Research on OTFS Performance Based on Joint-Sparse Fast Time-Varying Channel Estimation

Wenjing Gao[1,2](✉), Shanshan Li[1], Lei Zhao[1], Wenbin Guo[1,2], and Tao Peng[1]

[1] Wireless Signal Processing and Network Laboratory, Beijing University of Posts and Telecommunications, Beijing 100876, China
{gaowenjing,lishanshan,leizhao,gwb,pengtao}@bupt.edu.cn

[2] Science and Technology on Information Transmission and Dissemination in Communication Networks Laboratory, Beijing, China

Abstract. Contraposing the problem of high pilot overhead and poor estimation performance for OFDM system in fast time-varying channels, a novel channel estimation method based on joint-sparse basis expansion model is proposed. In order to resist the inter-carrier interference (ICI) of OFDM system over fast time-varying channel, we introduce the OTFS (Orthogonal Time Frequency Space) technique and propose an implementation scheme of OTFS system based on time-frequency domain channel estimation. Simulation results demonstrate that the proposed OTFS system has higher reliability and better adaptability than the OFDM system in high dynamic scenarios.

Keywords: Time-varying channel estimation · OTFS · Joint-sparse basis expansion model · Compressed sensing

1 Introduction

Nowadays, the communication requirements in high mobility scenarios such as high-speed railway system have received increasing attention. In these scenarios, the channel parameters are no longer constant during each symbol period and this type of channel is called a fast time-varying channel. The amount of parameters to be estimated in each symbol over the fast-changing channel is much larger than the observable number. The Linear Time Varying (LTV) model [1,2] and Basis Expansion Model (BEM) [3] are two important models to effectively reduce the number of parameters. LTV models the channel taps of adjacent OFDM symbols as a piecewise linear time-varying relationship, it has a good approximation performance when the normalized Doppler shift is no more than 0.2. In BEM, channel taps are represented as a linear superposition of several two-dimensional basis functions and it has been widely studied [4–6] because it can better describe the nonlinear variation of channels. In addition, the fast time-varying channel exhibits sparsity in delay-Doppler domain. It has become a hot research topic to reduce pilot overhead by utilizing the channel sparsity [7,8].

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The OFDM system in fast time-varying channels suffers ICI due to its frequency offset sensitivity, which seriously affects the reliability of multi-carrier systems. Although some scholars have studied ICI cancellation or suppression methods [9,10], they are of high complexity and cannot adapt to higher dynamic communication scenarios for instance that the future high-speed trains need to support a speed of 500 km/h. In order to solve the above problem, R. Hadani first proposed a new modulation method named Orthogonal Time Frequency Space (OTFS) [11,12] to meet the requirements of high spectral efficiency in high Doppler scenarios while supporting the application of large-scale antennas. This modulation focuses on making the data itself subject to interference as small as possible rather than the subsequent interference elimination. It is worth considering whether to use the OFDM or the OTFS in the future mobile communication standards.

For the estimation problem of fast time-varying channels, a joint-sparse basis expansion model and a corresponding channel estimation method are proposed. This method converts the estimation of channel impulse response into an estimation of basis coefficients meanwhile considers the sparsity and joint sparsity of the coefficients. In order to improve the anti-interference ability of the system in fast time-varying channels, we propose an implementation of OTFS system based on time-frequency domain channel estimation. The simulation results manifest that the BER performance of the OTFS system using the proposed channel estimation method is significantly better than that of the OFDM system. The OTFS system can achieve high spectral efficiency and high reliability simultaneously and it has better adaptability over high dynamic channels.

The structure of this paper is organized as follows: In Sect. 2, the OFDM system model based on BEM model is derived. In Sect. 3, the proposed channel estimation method based on the joint-sparse BEM model is introduced in detail. In Sect. 4, the basic principles of the OTFS are described and an implementation scheme of the OTFS system is given. Simulation results are provided to compare the performance of OTFS and OFDM systems over fast time-varying channels in Sect. 5. The conclusion is presented in Sect. 6.

2 System Model

In this section, we will derive an OFDM system model over fast time-varying channel under the basis expansion model.

2.1 OFDM System-Basis Expansion Model with Pilots

In the case of fast time-varying channel, the ICI is unavoidable and the channel impulse response changes within each OFDM symbol period, which brings great difficulty to channel estimation. This paper introduces the basis expansion model to reduce the amount of estimation. Let the discrete form of the l-th channel tap at the n-th moment be $h(n, l)$, where $n = 0 \dots N-1, l = 0 \dots L-1$, under the basis expansion model, the l-th channel tap $\mathbf{h}_l$ can be written as:

$$\mathbf{h}_l = (\mathbf{b}_0, ..., \mathbf{b}_{Q-1}) \begin{bmatrix} g(0,l) \\ \vdots \\ g(Q-1,l) \end{bmatrix} + \xi_l = \mathbf{B}\mathbf{g}_l + \xi_l \tag{1}$$

where $\mathbf{h}_l \in \mathbb{C}^{N\times 1}$, $\mathbf{b}_q = [b(0,q), ..., b(N-1,q)]^T \in \mathbb{C}^{N\times 1}$ is the basis expansion vector, $\mathbf{B} = (\mathbf{b}_0, ..., \mathbf{b}_{Q-1}) \in \mathbb{C}^{N\times Q}$ is the basis function matrix, $\mathbf{g}_l = [g(0,l), ..., g(Q-1,l)]^T \in \mathbb{C}^{Q\times 1}$ is the BEM coefficient vector of the l-th channel tap, and $\xi_l \in \mathbb{C}^{N\times 1}$ is the model error vector. The model order Q satisfies $2f_{nds} + 1 \leqslant Q \ll N$, where f_{nds} is the normalized Doppler shift.

In the time-frequency domain, the transmission equation of OFDM system is:

$$\mathbf{Y} = \mathbf{F}\mathbf{H}_T\mathbf{F}^H\mathbf{X} + \mathbf{W} = \mathbf{H}_F\mathbf{X} + \mathbf{W} \tag{2}$$

where $\mathbf{X} \in \mathbb{C}^{N\times 1}$ and $\mathbf{Y} \in \mathbb{C}^{N\times 1}$ represent transmitted signal and received signal in the frequency domain, respectively, $\mathbf{H}_T \in \mathbb{C}^{N\times N}$ is the channel matrix in time domain, namely $[\mathbf{H}_T]_{i,j} = h(i, \mathrm{mod}(i-j, N))$, $\mathbf{F} \in \mathbb{C}^{N\times N}$ is the normalized Fourier transform matrix of N points, $\mathbf{H}_F \in \mathbb{C}^{N\times N}$ is called the channel matrix in frequency domain, and $\mathbf{W} \in \mathbb{C}^{N\times 1}$ is the frequency domain noise vector.

Combining (1) and (2), the received signal $\mathbf{Y}$ can be written as:

$$\begin{aligned} \mathbf{Y} &= \sum_{q=0}^{Q-1} \mathbf{F} diag(\mathbf{b}_q)\mathbf{F}^H diag(\mathbf{F}_L\mathbf{g}_q)\mathbf{F}\mathbf{F}^H\mathbf{X} + \mathbf{W} \\ &= \sum_{q=0}^{Q-1} \underbrace{\mathbf{F} diag(\mathbf{b}_q)\mathbf{F}^H}_{\mathbf{A}_q} diag(\mathbf{F}_L\mathbf{g}_q)\mathbf{X} + \mathbf{W} \end{aligned} \tag{3}$$

where $\mathbf{F}_L \in \mathbb{C}^{N\times L}$ represents the submatrix consisting of the first L columns of the Fourier transform matrix, and $\mathbf{W} \in \mathbb{C}^{N\times 1}$ represents the noise term including the model error. Using the commutative law $diag(\mathbf{F}_L\mathbf{g}_q)\mathbf{X} = diag(\mathbf{X})\mathbf{F}_L\mathbf{g}_q$, the above equation can be rewritten as:

$$\begin{aligned} \mathbf{Y} &= \sum_{q=0}^{Q-1} \mathbf{A}_q diag(\mathbf{X})\mathbf{F}_L\mathbf{g}_q + \mathbf{W} \\ &= [\mathbf{A}_0, ..., \mathbf{A}_{Q-1}] \{\mathbf{I}_Q \otimes [diag(\mathbf{X})\mathbf{F}_L]\} \mathbf{g} + \mathbf{W} \end{aligned} \tag{4}$$

where $\mathbf{I}_Q$ represents an identity matrix of size Q, $\otimes$ denotes the Kronecker product, and $\mathbf{g} = [\mathbf{g}_0, ..., \mathbf{g}_{Q-1}]^T \in \mathbb{C}^{LQ\times 1}$ is the complete form of the BEM coefficient vector.

Let the number of pilots be P, then the received signal at the pilot position $\mathbf{Y}_P \in \mathbb{C}^{P\times 1}$ can be represented as:

$$\begin{aligned} \mathbf{Y}_P = {} & [\mathbf{A}_{0,P}, ..., \mathbf{A}_{Q-1,P}] \{\mathbf{I}_Q \otimes [diag(\mathbf{X}_P)\mathbf{F}_P]\} \mathbf{g} \\ & + [\mathbf{A}_{0,D}, ..., \mathbf{A}_{Q-1,D}] \{\mathbf{I}_Q \otimes [diag(\mathbf{X}_D)\mathbf{F}_D]\} \mathbf{g} + \mathbf{W}_P \end{aligned} \tag{5}$$

where $\mathbf{A}_{q,P} \in \mathbb{C}^{P\times P}$ denotes a submatrix of $\mathbf{A}_q$ formed by selecting P rows and P columns from where the pilots are located, $\mathbf{A}_{q,D} \in \mathbb{C}^{P\times(N-P)}$ represents the submatrix of $\mathbf{A}_q$ formed by selecting P rows where the pilots are located and $(N-P)$ columns where the data are located, $\mathbf{F}_P \in \mathbb{C}^{P\times L}$ and $\mathbf{F}_D \in \mathbb{C}^{(N-P)\times L}$ represent the submatrices of the Fourier transform submatrix $\mathbf{F}_L$ composed of selecting P rows where the pilot takes and $(N-P)$ rows where the data takes, respectively. The second term in the equation is the interference term which includes the system ICI. The interference term, model error and noise are synthesized into $\tilde{\mathbf{W}}_P$, then the BEM coefficient estimation equation of the j-th symbol in the OFDM system is:

$$\mathbf{Y}_P^j = \underbrace{\left[\mathbf{A}_{0,P}^j, ..., \mathbf{A}_{Q-1,P}^j\right]\left\{\mathbf{I}_Q \otimes \left[diag(\mathbf{X}_P^j)\mathbf{F}_P^j\right]\right\}}_{\mathbf{\Phi}_P}\mathbf{g}^j + \tilde{\mathbf{W}}_P^j = \mathbf{\Phi}_P^j\mathbf{g}^j + \tilde{\mathbf{W}}_P^j \tag{6}$$

It can be seen that the basis expansion model reduces the estimated parameters of fast-changing channel from NL to QL and $Q << N$, hence the complexity of channel estimation can be effectively reduced.

3 Proposed Channel Estimation

In this section, the proposed joint-sparse basis expansion model is introduced first and then a channel estimation method based on the joint-sparse BEM is presented.

3.1 Joint-Sparse Basis Expansion Model

When the fast time-varying channel is fitted by basis expansion model, the sparsity of basis coefficient also characterizes the sparsity of the channel in the delay-Doppler domain [13]. Let Γ denotes a set containing all non-zero path positions of the channel, then

$$\mathbf{h}_l = [h(0,l), ..., h(N-1,l)]^T = \mathbf{0}^T,\ l \notin \Gamma \tag{7}$$

According to (1), when the model error is ignored, the BEM coefficient vector of the lth channel tap can be expressed as:

$$\mathbf{g}_l = (g[0,l], ..., g[Q-1,l])^T = \mathbf{B}^\dagger \mathbf{h}_l \tag{8}$$

where $\mathbf{B}^\dagger$ is the pseudo-inverse of the basis function matrix.

Combining (7) and (8) we can know that the basis coefficient satisfies the following characteristics: $g[0,l] = \cdots = g[Q-1,l] = 0$, $l \notin \Gamma$, that is, the basis coefficient vector $\mathbf{g} = [\mathbf{g}_0, ..., \mathbf{g}_{Q-1}]^T \in \mathbb{C}^{LQ\times 1}$ is a sparse vector and its sparsity is KQ at most, the specific sparsity S is related to the system Doppler frequency.

Although the channel amplitude changes within each OFDM symbol, the multipath structure of time-varying channel exhibits strong correlation between consecutive symbols [14]. In this paper, we assume that the multi-path delay structure of channel remains unchanged for consecutive J OFDM symbols, thus the corresponding J basis coefficient vectors exhibit joint sparsity. Based on this, a joint-sparse basis expansion model is established, let $\theta_g = [\theta_0, ..., \theta_l, ..., \theta_{QL-1}]^T \in \mathbb{C}^{LQ\times 1}$ denote a joint-sparse support set, then the joint-sparse basis expansion model is expressed as:

$$\mathbf{g}^j = \mathrm{diag}(\theta_g)\mathbf{s}_g^j, j = 1, ..., J \tag{9}$$

The superscript j represents the serial number of the OFDM symbol, and $\mathbf{s}_g^j \in \mathbb{C}^{LQ\times 1}$ represents the amplitude of the basis coefficient corresponding to the j-th symbol. According to the joint-sparse basis expansion model, the joint multi-symbol channel estimation model of OFDM system for fast time-varying scenario can be derived as:

$$\begin{cases} \mathbf{Y}_P^1 = \mathbf{\Phi}_P^1\mathbf{g}^1 + \tilde{\mathbf{W}}_P^1 \\ \mathbf{Y}_P^2 = \mathbf{\Phi}_P^2\mathbf{g}^2 + \tilde{\mathbf{W}}_P^2 \\ \vdots \\ \mathbf{Y}_P^J = \mathbf{\Phi}_P^J\mathbf{g}^J + \tilde{\mathbf{W}}_P^J \end{cases} \tag{10}$$

The joint channel estimation model described above converts the estimation of the channel impulse response that changes within each symbol into an estimation of the invariant basis coefficient within each symbol, it reduces the amount of estimation and meanwhile fully considers to the sparsity of basis coefficients and the joint-sparse property between successive symbols, thus it can be used to guide channel estimation for low pilot overhead over fast-varying channels.

3.2 The Proposed Channel Estimation Scheme

The joint channel estimation problem shown in (10) is equivalent to solving the following optimization formula:

$$\hat{\mathbf{g}}^j = \arg\min\left\|\mathbf{g}^j\right\|_0 \text{ s.t. } \sum_{j=1}^{J}\left\|\mathbf{Y}_P^j - \mathbf{\Phi}^j\mathbf{g}^j\right\|_2^2 \leqslant \varepsilon \tag{11}$$

In this paper, the SOMP algorithm [15] of distributed compressed sensing is used to solve the channel BEM coefficients of J OFDM symbols. Furtherly according to (1), the estimated value of the corresponding channel impulse response is obtained by applying the following equation:

$$\hat{\mathbf{h}}^j = (\mathbf{B} \otimes \mathbf{I}_L)\hat{\mathbf{g}}^j \tag{12}$$

where $\hat{\mathbf{h}}^j = [\hat{h}(0,0), ..., \hat{h}(0, L-1), ..., \hat{h}(N-1, 0), ..., \hat{h}(N-1,\ L-1)]^T \in \mathbb{C}^{NL\times 1}, j = 1, ..., J$.

We adopt the linear time varying model's derivative smoothing method–piecewise linear smoothing [16] to perform the subsequent processing of the initial channel estimation values obtained by the SOMP algorithm. The core idea of piecewise linear smoothing is using the correlation of channel amplitudes between successive symbols to reduce the model error further. In practical applications, the piecewise linear smoothing method adopts the sliding window in Fig. 2.

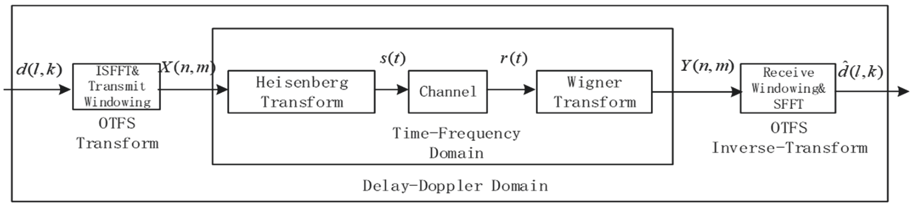

Fig. 1. OTFS system block diagram [17]

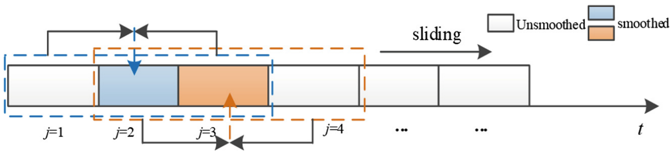

Fig. 2. Sliding window method of piecewise linear smoothing

4 Time-Frequency Domain Channel Estimation Based OTFS Scheme

In this section, we first introduce specific analysis of OTFS modulation and demodulation and then an implementation scheme of OTFS system based on time-frequency domain channel estimation is proposed.

4.1 OTFS Mod/demod Block Diagram

The block diagram of the OTFS system is shown in Fig. 1.

OTFS Modulation. The OTFS transform can be expressed as:

$$X[n,m] = w_{tx}[n,m] \cdot \text{ISFFT}(d[l,k]) \tag{13}$$

where $d[l,k]$ is the data symbol in delay-doppler domain, $X[n,m]$ is the symbol in time-frequency domain and $w_{tx}[n,m]$ is the transmitting window function.

Then $X[n, m]$ are mapped to a time domain waveform $s(t)$ by a time-frequency modulator which superposing the delay-and-modulate operation on the pulse waveform $g_{tx}(t)$, namely

$$s(t) = \sum_{n=-N/2}^{N/2} \sum_{m=0}^{M-1} X[n, m] g_{tx}(t - m\Delta t) e^{j2\pi n\Delta f(t - m\Delta t)} \quad (14)$$

The operation in (14) is called the Heisenberg transform of $X[n, m]$. Then the time domain waveform is transmitted through the wireless channel $h(\tau, \upsilon)$ and the received signal $r(t)$ is obtained as:

$$r(t) = \iint h(\tau, \upsilon) s(t - \tau) e^{j2\pi\upsilon(t-\tau)} d\upsilon d\tau \quad (15)$$

OTFS Demodulation. The OTFS demodulation includes two links of Wigner transform and OTFS inverse transform, wherein the Wigner transform is an inverse operation of Heisenberg transform and the OTFS inverse transform specifically includes windowing and SFFT transform.

Firstly, the time domain signal $r(t)$ is transformed back to the time-frequency domain via Wigner transform given by

$$Y[n, m] = A_{g_{rx}, r}(\tau, \upsilon)|_{\tau = mT, \upsilon = n\Delta f} \quad (16)$$

where $A_{g_{rx}, r}(\tau, \upsilon)$ is the cross ambiguity function given by

$$A_{g_{rx}, r}(\tau, \upsilon) \triangleq \int g_{rx}^*(t - \tau) r(t) e^{-j2\pi\upsilon(t-\tau)} dt \quad (17)$$

The above equation is sampled to obtain the discrete received signal $Y[n, m]$ of the matched filter output and its windowed by the receiving window function $w_{rx}[n, m]$ to obtain $Y_w[n, m]$:

$$Y_w[n, m] = w_{rx}[n, m] Y[n, m] \quad (18)$$

Then the $Y_w[n, m]$ are converted to symbols in the delay-Doppler domain via SFFT:

$$\hat{d}[l, k] = \mathrm{SFFT}(Y_w[n, m]) \quad (19)$$

The relation of input and output in OTFS modulation can be derived as:

$$\hat{d}[l, k] = \frac{1}{NM} \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} d[l, k] h_w(\frac{k - m}{MT}, \frac{l - n}{N\Delta f}) \quad (20)$$

where

$$h_w(\frac{k - m}{MT}, \frac{l - n}{N\Delta f}) = h_w(\upsilon', \tau')|_{\upsilon' = \frac{k-m}{MT}, \tau' = \frac{l-n}{N\Delta f}} \quad (21)$$

and where $h_w(\upsilon', \tau')$ is the circular convolution of the channel response $\mathrm{h}(\tau, \upsilon)$ and the windowing function $w(\upsilon, \tau)$, given by

$$h_w(\upsilon', \tau') = \iint h(\tau, \upsilon) w(\upsilon' - \upsilon, \tau' - \tau) e^{-j2\pi\upsilon\tau} d\tau d\upsilon \tag{22}$$

where

$$w(\upsilon, \tau) = \mathrm{SFFT}(w_{tx}[n, m] \cdot w_{rx}[n, m]) \tag{23}$$

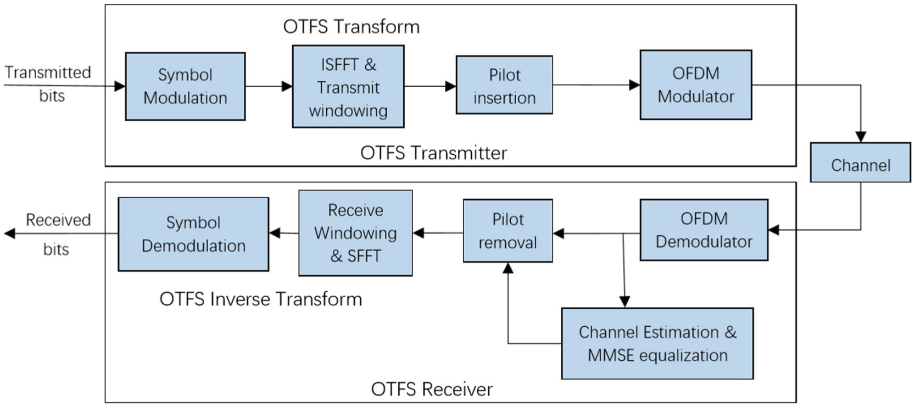

Fig. 3. Block diagram of OTFS system based on time-frequency domain channel estimation

4.2 Time-Frequency Domain Channel Estimation Based on OTFS Scheme

As shown in Fig. 3, an implementation scheme of OTFS system based on time-frequency domain channel estimation is presented which can take into account both the high spectral efficiency and reliability under the premise of compatible OFDM system.

If the number of system subcarriers is N and the number of multicarrier symbols is M, then the time-frequency domain and the corresponding delay-Doppler domain have a lattice size of $M \times N$. The transmitter obtains the constellation symbols by encoding and symbol modulation of the binary bits and maps them to the delay-Doppler domain to obtain the transmission sequence $d[l, k] l = 0 \ldots N-1, k = 0 \ldots M-1$, after which the OTFS transform completes the conversion from the delay-Doppler domain to the time-frequency domain. For the sake of simplicity, we adopt a rectangular window which can simplify the OTFS transform into an ISFFT transform:

$$\begin{aligned} X[n, m] &= \mathrm{ISFFT}(d[l, k]) \\ &= \frac{1}{\sqrt{MN}} \sum_{l=0}^{N-1} \sum_{k=0}^{M-1} d[l, k] e^{-j2\pi\left(\frac{nl}{N} - \frac{mk}{M}\right)} \end{aligned} \tag{24}$$

where m and n represent the time domain and frequency domain, respectively, $m = 0 \ldots M - 1, n = 0 \ldots N - 1$.

In this paper, the receiver adopts the proposed channel estimation method and the MMSE channel equalization as shown below:

$$\hat{X}[n, m] = \frac{Y[n, m]\hat{H}[n, m]^*}{\left|\hat{H}[n, m]\right|^2 + \sigma^2} \tag{25}$$

where $Y[n, m]$ and $H[n, m]$ represent the received signal and channel parameters in the time-frequency domain, respectively, and the noise power is σ^2. Then $\hat{X}[n, m]$ is converted to the delay-Doppler domain by SFFT and the estimated value of the transmitted constellation symbol is obtained, finally the binary information bits are restored by operations such as demodulation and decoding.

5 Simulation Results and Discussion

This section studies the performance of both OFDM and OTFS systems. Firstly, the BER performance of OFDM system under different channel estimation methods is simulated. Then, the BER performance of OTFS and OFDM system is compared using the proposed channel estimation method. The OFDM system compares four methods of compressed sensing channel estimation, all of which use random pilots and the pilots between the symbols in the joint multi-symbol estimation method are identical to each other. The algorithms for comparison are as follows: (1) OMP [18]: obtaining the BEM coefficients symbol by symbol according to (6); (2) OMP smooth: performing piecewise linear smoothing on the preliminary estimation of the channel obtained by (1); (3) SOMP: obtaining the BEM coefficients of $J = 5$ symbols jointly according to (10); (4) SOMP Smooth: performing the piecewise linear smoothing process on the initial value obtained in (3).

Table 1. Simulation parameters

Parameter	Value
Number of subcarrier	$N = 256$
Number of multi-carrier symbol	$M = 15$
CP length	$N_{CP} = 64$
Channel tap number	4
Channel length	$L = 64$
Modulation mode	QPSK
Subcarrier spacing	15 KHz
Carrier frequency	4 Ghz
Channel knowledge	unknown

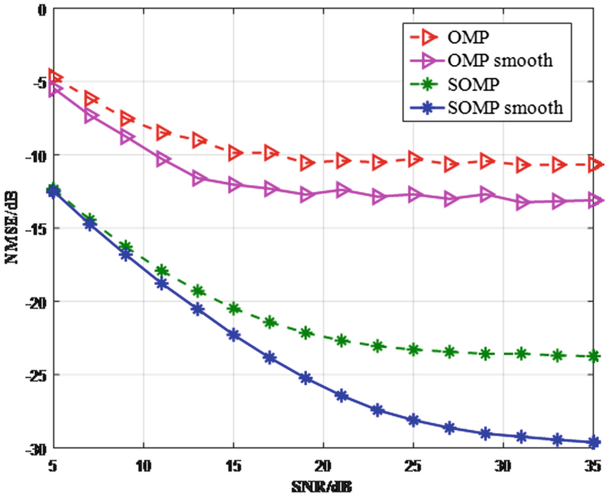

Fig. 4. OFDM NMSE performance of various channel estimation methods with $f_{nds} = 0.05$, 202.5 Kmph

We first generate channel based on the Jake's model. To describe the time variation of the channel, the definition of normalized Doppler shift (NDS) is given: $f_{nds} = f_d/\Delta f$, where f_d and Δf is the Doppler frequency and the system subcarrier spacing, respectively. The simulation adopts the DPS-BEM model with a model order of $Q = 3$, and other system parameters are shown in Table 1.

Figure 4 shows the normalized mean square error(NMSE) performance of OFDM system adopting different channel estimation methods when the f_{nds} is 0.05 (the corresponding maximum UE speed is 202.5 Kmph). It can be seen that the performance result is SOMP smooth>SOMP>OMP smooth>OMP. The performance of OMP algorithm is the worst and an error platform appears when SNR is above 10 dB. This is because OMP algorithm merely utilizes the sparsity of BEM coefficients without considering the correlation between consecutive symbols. After using the smoothing treatment, OMP gets a very limited performance boost. Our proposed channel estimation method gets the best performance because it makes full use of the sparsity of channel as well as reduces the model error by the smoothing treatment. Next, the BER performance of OTFS and OFDM will be simulated.

We simulate the BER performance of OFDM and OTFS using the proposed channel estimation method and MMSE channel equalization. The BER performance for both uncoded and (2,1,7) convolutional code are compared. Figure 5 shows the BER performance of OFDM and OTFS system using the SOMP smooth channel estimation method with a f_{nds} of 0.05. It can be seen that in the case of both coded and uncoded, the performance of OFDM is slightly better than that of OTFS in the relatively low SNR regime, while as SNR increases the advantages of OTFS becomes more prominent and the system performance

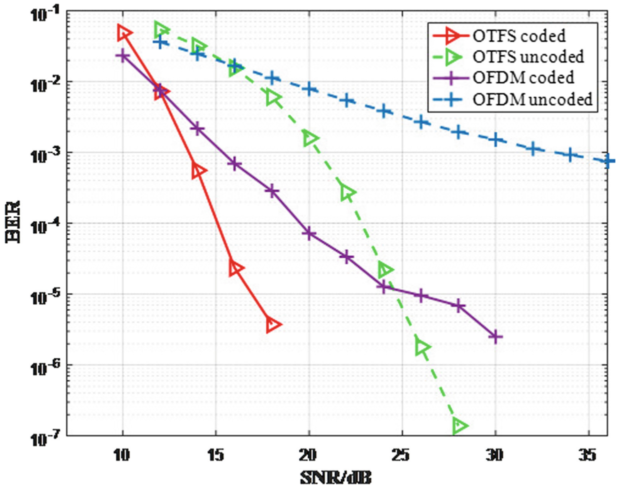

Fig. 5. BER performance of two systems with the proposed channel estimation method ($f_{nds} = 0.05$, 202.5 Kmph)

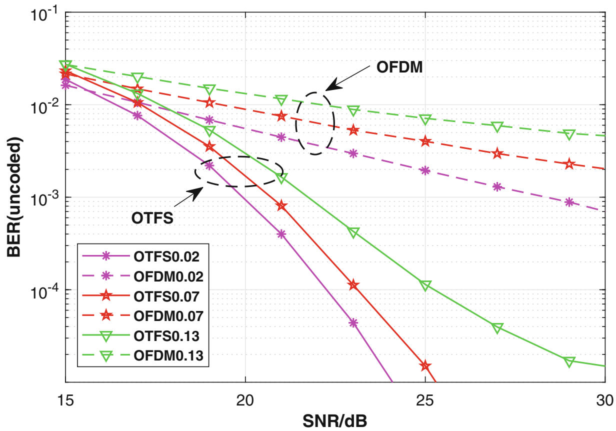

Fig. 6. BER performance of two systems over different time-varying channels (uncoded)

is far superior to OFDM, which indicates that OTFS can effectively resist system ICI. After adopting the proposed channel estimation method, it can obtain significantly superior BER performance and higher system reliability.

Figures 6 and 7 compare the BER performance of the OFDM system and the OTFS system with different normalized Doppler shifts (0.02, 0.07, 0.13) (the corresponding UE speed are 81 Kmph, 283.7 Kmph and 526.5 Kmph) in the case of uncoded and coded, respectively. For OFDM system, it can be seen that

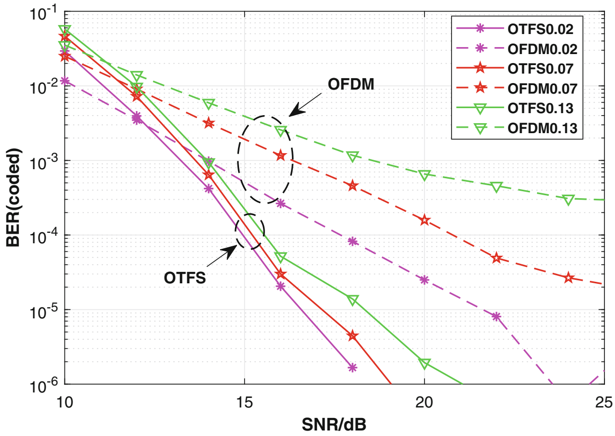

Fig. 7. BER performance of two systems over different time-varying channels (convolutional code with coding rate of 1/2)

the BER performance degrades significantly with the increase of channel time-variability. In the case of uncoded system, the difference of BER performance under the three Doppler shifts is about 4 dB (the signal-to-noise ratio when the BER is 1e-3). And in the case of coded system, the BER performance under the three f_{nds} differs more. In contrast, the BER performance of the OTFS system under the three f_{nds} is relatively stable. There is merely a difference of a few tenths of a dB in the case of coded OTFS system, which further illustrates the reliability and adaptability of the OTFS system over time-varying channels. In general, the simulation results indicate that our proposed OTFS implementation scheme outperforms OFDM in high dynamic scenarios.

6 Conclusion

In this paper, we have studied the channel estimation method based on the joint-sparse basis expansion model by fully exploiting the sparsity and correlation of fast time-varying channels. Based on the proposed fast time-varying channel estimation method, we study the performance of OTFS system and OFDM system. The simulation results illustrate that with the same multi-carrier parameters, the BER performance of OTFS system using the proposed channel estimation method is significantly superior than that of the OFDM system, which indicates that the OTFS system has higher reliability and better adaptability over high dynamic channel.

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