Abstract—This paper proposes a spectrum-efficient and low-complexity compressive sensing (CS) based sparse channel estimation scheme for time domain synchronous OFDM (TDS-OFDM) systems. Compared with the conventional channel estimation schemes for TDS-OFDM which suffer from an obvious performance loss over doubly-selective fading channels or reduction in spectral efficiency, the proposed method outperforms its counterparts in estimation accuracy and spectral efficiency. First, we propose an overlap-add method of the time-domain training sequence (TS) to obtain the coarse channel estimation, whereby the temporal correlation of wireless channels is exploited to effectively improve the robustness of the coarse channel estimation to severe doubly-selective fading channels. Second, a priori information aided iterative hard threshold (PIA-IHT) algorithm is proposed to acquire the accurate channel estimation with low complexity, whereby the priori information from the coarse channel estimation is utilized to improve the channel estimation accuracy. Finally, simulation results demonstrate that the proposed scheme is superior to the state-of-the-art schemes in typical 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, e.g., European second generation digital video broadcasting standard (DVB-T2) and Chinese digital terrestrial multimedia broadcasting standard (DTMB), due to its excellent robustness to multipath channels [1]. Unlike cyclic prefix OFDM (CP-OFDM) adopted by DVB-T2, where the cyclic prefix is used to avoid the 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 the ISI as well as acquire synchronization and channel estimation. Therefore, TDS-OFDM is superior to CP-OFDM in terms of fast synchronization and channel estimation, and it also possesses a higher spectral efficiency [1]–[3].

Nevertheless, in TDS-OFDM systems, due to the mutual interferences between the TS and the OFDM data block, an iterative interference cancellation based channel estimation method has been proposed to decouple the TS and the OFDM data block for channel estimation and frequency-domain data demodulation [2]. However, this iterative interference cancellation suffers from an obvious performance degradation in doubly-selective fading channels since the mutual interference between the TS and the OFDM data block is difficult to be perfectly eliminated [3]. By contrast, a dual pseudo-noise OFDM (DPN-OFDM) scheme is paid more attention due to its simple and accurate channel estimation [3]. However, this scheme suffers from an obvious reduction in spectral efficiency due to the used dual PN sequences. Recently, a compressive sensing (CS) based channel estimation method has been proposed for the current DTMB system [4]. In this scheme, the inter-block-interference (IBI) free region of small size in the received TS is exploited to reconstruct the multipath channel of large size, whereby the CS signal recovery algorithm called compressive sampling matching pursuit (CoSaMP) [5] is utilized. However, this scheme suffers from high computational complexity due to the required matrix inversion in CoSaMP algorithm as well as the obvious performance loss over severe multipath channels with long delay spread.

This paper proposes a low-complexity sparse channel estimation scheme which can achieve a competitive channel estimation performance with high spectral efficiency compared with state-of-the-art schemes. Our contribution is twofold. Firstly, an overlap-add method of the TS is proposed to acquire the coarse estimation of wireless channels, whereby the temporal correlation of wireless channels is exploited to improve the robustness of the coarse channel estimation, especially under severe multipath channels with long delay spread. Secondly, a low-complexity priori information aided iterative hard threshold (PIA-IHT) algorithm is proposed to acquire the accurate channel estimation. Unlike the classical IHT algorithm [6] whose convergence requires the $l_2$ norm of the measurement matrix being less than 1, the proposed PIA-IHT algorithm removes such a restriction due to the benefit from the priori information of the coarse channel estimation. Meanwhile, in contrast to conventional CS based channel estimation methods, e.g., the modified CoSaMP algorithm [4], which require the matrix inversion operation, the proposed PIA-IHT algorithm avoids the matrix inversion and thus reduces the computational complexity.

The rest of the paper is organized as follows: Section II presents the TDS-OFDM system model and several conventional channel estimation schemes for TDS-OFDM. Section III proposes the PIA-IHT based 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 * and ⊗ represent the linear convolution and circular correlation, respectively. $\delta[\cdot]$ represents the unit impulse function, $\| \cdot \|_p$ denotes the $l_p$ norm operation, and $[\cdot]$ denotes the integer floor operator. While the transpose, conjugate transpose and Moore-Penrose matrix inversion are denoted by $(\cdot)^T$, $(\cdot)^H$ and $(\cdot)^+$, respectively. $\text{supt}\{\cdot\}$ denotes the support of the vector $\cdot$, and $\text{abs}\{\cdot\}$ is the vector whose elements are the absolute values of the corresponding elements of the vector $\cdot$. The $r$-sparse vector of $\cdot$ is denoted by $\cdot|_{r}$, which is generated by retaining the $r$ largest elements of $\cdot$ and setting the rest of the elements to zero. $\cdot|_{\Gamma}$ denotes the entries of $\cdot$ defined in the set $\Gamma$, while $\Phi|_{\Gamma}$ denotes the sub-matrix whose columns comprise the columns of $\Phi$ defined in the set $\Gamma$.

II. System Model and Existing Channel Estimation Schemes for TDS-OFDM

In the time domain, TDS-OFDM signals are grouped in symbols, and each TDS-OFDM symbol consists of a TS and each TDS-OFDM symbol comprises the columns of $\Phi$ defined in the set $\Gamma$. The operators * and ⊗ represent the linear convolution and circular correlation, respectively. $\delta[\cdot]$ represents the unit impulse function, $\| \cdot \|_p$ denotes the $l_p$ norm operation, and $[\cdot]$ denotes the integer floor operator. While the transpose, conjugate transpose Moore-Penrose matrix inversion is denoted by $(\cdot)^T$, $(\cdot)^H$ and $(\cdot)^+$, respectively. $\text{supt}\{\cdot\}$ denotes the support of the vector $\cdot$, and $\text{abs}\{\cdot\}$ is the vector whose elements are the absolute values of the corresponding elements of the vector $\cdot$. The $r$-sparse vector of $\cdot$ is denoted by $\cdot|_{r}$, which is generated by retaining the $r$ largest elements of $\cdot$ and setting the rest of the elements to zero. $\cdot|_{\Gamma}$ denotes the entries of $\cdot$ defined in the set $\Gamma$, while $\Phi|_{\Gamma}$ denotes the sub-matrix whose columns comprise the columns of $\Phi$ defined in the set $\Gamma$.

II. System Model and Existing Channel Estimation Schemes for TDS-OFDM

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

$$s_i = [c^T x_i^T]^T.$$  

At the receiver side, the received signal can be expressed as $r_j = s_i * h_i + n_j$, where $n_j$ is the zero mean additive white Gaussian noise (AWGN), and $h_i$ is the time-varying channel impulse response (CIR). Since $h_i$ can be considered as a quasi-static during the $i$th TDS-OFDM symbol, we get the vector form of CIR, i.e., $h_i = [h_{i,0}, h_{i,1}, \cdots, h_{i,L-1}]^T$, where $L$ is the CIR length. Meanwhile, due to the sparsity of wireless channels [7], [8], $h_i$ can also be modeled as $h_{i,l} = \sum_{p=0}^{P-1} \alpha_{i,p} \delta[l - \tau_{i,p}]$ for $0 \leq l \leq L - 1$, where $P$ is the number of resolvable propagation paths, $\alpha_{i,p}$ is the $p$th path gain, and $\tau_{i,p}$ is the $p$th path delay.

Fig. 1 illustrates several existing channel estimation schemes for TDS-OFDM systems, and they can not achieve satisfactory performance. The conventional iterative interference cancellation scheme using single PN has advantage in high spectral efficiency as shown in Fig. 1 (a). However, the mutual interferences between the PN sequence and OFDM data block can not be effectively removed over fast time-varying channels [2], which restricts its application in mobile scenarios. DPN-OFDM scheme as shown in Fig. 1 (b) can achieve good channel estimation performance since an extra PN sequence is adopted to prevent the second PN sequence from being contaminated by the preceding OFDM data block. This scheme enjoys simple and accurate channel estimation, however, at the cost of the obvious reduction in spectral efficiency, especially when the guard interval should be long for broadcasting systems.

Generally, the length of the TS in TDS-OFDM systems is designed to be longer than the maximum CIR length to ensure the reliable system performance in the worst case. Moreover, the actual channel length $L$ is often less or even much less than the length of 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), [4] 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 [7]. However, this scheme has high computational complexity due to the required matrix inversion operations in CS algorithm and suffers from obvious performance loss over severe multipath channels with long delay spread due to the reduced size of the IBI-free region.

The temporal correlation of wireless channels enlightens us to solve the existing problems in TDS-OFDM. For time-varying channels, the path delays usually vary slower than its gains [9]. Even in mobile scenarios, although path gains of several adjacent TDS-OFDM symbols change obviously, path delays almost remain unchanged [10]. Fig. 2 describes CIRs during four adjacent TDS-OFDM symbols over International Telecommunications Union Vehicular B (ITU-VB) channel [11] with $120$km/h receiver velocity. From Fig. 2, it can be observed that although path gains are different during adjacent TDS-OFDM symbols, path delays are nearly invariable. Therefore, the temporal correlation of wireless channels inspires us to jointly exploit several adjacent IBI-free regions to improve the robustness and accuracy of the channel estimation.
III. PROPOSED PIA-IHT BASED CHANNEL ESTIMATION

In this section, we introduce a spectrum-efficient channel estimation method based on the proposed low-complexity PIA-IHT algorithm for TDS-OFDM systems. Meanwhile, we also discuss the computational complexity and spectral efficiency.

A. The Proposed PIA-IHT Based Channel Estimation Method

The proposed channel estimation method consists of four steps. Firstly, coarse CIR length and path delays are acquired. Secondly, coarse channel gains are obtained. Thirdly, the proposed PIA-IHT algorithm is used to estimate accurate path delays with the aid of priori information from the first two steps. Finally, a least squares (LS) criterion is used to refine the accurate path gains.

For time-varying channels, as discussed in Section II, the CIR in the time interval of $\tau_0$ can be considered to share the same sparse pattern due to the temporal correlation of wireless channels [9], [10]. Hence channel delays can be considered to remain almost unchanged during $2R_d - 1$ TDS-OFDM symbols, where $R_d = \left\lceil \frac{2\pi f_d}{2\pi (\tau_0 + N_T)} \right\rceil$. Meanwhile, over the time interval of $\tau_0$, channel gains can be expressed as $|\alpha_{i,k}| \exp(\phi_0 + 2\pi f_d t)$ [12], where $\phi_0$ is the initial phase, $t$ denotes time, and $f_d$ is doppler frequency offset and it can be estimated at the receiver [12]. Hence the phase variation of the complex path gain is less than $\pi$ over the time interval of $1/(2f_d)$, or equivalently during $R_g = \left\lceil \frac{1}{2f_d T_{\text{OFDM}}} \right\rceil$ 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 then acquire more accurate channel estimate. 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.

1) Step 1: Acquisition of Coarse Channel Length 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, where the overlap-add method of the TS can be illustrated in Fig. 3. Specifically, the overlap-add method of the TS superposes the TS tail part caused by the multipath channel in Fig. 3. Specifically, the overlap-add of the TS can be illustrated as

$$\mathbf{c} \otimes \sum_{k=q}^{q+R_g} \mathbf{r}_k$$

where $\mathbf{c}$ is the overlap-add method of the TS.

Therefore, the coarse channel estimation $\hat{\mathbf{h}}$ is

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

As a result, path delays of the most significant taps $D_0 = \{\tau_{j_0} : |\hat{\mathbf{h}}_{\tau_{j_0}}| \geq E_{\text{th}}\}^{L-1}_{j_0=0}$ are retained, where $\{\hat{\mathbf{h}}_{\tau_{j_0}}\}^{L-1}_{j_0=0}$ are the elements of $\hat{\mathbf{h}}$, and $E_{\text{th}}$ is the power threshold according to [13]. Consequently, the channel length can be estimated from the coarse channel estimation, i.e., $\hat{L} = \max\{D_0\}$. Meanwhile, initial channel sparsity level is $S_0 = \| \hat{D}_0 \|_0$ and the channel sparsity level is $S = S_0 + a$, where $a$ is a non-negative number used to combat the interference since some low path powers may be treated as noise [10].

2) Step 2: Estimation of Coarse Path Gains: The received TSs of the $i$th and $(i+1)$th TDS-OFDM symbols are jointly exploited to acquire the priori information of coarse channel path gains, i.e.,

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

where $\mathbf{r}_{k,\text{tail}}'$ is the vector whose first $\hat{L}$ elements are the first $\hat{L}$ of $\mathbf{r}_{k,\text{tail}}$, while its rest elements are all zeros.

The coarse estimations of the channel length, the channel 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-IHT algorithm in the following two steps.
3) Step 3: PIA-IHT to Obtain Accurate Path Delay Estimation: The proposed PIA-IHT algorithm exploits the priori information from the coarse channel estimation to improve the signal recovery accuracy and reduce the computational complexity as well as the number of required iterations. The measurement vector is

$$\hat{y} = \sum_{k=i}^{i+1} \hat{y}_k/2 = \sum_{k=i}^{i+1} (\Phi h_k + n_k)/2,$$  \hspace{1cm} (7)

where \( \hat{y}_k \) of size \( \hat{G} = M - \hat{L} + 1 \) is the estimated IBI-free region of the \( k \)-th TDS-OFDM symbol, \( n_k \) is zero mean AWGN, and

$$\Phi = \begin{bmatrix}
c_{L-1} & c_{L-2} & \cdots & c_0 \\
c_L & c_{L-1} & \cdots & c_1 \\
\vdots & \vdots & \ddots & \vdots \\
c_{M-1} & c_{M-2} & \cdots & c_{M-L}
\end{bmatrix}_{G \times L}.$$  \hspace{1cm} (8)

Note that the size of the measurement matrix \( \Phi \) is adaptive to \( \hat{L} \).

The pseudocode of the proposed PIA-IHT algorithm is summarized in Algorithm 1. The accurate estimation of path delays are \( D = \{ r_2 : |h_{r_2}| > 0 \}_{r_2=0}^{L-1} \), where \( \{ h_{r_2} \}_{r_2=0}^{L-1} \) are the elements of \( \hat{h} \).

4) Step 4: Accurate Path Gain Estimation Based on LS Criterion: After Step 3, we have obtained the accurate estimation of path delays. Hence the accurate estimation of path gains is to acquire \( \hat{h}' \)|\( _D \), where \( \hat{h}' \) of size \( M \) is the final channel estimation, and its elements outside the set \( D \) are zeros. According to (7), the acquisition of accurate path gains is equivalent to solve the problem below,

$$\min_{\hat{h}'|_D} \left\| \hat{y} - \Phi_{|D} \hat{h}' \right\|_2.$$  \hspace{1cm} (9)

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

$$\hat{h}'|_D = \Phi_{|D}^\dagger \hat{y} = (\Phi_{|D}^H \Phi_{|D})^{-1} \Phi_{|D}^H \hat{y}.$$  \hspace{1cm} (10)

B. Advantages of Proposed PIA-IHT by Intuitive Explanations

In contrast to the classical IHT algorithm or other CS based algorithms, the proposed algorithm has several attractive features. Firstly, the PIA-IHT algorithm exploits the available priori information of the coarse path delays and gains (or equivalently the locations and values of the partial large components in the target signal) as the initial condition, and this significantly enhances the signal recovery accuracy and reduces the number of required iterations. Secondly, unlike the modified CoSaMP algorithm [4], the sizes of the IBI-free region and the measurement matrix are adaptively determined by the coarse channel length estimate \( \hat{L} \). Thirdly, the coarse path gains serve as the nonzero element values of the target signal in every iteration. By contrast, in order to obtain these values, the modified CoSaMP algorithm has to apply the LS estimation with high-complexity matrix inversion operation while the classical IHT algorithm uses the correlated results of the measurement matrix and the residual error [6], whose convergence requires the \( l_2 \) norm of the measurement matrix being less than 1.

C. Comparison of Computational Complexity with Other CS Based Schemes

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 \( O(M \log_2 M) \). While in Step 3, our algorithm avoids the matrix inversion operation due to the priori information of the acquired coarse channel gains. In Step 4, the LS criterion requires the matrix inversion operation with the complexity of \( O(GS + S^3) \). Consequently, the main computational burden comes from Step 4. Hence the complexity of our proposed algorithm is \( C_{PIA-IHT} = O(GS^2 + S^3) \).

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

Considering the typical case of the ITU-VB channel [11] where we have \( S = 6 \), \( G = 104 \) and \( S_0 = 4 \), based on the discussion above, we have \( C_{PIA-IHT}/C_{CoSaMP} \approx 3.95\% \) and \( C_{PIA-IHT}/C_{mCoSaMP} \approx 11.85\% \).
D. Comparison of Spectral Efficiency

Table I compares the spectral efficiency of DPN-OFDM scheme, the modified CoSaMP algorithm based scheme, and the proposed PIA-IHT algorithm based scheme for TDS-OFDM systems. DPN-OFDM scheme suffers from an obvious spectral efficiency reduction since an extra PN sequence is used to prevent the second PN sequence from being contaminated by the preceding OFDM symbol. By contrast, both the proposed PIA-IHT algorithm based scheme and the modified CoSaMP algorithm based scheme enjoy high spectral efficiency since only a single PN sequence is used. Even in the extreme case that the actual CIR length equals 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 spectral 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.

Note that our proposed PIT-IHT based channel 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 spectral efficiency of our proposed scheme is higher than that of the modified CoSaMP based scheme.

<table>
<thead>
<tr>
<th>TS length</th>
<th>DPN-OFDM</th>
<th>Modified CoSaMP</th>
<th>PIA-IHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M = N/4$</td>
<td>66.67%</td>
<td>80.00%</td>
<td>80.00%</td>
</tr>
<tr>
<td>$M = N/8$</td>
<td>80.00%</td>
<td>88.89%</td>
<td>88.89%</td>
</tr>
<tr>
<td>$M = N/16$</td>
<td>88.89%</td>
<td>94.12%</td>
<td>94.12%</td>
</tr>
</tbody>
</table>

IV. Simulation Results

This section investigated the performance of the proposed PIA-IHT algorithm based channel estimation scheme for TDS-OFDM systems, where the state-of-the-art schemes: the modified CoSaMP algorithm based scheme [3] and DPN-OFDM scheme [4] were adopted for comparison. The system parameters were set as follows: $f_c = 643$MHz, $1/T_s = 7.56$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-VB channel model and the China digital television test 8th channel model (CDT-8) [3].

Fig. 4 shows the signal recovery probability against the varying IBI-free region sizes of four different CS signal recovery algorithms under the static ITU-VB cannel at SNR = 20 dB. In this simulation, we define that if the mean square error (MSE) of the signal estimation is lower than $10^{-2}$, the recovery result is considered to be correct and thus the signal recovery probability was assumed to be 1 [4]. From Fig. 4, it can be observed that the proposed PIA-IHT algorithm outperforms other conventional CS algorithms. The classical IHT algorithm fails to work, because its convergence requires the $l_2$ norm of the measurement matrix being less than 1 [6], and the measurement matrix in TDS-OFDM does not meet the condition. Compared with the CoSaMP algorithm and the modified CoSaMP algorithm which require the IBI-free region of size 30 and 40 to recovery signal with the probability 1, respectively, the proposed PIA-IHT algorithm only needs 7 observation samples. This means that, compared with the CoSaMP algorithm and the modified CoSaMP algorithm, PIA-IHT algorithm reduces 82.5% and 76.7% observation samples, respectively. It is because that the proposed PIA-IHT algorithm benefits from the priori information, i.e., not only the locations, but also the values of the partial large components in the target signal. Therefore, the proposed PIA-IHT algorithm can combat the CIR with longer delay spread. By contrast, to combat the CIR with very long delay spread, the existing CS based schemes require more number of observation samples or larger size of the TS, and thus reduce the spectral efficiency.

Fig. 5 and Fig. 6 provide the channel estimation MSE and data demodulation bit error rate (BER) performance comparison of three transmission schemes, respectively. Channel models of CDT-8 and ITU-VB with the mobile speed of 120km/h were adopted to investigate their performance. From Fig. 5 and Fig. 6, it can be observed that the modified CoSaMP based channel estimation scheme is better than DPN-OFDM scheme over ITU-VB channel, but it suffers from a great performance loss over CDT-8 channel. Meanwhile, our PIA-IHT based transmission scheme outperforms other schemes in various scenarios, especially under severe multipath channels with long delay spread, e.g., CDT-8 channel with 120km/h receiver velocity. Note that the proposed PIA-IHT based TDS-OFDM transmission scheme has higher spectral efficiency than the DPN-OFDM scheme.

The superior performance of the proposed scheme over severe multipath channels is contributed by three reasons. First, the overlap-add method of the TS based on several
the temporal correlation of wireless channels is exploited to improve its accuracy and robustness, especially under severe fading channels with long delay spread. Besides, we also proposed a low-complexity CS algorithm to acquire the accurate channel estimation. In contrast to the classical IHT algorithm whose convergence requires the $l_2$ norm of the measurement matrix being less than 1, the proposed PIA-IHT algorithm removes such a convergence restriction and reduces the number of iterations due to the priori information from the coarse channel estimation. Meanwhile, compared with the CoSaMP algorithm and the modified CoSaMP algorithm, the proposed PIA-IHT algorithm reduces computational complexity and the required observations. Hence the proposed PIA-IHT algorithm can combat longer CIR compared with the conventional CS based schemes. Simulation results demonstrate that the proposed scheme is superior to the state-of-the-art schemes, especially under time-varying severe multipath channels with long delay spread.

Fig. 5. MSE performance comparison between the PIA-IHT based channel estimation and its conventional counterparts.

Fig. 6. BER performance comparison between the proposed PIA-IHT algorithm based scheme and its conventional counterparts.

From this, we proposed a spectrum-efficient channel estimation scheme based on the proposed low-complexity PIA-IHT algorithm for TDS-OFDM systems. The proposed scheme effectively solves the existing problems in the conventional channel estimation for TDS-OFDM without degrading the spectral efficiency. An overlap-add method of the TS was proposed to obtain the coarse channel estimation, whereby the temporal correlation of wireless channels is exploited to improve its accuracy and robustness, especially under severe fading channels with long delay spread. Besides, we also proposed a low-complexity CS algorithm to acquire the accurate channel estimation. In contrast to the classical IHT algorithm whose convergence requires the $l_2$ norm of the measurement matrix being less than 1, the proposed PIA-IHT algorithm removes such a convergence restriction and reduces the number of iterations due to the priori information from the coarse channel estimation. Meanwhile, compared with the CoSaMP algorithm and the modified CoSaMP algorithm, the proposed PIA-IHT algorithm reduces computational complexity and the required observations. Hence the proposed PIA-IHT algorithm can combat longer CIR compared with the conventional CS based schemes. Simulation results demonstrate that the proposed scheme is superior to the state-of-the-art schemes, especially under time-varying severe multipath channels with long delay spread.

VI. ACKNOWLEDGMENTS

This work was supported by National Key Basic Research Program of China (Grant No. 2013CB329201), National Natural Science Foundation of China (Grant No. 61201185), and the ZTE fund project (Grant No. CON1307250001).

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