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INCREASED SPECTRAL EFFICIENCY AND RELIABLE PERFORMANCE OF TIME FREQUENCY TRAINING OFDM USING MIMO TECHNIQUE

Ayappasamy K1, Venkatesh P2, Prakash S3 and Shanmuga priyan R4

1234Department of Electronics and Communication Engineering,
1234Dr. S.J.S. Paul Memorial College of Engineering and Technology, Puducherry - 605 502, India
1ayappasamypec@gmail.com,2venkeeeys@gmail.com, 3sprsuccess1511@gmail.com, 4shanfrndforu@gmail.com

ABSTRACT

In this paper, the high spectral efficiency of a transmission scheme called Time frequency training (TFT) Orthogonal frequency division multiplexing (OFDM) using MIMO system is proposed. The time frequency joint channel estimation for TFT-OFDM utilizes the time-domain training sequence without interference cancellation to merely acquire the time delay profile of the channel, while the path coefficients are estimated by using the frequency-domain group pilots. The redundant group pilots only occupy about 1% of the useful subcarriers, thus TFT-OFDM still has much higher spectral efficiency than Cyclic prefix OFDM (CP-OFDM) by about 10% and by extending it using Multiple Input Multiple Output (MIMO) which produce much higher spectral efficiency than TFT-OFDM. Simulation results also demonstrate that TFT-OFDM using MIMO gives better performance than CP-OFDM and TFT-OFDM over time-varying channels.

Keywords:

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

1 INTRODUCTION

THE broadly used CP-OFDM scheme utilizes the cyclic prefix to eliminate the Inter-Block Interference (IBI) as well as the Inter-Carrier Interference (ICI). The Cyclic prefix is replaced by zero samples in Zero Padding OFDM (ZP-OFDM) to deal with the channel null problem and improve the equalization performance.

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 cyclic prefix, the known training sequence such as the pseudorandom noise sequence, is used as the guard interval in the Time Domain Synchronous OFDM (TDS-OFDM) scheme in [1]. Since the training sequence is known to the receiver, it can be also used for synchronization as well as channel estimation. Consequently, the large amount of frequency domain pilots used in the CP-OFDM and ZP-OFDM could be saved. Thus, TDS-OFDM outperforms CP-OFDM and ZP-OFDM in spectral efficiency by about 10%. As the key technology, TDS-OFDM has been successfully adopted by Chinese national digital television standard, whose performance has been extensively investigated and verified in China, Hong Kong, South America, etc.

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. Therefore, channel estimation and channel equalization are mutually conditional in TDS-OFDM, and the iterative interference cancellation algorithm would suffer from high complexity as well as poor performance over fast fading channels.

In addition, the inserted redundant pilots have much higher average power than the normal OFDM data, 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 but the effect is not obvious.

After down conversion and analog to digital conversion, the Fast Fourier Transform (FFT) is used to demodulate the N subcarriers of the OFDM signal. For each symbol, the FFT output contains N Quadrature Aptitude Modulation (QAM) values. However, these values contain random phase shifts and amplitude variations caused by the channel response, local oscillator drift, and timing offset. It is the task of the channel estimation block to learn the reference phases and amplitudes for all subcarriers, such that the QAM symbols can be converted to binary soft decisions in [3].

The most effective solution to the interference problem of TDS-OFDM is to duplicate the training sequence twice, resulting in the Dual-Pseudo Noise OFDM (DPN-OFDM) scheme. 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 and subtraction operation. 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 training sequence. Therefore, to achieve high spectral efficiency and good performance over fast fading channels at the same time is really challenging for the currently available OFDM-based transmission schemes, CP-OFDM, ZP-OFDM, TDS-OFDM, cyclic postfix OFDM and DPN OFDM in [1].

The main drawback of above techniques is that, the time domain training sequence 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 i.e., the IBI from the OFDM data block to the training sequence must be eliminated before the training sequence based time domain channel estimation, while the IBI caused by the training sequence to the OFDM data has to be removed to achieve reliable channel equalization.

2 TFT- OFDM SYSTEM MODEL

The Inter Block Interference (IBI) from the training sequence to the OFDM data block and the IBI caused by the OFDM block to the training sequence have distinct features in TDS-OFDM. The interference caused by the training sequence can be completely removed if the channel estimation is perfect, since the training sequence is known at the receiver. In addition, this IBI can be calculated with relatively low complexity since the training sequence 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 cannot 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.

Therefore, the training sequence 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 training sequence, which would deteriorate the OFDM equalization performance in the next iteration. Consequently, the performance loss is unavoidable.

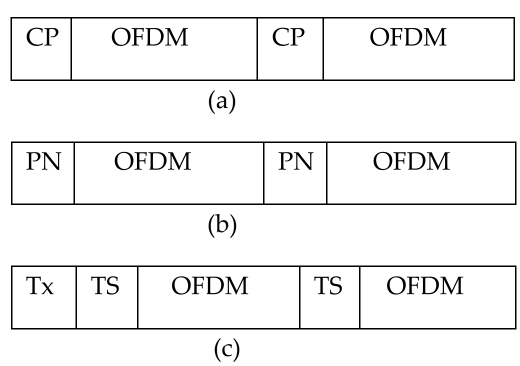


Fig.1. Signal structure comparison between (a) CP-OFDM (b) TDS-OFDM (c) TFT-OFDM.

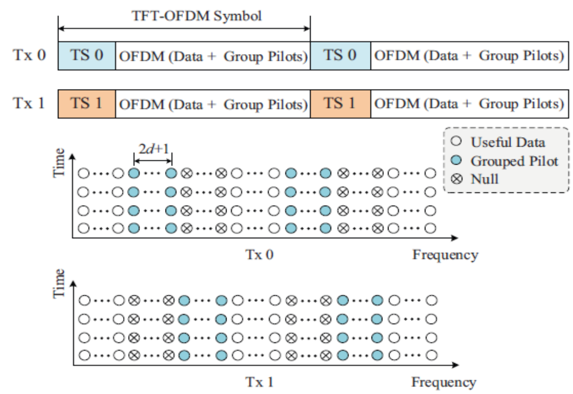
In the TFT-OFDM scheme, unlike the conventional method where both the channel path delays and the channel path coefficients are estimated by using the clean received after IBI cancellation, it do not remove the IBI imposed on the training sequence, but directly use the contaminated without IBI cancellation 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 in [1].

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 3% of the total subcarriers in the proposed TFT-OFDM solution. Since the single carrier training sequence occupies the whole signal bandwidth of the OFDM data block, it is known that extending TDS-OFDM to MIMO applications is difficult due to much more complicated time domain interference than that in the single antenna TDS-OFDM system.

In the space time shifted training sequence is proposed to achieve transmit diversity for TDS-OFDM systems, but the system overhead is obviously increased, leading to the inevitable decrease in spectral efficiency. On the other hand, CP-OFDM can be easily extended to MIMO systems by adopting orthogonal pilots, at the high cost of the linearly increased pilot number with respect to the transmit antenna number.

3 TFT- OFDM USING MIMO RECEIVER DESIGN

This system provides a very promising means to increase the spectral efficiency. Equipped with space time block encoding in the transmitter and applied the intelligent signal processing at the receiver, MIMO systems can provide diversity and coding gains over single antenna system. The Orthogonal Frequency Division Multiplexing (OFDM) technique has been widely adopted for high speed wireless communications, due to its robustness of multi-path propagation.



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At the receiver end, by removing the added redundant sequence the effect of Inter Channel Interference (ICI) could be alleviated, effectively. The Pseudo Random Process OFDM (PRP-OFDM) system with single antenna was extended to the Multiple Input Multiple Output (MIMO) case, by encoding the transmitted signal and postfixes vectors with two different space time encoder, and is referred as the Multiple Input Multiple Output OFDM (MIMO-OFDM) systems.

In order to determine the minimum pilot spacing in time and frequency, we need to find the bandwidth of the channel variation in time and frequency, these bandwidths are equal to the Doppler spread in the time domain and the maximum delay spread maximum in the frequency domain. Hence, the requirements for the pilot spacing in time and frequency in [4]. These simple equations can be used to estimate the theoretical limits of the standard. In terms of Doppler Effect, and considering that the pilot signals are transmitted continuously, the pilot spacing in time is not a limitation.

The spacing in frequency imposes a limit to the delay spread. The pilot signals are the subcarriers number -21, -7, 7 and 21. This means that the spacing between pilots is 4.375 MHz (21×0.3125 MHz). In these conditions, the maximum delay spread maximum to be allowed is 228 sec. In the literature, there are several algorithms to estimate the OFDM channel the one explained. This algorithm can be used with the parameters indicated by the standard. According to it, the pilots must be BPSK modulated by a pseudo binary sequence to prevent the generation of spectral lines.

4 SPECTRAL EFFICIENCY OF TFT-OFDM USING MIMO

4.1 Spectral efficiency

It is defined as the ratio of net bit rate to signal bandwidth.

(1)

= (bits/s/Hz)

i.e., = 4 for 16QAM

TABLE I

PARAMETERS USED IN TFT-OFDM

No. of Subcarriers	64
Coding used	Convolution coding
Single frame size	96 bits
Total no. of frames	100
No. of pilots	4
Cyclic extension	25 %
Modulation	16-QAM

4.2 Spectral efficiency of TFT-OFDM

The spectral efficiency of TFT-OFDM was calculated by the following,

(2)

Where,

Np - Frequency domain grouped pilots

N - Length of OFDM data block

M - Length of training sequence

Eideal = 4(bits/sec/Hz)

(3)

The frequency domain grouped pilots is Np = 120. And the length of OFDM data block is N = 4096 (4K Mode). By taking M = N/8, the obtained value is M = 512. The value of *Ereal* is 3.4512. So, the spectral efficiency is calculated by

(4)

.

The Spectral efficiency of TFT-OFDM is,

Eo = 86.28%

The spectral efficiency of TFT-OFDM using MIMO is calculated by

(5)

Where, L is the number of resolvable path, Q is doppler spread in the fading channel and d is the length of each data block. So the value of *Eo* is

Eo=88.10%

So, the proposed TFT-OFDM using MIMO has spectral efficiency of about 10% greater than CP-OFDM and 2% greater than TFT-OFDM.

5 SIMULATION RESULTS AND DISCUSSION

5.1 BER Performance of OFDM

Simulations were carried out to investigate the performance of the proposed TFT-OFDM using Multiple input multiple output (MIMO). In CP-OFDM , the comb type pilots were used for the least square channel estimation, and then discrete Fourier interpolation is used [1]. The Fig. 2. shows the Bit error performance for OFDM. We can observe the TFT-OFDM has superior BER performance over conventional OFDM transmission scheme. In this the SNR value is 14 dB at 10^{-4} Bit Error Rate. The spectral efficiency can be increased by extending Multiple input multiple output (MIMO) in Time frequency training OFDM by eliminating cross-correlation or have ideal autocorrelation for accurate time domain channel estimation.

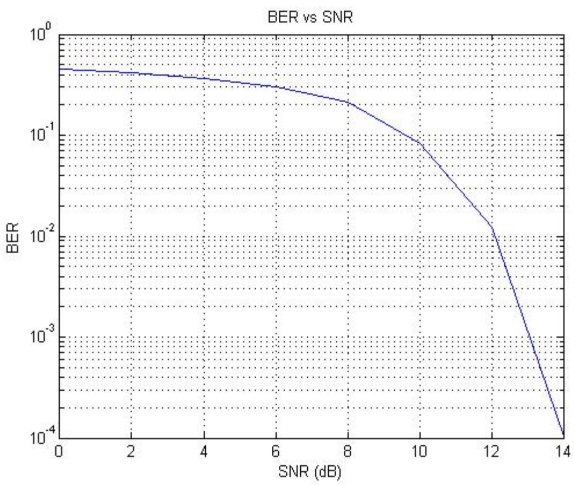

Fig. 2. BER Performance of OFDM

5.2 Spectral Efficiency Response for Existing Techniques at K=N/8

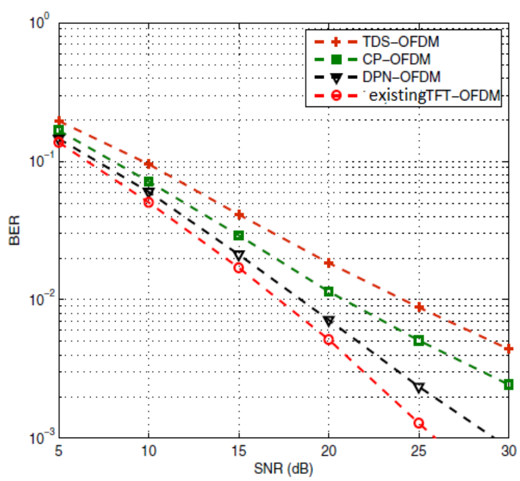

Fig. 3. Spectral Efficiency Comparison for Existing Model at K=N/8.

Fig. 3. shows that the spectral efficiency comparison for the existing CP–OFDM,TDS-OFDM. The CP-OFDM can be easily extended to systems by adopting orthogonal pilots, at the high cost of the linearly increased pilot number with respect to the transmit antenna number. However, without the obvious increase in the overhead, the proposed TFT-OFDM can be easily adapted configuring quasi-orthogonal time domain training sequence each transmit antenna, and using orthogonal pilots in the frequency domain. The residual IBI will not seriously affect the training sequence based channel path delay estimation. And the training sequence among different transmit antennas in TFT-OFDM system need not have perfect cross correlation to eliminate the mutual interferences or have ideal autocorrelation for accurate time domain channel estimation. Therefore, the training sequence in TFT-OFDM can be designed more easily than those in TDS-OFDM. More importantly, TFT-OFDM has much higher spectral efficiency than CP-OFDM.

By taking N = 4096, M = N/8, Np = 120, NT = 4 as an example, we can find that 50% of the used subcarriers would be occupied by the pilots in CP-OFDM, while the grouped pilots in TFT-OFDM take up only 11.72% of the signal bandwidth.

The existing TFT-OFDM has SNR value of 25 dB at 10^{-3} Bit Error Rate when training sequence K= N/8.

5.3 Spectral Efficiency Response for Existing Techniques at K= N/16

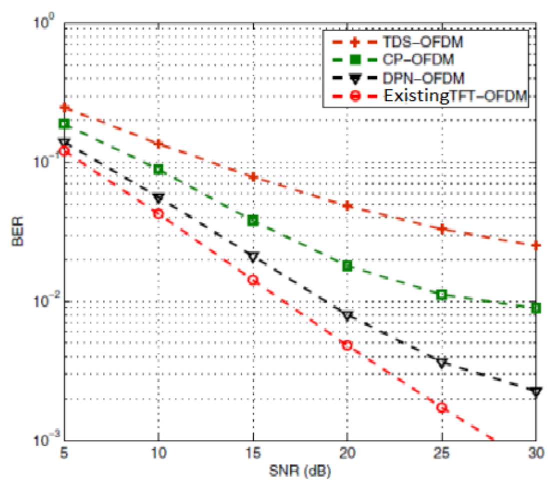

Fig. 4. Spectral Efficiency Comparison for Existing Model at K= N/16

The Spectral Efficiency of existing technique when training sequence K= N/16 is shown in Fig. 4. The TFT-OFDM has SNR value is nearly 28 dB at 10^{-3} Bit Error Rate.

5.4 Proposed TFT-OFDM Technique

The Spectral efficiency comparison response for existing CP-OFDM, TDS-OFDM and the proposed TFT-OFDM is shown in Fig. 5. In the TFT-OFDM scheme the addition of training sequence is increased the Bit Error Rate performance and also the null nodes are added in between data and pilot nodes. The adapted time domain training sequence and large number of grouped pilots in frequency domain increased the performance of the TFT-OFDM.

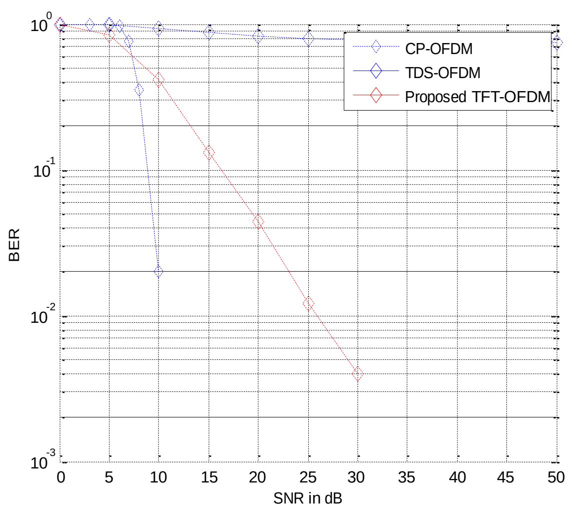

Fig. 5. Proposed TFT-OFDM technique compared with other techniques

Therefore, the spectral efficiency of the TFT-OFDM has the SNR value of 30 dB at 10^{-3} Bit Error Rate. So, it is shown that the TFT-OFDM with addition of null nodes in between data and pilot nodes is giving better bit error performance than other techniques.

5.5 Spectral efficiency response of proposed TFT-OFDM using MIMO technique

The spectral efficiency of proposed TFT-OFDM using MIMO has SNR value of 40dB at 10^{-3} Bit Error Rate. And the training sequence among different transmit antennas in TFT-OFDM system need not have perfect cross correlation to eliminate the mutual interferences or have ideal autocorrelation for accurate time domain channel estimation. The transmitting antenna is placed before every data block. So it is shown that extending TFT-OFDM using MIMO produce much higher spectral efficiency and performance than TFT-OFDM.

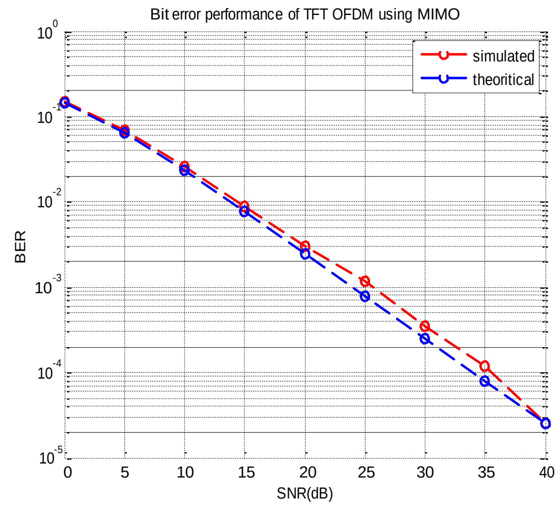

Fig.6. BER performance of TFT-OFDM using MIMO

5.6 Comparison of spectral efficiency reduction techniques

The spectral efficiency of CP-OFDM, TDS-OFDM, TFT-OFDM and proposed TFT-OFDM using MIMO is listed in Table II. Among this the proposed TFT-OFDM using MIMO with addition of null nodes gives better spectral efficiency of 96.23% at training sequence (K= N/16) where, N is the length of OFDM data block.

TABLE II

Comparison of Spectral Efficiency Reduction Techniques

TRAINING SEQUENCE LENGTH	CP-OFDM	TDS-OFDM	TFT-OFDM	PROPOSED TFT-OFDM using MIMO
K=N/4	60.00%	66.67%	80.00%	81.17%
K=N/8	77.78%	80.00%	86.24%	88.11%
K=N/16	88.23%	88.89%	94.12%	96.23%

6 Conclusion

In this paper the proposed OFDM-based transmission scheme called TFT-OFDM using MIMO, whereby the training information exists in both time and frequency domains and a transmitting antenna is placed before every OFDM data block. The corresponding joint time frequency channel estimation utilizes the time domain training sequence without interference cancellation to estimate the channel path delays. So, the spectral efficiency of the TFT-OFDM using MIMO is increased simultaneously.

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Ayappasamy K received the B.tech and M.tech degree in Electronics and Communication Engineering from Pondicherry University, Puducherry, India in 2007 and 2011 respectively.

Presently he is working as Assistant Professor in Dr. S. J. S. Paul Memorial college of Engineering and Techology, Puducherry, India. His Area of Interests are OFDM and Digital Signal Processing. He has published papers in International Conference in NIT's and Engineering colleges.

Venkatesh P pursuing his B.Tech degree in Electronics and Communication Engineering in Dr. S. J. S. Paul Memorial College of Engineering and Technology, Puducherry, India. His Area of Interests are OFDM and WiMax networks.

Prakash S pursuing his B.Tech degree in Electronics and Communication Engineering in Dr. S. J. S. Paul Memorial College of Engineering and Technology, Puducherry, India. His Area of Interests are in OFDM and cryptography.

Shanmuga Priyan R pursuing his B.Tech degree in Electronics and Communication Engineering in Dr. S. J. S. Paul Memorial College of Engineering and Technology, Puducherry, India.

His Area of Interests are OFDM and Digital Signal Processing.