS-OFDM symbols are jointly exploited to acquire the rough estimation of path gains, i.e.,

$$\bar{\mathbf{h}}' = \mathbf{c} \otimes \sum_{k=i}^{i+1} (\mathbf{r}_{k,\text{main}} + \mathbf{r}'_{k,\text{tail}})/(2M), \quad (6)$$

where $\mathbf{r}'_{k,\text{tail}}$ is the vector whose first $\widehat{L}$ elements are the first $\widehat{L}$ elements of $\mathbf{r}_{k,\text{tail}}$, while its rest elements are set to zero.

The rough estimations of the delay spread, path delays and path gains acquired in *Steps 1* and *2* provide the priori information of wireless channels to assist the accurate channel estimation using the PIA-MP algorithm in the following two steps.

3) Step 3: Accurate Estimation of Path Delays Using PIA-MP Algorithm: The proposed PIA-MP algorithm exploits the priori information from the rough channel estimation to improve the signal recovery accuracy and reduce the computational complexity as well as the number of iterations. To be specific, the measurement vector for Algorithm 1 is

$$\bar{\mathbf{y}}=\sum_{k=i}^{i+1}\hat{\mathbf{y}}_k/2=\sum_{k=i}^{i+1}(\mathbf{\Phi}\mathbf{h}_k+\mathbf{n}_k)/2, \tag{7}$$

where $\hat{\mathbf{y}}_k$ of size $\hat{G}=M-\hat{L}+1$ is the estimated IBI-free region of the kth TDS-OFDM symbol, $\mathbf{n}_k$ is zero mean AWGN, and

$$\mathbf{\Phi}=\begin{bmatrix} c_{\hat{L}-1} & c_{\hat{L}-2} & \cdots & c_0 \\ c_{\hat{L}} & c_{\hat{L}-1} & \cdots & c_1 \\ \vdots & \vdots & \vdots & \vdots \\ c_{M-1} & c_{M-2} & \cdots & c_{M-\hat{L}} \end{bmatrix}_{\hat{G}\times\hat{L}}. \tag{8}$$

It should be pointed out that the size of the measurement matrix $\mathbf{\Phi}$ is adaptive to $\hat{L}$.

The pseudocode of the proposed PIA-MP algorithm is summarized in Algorithm 1. The accurate estimation of path delays are $D=\{\tau_2:|\hat{h}_{\tau_2}|>0\}_{\tau_2=0}^{L-1}$, where $\{\hat{h}_{\tau_2}\}_{\tau_2=0}^{L-1}$ are the elements of $\hat{\mathbf{h}}$.

4) Step 4: Accurate Estimation of Path Gains Using MMSE Algorithm: After *Step 3*, we have obtained the accurate estimation of path delays. According to (7), the estimation of accurate path gains is equivalent to solve the problem below,

$$\min_{\hat{\mathbf{h}}'|_D}\left\|\bar{\mathbf{y}}-\mathbf{\Phi}|_D\,\hat{\mathbf{h}}'\Big|_D\right\|_2. \tag{9}$$

Obviously, (9) is an overdetermined problem since the size of $\hat{\mathbf{h}}'\Big|_D$ is smaller than that of $\bar{\mathbf{y}}$. Therefore, we can use the MMSE algorithm to acquire the solution to (9), i.e.,

$$\hat{\mathbf{h}}'\Big|_D=(\sigma^2\mathbf{I}_S+\mathbf{\Phi}_D^H\mathbf{\Phi}_D)^{-1}\mathbf{\Phi}_D^H\bar{\mathbf{y}}, \tag{10}$$

where $\mathbf{I}_{D\times D}$ is the identity matrix with the size of $S\times S$.

B. Advantages of Proposed PIA-MP Algorithm

Compared with conventional CS based channel estimation algorithms, the proposed algorithm has several attractive features. Firstly, the PIA-MP algorithm exploits the rough estimation of path delays and gains (or equivalently the locations and values of the partial large components in the target signal) as the priori information, which significantly enhances the signal recovery accuracy and reduces the number of iterations. Secondly, unlike the modified CoSaMP algorithm [5], the sizes of the IBI-free region and the measurement matrix are adaptively determined by the delay spread estimation $\widehat{L}$. Thirdly, the rough estimation of path gains is used to acquire the values of the nonzero elements in the target signal in every iteration (*Line 11* in Algorithm 1). In contrast, to obtain these values, the modified CoSaMP algorithm has to use MMSE, which will result in the high computation complexity.

Algorithm 1 Priori Information Aided Matching Pursuit (PIA-MP).

Input: 1) Initial path delay set D_0, rough channel estimation $\bar{\mathbf{h}}'$, the initial channel sparsity level S_0;
2) Noisy measurements $\bar{\mathbf{y}}$, observation matrix $\mathbf{\Phi}$.

Output: $\widehat{\mathbf{h}}$.

1: $\mathbf{x}^0\big|_{D_0}\leftarrow\bar{\mathbf{h}}'\Big|_{D_0}$;
2: $u_{\text{current}}\leftarrow\left\|\bar{\mathbf{y}}-\mathbf{\Phi}\mathbf{x}^0\right\|_2$;
3: $u_{\text{last}}\leftarrow 0$;
4: $u\leftarrow+\inf$;
5: $l\leftarrow 0$;
6: $S\leftarrow S_0$;
7: **while** $u_{\text{current}}<u$, **do**
8: **while** $u_{\text{current}}<u_{\text{last}}$, **do**
9: $l\leftarrow l+1$;
10: $\mathbf{z}^l\leftarrow\bar{\mathbf{y}}-\mathbf{\Phi}\mathbf{x}^{l-1}$;
11: $\mathbf{r}^l\leftarrow\mathbf{\Phi}^H\mathbf{z}^l$;
12: $\Gamma\leftarrow\text{supt}\left\{\mathbf{r}^l\rangle_S\right\}$;
13: $\Omega=\Gamma\cup\text{supt}\left\{\mathbf{x}^{l-1}\right\}$;
14: $\mathbf{x}^l\big|_\Omega\leftarrow\bar{\mathbf{h}}'\Big|_\Omega$;
15: $\mathbf{x}^l\big|_{\Omega^c}\leftarrow\mathbf{0}$;
16: $\mathbf{x}^l\leftarrow\mathbf{x}^l\rangle_S$;
17: $u_{\text{last}}\leftarrow u_{\text{current}}$;
18: $u_{\text{current}}\leftarrow\left\|\bar{\mathbf{y}}-\mathbf{\Phi}\mathbf{x}^l\right\|_2$;
19: **end while**
20: $u\leftarrow u_{\text{current}}$;
21: $S\leftarrow S+1$;
22: $\mathbf{x}_S\leftarrow\mathbf{x}^{l-1}$;
23: **end while**
24: $\widehat{\mathbf{h}}\leftarrow\mathbf{x}_{S-1}$.

C. Computational Complexity Analysis

In the proposed channel estimation scheme, *Steps 1* and *2* implement the M-point circular correlation using fast Fourier transform (FFT), whose complexity is in the order of $\mathcal{O}\big((M\log_2 M)/2\big)$. While in *Step 3*, our algorithm avoids the matrix inversion operation due to the rough estimation of path gains. In *Step 4*, the MMSE operation requires the matrix inversion operation with the complexity of $\mathcal{O}\big(GS^2+S^3\big)$. Consequently, the main computational burden comes from *Step 4*. Hence the complexity of our proposed algorithm is $C_{\text{PIA-MP}}=\mathcal{O}\big(GS^2+S^3\big)$.

The conventional CoSaMP algorithm and the modified CoSaMP algorithm can be shown to have the computational complexity of $C_{\text{CoSaMP}}=\mathcal{O}\big(4GS^3+8S^4\big)$ and $C_{\text{mCoSaMP}}=\mathcal{O}\big((S-S_0)(4GS^2+8S^3)\big)$, respectively [5]. In contrast, our algorithm acquires this information at the cost of very low complexity of $\mathcal{O}\big((M\log_2 M)/2\big)$.

Considering the typical case of the ITU-VA channel [17] where we have $S=6$, $G=236$ and $S_0=4$, based on the discussion above, we have $C_{\text{PIA-MP}}/C_{\text{CoSaMP}}\approx 4.07\%$ and $C_{\text{PIA-MP}}/C_{\text{mCoSaMP}}\approx 12.20\%$.

TABLE I
SPECTRUM EFFICIENCY COMPARISON

TS length	DPN-OFDM	Modified CoSaMP	PIA-MP
$M = N/4$	66.67%	80.00%	80.00%
$M = N/8$	80.00%	88.89%	88.89%
$M = N/16$	88.89%	94.12 %	94.12%

D. Spectrum Efficiency Analysis

According to the definition of spectrum efficiency for TDS-OFDM systems [16], we compare the spectrum efficiency of DPN-OFDM scheme, the modified CoSaMP algorithm based scheme, and the proposed channel estimation scheme. DPN-OFDM scheme suffers from an obvious reduction of spectrum efficiency since an extra PN sequence is used to prevent the second PN sequence from being contaminated by the preceding OFDM symbol. In contrast, both the proposed channel estimation scheme and the modified CoSaMP algorithm based scheme have the high spectrum efficiency since only a single PN sequence is used. Even in the extreme case that the actual delay spread is equal to the TS length, we can slightly extend the length of the TS to guarantee an IBI-free region. Although this TS extension would reduce the spectrum efficiency, the penalty is very small since the required size of the IBI-free region to reconstruct the CIR is small compared with the size of the TS.

It should pointed out that our proposed channel estimation scheme requires smaller size of IBI-free region than that of the modified CoSaMP based scheme in practice, which will be discussed in Section IV. Therefore, to combat channels with long delay spread, the spectrum efficiency of our proposed scheme is higher than that of the modified CoSaMP based scheme.

IV. Simulation Results

This section investigated the mean square error (MSE) performance of the proposed channel estimation scheme for TDS-OFDM systems, where the MSE performance of DPN-OFDM scheme [3] and the modified CoSaMP algorithm based scheme [5] were provided for performance comparison. The system parameters were set as follows: $f_c = 643$ MHz, $f_s = 7.56$ MHz, $N = 2048$, and $M = 256$ for single PN based TDS-OFDM transmission schemes or $M = 2 \times 256$ for DPN-OFDM transmission scheme. Uncoded QPSK modulation scheme was used in simulations. Besides, simulations adopted ITU-VA channel model and the China digital television test 8th channel model (CDT-8) [3].

Fig. 3 shows the sparse signal recovery probability of four different CS signal recovery algorithms against the varying sizes of the IBI-free region , where the static ITU-VA channel at SNR = 20 dB is considered. In the simulation, we consider that if the MSE performance of the signal estimation is lower than 10^{-2}, the recovery result is regarded to be correct [5]. From Fig. 3, it can be observed that the proposed PIA-MP algorithm outperforms other conventional CS algorithms. The CoSaMP algorithm and the modified CoSaMP algorithm

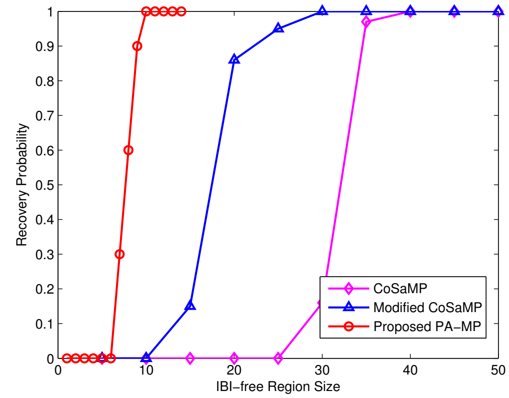

Fig. 3. Target signal recovery probability against the IBI-free region size at SNR=20dB.

require the IBI-free region sizes 30 and 40 to recovery the sparse signal with the probability one, respectively. In contrast, the proposed PIA-MP algorithm only needs 7 observation samples. This indicates that, compared with the CoSaMP algorithm and the modified CoSaMP algorithm, PIA-MP algorithm reduces 82.5% and 76.7% observation samples, respectively. It is because that the proposed PIA-MP algorithm benefits from the priori information from the rough channel estimation, i.e., not only the locations, but also the values of the partial large components in the target signal. Therefore, the proposed PIA-MP algorithm can combat the CIR with longer delay spread. That is to say, to combat the CIR with very long delay spread, the proposed scheme requires much smaller number of observation samples or smaller size of the TS than the conventional CS algorithms, which implies the proposed algorithm enjoys higher spectrum efficiency since the required overhead for channel estimation is reduced.

Fig. 4 and Fig. 5 compare the MSE performance of channel estimation and bit error rate (BER) performance of data demodulation of different channel estimation schemes, respectively. In the simulation, we consider ITU-VA channel and CDT-8 channel with the receiver's mobile speed of 120km/h. From Fig. 4 and Fig. 5, it can be observed that the modified CoSaMP based channel estimation scheme is better than DPN-OFDM scheme over ITU-VA channel, but it suffers from an obvious performance loss over CDT-8 channel. Meanwhile, the proposed scheme outperforms other schemes in various scenarios, especially under severe multipath channels with long delay spread (e.g., the time-varying CDT-8 channel). It should be pointed out that the proposed channel estimation scheme has higher spectrum efficiency than the DPN-OFDM scheme.

The superior performance of the proposed scheme over severe multipath channels is contributed by three reasons. First, we exploit the overlap-add results of TSs in several continuous TDS-OFDM symbols to improve the accuracy of rough channel estimation, whereby the temporal correlation of wireless channels is leveraged. Second, the sizes of IBI-free region and measurement matrix are adaptive, which can improve the signal recovery accuracy of the PIA-MP algorithm. Third, the proposed PIA-MP algorithm uses the priori information to further improve the channel estimation

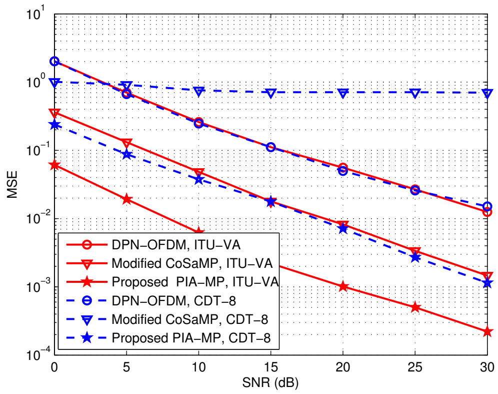

Fig. 4. MSE performance comparison between the proposed channel estimation scheme and its conventional counterparts in high-speed scenario with the

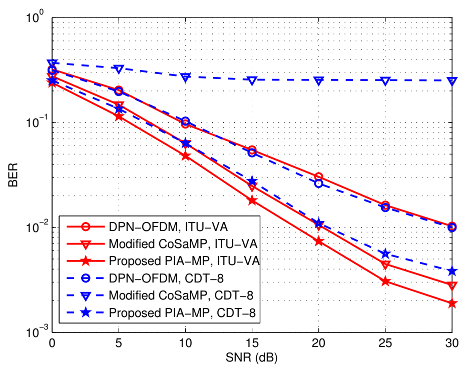

Fig. 5. BER performance comparison between the proposed channel estimation scheme and its conventional counterparts in high-speed scenario with the receiver's mobile speed of 120km/h.

performance. Therefore, the proposed scheme can achieve accurate channel estimation without extra overhead for TDS-OFDM systems.

V. Conclusion

In this paper, we propose a sparse channel estimation scheme for TDS-OFDM in high-speed scenarios, whereby the temporal correlation of wireless channels is exploited to improve the channel estimation performance. By leveraging the sparsity and temporal correlation of channels, the proposed channel estimation scheme can achieve both reliable channel estimation performance and high spectrum efficiency, even in high-speed scenarios. Specifically, an overlap-add method of the TS was proposed to obtain the rough channel estimation, whereby the temporal correlation of wireless channels is exploited to achieve the reliable channel estimation performance, especially under severe fading channels with long delay spread. Second, we propose a low-complexity PIA-MP algorithm to acquire the accurate channel estimation, whereby the priori information from the rough channel estimation can be exploited to improve the channel estimation accuracy. The proposed PIA-MP algorithm has low computational complexity, and it can combat the channels with larger delay spread than conventional CS based schemes. Simulation results have verified that the proposed scheme is superior to the state-of-the-art schemes, especially under time-varying multipath channels with long delay spread.

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