Time-Frequency Training OFDM using Matlab for high speed environments

Shailu Jain

Guided by
Dr. Soni Changlani (Head Of Department)
(Electronics and Communication Department, Lakshmi Narain College Of Technology and Science Bhopal, M.P. India)
Email:shailu_jain30@yahoo.com)

Abstract: Orthogonal frequency division multiplexing (OFDM) is widely recognized as the key technology for the next generation broadband wireless communication (BWC) systems. Besides high spectral efficiency, reliable performance over fast fading channels is becoming more and more important for OFDM-based BWC systems, especially when high speed cars, trains and subways are playing an increasingly indispensable role in our daily life. The time domain synchronous OFDM (TDS-OFDM) has higher spectral efficiency than the standard cyclic prefix OFDM (CP-OFDM), but suffers from severe performance loss over high speed mobile channels since the required iterative interference cancellation between the training sequence (TS) and the OFDM data block. In this paper, a fundamentally distinct OFDM-based transmission scheme called time-frequency training OFDM (TFT-OFDM) is proposed, whereby every TFT-OFDM symbol has training information both in the time and frequency domains. Simulation results also demonstrate that TFT-OFDM outperforms CP-OFDM and TDS-OFDM in high speed mobile environments. This work based on simulation using MATLAB 7.11.

Keywords: Orthogonal frequency division multiplexing (OFDM), time-frequency training (TFT), joint time frequency channel estimation, interference cancellation, spectral efficiency, fast fading channels**.**

I. INTRODUCTION

Due to the robustness to the frequency-selective multipath channel and the low complexity of the frequency domain equalizer, orthogonal frequency division multiplexing (OFDM) has been widely recognized as one of the key techniques for the next generation broadband wireless communication (BWC) systems [2]. One fundamental issue of OFDM is the block transmission scheme. Basically, there are three types of OFDM-based block transmission schemes: cyclic prefix OFDM (CP-OFDM) [3], zero padding OFDM (ZP-OFDM) [4], and time domain synchronous OFDM (TDS-OFDM) [5]. The broadly used CPOFDM scheme utilizes the CP to eliminate the inter-block interference (IBI) as well as the inter-carrier-interference (ICI) [6]. For both the CP-OFDM and ZP-OFDM schemes, some dedicated frequency-domain pilots are required for synchronization and channel estimation, thus the spectral efficiency is reduced. To solve this problem, instead of the CP, the known training sequence (TS) such as the pseudorandom noise (PN) sequence, is used as the guard interval in the TDS-OFDM scheme [5]. Since the TS is known to the receiver, it can be also used for synchronization as well as channel estimation [7]. Consequently, the large amount of frequency-domain pilots used in CP-OFDM and ZP-OFDM could be saved. Thus, TDS-OFDM outperforms CP-OFDM and ZP-OFDM in spectral efficiency by about 10% [8]. However, the main drawback of TDS-OFDM is that, the time-domain TS and the OFDM data block will cause IBI to each other. Thus, the iterative interference cancellation algorithm has to be used for channel estimation and equalization [7], [8], i.e., the IBI from the OFDM data block to the TS must be eliminated before the TS-based time-domain channel estimation, while the IBI caused by the TS to the OFDM data has to be removed to achieve reliable channel equalization. On one hand, the interference cancellation before channel estimation needs the equalized OFDM data information to calculate the IBI caused by the OFDM block, while on the other hand, channel estimation is prerequisite to obtain the equalized OFDM block. One exciting solution to the interference problem of TDS-OFDM is the cyclic postfix OFDM scheme [10], [11], whereby the TS serving as the cyclic postfix is not independent of the OFDM block like that in TDS-OFDM, but is generated by the redundant frequency-domain comb-type pilots within the OFDM symbol. In this way, the IBI from the TS to the OFDM data block can be avoided. However, the cyclic postfix OFDM scheme does not solve the problem of the interference from the OFDM data block to the next TS, thus the iterative interference cancellation with poor performance over fast time-varying channels is still required for channel estimation and OFDM equalization [12]. In addition, the inserted redundant pilots have much higher average power than the normal OFDM data [13], thus the equivalent signal-to-noise ratio (SNR) at the receiver will be reduced if the identical transmitted signal power is permitted. Such SNR loss can be slightly alleviated by changing the positions of the redundant pilots or adding more pilots in the frequency domain [14], but the effect is not obvious. The most effective solution to the interference problem of TDS-OFDM is to duplicate the TS twice, resulting in the dual-PN OFDM (DPN-OFDM) scheme [15]. The second received PN sequence immune from the interference caused by the preceding OFDM data block can be directly used for channel estimation, and the interference cancellation before channel equalization can be replaced by the cyclic prefix reconstruction which is accomplished by the simple add-subtraction operation [15]. In this way, the iterative interference cancellation algorithm could be avoided, leading to the reduced complexity and improved performance over fast fading channels. However, the spectral efficiency of the DPN-OFDM solution is remarkably decreased by the doubled length of the TS.

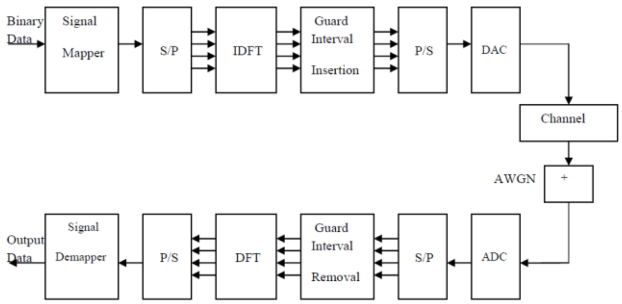

Figure 1: The basic block diagram of an OFDM system in AWGN channel

II. TFT-OFDM SYSTEM MODEL

In this section, the basic concept of the proposed TFTOFDM system is generalized at first, then the TFT-OFDM system model is outlined.

A. *Basic Concept of the TFT-OFDM System*

As shown in Figure. 2, the IBI from the TS to the OFDM data block and the IBI caused by the OFDM block to the TS have distinct features in TDS-OFDM. The interference caused by the TS can be completely removed if the channel estimation is perfect, since the TS is known at the receiver. In addition, this IBI can be calculated with relatively low complexity since the TS length is not large. However, the interference caused by the OFDM data block has to be calculated with high complexity, since the OFDM block length is usually large. More importantly, such interference can not be totally eliminated even when the channel estimation is ideal, because the OFDM data block is random and unknown, and perfect OFDM detection is difficult due to the noise, the ICI, the imperfect channel equalization, and so on, especially when the channel is varying fast. Therefore, the TS-based time-domain channel estimation in TDS-OFDM is not accurate over fast fading channels. Such estimation error would in turn result in the unreliable cancellation of the IBI caused by the TS, which would deteriorate the OFDM equalization performance in the next iteration. Consequently, the corresponding performance loss is unavoidable in TDS-OFDM.

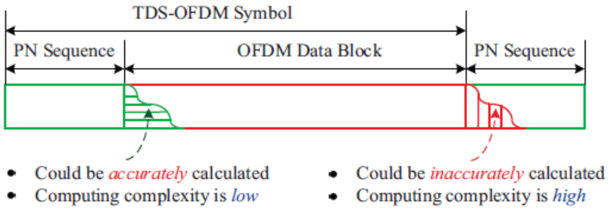

Figure 2: Distinct features of the IBIs in TDS-OFDM [1]

Based on the observations that the IBI caused by the OFDM data block has to be removed for reliable channel estimation, and the complete cancellation of such IBI is difficult even when the channel estimation is perfect, TFTOFDM is derived in this paper to provide a fundamentally distinct solution. In the proposed TFT-OFDM scheme, unlike the conventional method where both the channel path delays and the channel path coefficients are estimated by using the “clean” received TS after IBI cancellation, we do not remove the IBI imposed on the TS, but directly use the “contaminated” TS without IBI cancellation to obtain the partial channel information: the path delays of the channel, while the rest part of the channel information: the path coefficients, are acquired by utilizing the small amount of grouped pilots in the frequency domain. In this way, the IBI caused by the OFDM data block needs not to be removed, leading to the breaking of the mutually conditional relationship between the channel estimation and channel equalization in TDS-OFDM. Consequently, the iterative interference cancellation algorithm with poor performance could be avoided. The only cost is the extra frequency-domain grouped pilots, which lead to the spectral efficiency loss compared with TDS-OFDM. However, such loss is negligible, since the pilots used to estimate the path coefficients only occupy about less than 3% of the total subcarriers in the proposed TFT-OFDM solution.

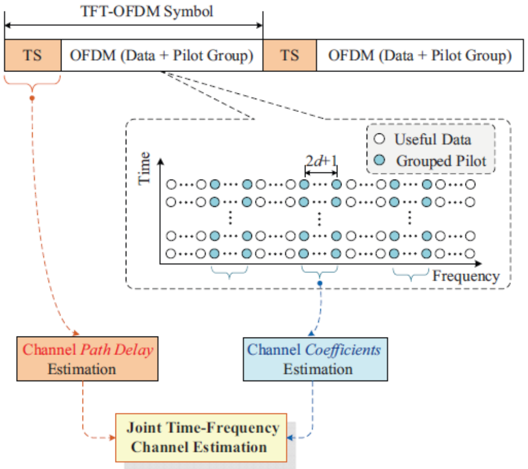

Figure 3: Proposed signal structure and the corresponding joint time-frequency channel estimation of the TFT-OFDM scheme [1]

B. *TFT-OFDM System Model*

Unlike TDS-OFDM or CP-OFDM where the training information only exists in the time or frequency domain, Fig. 2 shows that TFT-OFDM has training information in both time and frequency domains for every TFT-OFDM symbol, i.e., the time-domain TS and the frequency-domain grouped pilots scattered over the signal bandwidth are used in TFTOFDM. The signal structure of the TFT-OFDM scheme can be described in the time domain and frequency domain, respectively.

In the time domain, the ith TFT-OFDM symbol $S_i = [s_{i,-M} \cdots s_{i,-1}\ s_{i,0}\ s_{i,1} \cdots s_{i,N-1}]^T$ is composed of the known time-domain TS $C_i = [c_{i,0}\ c_{i,1} \cdots c_{i,M-1}]^T$ and the OFDM data block $X_i = [x_{i,0}\ x_{i,1} \cdots x_{i,N-1}]^T$ as below

$$S_i = \begin{bmatrix} C_i \\ X_i \end{bmatrix}_{P\times 1} = \begin{bmatrix} I_M \\ 0_{N\times M} \end{bmatrix}_{P\times M} C_i + \begin{bmatrix} 0_{M\times N} \\ I_N \end{bmatrix}_{P\times N} F_N^H X_i \tag{1}$$

Where M is length of the TS, N is the length of the OFDM data block, P=M+N presents the length of the TFT-OFDM symbol, $X_i = [x_{i,0}\ x_{i,1} \cdots x_{i,N-1}]^T$ denotes the frequency-domain OFDM symbol, and $x_i = F_N^H X_i$.

Being different from the time-domain PN sequence used in TDS-OFDM, the TS in TFT-OFDM could be any kind of sequences with desirable specific features defined in the time or frequency domain. Normally, the sequences with perfect or good autocorrelation property are preferred for channel estimation, e.g., the constant amplitude zero auto-correlation (CAZAC) sequence with constant envelop in both time and frequency domains [16], or the PN sequence used in TDS-OFDM [9]. Here we use the TS having constant envelope in the frequency domain, i.e., $c_i = F_N^H C_i$ where $C_i = [c_{i,0}\ c_{i,1} \cdots c_{i,M-1}]^T$. It can be proved that such TS with any length have perfect circular autocorrelation property, since the circular correlation theorem [17] allows. In the frequency domain, unlike TDS-OFDM where all active subcarriers are used to carry the useful data [18], TFT-OFDM has N_d data subcarriers and N_{group} groups of binary phase-shift keying (BPSK) modulated pilots scattered over the signal bandwidth. Each pilot group has $2d + 1$ pilots. The discrete multipath channel during the i^{th} TFT-OFDM symbol at the time instant n $(-M \le n \le N - 1)$ can be modeled as $h_{i,n} = [h_{i,n,0}\ h_{i,n,1} \cdots h_{i,n,L-1}]^T$ of the maximum length L, where $h_{i,n,l}$ denotes the coefficient of the l^{th} path with the delay nl. After the cyclic prefix reconstruction of the received OFDM block has been accomplished (the hybrid domain cyclic prefix reconstruction method [20] based on the well-known overlap and add (OLA) scheme in ZP-OFDM systems [4] can be directly utilized, since TFT-OFDM is essentially equivalent to ZP-OFDM after removing the known TS at the receiver), the time-domain received OFDM block $Y_i = [y_{i,0}\ y_{i,1} \cdots y_{i,N-1}]^T$ is

$$Y_i = H_i X_i + W_i \tag{2}$$

where $\mathbf{W_i}$ is the additive white Gaussian noise (AWGN) vector with zero mean and covariance of $\sigma^2 \mathbf{I}_N$, and the time-domain system matrix H_i. Using FFT to the above signal (2), we have the frequency domainOFDM block $Y_i = [y_{i,0}\ y_{i,1} \cdots y_{i,N-1}]^T$ as

$$Y_i = G_i X_i + W_i \tag{3}$$

where $\mathbf{Y_i} = F_{NYi}$, $\mathbf{W_i} = F_{NWi}$, and $\mathbf{G}i$ is the $N \times N$ channel frequency response (CFR) matrix with the $(p+1, q+1)^{th}$ entry Gi,p,q being [21]

$$G_{i,p,q} = \sum_{l=0}^{L-1} \left(\frac{1}{N} \sum_{n=0}^{N-1} h_{i,n,l}\, e^{-j\frac{2\pi}{N} n(p-q)} \right) e^{-j\frac{2\pi}{N} qnl} \tag{4}$$

If the channel is time-invariant within each TFT-OFDM symbol, the ICI coefficient Gi,p,q $(p = q)$ equals to zero, and If the channel is time-invariant within each TFT-OFDM symbol, the ICI coefficient Gi,p,q $(p = q)$ equals to zero, and G_i becomes a diagonal matrix. Consequently, the one-tap equalizer can be used for data detection with low complexity.

It is clear from (4) that the channel information, including the channel path delays as well as the path coefficients has to be obtained for data detection.

III. TFT-OFDM RECEIVER DESIGN

Based on the time-frequency training information and signal structure of the TFT-OFDM scheme in Section II, this section presents the TFT-OFDM receiver design, including the joint time-frequency channel estimation, and channel equalization as well.

A. *Joint Time-Frequency Channel Estimation*

Unlike CP-OFDM or TDS-OFDM where the channel estimation is solely dependent on the frequency-domain pilots or the time-domain TS, whereby the path delays and path coefficients are simultaneously estimated by the time- or frequency-domain training information [7], [15] channel estimation in TFT-OFDM is jointly accomplished by time-frequency processing of the received TFT-OFDM signal.

B. *TS-Based Path Delay Estimation*

The received TS will be contaminated by the IBI from the previous OFDM data block after multi-path propagation

To achieve reliable channel estimation in TDS-OFDM, IBI cancellation and cyclic prefix reconstruction of the received TS are required to fully utilize the good autocorrelation property of the TS [7]

C. *Channel Equalization*

Soft-decision aided MMSE channel equalization with iterative ICI cancellation exploiting the extrinsicinformation from the soft-in soft-out (SISO) channel decoder is the widely used scheme with reliable equalization performance [23]. Here, we adopt the *0*(*N*)-complexity equalizer with the following procedure [24]:

D. *Initial MMSE symbol detection*: Using the MMSE detection criterion, the initial channel equalization is performed by

$$\hat{X}^{(0)}_{i,k} = \frac{Y_{i,k}\hat{G}^{*}_{i,k,k}}{\left|\hat{G}^{*}_{i,k,k}\right|^{2} + \sigma^{2}}, \quad k \notin \psi \qquad (5)$$

It should be pointed out that, although the iterative ICI removal based channel equalization above is used in TFTOFDM to remove the ICI over the fast fading channels, it is essentially different from the iterative IBI cancellation method in TDS-OFDM where both the channel estimation and channel equalization are involved and coupled together. If the channel can be assumed quasi-stationary during each TFTOFDM symbol, the iterative ICI removal is not necessary any more since no significant ICI will be introduced. However, even when the channel is static, TDS-OFDM still requires the iterative IBI cancellation, whereby channel estimation and channel equalization are iteratively involved to remove the IBIs as completely as possible.

IV. PERFORMANCE ANALYSIS OF TFT-OFDM

The system performances of the proposed TFT-OFDM scheme, including the spectral efficiency, pilot power and the corresponding SNR loss, the equivalent SNR loss due to the cyclic prefix reconstruction, the receiver performance over time-varying channels, and the receiver complexity, are analyzed in this section

TABLE: I
Spectral Efficiency Comparison [1]

TS Length	CP-OFDM	TDS-OFDM	DPN-OFDM	TFT-OFDM
K=N/4	60.00%	80.00%	66.67%	77.66%
K=N/8	77.78%	88.89%	80.00%	86.28%
K=N/16	88.23%	94.12%	88.89%	91.36%

A. *Spectral Efficiency*

One major merit of OFDM is its high spectral efficiency due to the orthogonality between the subcarriers although they are overlapped. The spectral efficiency is defined as the net bit rate over a certain signal bandwidth, i.e., the ideal OFDM system without guard interval or pilots has the spectral efficiency [25]

$$E_{ideal} = \frac{N\alpha / T}{N / T} = \alpha \quad (\text{bit /s / Hz}) \qquad (6)$$

where 2α denotes the constellation points of the modulation scheme, e.g., $\alpha = 4$ for 16QAM, $N\alpha/T$ stands for the net bit rate, and N/T is the signal bandwidth. However, both the time-domain guard interval and the frequency-domain pilots would reduce the actual spectral efficiency of the practical OFDM systems [25]. So the spectral efficiency of TFT-OFDM is

$$E_{real} = E_{ideal}\frac{N - N_p}{M + N} \quad (\text{bit /s / Hz}) \qquad (7)$$

When the same modulation scheme is taken into account, we define the *normalized spectral efficiency* in the form of percentage as below:

$$E_0 = \frac{E_{real}}{E_{ideal}} = \frac{N - (Q+1)(2d+1)S}{M + N} \times 100\% \qquad (8)$$

The key advantage of TDS-OFDM over CP-OFDM is the increased spectral efficiency since no pilot is used in TDSOFDM, but the IBIs between the TS and the OFDM data block deteriorate the system performance over fast fading channels. The DPN-OFDM solution can solve the performance loss problem, but the doubled TS length obviously reduces the spectral efficiency. Regarding to the TFT-OFDM scheme proposed in this paper, the TS has the same length as the guard interval in TDS-OFDM and CP-OFDM systems, while only N_p= 120 frequency-domain grouped pilots can be configured with some design margin. For digital broadcasting systems like DVB-T2 [19], typically N = 4096 (4K mode) is used (In Chinese national digital television standard [9], N = 3780 is adopted), which means that the grouped pilots only occupy less than 3% of the signal bandwidth. Table I shows the spectral efficiency comparison between CP-OFDM, TDS-OFDM, DPN-OFDM and the proposed TFTOFDM schemes.

TABLE: II
The SNR loss due to pilot power boosting [1]

Guard Interval Length	CP-OFDM	TFT-OFDM
K=N/4	0.77 dB	0.098 dB
K=N/8	0.40 dB	0.098 dB
K=N/16	0.21 dB	0.098 dB
K=N/32	0.10 dB	0.098 dB

B. *Pilot Power and the Corresponding SNR Loss*

In standard CP-OFDM systems, the power boosting technique [19] is commonly used to increase the average power of the pilots to achieve more reliable channel estimation, which leads to the equivalent SNR loss at the receiver

$$SNR_{loss} = 10\log_{10}\left(\frac{N_p E_p + (N - N_p)E_d}{NE_d}\right) \qquad (9)$$

where E*p* and E*d* denote the average power of the pilot and data, respectively. Such SNR loss is not negligible, especially when the pilot number is large in CP-OFDM. However, the proposed

TFT-OFDM scheme only requires a small amount of grouped pilots, so the SNR loss will be small. Table II compares the SNR loss in CP-OFDM and TFT-OFDM, where the case that E_p is 2.5 dB higher than E_d as specified by DVBT2 [19] is taken as an example. It can be found that the SNR loss in CP-OFDM is relative to the guard interval length, and 0.40 dB SNR loss will be introduced when $M = N/8$, while the negligible SNR loss in TFT-OFDM is 0.098 dB, which is independent of the guard interval length. Furthermore, if the same SNR loss is permitted in TFTOFDM as that in CP-OFDM, the pilot power in TFT-OFDM could be much higher than that in CP-OFDM. As shown in Table III, if the SNR loss of 0.40 dB is affordable when $M = N/8$, the boosted pilot power in TFT-OFDM could be 3.86 dB higher than that in CP-OFDM, which is beneficial for more accurate channel estimation. Due to the lower pilot occupation ratio in TFT-OFDM than CP-OFDM, the pilot power boosting technique is more efficient for more reliable channel estimation, e.g., the boosted pilot power from 2.5 dB to 3.0 dB in CP-OFDM is equivalent to the boosted pilot power from 6.36 dB to 7.20 dB in TFT-OFDM.

C. SNR Loss Due to Cyclic Prefix Reconstruction

The cyclic prefix reconstruction with the OLA method [4] would result in the noise enhancement effect caused by removing the “tail” of the OFDM data block to its head. Thus, similar to ZP-OFDM, TFT-OFDM also suffers from the SNR loss

$$SNR_{TFT,loss} = 10\log_{10}\left(\frac{M+N}{N}\right) \qquad (10)$$

When $M = N/8$, the SNR loss is 0.51 dB, and when $M = N/16$, the SNR loss is 0.26 dB. Similarly, the cyclic prefix reconstruction is also required in every iteration step in TDSOFDM, thus TDS-OFDM would sacrifice the SNR loss

$$SNR_{TDS,loss} = J.SNR_{TFT,loss} \qquad (11)$$

where J is the iteration number of the iterative IBI removal at the TDS-OFDM receiver. Since $J = 3$ is normally required in TDS-OFDM, the SNR loss in TFT-OFDM will be smaller than that in TDS-OFDM.

D. Receiver Performance over Time-Varying Channels

Compared with TDS-OFDM, TFT-OFDM could improve the receiver performance at the cost of marginally reduced spectral efficiency due to the small amount of the grouped pilots. When equalizing the OFDM data block between two adjacent TSs over fast fading channels, only the linear interpolation or other more complicated interpolation methods can be used to track the channel variation [26]. However, the proposed joint time-frequency channel estimation can accurately track the fast time-varying channel during the OFDM block by using the scattered pilots in the frequency domain. TDS-OFDM requires that the IBIs between the TS and OFDM block should be removed completely, leading to the mutually conditional relationship between channel estimation and channel equalization, and performance loss is unavoidable over fast fading channels. However, in TFT-OFDM, the joint time-frequency channel estimation is achieved by using the received “contaminated” TS without IBI cancellation and the frequency domain grouped pilots, so the channel estimation performance is independent of the channel equalization quality.

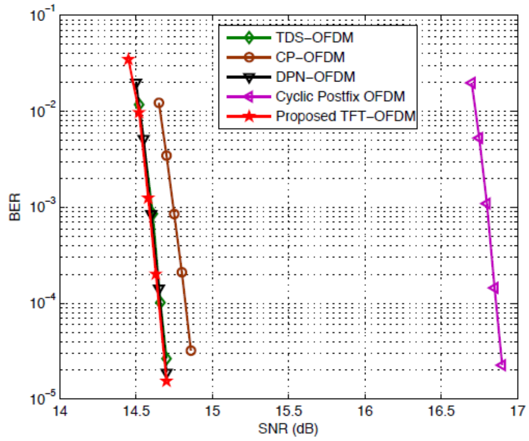

Figure 4: BER performance comparison between the proposed TFT-OFDM scheme and the traditional schemes over the AWGN channel[1]

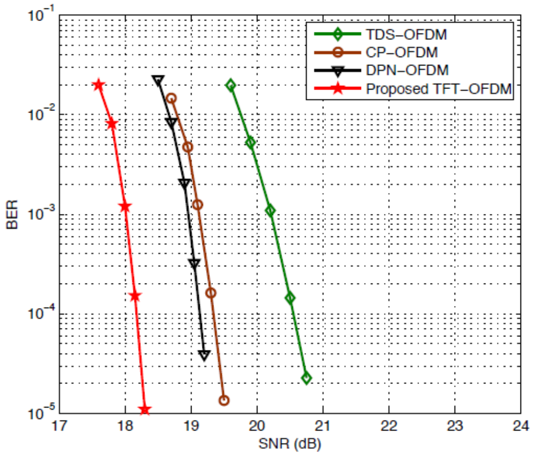

Figure 5: BER performance comparison between the proposed TFT-OFDM scheme and three traditional schemes over the Vehicular B channel with the receiver velocity of 28 km/h.[1]

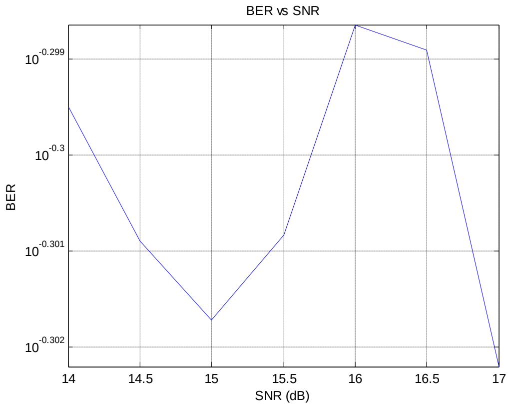

Figure 6: BER performance proposed new TFT-OFDM scheme.

V. SIMULATION RESULTS AND DISCUSSION

Simulations were carried out to investigate the performance of the proposed TFT-OFDM transmission scheme. The signal bandwidth was 7.56 MHz at the central radio frequency of 770 MHz, and the subcarrier spacing was 2 kHz. The modulation scheme 64QAM was adopted. Other system parameters were consistent with those specified as $N = 3780$, $M = 420$, $N_{group}= 40$, $Q = 1$, $d = 1$, $S = 20$, $J_0 = 3$. Based on the fact that now a days almost all OFDM based systems use channel coding for reliable performance, we adopted the powerful low-density parity-check (LDPC) code with the block length of 64, 8000 bits and code rate of 2/3 as specified by the standard [19]. The maximum Doppler spread of 20 Hz and 100 Hz were considered, which corresponded to the relative receiver velocity of 28 km/h and 140 km/h @ 770 MHz, respectively. In the simulations, we assumed M equally spaced combo type pilots were used in CP-OFDM, since it has been proved that such scheme could achieve the best channel estimation performance under static channels. The classical iterative algorithm in [7] was used for TDS-OFDM. DPN-OFDM adopted the receiver algorithm proposed in [15]. The cyclic postfix OFDM used the PN sequence as the unique word [13], and the channel estimation method in [12] was used. Figure 4 compares the coded bit error rate (BER) performance of the conventional CP-OFDM, TDS-OFDM, and cyclic postfix OFDM schemes with the proposed TFT-OFDM solution over the AWGN channel. The ideal channel estimation is assumed for all those systems. We can find that TFT-OFDM and TDS-OFDM have very close BER performance, and they have the SNR gain of 0.18 dB compared with CP-OFDM. The reason is that, the equivalent SNR at the receiver is reduced by the large amount of pilot with boosted power in CP-OFDM. Figure 5 compares the coded BER performance of TFT-OFDM with CP-OFDM, TDS-OFDM and DPN-OFDM over the Vehicular B channel with the receiver velocity of 28 km/h. The performance of CP-OFDM is between that of TDS-OFDM and DPN-OFDM, while the proposed TFT-OFDM scheme has superior BER performance to those three conventional OFDM transmission schemes. For example, when the BER equals to 10^{-4}, TFT-OFDM outperforms DPN-OFDM, CP-OFDM and TDS-OFDM by the SNR gain of 0.95 dB, 1.15 dB and 2.40 dB, respectively. Compared with DPN-OFDM, CP-OFDM and TDS-OFDM, the SNR gain achieved by TFT-OFDM is increased to be about 1.15 dB, 2.25 dB and 4.40 dB, respectively. Compared with CP-OFDM and DPN-OFDM, TFT-OFDM achieves the performance improvement because the proposed joint channel estimation can accurately track the channel variation, and ICI is removed before the frequency domain equalization. After reducing some pilot then again simulate data while given above and perform the BER analysis with SNR as Figure 6.

VI. CONCLUSIONS

This paper proposes a novel OFDM-based transmission scheme called TFT-OFDM, whereby the training information exists in both time and frequency domains. The corresponding joint time-frequency channel estimation utilizes the time domain TS without interference cancellation to estimate the channel path delays, while the channel path coefficients are acquired by using the pilot groups scattered within the OFDM symbol. The variation of the fast fading channels within every TFT-OFDM symbol can be well tracked. The iterative ICI removal method further improves the system performance. The grouped pilots in TFT-OFDM occupy only about less than 3% of the signal bandwidth. Therefore, high spectral efficiency as well as good performance over fast time-varying Channels could be simultaneously realized, which makes TFT-OFDM a promising physical layer transmission technique for BWC systems in high speed mobile environments.

REFERENCES

[1] D. linglong, Z.Wang and Z.Yang , “Time-Frequency Training OFDM with High Spectral Efficiency and Reliable Performance in High Speed Environments” IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 30, NO. 4,pp-695-707, MAY 2012.

[2] F. Adachi and E. Kudoh, “New direction of broadband wireless technology,” *Wirel. Commun. Mob. Com.*, vol. 7, no. 8, pp. 969–983, Oct. 2007.

[3] X. Yuan, Q. Guo, X. Wang, and L. Ping, “Evolution analysis of lowcost iterative equalization in coded linear systems with cyclic prefixes,” *IEEE J. Sel. Areas Commun.*, vol. 26, no. 2, pp. 301–310, Feb. 2008.

[4] B. Muquet, Z. Wang, G. Giannakis, M. De Courville, and P. Duhamel, “Cyclic prefixing or zero padding for wireless multicarrier transmissions?” *IEEE Trans. Commun.*, vol. 50, no. 12, pp. 2136–2148, Dec. 2002.

[5] C. yen Ong, J. Song, C. Pan, and Y. Li, “Technology and standards of digital television terrestrial multimedia broadcasting,” *IEEE Commun.Mag.*, vol. 48, no. 5, pp. 119–127, May 2010.

[6] X. Wang, P. Ho, and Y. Wu, “Robust channel estimation and ISI cancellation for OFDM systems with suppressed features,” *IEEE J. Sel.Areas Commun.*, vol. 23, no. 5, pp. 963–972, May 2005.

[7] J. Wang, Z. Yang, C. Pan, and J. Song, “Iterative padding subtraction of the PN sequence for the TDS-OFDM over broadcast channels,” *IEEETrans. Consum. Electron.*, vol. 51, no. 11, pp. 1148–1152, Nov. 2005.

[8] J. Song, Z. Yang, L. Yang, K. Gong, C. Pan, J. Wang, and Y. Wu, “Technical review on Chinese digital terrestrial television broadcasting standard and measurements on some working modes,” *IEEE Trans.Broadcast.*, vol. 53, no. 1, pp. 1–7, Feb. 2007.

[9] *Framing Structure, Channel Coding and Modulation for Digital Television Terrestrial Broadcasting System*. Chinese National Standard, GB20600-2006, Aug. 2006.

[10] J. Kim, S. Lee, and J. Seo, “Synchronization and channel estimation in cyclic postfix based OFDM system,” in *Proc. IEEE 63rd VehicularTechnology Conference (VTC’06-Spring)*, Melbourne, Vic, May 2006, pp. 2028–2032.

[11] , “Synchronization and channel estimation in cyclic postfix based OFDM system,” *IEICE Trans. Commun.*, vol. E90-B, no. 3, pp. 485– 490, Mar. 2007.

[12] S. Tang, K. Peng, K. Gong, and Z. Yang, “Channel estimation for cyclic postfixed OFDM,” in *Proc. International Conference on Communications,Circuits and Systems (ICCCAS’08)*, Fujian, China, May 2008, pp.
246–249.

[13] M. Huemer, C. Hofbauer, and J. Huber, “Unique word prefix in SC/FDE and OFDM: A comparison,” in *Proc. IEEE Global TelecommunicationsConference (GLOBECOM’10)*, Miami, USA, Dec. 2010, pp. 1321– 1326.

[14] A. Onic and M. Huemer, “Direct vs. two-step approach for unique word generation in UW-OFDM,” in *Proc. the 15th International OFDMWorkshop(InOWo’10)*, Los Alamitos, CA, Sep. 2010, pp. 145–149.

[15] J. Fu, J. Wang, J. Song, C. Pan, and Z. Yang, “A simplified equalization method for dual PN-sequence padding TDS-OFDM systems,” *IEEETrans. Broadcast.*, vol. 54, no. 4, pp. 825–830, Dec. 2008.

[16] L. Bomer and M. Antweiler, “Perfect N-phase sequences and arrays,” *IEEE J. Sel. Areas Commun.*, vol. 10, no. 4, pp. 782–789, May 1992.

[17] A. V. Oppenheim, R. Schafer, and J. Buck, *Discrete-Time Signal Processing, 4th ed.* NJ, USA: Prentice Hall, 2010.
[18] L. Dai, Z. Wang, C. Pan, and S. Chen, “Positioning in Chinese digital television network using TDS-OFDM signals,” in *Proc. IEEEInternational Conference on Communications (ICC’11)*, Kyoto, Japan, Jun. 2011, pp. 1–5.
[19] *Frame Structure, Channel Coding and Modulation for a Second Generation Digital Terrestrial Television Broadcasting System (DVB-T2)*.ETSI Standard, EN 302 755, V1.1.1, Sep. 2009.
[20] X. Wang, H. Li, and H. Lin, “A new adaptive OFDM system with precoded cyclic prefix for dynamic cognitive radio communications,” *IEEE J. Sel. Areas Commun.*, vol. 29, no. 2, pp. 431–442, Feb. 2011.
[21] W. Song and J. Lim, “Channel estimation and signal detection for MIMO-OFDM with time varying channels,” *IEEE Commun. Lett.*, vol. 10, no. 7, pp. 540–542, Jul. 2006.
[22] W. Jeon, K. Chang, and Y. Cho, “An equalization technique for orthogonal frequency-division multiplexing systems in time-variant multipath channels,” *IEEE Trans. Commun.*, vol. 47, no. 1, pp. 27–32, Jan. 1999.
[23] P. Schniter, “Low-complexity equalization of OFDM in doubly-selective channels,” *IEEE Trans. Signal Process.*, vol. 52, no. 4, pp. 100–1011, Apr. 2004.
[24] V. Namboodiri, H. Liu, and P. Spasojevi`c, “Low complexity turbo equalization for mobile OFDM systems with application to DVB-H,” in *Proc. IEEE Global Telecommunications Conference (GLOBECOM’10)*, Miami, USA, Dec. 2010, pp. 1328–1333.
[25] X. Wang, Y. Wu, J. Chouinard, and H. Wu, “On the design and performance analysis of multisymbol encapsulated OFDM systems,” *IEEE Trans. Veh. Technol.*, vol. 55, no. 3, pp. 990–1002, May 2006.
[26] X. Dong, W.-S. Lu, and A. Soong, “Linear interpolation in pilot symbol assisted channel estimation for OFDM,” *IEEE Trans. Wireless Commun.*, vol. 6, no. 5, pp. 1910–1920, May 2007.

AUTHOR

Shailu Jain
M.Tech, IV sem
Electronics and Communication Department
Lakshmi Narain College Of Technology and Science Bhopal,
M.P. India)
Email:shailu_jain30@yahoo.com)