A Virtually Blind Spectrum Efficient Channel Estimation Technique for MIMO-OFDM Systems

M. Obaid Ullah[1], E. Alsusa[2]

[1]*Electronic Engineering Department, U.E.T. Taxila, Pakistan*
[2]*School of Electrical and Electronic Engineering, UoM, Manchester, U. K.*
[1]obaid.ullah@uettaxila.eud.pk

*Abstract-*Multiple-Input Multiple-Output antennas in conjunction with Orthogonal Frequency-Division Multiplexing is a dominant air interface for 4G and 5G cellular communication systems. Additionally, MIMO-OFDM based air interface is the foundation for latest wireless Local Area Networks, wireless Personal Area Networks, and digital multimedia broadcasting. Whether it is a single antenna or a multi-antenna OFDM system, accurate channel estimation is required for coherent reception. Training-based channel estimation methods require multiple pilot symbols and therefore waste a significant portion of channel bandwidth. This paper describes a virtually blind spectrum efficient channel estimation scheme for MIMO-OFDM systems which operates well below the Nyquist criterion.

*Keywords-*OFDM, MIMO, Channel Estimation, Virtually Blind, CFR Inversion.

I. INTRODUCTION

Owing to excessive complexity involved in the design of equalizer in the receiver, a high data rate transmission using conventional single-carrier system is not feasible [i]. Orthogonal Frequency Division Multiplexing (OFDM) a special case of multicarrier modulation (MCM) has the ability to transform frequency selective channel into a set of parallel flat fading channels and consequently requires very simple equalizers. Other advantages of OFDM include higher spectral efficiency, ability to support adaptive modulation schemes, low-complexity implementation and high flexibility in resource allocation [ii-iii].

The wireless channel distorts the amplitude and phase of each subcarrier of OFDM symbol independently which can be modelled by a single complex-valued coefficient. For coherent detection of transmitted information, this multiplicative distortion must be compensated. This compensation process is called channel equalization and requiresthe estimates of channel impulse response [ii]. Although differential PSK (DPSK) could be used in OFDM systems without requiring channel estimates, but it limits the number of bits per symbol and incurs about 3 dB loss in SNR as compared to coherent detection [iv, v]. Moreover, new standards are based on Quadrature Amplitude Modulation (QAM) and thus channel estimation is mandatory.

Channel estimation (CE) techniques developed for OFDM systems can be broadly classified into three categories: (i) Pilot-aided CE techniques, (ii) Blind CE techniques, and (iii) Semi-blind CE techniques[vi]. Pilot aided schemes exploit periodically embedded training sequences known as pilots, while blind or pilot-less techniques exploi tthe statistical behavior of received signal and the inherent redundancy present in the transmitted signal to get channel state information (CSI) [vii].

Various pilot-aided CE methods have been developed and investigated for OFDM systems and the references [iv, viii-xii]represent a good sample of such techniques. The maximum likelihood estimator (MLE) analyzed in [iv] assumes that the channel vector is deterministic. MLE is simpler to implement as it does not require the knowledge of operating SNR and channel statistics. The minimum mean square error (MMSE) and least square (LS) channel estimators are discussed in [viii]. The LS estimator does not require the knowledge of channel statistics and has high mean square error. The MMSE estimator requires a priori knowledge of noise variance and channel covariance and provides good performance but suffers from high complexity. MLE and MMSE estimators give comparable performance at intermediate and high values of SNRs as long as the number of pilots is sufficiently higher than the duration of channel vector [iv]. Low-rank approximations of linear MMSE estimator based on discrete Fourier transform (DFT) have been proposed in [iv]. Such approximations require the knowledge of operating SNR and channel frequency correlation. Channel estimator investigated in [x] uses robust interpolation that is based on 2D FFT and IFFT; and is highly robust to Doppler frequency for dispersive fading channels with noise impairment though its performance degrades at lower Doppler

frequencies. Specially designed pilot sequences [xi] can also aid in control signal estimation in addition to simple channel estimation.

Blind and semi-blind CE techniques can be further classified into two categories: subspace-based and decision directed methods. Subspace based CE techniques exploit redundancy introduced by cyclic prefix(CP) and/or virtual carriers (VCs) to estimate the channel state information [xii] and [xiii] while Decision directed (DD) CE methods exploit previous data estimates (decisions) along with few pilots to improve the accuracy of channel estimates [xiv].

Historically CE techniques were initially developed for single antenna OFDM systems. The advent of MIMO-OFDM systems then arose the need of CE methods specific to multiple antenna systems. Both the modified versions of CE for SISO-OFDM systems adapted for MIMO-OFDM systems as well as novel techniques that exploit MIMO specific features have been proposed in literature [xv].

The performance of various multipleinput multiple-output channel estimation methods using training sequences have been analyzed in [xvi]. In addition to the popular linear least squares (LS) and minimum mean-square-error (MMSE) approaches, the authors of [xvi] proposed scaled LS (SLS) and relaxed MMSE techniques which requireless knowledge of the channel second-order statistics. A robust superimposed training sequence (overlaid into the data stream) design is proposed in [xvii] for spatially correlated MIMO CE which does not require accurate knowledge of the spatial correlation matrix. This scheme is shown to outperform previously proposed robust correlated MIMO CE such as relaxed MMSE (RMMSE) and relaxed least-square (RMMSE) schemes. In [xviii], differential evolution (DE) is used for optimizing the placement and power of the pilot tones that are utilized by LS algorithm in MIMO-OFDM systems. It is shown that the performance of the LS algorithm was increased by optimizing the pilot tones with the DE algorithm instead of locating them orthogonally. A blind channel estimation approach for orthogonally coded MIMO-OFDM systems is proposed in [xix] which shows that using the semi-definite relaxation (SDR) technique, channel estimation problem can be approximated as a convex semi-definite programming (SDP) problem and can be solved efficiently usingmodern convex optimization methods.

In general, pilot-less blind CE schemes are bandwidth efficient but offer poor performance and high latency while the pilot-based CE techniques offer good performance and low latency at the cost of bandwidth wastage. Semi-blind algorithms try to improve the performance of blind algorithms by simultaneously exploiting the knowledge of both known pilot symbols and properties of the transmitted signals [ii]. Moreover, pilot-based techniques reduce the effective SNR that is available for data symbols

[xx]. Motivated by this, a virtually blind (VB) CE technique for OFDM systems which uses only one pilot symbol to estimate the channel state information has been proposed in [xxi]. The original VB CE scheme proposed in [xxi] suffers from the problem of CFR inversion which drastically degrades the system performance. This paper proposes a second-derivative based approach to locate CFRI location which consequently improves the performance radically. Moreover, the extension of VB CE technique to MIMO-OFDM systems is proposed as well. The rest of the paper is organized as follows. Section II briefly describes system model. In section III, Virtually blind (VB) CE method, CFR inversion problem and its solution is described. This section also shows that the proposed VB CE technique can be satisfactorily used for MIMO-OFDM systems. Simulation results are presented in section IV while section V concludes the paper.

II. SYSTEM MODEL

Pilot signals are the known signals which many popular OFDM standards place at regular subcarriers positions [xxii]. These pilot signals are primarily used for channel"sampling" and waste some percentage of subcarriers in every OFDM symbol. Let us consider an OFDM system where every OFDM symbol has a total of N_c subcarriers, N_p pilot subcarriers and N_c- N_p data subcarriers. Therefore, the transmitted OFDM symbol $X[k]$ can be represented as [xxi]

$$X[k] = \begin{cases} D[k] & k \notin \varphi \\ P[k] & k \in \varphi \end{cases} \qquad (1)$$

Where $D[k]$ and $P[k]$ represent data symbols and pilot symbols transmitted over k^{th} subcarriers, respectively. φ is a subset of N_c subcarriers consisting of N_p pilot subcarriers. The received OFDM symbol can be expressed as

$$Y[k] = X[k] \cdot H[k] + N[k] \qquad (2)$$

Where $Y[k]$ is the received OFDM symbol, $X[k]$ is the transmitted OFDM symbol, $H[k]$ is the channel frequency response (CFR) vector and $N[k]$ is the additive white Gaussian noise (AWGN) vector.

III. VIRTUALLY BLIND CHANNEL ESTIMATION

Virtually blind (VB) channel estimation scheme uses only one pilot [xxi] which is placed at the beginning of OFDM symbol (cf. Fig. 1). This only pilot is used to initialize the estimate of the channel frequency response (CFR) at the first subcarrier using a simple least square (LS) method. If the channel is slowly varying in frequency such that there is a high

correlation between adjacent CFR samples, then channel estimate at first subcarrier can be used to decode the data symbol at the second subcarrier. This data decision acts as a pilot, and in turn, is used to estimate the CFR at second subcarrier. Hence, in general, CFR at n^{th} subcarrier is estimated using the nth received symbol and data decision at n^{th} subcarrier which in turn is calculated using the estimated CFR at $(n$ - $1)^{th}$ subcarrier. Hence, the VB CE method estimates the CFR in an iterative fashion based on the estimated CFR at previous location.
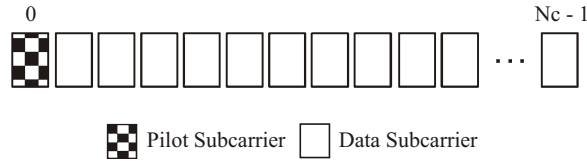

Fig. 1. Virtually Blind CE Using Single Pilot

Using the only available pilot, the LS estimate of CFR at the first subcarrier location is

$$\widehat{H}_1 = \frac{Y_1}{X_1} \qquad (3)$$

where Y_1 is the received symbol over first subcarrier and X_1 is the only pilot transmitted at the first subcarrier. Assuming $H_2 \approx H_1$, the estimated CFR at the first subcarrier, $\widehat{H}_1$, can be used to detect the transmitted data symbol at the second subcarrier. For BPSK case, it can be expressed as

$$\widehat{X}_2 = sign\left[\Re\left(\frac{Y_2}{\widehat{H}_1}\right)\right] \qquad (4)$$

where $\Re$ denotes the real part of complex signal and its argument represents the Zero Forcing (ZF) equalization process while $sign(\cdot)$ represents the hard decision operation. This symbol decision, $\widehat{X}_2$, is used to estimate the CFR at the second subcarriers as

$$\widehat{H}_2 = \frac{Y_2}{\widehat{X}_2} = \frac{X_2 H_2}{\widehat{X}_2} \approx H_2 \qquad (5)$$

In a similar fashion, $\widehat{H}_3$ can be approximated by exploiting $\widehat{H}_2$, and so on. In general

$$\begin{aligned} \widehat{H}_n &= \frac{Y_n}{\widehat{X}_n} = \frac{X_n H_n}{\widehat{X}_n} \\ &= \frac{X_n H_n}{sign\left[\Re\left(\frac{Y_n}{\widehat{H}_{n-1}}\right)\right]} \\ &\approx H_n \end{aligned} \qquad (6)$$

A. CFR Inversion

CFR inversion (CFRI) isthe sign reversal of estimated CFR as compared to actual CFR. It occursat the instants when the channel gain values are very small

i.e., when thepower of actual CFR is in the vicinity of zero. When the power of actualCFR is very low, the received symbol's power (being a product of inputsymbol and CFR sample) is also very low. Under such circumstances, thedecoding decision occasionally gets wrong because of either additive whitenoise or zero crossing of CFR values. Consequently the estimated CFRsample gets inverted. According to (5), if $\widehat{X}_2 = -X_2$ then $\widehat{H}_2 \approx -H_2$ and this sign reversal of channel gain estimate causes CFR inversion. The left part of Fig. 2 depicts an instance of occurrence of CFRI phenomenon in the absence of noise for an OFDM symbol with 256 subcarriers. In this particular case, the CFR inversion hits the channel at about 45^{th}subcarrier after which the estimated CFR is the reflected (sign reversed) approximation of true CFR. Similarly, the right part of Fig. 2 depicts an instance of occurrence of CFRI phenomenon in the presence of additive noise at SNR = 20 dB. In this particular case, the CFR inversion hits the channel at about 145th subcarrier after which theestimated CFR is the reflected (sign reversed) approximation of true CFR.It is this CFRinversion that changes the channel estimates by 180° and is the major cause of poor performance of VB channel estimator (cf. Fig. 5).

As stated earlier, the CFR inversion may occur even in the absence of additive noise. It means no matter how strong is the signal as compared to noise,the CFR inversion may hit the channel. The noise-free CFR inversion occurs when the two consecutive CFR samples are of opposite sign i.e., when the CFR amplitude crosses the zero axis; provided the CFR poweris very small. In that case, the assumption $H_{n+1} \approx H_n$ is no longer valid, and the estimated CFR at n^{th} subcarrier can be expressed as

$$\begin{aligned} \widehat{H}_n &= \frac{Y_n}{sign\left[\Re\left(\frac{Y_n}{\widehat{H}_{n-1}}\right)\right]} \\ &= \frac{X_n H_n}{sign\left[\Re\left(\frac{X_n H_n}{\widehat{H}_{n-1}}\right)\right]} \\ &= \frac{X_n H_n}{sign[\Re(X_n \times -1)]} \\ &\approx -H_n \end{aligned} \qquad (7)$$

This shows that the CFR's "zero crossing" may cause wrong decoding decision and subsequently may lead to CFR inversion depending on the term $sign\left[\Re\left(\frac{H_n}{H_{n-1}}\right)\right]$. Let a and c be the real parts; and b and d the imaginary parts of two consecutive CFR samples H_n and H_{n-1}, respectively. Then

$$sign\left[\Re\left(\frac{H_n}{H_{n-1}}\right)\right] = sign\left[\Re\left(\frac{a+jb}{c+jd}\right)\right]$$

$$= sign\left[\Re\left(\frac{ac+bd}{c^2+d^2}\right.\right.\qquad(8)$$

$$\left.\left.+j\frac{bc-ad}{c^2+d^2}\right)\right]$$

$$= sign(ac+bd)$$

When (8) results in "-1" (cf. (7)), the receiver makes an erroneousdecision and the VB estimator suffers from CFR inversion. Therefore, itcan be concluded that the CFR inversion, even in the absence of additive noise, occurs when:
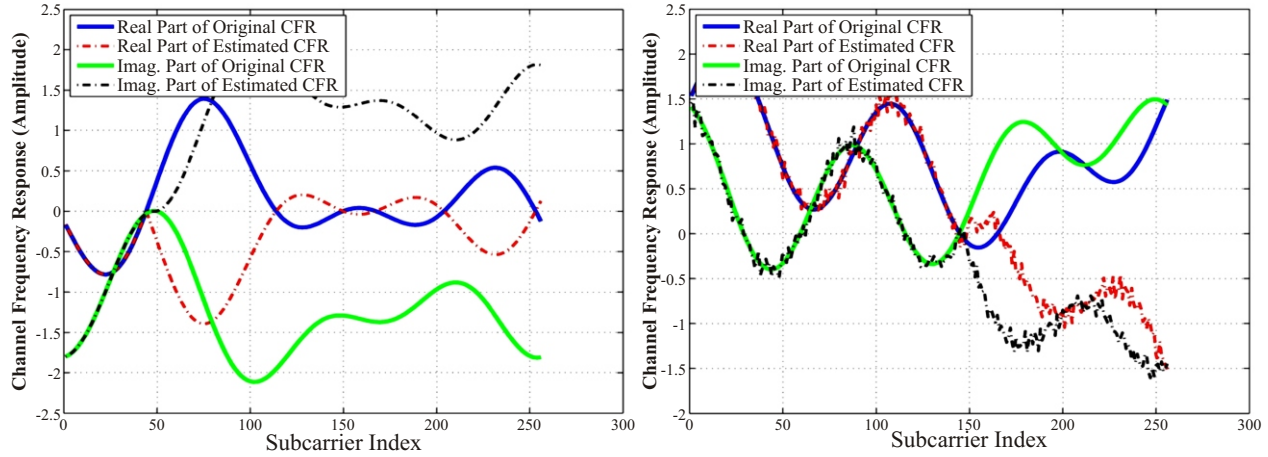

Fig. 2. CFR Inversion in the absence (left) and in the presence (right) of noie at 20 dB

Both real and imaginary CFR amplitudes cross zero axis (equivalently, both product terms and in (8) are negative).

One of the real or imaginary CFR amplitudes crosses zero axis(equivalently, either or term is negative and its magnitude is higher than that of positive product).

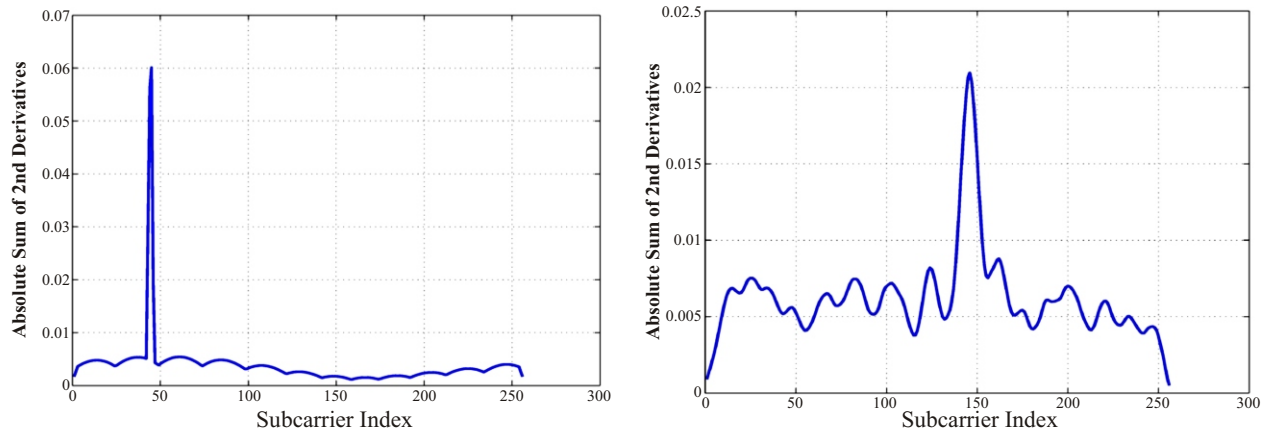
Fig. 3. Using 2nd Derivative to Locate CFR Inversion in the absence (left) and in the presence (right) of noie at 20 dB

Regardless of the original cause of CFR inversion, the CFR inversionripples forward along with wrong decoding decisions at all subsequentsubcarriers. This is because VB channel estimate at current subcarrierlocation is based on the previous estimate. The situation prevails untiland unless a second CFR inversion hits the channel. In the event of secondCFR inversion, the re-inverted CFR automatically gets rectified.

B. Locating CFR Inversion Using Second Derivatives

If we can find the exact location of CFRI by some means, then it is quite straightforward to reverse the effects of CFRI.

This section explains how second-derivative can be used to locate CFRI. The noise free case is used first to provide further insight into the CFR inversion problem. Since the amplitude of estimated CFR abruptly changes it direction at the instant of CFR inversion, the derivative of estimated CFR can help us

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to locate CFR inversion position. At the point of CFR inversion, the estimated CFR abruptly changes it slope, hence the derivative at CFRI location has an abrupt change in it sign. If we take the second derivative of estimated CFR, it highlights the location of CFR inversion more clearly with a spike. If we add the absolute values of second derivatives for real and imaginary parts, it gives us a spike with higher peak to average ratio. This absolute sum of 2nd derivatives is shown in left pane of Fig. 3 where aspike around 45th subcarrier clearly indicates the CFRI location for noise-free case. The BERfor noise-free case for 256 subcarriers OFDM systems in 4-tap Rayleigh fading channel was found to be 1.96×10^{-2} using VB CE before correction. After finding the CFRI location with the help of second derivative and consequently rectifying the estimated CFR, the BER for noise-free case becomes 8.54×10^{-5}.

The location finding of CFR inversion is more challenging in the presence of additive noise. It is important to reduce the effects of noise before taking a derivative. One way to do so is to use a moving average filter which removes the noise and hence smooths a noisy signal. However, as the number of points in the filter is increased to reduce noise further, the signal becomes more and more smooth and the sharp features of the signal itself start losing their sharpness. It means that the noise reduction process also eliminates the abrupt amplitude changes at CFR inversion. Therefore, there exists a trade-off between noise reduction and locating CFR inversion. After reducing the noise, the abrupt change(s) in estimated CFR amplitude are measured by taking its second derivative. The peaks of the second derivative indicate the potential location(s) of CFR inversion. The right pane of Fig. 3 shows the use of second derivative to locate CFR inversion in thepresence of additive noise at SNR = 20dB. There is a sharp spike around 145th subcarriers in the 2nd derivative indicating the CFRI location.

C. Dynamically Allocated Additional Pilots

As discussed in section III-A, when the CFR amplitude values lie close to zero, the chances of CFR inversion increase. Therefore, when the amplitude of CFR goes below a certain threshold level, the likelihood of occurrence of CFR inversion increases. The detailed analysis of CFRI problem reveals two important points that provide us more insight regarding the behavior of CFRI. First, the probability of CFR inversion decreases as the threshold level increases at a fixed SNR. This means that the probability of CFR inversion is inversely proportional to threshold level i.e.,

$$P[CFRI] \propto (Threshold\ Level)^{-1} \qquad (9)$$

Secondly, for a fixed threshold, the probability of CFR inversion at higher SRN values is considerably

less than that at lower SRN values. Both of these observations are in line with our intuition as well. Since probability of CFR inversion is inversely proportional to threshold level, hence BER decreases with the increasein threshold. Moreover, since probability of CFR inversion introduces errors in the estimated CFR, hence BER is directly proportional to probability of inversion[xxi].

Utilizing this knowledge of how probability of CFR inversion and the level of channel gains are related to each other, we can design a closed-loop system to dynamically assign additional pilots in order to improve the CE performance. This channel estimation scheme is comprised of two steps namely: acquisition and tracking. An acquisition pilot is sent at 1st subcarrier of first OFDM symbol of every OFDM frame. The receiver then performs VB CE using this only pilot according to (6) and decides about the potential locations of CFRI as well. The receiver does the latter job by utilizing the knowledge of probability of occurrence of CFR in accordance with (9). Information regarding the potential CFRI locations is then sent back to the transmitter through a feedback channel. The transmitter then responds to this information by sending pilots in the next OFDM symbol at the subcarriers pointed out by the receiver.

D. CE for MIMO-OFDM Systems

Fig. 4 shows a simple schematic for 2×2 MIMO-OFDM system. We use spatial multiplexing technique in order to achieve higher data rates which involves the transmission of multiple independent data streams from different transmit antennas. Furthermore, keeping in view the basic idea of VB CE method along with dynamically assigned additional pilots, it becomes clear that for 2×2 MIMO scheme we need two null OFDM symbols from each of the two transmitting antennas. When one of the transmit antenna transmits either initial acquisition pilot or dynamically requested pilots, the other transmit antenna must be silent at that time.

X_{mn} and Y_{mn} represent the transmitted and received OFDM symbols respectively with the first subscript, m, representing (transmit or receive) antenna index and the second subscript, n, representing the time index. For example, X_{12} is the 2nd OFDM symbol transmitted from 1st transmit antenna and Y_{24} is the 4th OFDM symbol received at 2nd receive antenna. The first two OFDM symbols received at both antennas can be expressed in terms of CFRs as:

$$Y_{11} = X_{11}H_{11} + X_{21}H_{21} + N_1 \qquad (10\,a)$$
$$Y_{21} = X_{11}H_{12} + X_{21}H_{22} + N_2 \qquad (10\,b)$$
$$Y_{12} = X_{12}H_{11} + X_{22}H_{21} + N_3 \qquad (10\,c)$$
$$Y_{22} = X_{12}H_{12} + X_{22}H_{22} + N_4 \qquad (10\,d)$$

Where N_1, N_2, N_3, and N_4 represent AWGN noise vectors. The four received OFDM symbols Y_{11}, Y_{21}, Y_{12},

and Y_{22} are used to obtain the initial versions off our channel responses i.e. $\breve{H}_{11}$, $\breve{H}_{12}$, $\breve{H}_{21}$, and $\breve{H}_{22}$ respectively. These four estimates are obtained using only two acquisition pilots with the aid of two null OFDM symbols. These initial estimates are used to estimate the potential CFR inversion locations. The potential locations are then fedback to transmitters which accordingly respond by sending additional pilot

sat requested subcarriers in the next OFDM symbols. The receivers receive the additional dynamic pilots in the following four OFDM symbols:

$$Y_{15} = X_{15}H_{11} + X_{25}H_{21} + N_5 \qquad (11\,a)$$
$$Y_{25} = X_{15}H_{12} + X_{25}H_{22} + N_6 \qquad (11\,b)$$
$$Y_{16} = X_{16}H_{11} + X_{26}H_{21} + N_7 \qquad (11\,c)$$
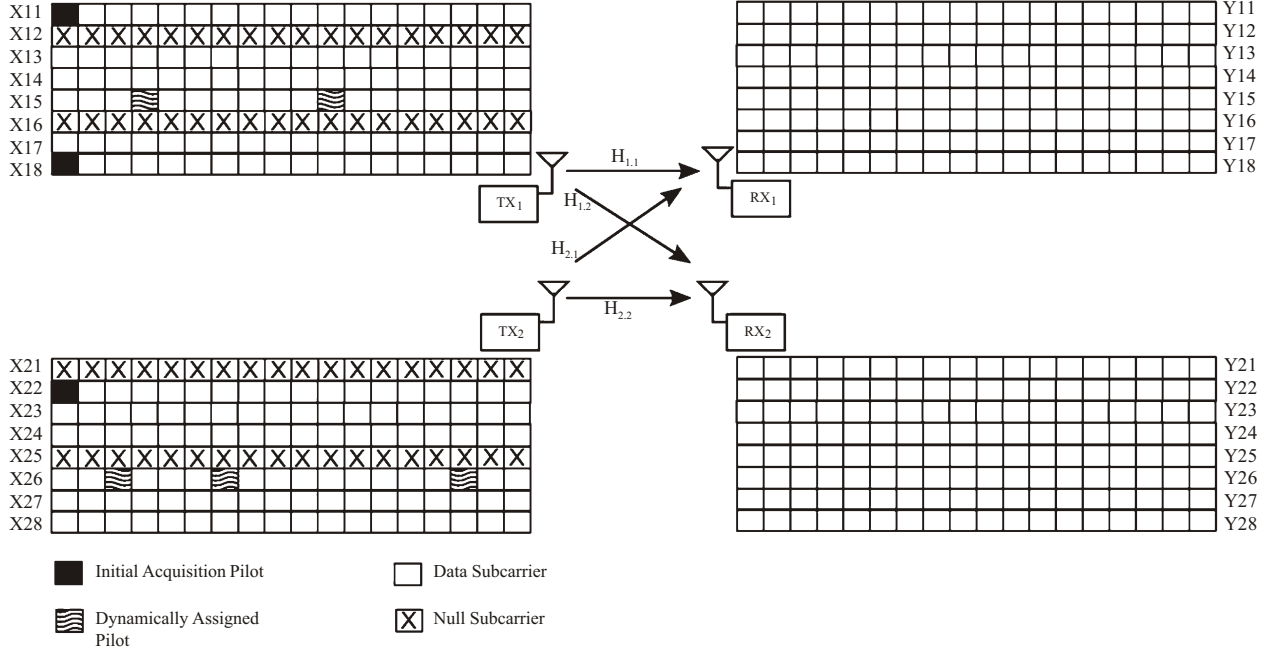$$Y_{26} = X_{16}H_{12} + X_{26}H_{22} + N_8 \qquad (11\,d)$$

Fig. 4. Schematic For 2X2 MIMO-OFDM system Employing VB CE with Dynamic Pilots

The receivers then reconstruct the final CFR estimates $\widehat{H}_{11}$, $\widehat{H}_{12}$, $\widehat{H}_{21}$, and $\widehat{H}_{22}$ using the additional dynamic pilots in order to rectify the CFR inversion(s). These estimated CFRs are then used to demodulate the OFDM symbols using the zero-forcing (the de-correlator) receiver as follow:

$$\widehat{X}_{11} = \frac{(Y_{11}\widehat{H}_{22} - Y_{21}\widehat{H}_{22})}{|\widehat{H}|} \qquad (12\,a)$$

$$\widehat{X}_{12} = \frac{(Y_{12}\widehat{H}_{22} - Y_{22}\widehat{H}_{22})}{|\widehat{H}|} \qquad (12\,b)$$

$$\widehat{X}_{21} = \frac{(Y_{21}\widehat{H}_{11} - Y_{11}\widehat{H}_{12})}{|\widehat{H}|} \qquad (12\,c)$$

$$\widehat{X}_{22} = \frac{(Y_{22}\widehat{H}_{11} - Y_{12}\widehat{H}_{12})}{|\widehat{H}|} \qquad (12\,d)$$

where $|\widehat{H}|$ is the determinant of estimated channel mixing matrix and is defined as:

$$|\widehat{H}| \triangleq \widehat{H}_{11}\widehat{H}_{22} - \widehat{H}_{12}\widehat{H}_{21} \qquad (13)$$

Equations (12a) - (12d) are the ZF solutions of (10a) - (10d).

IV. RESULTS AND PERFORMANCE ANALYSIS

The results presented in this section are based on an OFDM system with $N_c = 256$ in Rayleigh fading environment. The Rayleigh fading model assumes channel coefficients, h_l, as complex Gaussian random variables i.e., $h_l \sim \mathcal{CN}(0, \sigma_l^2)$, where σ_l^2 is the variance. Moreover, exponentially decaying channel power delay profile is assumed i.e., $\sigma_l^2/\sigma_0^2 := \exp(-l/c_{att})$, $l = 0,1,...,N_{ch}$ - 1 where c_{att} is the attenuation constant and N_{ch} is the number of multipath. The maximum delay spread of the channel, τ_{max}, is taken as 6.25% of OFDM symbol duration.

The performance of VB channel estimator for an OFDM system with 256 subcarriers in Rayleigh channel based on (6) is shown in Fig. 5. Obviously, the performance of VB estimator is quite unsatisfactory especially at higher SNR values. The BER

performance curve saturates after SNR = 40dB with an error floor above 10^{-2}. The source of this poor performance is the occasional occurrence of CFR inversion (cp. section III-A).

Fig. 5 also shows the performance of VB estimator after 2nd derivativebased correction (cf. section III-B) in Rayleigh fading environment. As evident from Fig. 5, 2nd derivative based auto-correction of CFRI brings about a significant performance improvement; especially the saturation effect at higher SNR values is no longer there. Fig. 6 shows the performance with dynamically inserted pilots for an OFDM system with 256 subcarriers in 4-tap Rayleigh fading channel.
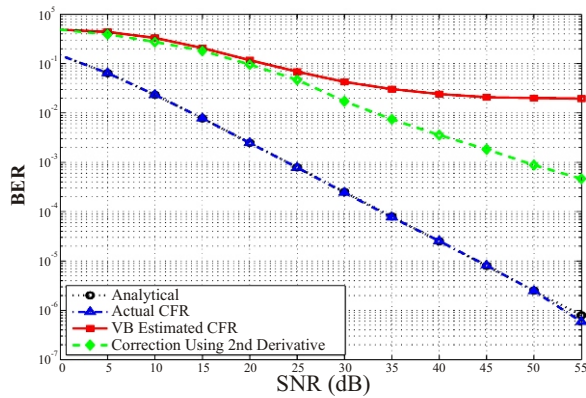

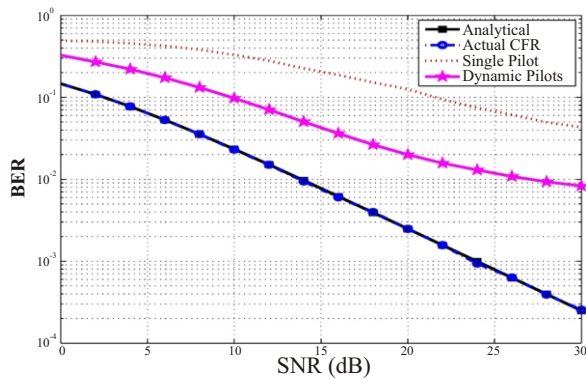Fig. 5. Performance of VB CE Before and After Correction

Fig. 6. BER Performance with Dynamic Pilots

As evident from Fig. 6, the dynamic assignment of additional pilots provides further improvement in BER. The reason behind this performance improvement is the dynamic insertion of additional pilots at potentially vulnerable CFRI locations by exploiting the knowledge of probability of CFRI. Every newly inserted pilot restrict the detrimental effects of previous CFR inversion, if any, up to its location at most. In other words, since every new pilot gets a new channel sample at alocation far away from the previous pilot, the detrimental effects of previous CFR inversion, if any, doesn't propagate beyond this point. The downside of this scheme, however, is the increased computational complexity and the increased latency on account of the computation of probability of CFR inversion and the inclusion of a feedback channel.

Fig. 7 shows the average number of tracking pilots per OFDM frame as a function of SNR. As evident from the Fig., the number of dynamically assigned pilots decreases rapidly with increasing SNR value. The overall average number of dynamic pilots for 256 subcarrier OFDM system is 4.9.

Fig. 8 shows the BER performance of VB CE with dynamically added pilots for 2×2 MIMO-OFDM system. As compared to SISO case, the BER performance offered by 2×2 MIMO system is substantially better. The reason for this improvement is that each MIMO receiver requests additional pilots for two different CFRs to the same transmitter. Hence, the received additional pilots are combination of request for two CFRs. Therefore, the improved performance is achieved at the cost of additional pilot overhead.
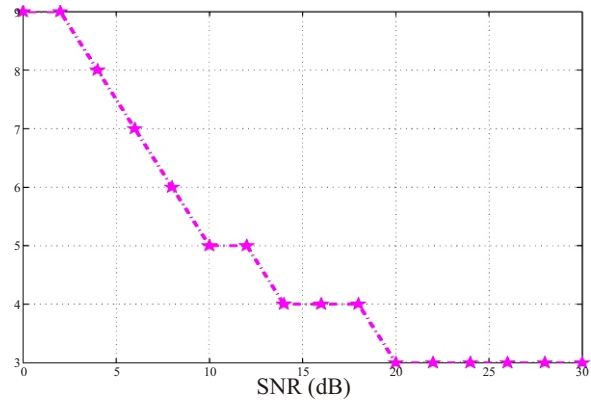

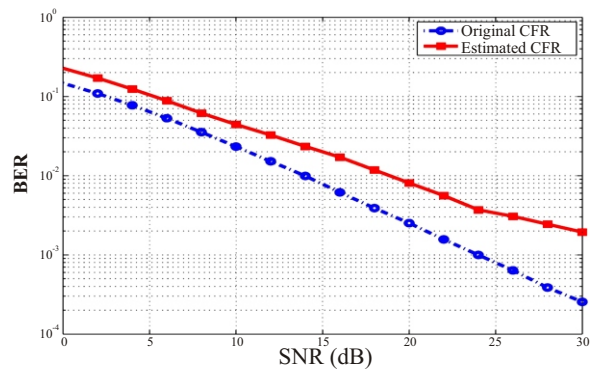Fig. 7. Average No. of Dynamic Pilots per OFDM Frame

Fig. 8. Performance of VB CE with Dynamic Pilots for 2X2 MIMO-OFDM system

V. CONCLUSIONS

In this paper, a virtually blind channel estimation scheme for MIMO-OFDM systems is proposed which in its primitive form needs single pilot. This channel estimator inherently suffers from CFR inversion which

Restricts its performance. It was shown that the proposed 2nd-derivative based inversion location scheme works satisfactorily and provides radical performance improvement. Dynamically assigned pilots were then augmented with the only pilot in order to take more samples of channel and to stop propagating CFRI effect further to remaining subcarriers, if undetected by the inversion locator. The proposed scheme operates well below the Nyquist criterion. Its others features include high spectrum efficiency and high effective SNR available for data symbols. For static and quasi-static channel scenarios like WLAN, the proposed scheme can be effectively used. Unlike some popular CE techniques, the proposed scheme does not require the knowledge of channel parameters like noise variance and channel covariance matrix as well as operating SNR, and hence is easier to implement.

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