Compressive Sensing based channel estimation for TFT-OFDM system

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Abstract- *Channel estimation is one of the big challenge, ever since high resolution channel estimation can significantly improve the equalization at the receiver and consequently enhance the communication quality. Since TDS-OFDM performance suffer from fading channels with long delays and has issue supporting high order modulations like 256 QAM, which cannot accommodate the emerging ultra high definition TV services . The major challenging task in multiple input multiple output (MIMO)OFDM systems is to design a good channel estimation method with less computational complexity and lower value of bit error rate (BER). To overcome the problem in OFDM a high accurate , low complexity compressive sensing based channel estimation method in CS-OFDM is proposed . Compressive sensing (CS) based channel estimation namely Auxiliary information based Subspace Pursuit(ASP) in TFT-OFDM systems gives high accuracy and lower complexity .This channel estimation method is based on two steps. Firstly by using time domain training sequence(TS) path delay can be estimated . Then secondly by using a small amount of frequency domain pilots inserted into the OFDM data block channel cab be perfectly estimated . The auxiliary information obtained in the first step are used to reduce the complexity of classical SP algorithms and also reduce the number of pilots require for channel estimation . Simulation results shows that proposed ASP algorithm outperforms the conventional DPN-OFDM and TDS-OFDM schemes .Also the proposed algorithm gives lower BER ,high speed , high reliability for both local and long distance telephony services , and supports high order modulation like 256 QAM.*

Keywords: Channel Estimation(CE); Compressive Sensing(CE); Orthogonal Frequency Division Multiplexing(OFDM); Signal to Noise Ratio(SNR); Time Frequency Training OFDM(TFT-OFDM);Auxiliary Information Based Subspace Pursuit (ASP).

I. INTRODUCTION

Orthogonal Frequency Divison Multiplexing (OFDM)is an emerging technology for high data rates. OFDM is a form of multi-carrier transmission technique and is suited for high data rates . The basic principle of OFDM is to split a high data rate streams into a number of lower data rate streams and then transmitted these streams in parallel using several orthogonal sub-carriers.Due to this parallel transmission the symbol duration increases thus decreases the relative amount of dispersion in time caused by multipath delay spread . OFDM is widely used in high speed broad band wireless communications because of its great immunity to fast fading channels and inter-symbol interference (ISI).It has been adopted in several wireless standards such as digital audio broadcasting,digital video broadcasting, the wireless local area network , IEEE 802.11a and IEEE802.16 a .In the OFDM system channel estimation is important to obtain the channel state information (CSI) for reducing the bit error speed.In wireless communications the signal goes through a medium called channel and the signal gets distorted or various noises is added to the signal while the signal goes through the channel . To properly decode the received signal without much error are to remove the distortion and noise applied by the channel from the received signal .To do this first step is to figure out the characteristics of the channel that the signal has gone through . The techniques to characterised the channel is called channel estimation.

The channel estimation process in OFDM system is broadly divided into various types such as training symbol based channel estimation, DFT based channel estimation , Decision direct channel estimation and other advance channel estimation techniques.Pilot symbol which is inserted in the data signals are of different types which are block type ,comb type and lattice type.In block type pilot estimation pilots are inserted into all frequency bins within the periodic intervals of OFDM blocks.And in comb type pilot estimation pilots are inserted into each OFDM symbol with a specific period of frequency.

Recently compressed sensing based channel estimation is introduced which allows the efficient rebuilding of sparse signals from very limited number of measurements. This technique has gained much attention in the applied mathematics and signal processing communities.It has been applied in various areas such as imaging , radar , speech recognition and data acquisition.In coventional method channel estimation is not capable to use the inherent sparsity of transmission channel which is by the reason of the sparse distribution of scatters in space . CS provides a constructive way for exploiting this lack in order to less the number of pilots and hence increases spectral efficiency. In referenced paper the work is done on SP algorithms in compressed sensing for channel estimation which is more complex and QAM used is not of higher value . In this paper the proposed channel estimation is based on A-SP algorithms along with 256 QAM technique which achieves better data rate and is less complex.

II. System model

CS-OFDM is similar to conventional OFDM. In CS-OFDM , the modulated symbols are processed block by block. Assume that there are N=LM modulated symbols in one block. Different from conventional OFDM, CS-OFDM further divides the length N block into vector block (VB) , where each VB has size M. Instead of doing IFFT of size N as in conventional OFDM, CS-OFDM does component wise vector IFFT of size over the vector block (VB). The IFFT size is reduced from N to L by M times. This IFFT size reduction also reduces the PAPR. It has the merit of low PAPR and cost reduction for transceiver architecture.

The block diagram of CS-OFDM transmission system is shown in figure 1. Basically CS-OFDM block contains serial to parallel buffer , data scrambler, data mapper and compressive sensing encoder blocks in transmitter side and parallel to serial buffer , data descrambler , data demapper and compressive sensing decoder in receiver side. At the transmitter side the input data is converted into parallel. Here we consider number of sub-carriers data , which is scrambled to remove sensitive data from the input signal. Scrambled data is encoded and mapped by data mapper block. The pilots are inserted into data subcarriers at regular intervals in order to avoid the inter symbol interference (ISI) due to multipath delay spread. After performing N-point Inverse Fast Fourier Transform(IFFT) , the symbols are transmitted . At the receiver side, the received data are passed to Fast Fourier Transform (FFT) block. Then the received symbols are extracted by channel estimator which estimates the channel frequency response and delay spread parameters.

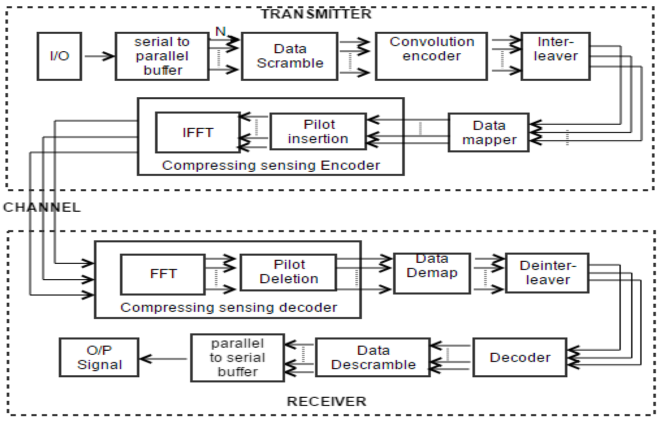

Figure1 : Block diagram of Compressive Sensing Orthogonal Frequency Division Multiplexing (CS-OFDM)

III. Basic Description of conventional schemes

In time domain synchronous orthogonal frequency divison multiplexing (TDS-OFDM) distinguishes the standard cyclic prefix OFDM by replacing CP with the prior known pseudorandom noise (PN) sequence as the guard interval(GI). The PN sequence can also work as the training sequence (TS) for both synchronisation and channel estimation (CE) at the receiver side which saves a large amount of frequency domain pilots commonly used in CP-OFDM. TDS-OFDM usually has higher spectral efficiency under the same condition .Additionaly faster and reliable synchronization could be also achieved by TDS-OFDM . Below given figure2 shows the system model for TDS-OFDM .

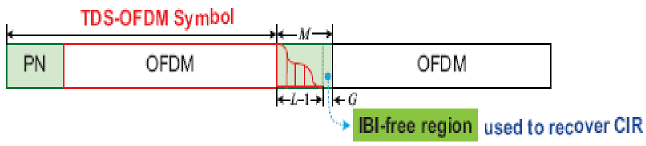

Figure2 System model for TDS-OFDM

In above figure 2 the system model for TDS-OFDM scheme utilizes the IBI free region of size G within the received PN sequence for CE but the maximum channel length s limited to L=M-G+1, where M is the length of the PN sequence. When the channel length L becomes larger , the size of the required IBI free region becomes smaller which leads to severe performance deterioration due to the reduced number of observations.

However the main drawback of TDS-OFDM is that the TS and the OFDM block will cause mutual inter block interfernce (IBI) to each OFDM block . The problem of TDS-OFDM under severly fading channels is difficult for the iterative algorithm to perfectly remove the IBI when the maximum channel spread is large which is common in the single frequency network (SFN) environment . It will cause the degradation of the whole system performance and the difficulty to support the high order modulations like 256 QAM to accommodate the emerging ultra-high definition television (UHDTV) service requirement.

In DPN-OFDM dual PN is added in OFDM where the PN sequence is duplicated twice to make the second PN sequence immune from the IBI caused by the preceding performance .Dual pseudo noise sequence OFDM (DPN-OFDM) is a scheme which is used to reduce performance degradation in severly fading channels and for effective channel estimation . In DPN-OFDM scheme an extra PN sequence is inserted to prevent the second PN sequence from being contaminated by the preceding OFDM data block . Below figure 3 shows the system model of DPN-OFDM.

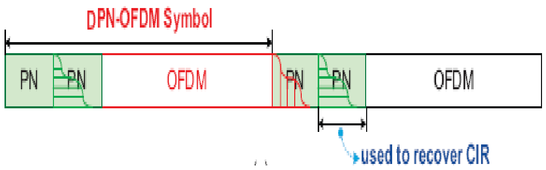

Figure3 System model for DPN-OFDM

There are some disadvantages in DPN-OFDM such as reduction of spectral efficiency due to doubled the length of PN sequence.

Both TDS-OFDM and DPN-OFDM have some disadvantages which is reduced by using TFT-OFDM.

IV PROPOSED MODEL AND CHANNEL ESTIMATION

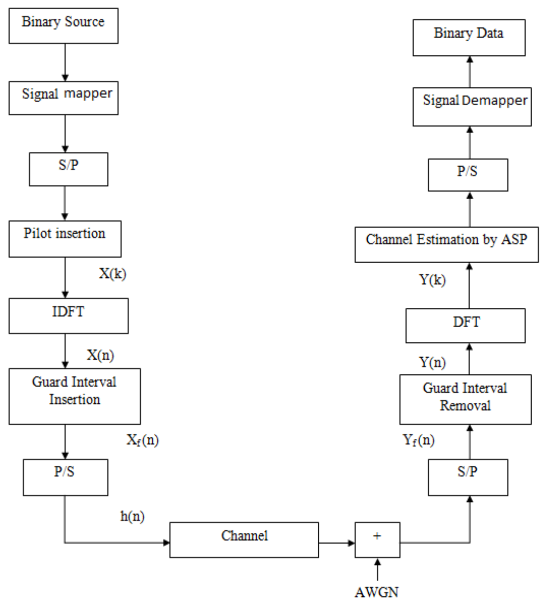

Figure4 Proposed system flow diagram

Implementation of Compressive Sensing Orthogonal Frequency Divison Multiplexing (CS-OFDM) is carried out in above firgure 4 the binary signal is moves towards signal mapper where the bits are mapped to symbols of either 16 QAM or 256 QAM . The data is then converted to parallel form . The number of subcarriers are N, and the bandwidth of each subcarrier 1/NT. Consider P subcarrier in N subcarrier OFDM system as pilots , these are inserted into data subcarriers at regular intervals. In order to avoid the intersymbol interference (ISI) due to multipath delay spread , a cyclic prefix (CP) of length equal or greater than the maximum expected time delay of the channel is inserted in each OFDM symbol prior to the transmission . The bandwidth of the system and the length of the cyclic prefix are all important parameters in the design of an OFDM system . In proposed system we consider number of subcarriers data, which is scrambled to remove sensitive data from the input signal . Scrambled data is encoded and mapped by data mapper block. After performing N-point Inverse Discrete Fourier Transform the symbols are transmitted and also again converted to serial form. Then the message signal is moves towards the channel where AWGN is connected after that the signal is again converted to parallel form than the guard interval is removed. At the receiver side , the received data are passed to Discrete Fourier Transform block. Then the received symbols are extracted by channel estimator which estimates the channel frequency response and delay spread parameters. In proposed system A-SP channel estimator is used for channel estimation .After moving from channel estimator the signal is again converted to parallel form then to signal demapper the signal converted to original form and we get the binary output in the same way which is send from the input side.

The proposed CS based ASP channel estimation method firstly utilizes the PN based correlation in the time domain to obtain the auxiliary channel information. Then the frequency domain pilots are use for exact CIR estimation which will results in performance degradation under severely fading channels. In TFT-OFDM system both time and frequency domain pilots are used for channel estimation.

The signal structure of the TFT-OFDM scheme is both in Time and Frequency domain.In time domain the i^{th} 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

$$\mathbf{s}_i = \begin{bmatrix} \mathbf{c}_i \\ \mathbf{x}_i \end{bmatrix}_{P\times 1} = \begin{bmatrix} \mathbf{I}_M \\ \mathbf{0}_{N\times M} \end{bmatrix}_{P\times M} \mathbf{c}_i + \begin{bmatrix} \mathbf{0}_{M\times N} \\ \mathbf{I}_N \end{bmatrix}_{P\times N} \mathbf{F}_N^H \mathbf{X}_i, \quad (1)$$

Where M 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 above two domain. TS with any length has perfect circular autocorrelation property.

Proposed TFT OFDM Frame Structure

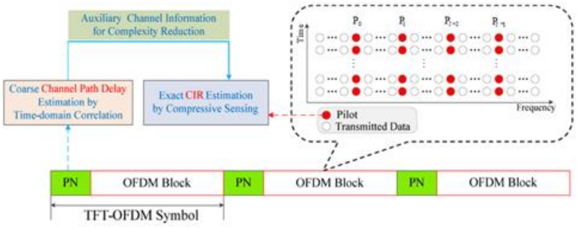

Fig.5 Proposed frame structure and the corresponding CS-based Channel Estimation for the TFT-OFDM scheme

Figure 5 shows that TFT OFDM has training information in both time and frequency domains . For every TFT OFDM symbol that is the time domain and frequency domain pilots scattered over the signal bandwidth are used .

Although the frequency domain pilots are very common in CP-OFDM systems , the grouped pilots in TFT-OFDM systems are different from the block type pilots or the comb type pilots used in most CP-OFDM systems. The second generation digital terrestrial broadcasting system (DVB-T2) and the next generation mobile wireless system called the Long Term Evolution (LTE), TFT-OFDM requires much less pilots than CP-OFDM.

ASP Based channel Estimation

The proposed ASP channel estimation method firstly utilises the PN based correlation in time domain to obtain the auxiliary channel information .Then the frequency domain pilots are used for exact CIR estimation.

The ASP based procedure for channel estimation is divided into four steps.

(1) PN based path delay estimation
(2) Cyclicity reconstruction of the OFDM block
(3) Exact estimation using ASP.
(4) Maximum likelihood estimation.

(1) PN based delay estimation : In this step the received PN sequence d is directly correlated with input PN sequence to acquire coarse channel estimate. Although the coarse path delay estimation is not accurate due to the existence of inter block interference (IBI) the good autocorrelation property of the PN sequence ensures that the auxiliary channel information is necessary for ASP algorithm.

(2) Cyclicity reconstruction of OFDM block: The cyclicity reconstruction of the OFDM block is achieved by subtracting the IBI caused by the PN sequence from the received OFDM block. Then adding the received PN sequence and finally subtracting linear convolution outputs between the PN sequence and the channel is obtained by computing the linear convolution between the input sequence and the estimated CIR obtained in the preceding OFDM data block. In the received PN it contains not only the useful part but it also contains useless part which is the IBI region which should be removed before estimation in the current OFDM block.

(3) Exact estimation using ASP: After step2 the pilots can be extracted from the OFDM block after cyclic reconstruction for final accurate channel estimation . Compared to the classical SP algorithm the proposed ASP algorithm has quite similar procedure but differs from SP in the following three aspects:

(i) Initial parameter is taken as path delays which is the auxiliary information available.

(ii) Significant entry identification is done by Sparsity level S which has S_o most significant entries unchanged and identify the next S-S_o most significant ones .

(iii) Iteration numbers are reduced as the initial sparsity levels is fixed which reduces the computational complexity.

(4) Maximum likelihood estimation: The accurate path gain can be estimated finally by using maximum likelihood estimation.

Using time frequency training (TFT) the channel estimate is done for transmission signal to receiver. If the channel is exactly known at the receiver the inter block interference (IBI) of the PN sequence on the OFDM block can be completely removed. In the proposed scheme the time domain PN sequence and the frequency domain pilots are jointly exploited to perform the channel estimation.

Algorithm (Auxiliary information based SP)

Inputs:

1. Initial coarse path delay set T_0,

   Channel sparsity level S, Initial channel sparsity level S_0.

2. Noise measurement $m \triangleq y^{-i}|r$
3. Observation matrix $\Phi \triangleq \text{diag}(x^{-i}|r)F_L^{\Gamma}$

Output:

1. $T^0 \leftarrow T_0;$ (Initial configuration)
2. $r \leftarrow m - \Phi_{T^0}\Phi^*_{T^0}m;$ (Initial residual)
3. $k \leftarrow 0;$ (Initial iteration flag)
4. while $k < S - S_0$ do
5. $k \leftarrow k + 1;$ (update iteration flag)

6. $p \leftarrow \Phi^H r$; (Generate target CIR proxy)
7. $\check{T}^k \leftarrow \check{T}^{k-1} \cup \sup(p_{S-S_n})$; (Significant entry identification)
8. $q \leftarrow \Phi^*_{\check{T}^k} m$; (least square signal estimation)
9. $T^k \leftarrow \sup(q_S)$; (select most significant entries)
10. $r \leftarrow y - \Phi_{T^k}\Phi^*_{T^k} m$; (Update residual)
11. end while
12. Actual path delay acquisition: $T \leftarrow T^k$;

V. Simulation Results

It this section presents results analysis and performance evaluation of the proposed CS-OFDM system. In this part, results are discussed for 16QAM and 256 QAM of ITU-VB and SARFT-8 channels.

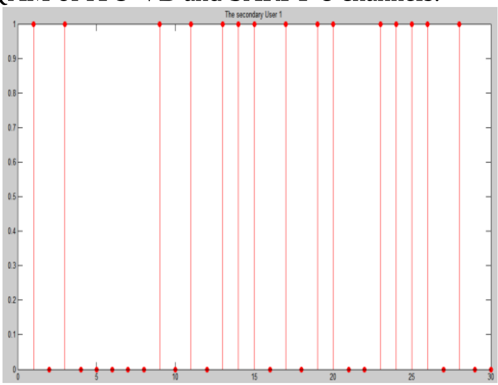

Fig.6 User 1 initialization

Fig.6 shows the user initialization for MIMO system. In MIMO system K no. of user is present in which one specific user 1 should be initialized by selection of user process in which a significant user 1 is used for processing data.

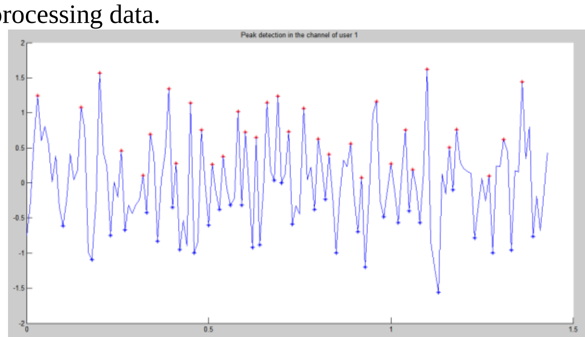

Fig.7 demonstrates the data peak validation process points of the specific user 1.

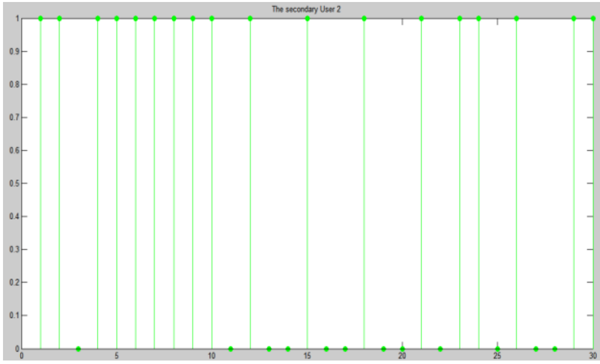

Fig.8 User 2 initialization

Fig.8 shows user 2 initialized by selection user process with a significant user 2 for processing data.

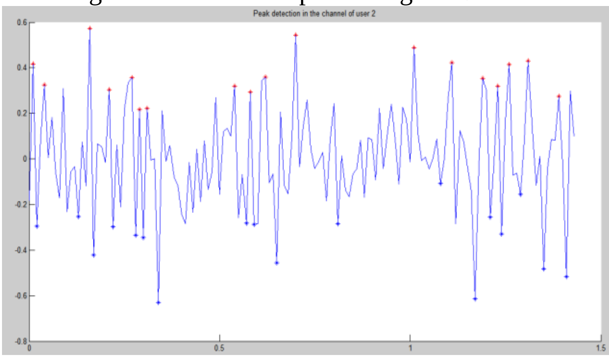

Fig.9 data peak validation by user 2

Fig.9 demonstrates the data peak validation points by user 2.

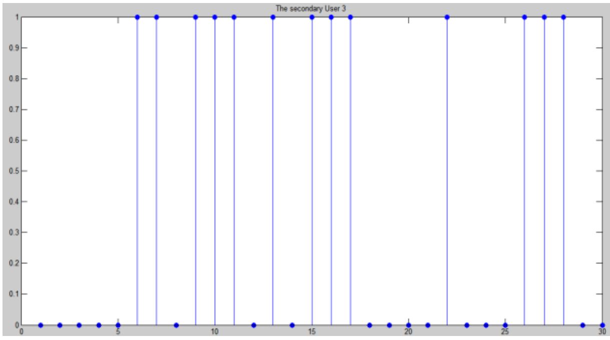

Fig.10 User 3 initialization

Fig.10 shows user 3 initialized by selection user process with a significant user 3 for processing data.

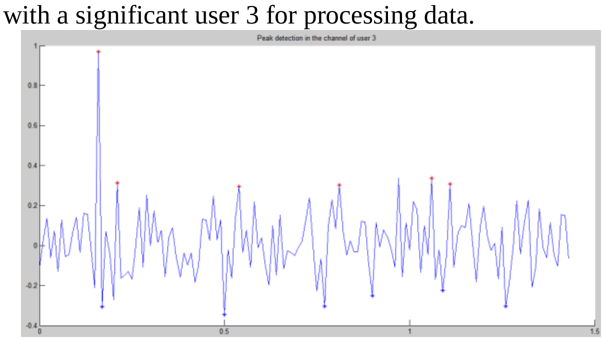

Fig.11 data peak validation by user 3

Fig.11 demonstrates the data peak validation points by user 3.

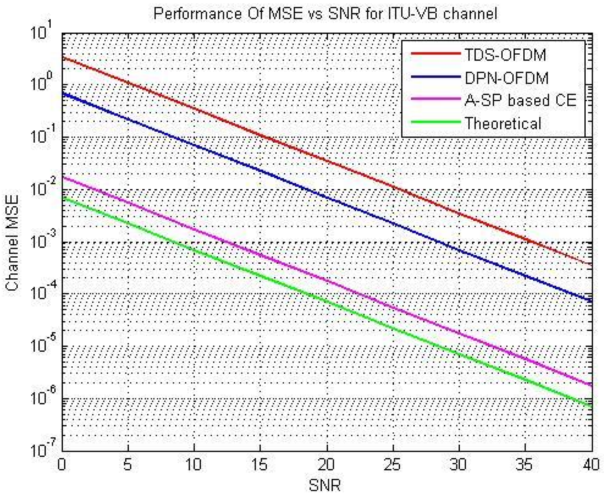

Fig.12: Performance of MSE vs. SNR for ITU-VB channel

In fig.12 we can see the graphical representation of the performance analysis of mean square error to the signal to noise ratio. The result of performance analysis of channel MSE vs. SNR for ITU-VB channel is done in which four parameters consider for analysis TDS-OFDM, DPN-OFDM, and A-SP based Channel estimation and theoretical output compression for ITU-VB channel. Here comparison is done with conventional OFDM techniques such as DPN-OFDM, TDS-OFDM with proposed A-SP based CE. The value of SNR is taken in db (decibel).

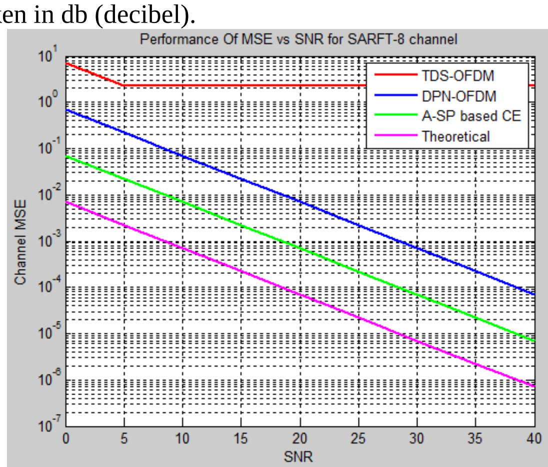

Fig.13: Performance of MSE vs SNR for SARFT-8 channel

In fig.13 we can see the graphical representation of the performance analysis of mean square error to the signal to noise ratio. The result of performance analysis of channel MSE vs. SNR for SARFT-8 channel is done in which four parameters consider for analysis TDS-OFDM, DPN-OFDM, A-SP based Channel estimation and theoretical output compression for SARFT-8 channel. Here also comparison is done with conventional OFDM techniques such as DPN-OFDM and TDS-OFDM with proposed A-SP based CE. SNR is taken in decibel (db).

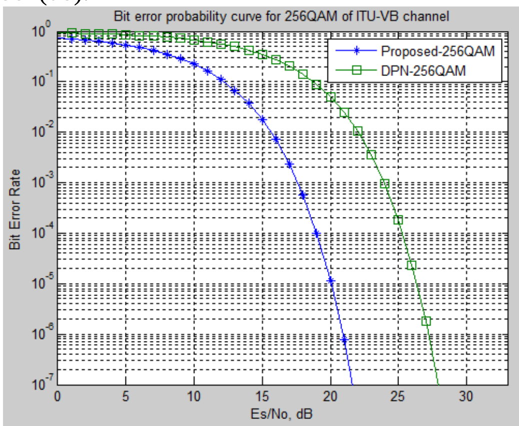

Fig.14: Bit error probability curve for 256QAM of ITU-VB channel

In fig.14 we can see the graphical representation of the Bit error probability curve for 256-QAM. The bit error probability curve analysis for ITU-VB channel for 256 QAM in which two parameters consider for analysis Proposed 256 QAM, DPN-256 QAM, based compression for ITU-VB channel. Comparison is done for both the output.

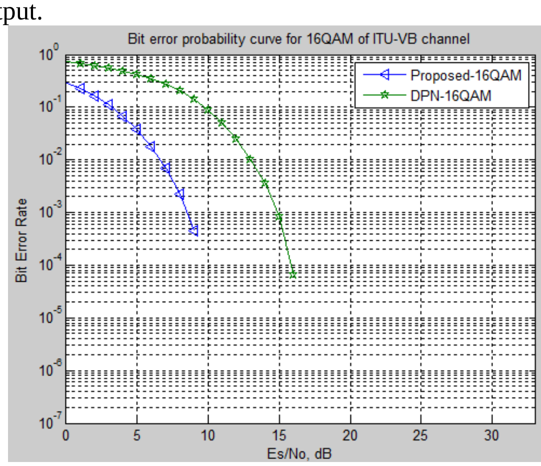

Fig.15: Bit error probability curve for 16QAM of ITU-VB channel

In fig.15 we can see the graphical representation of the Bit error probability curve for 16-QAM. The bit error probability curve analysis for ITU-VB channel for 16 QAM in which two parameters consider for analysis Proposed 16 QAM, DPN-16 QAM, based compression for ITU-VB channel. Comparison is done for both the output.

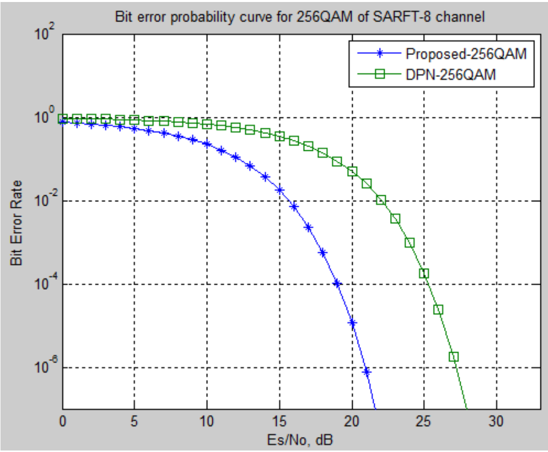

Fig.16: bit error probability curve for 256QAM of SARFT-8 channel

In fig.16 we can see the graphical representation of the Bit error probability curve for 256-QAM. The bit error probability curve analysis for SARFT-8 channel for 256 QAM in which two parameters consider for analysis Proposed 256 QAM, DPN-256 QAM, based compression for SARFT-8 channel. Comparison is done for both the output.

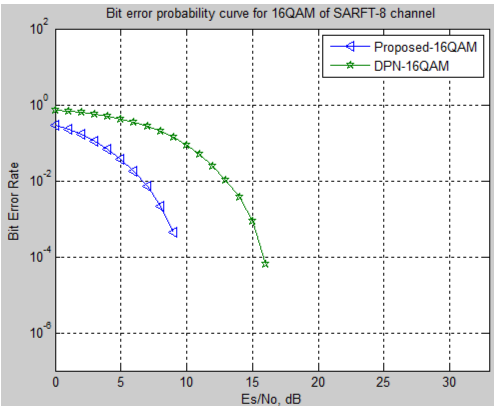

Fig.17: Bit error probability curve for 16QAM of SARFT-8 channel

In fig.17 we can see the graphical representation of the Bit probability curve for 16-QAM. The bit error probability curve analysis for SARFT-8 channel for 16 QAM in which two parameters consider for analysis Proposed 16 QAM, DPN-16 QAM, based compression for SARFT-8 channel. Comparison is done for both the output.

V. CONCLUSION

In this paper a channel estimation technique is proposed based on the recently introduced principle of compressed sensing (CS). Proposed results demonstrate that compressed sensing (CS) makes it possible to exploit the "delay-Doppler sparsity" of wireless channels for a reduction of the number of pilots required for channel estimation within multicarrier systems. The CS based channel estimation for OFDM transmission scheme called TFT-OFDM is proposed where the training information exists in both time and frequency domains. And the algorithm used is called as Auxiliary Information Based Subspace Pursuit (A-SP algorithm) which has lower complexity than the conventional SP algorithm. Simulation results show that the MSE performance of this method outperforms the conventional schemes, lower BER results are good in both static and mobile scenarios, high speed, high reliability for both local and long distance telephony services and can well support the 256 QAM especially when there is maximum channel delay spread .

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