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A NOVEL PREAMBLE DESIGN FOR CHANNEL ESTIMATION IN MIMO-OFDM SYSTEMS RESULTING IN ENHANCED THROUGHPUT

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Abstract: Multiple Input Multiple Output (MIMO) system combined with orthogonal frequency division multiplexing (OFDM) provides a reliable solution for enhanced data rate next generation wireless systems as MIMO produces additional parallel channels in spatial domain which allows high data rates to be achieved without extra bandwidth and transmitted power. While OFDM provides high bandwidth efficiency and robustness to multipath fading due to orthogonal subcarriers that convert frequency selective channel into parallel frequency flat channels. Channel estimation is integral part in coherent MIMO-OFDM systems. Burst communication system utilizes data aided channel estimation algorithms due to their fast convergence and accuracy relative to blind estimation algorithms. Data aided schemes in MIMO-OFDM employ periodic transmission of training data from transmitter for channel estimation at the receiver. In MIMO-OFDM systems higher number of transmit/receive antennas causes a bigger overhead for channel estimation. This paper proposes novel preamble design with low overhead for channel estimation. Simulation results and analysis of time based channel estimation algorithm resulting in spectrally efficient MIMO-OFDM system have also been provided.

Keywords: *Burst Communication, preamble design, time based channel estimation, MIMO-OFDM.*

I. INTRODUCTION

Next generation wireless communication system supports high data rate applications. Enhanced throughput and increased network capacity are major requirements of these systems. With the increased number of users, bandwidth allocation becomes very critical. Multiple antenna techniques become a promising solution for these requirements. Multiple Input Multiple Output (MIMO) systems incorporating Orthogonal Frequency Division Multiplexing (OFDM) appears to be a match, made in heaven as MIMO-OFDM provides high data rate with OFDM, integrated with multi-antenna system, reduces the complexity of overall system. MIMO provides parallel channels over the same time and frequency that can be used to achieve high data rates without the need of additional bandwidth and power.

MIMO techniques can be broadly split into space division multiplexing (SDM) and space time coding (STC). STC utilizes diversity techniques for performance enhancement whereas SDM makes use of multiple data streams to achieve high data rates.

OFDM divides the frequency selective channel into parallel frequency flat channels fighting multipath fading and Inter Symbol Interference (ISI) using Cyclic Prefix (CP) [1]. It thus provides robustness against frequency selective fading channels [2, 3].

MIMO-OFDM systems are used in WLAN standards and WIMAX and LTE [4, 5, 6]. Next generation of communication systems shall be employing MIMO techniques to meet the increasing data rate requirements and high spectral efficiency.

Unlike guided medium, wireless channel causes many unwanted effects to the radio signal like frequency, angle and time spreading. Often these effects put limitations on performance of the systems. To reduce these effects channel is estimated and equalized at the receiver. Channel estimation is critical in MIMO-OFDM systems, since in MIMO multiple streams are transmitted simultaneously thus error in channel estimates can more critically degrade the performance of the overall system. Channel estimation complexity increases significantly with multiple antennas. OFDM is therefore generally integrated with MIMO as OFDM converts frequency selective channel into independent parallel frequency flat channels that makes estimation of channel at the receiver less complex as single tap equalization is required.

The Channel Estimation (CE) techniques generally fall into two categories. Data aided and Blind channel estimation. Data aided techniques for channel estimation are generally employed in packet based communication systems as blind channel estimation consumes larger data and time for convergence. In OFDM, channel estimation can either be done by inserting pilot tones in all of the subcarriers (Block type CE) or by inserting pilot tones on particular subcarriers (Comb type CE) into each OFDM symbol. Comb type CE algorithms utilizes interpolation techniques to estimate channel at remaining subcarriers. Block type pilot channel estimation is used in slow fading channels whereas comb type pilot channel estimation is used to equalize the channel, changing from one OFDM symbol to the other.

For MIMO-OFDM training data used for channel estimation for particular transmit/receive antenna should be

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orthogonal in time, frequency or code to other transmit antennas. Preamble should be either time multiplexed, frequency multiplexed or code multiplexed. Similar techniques of channel estimation for Single Input Single Output (SISO-OFDM) can be applied to MIMO-OFDM system with some modification. Channel estimation techniques in MIMO systems generally convert the MIMO using orthogonal training sequences into independent SISO. The larger the number of transmit antennas, the greater the overhead for channel estimation as more pilot symbols are required for channel estimation.

System model of MIMO-OFDM is provided in section II. Analysis of channel estimation techniques for single antenna and multiple antenna systems is given in section III. Preamble design with low overhead for channel estimation in MIMO-OFDM system is proposed in section IV and simulation results and analysis are given in section V. Conclusion is presented in section VI.

II. SYSTEM MODEL

In MIMO-OFDM system, transmission is made from all transmit antennas simultaneously. Let's assume that MIMO-OFDM system operates with N_t transmit and N_r receive antennas. Let the signal from i_{th} transmit antenna, in baseband, is

$$x_i[n] = \sum_{k=0}^{N-1} X_i[k] e^{j\frac{2\pi k}{N}n}, -N_g \le n \le N-1 \qquad (1)$$

where N_g is the number of guard samples or cyclic prefix samples and N is the total subcarriers. X_i is the complex data that is modulated onto the subcarriers from i_{th} transmit antenna.

The multi-tap channel between i_{th} transmit antenna and j_{th} receive antenna is modeled as

$$h_{ji}(t,\tau) = \sum_{l=0}^{L} \alpha^{ji}{}_l(t)\delta(\tau-\tau_l) \qquad (2)$$

where L is the total number of complex taps, $\alpha^{ji}{}_l$ is the l_{th} complex path gain and τ_l is the corresponding path delay between i_{th} transmit antenna and j_{th} receive antenna. The received signal y_j at the j_{th} receiver antenna is,

$$y_j[n] = \sum_{i=1}^{N_t} \sum_{l=0}^{L-1} h_{ji}[l] x_i[n-l] + n_j[n] \qquad (3)$$

where $h_{ji}[l]$ is the l_{th} complex baseband sampled channel tap between i_{th} transmit antenna and j_{th} receive antenna. n_j is the complex baseband noise at the j_{th} receiver with power spectral density N_o. The guard or cyclic prefix interval is kept greater than total delay spread of channel. The received signal in frequency domain is,

$$Y_j[k] = \sum_{n=0}^{N-1} y_j[n] e^{-j\frac{2\pi n}{N}k}, 0 \le k \le N-1 \qquad (4)$$

where k is the subcarrier index and N is the total number of subcarriers. For a particular subcarrier k, the received signal is,

$$\begin{bmatrix} Y_1[k] \\ . \\ . \\ Y_{Nr}[k] \end{bmatrix} = \begin{bmatrix} H_{11}[k] & \dots & \dots & H_{1Nt}[k] \\ . & & & . \\ . & & & . \\ H_{Nr1}[k] & \dots & \dots & H_{NrNt}[k] \end{bmatrix} \begin{bmatrix} X_1[k] \\ X_1[k] \\ . \\ . \\ . \\ X_{Nt}[k] \end{bmatrix} + \begin{bmatrix} n_1[k] \\ . \\ . \\ n_{Nr}[k] \end{bmatrix} \qquad (5)$$

where $H_{ji}[k]$ is the complex baseband channel response at a particular subcarrier and $n_j[k]$ is the complex noise at a particular subcarrier k.

III. ANALYSIS OF CHANNEL ESTIMATION IN MIMO-OFDM SYSTEMS

A lot of literature is available on the techniques of channel estimation and equalization. Least Square (LS), Maximum Likelihood Estimation (MLE), Transform domain and Linear Minimum Mean Square Error (LMMSE) estimation techniques are commonly used [7]. For orthogonal frequency division multiplexed systems, time based and frequency or tone (pilot) based channel estimation techniques are studied. In time domain channel estimation, Channel Impulse Response (CIR) is first estimated in time domain and then transformed into frequency domain for equalization at each subcarrier [7]. In tone mode, only few subcarriers are used for channel estimation and then these estimates are interpolated and extrapolated to get the channel response at the non-pilot locations [8, 9].

With the ever increasing demand for high data rates, MIMO systems came into being. Generally channel estimation techniques for these systems are extended from SISO systems. Orthogonal training sequence converts MIMO-OFDM channel estimation to SISO-OFDM, so similar techniques of ML, LS and LMMSE can be used. In these channel estimation techniques MIMO-OFDM channel estimation is done by turning off the transmit antenna in time or frequency and sending pilot tones by only one antenna at a time [10, 11]. Data aided channel estimation techniques require long preambles for higher number of antennas especially in block type training as training must be orthogonal in time for different transmit antennas [12]. Comb based techniques are proposed for MIMO-OFDM which requires interpolation for null subcarriers as in the case of SISO-OFDM.

The performance and optimality of receivers and estimators have remained under considerable focus ever since [13,14,15]. However, no matching emphasis is seen in literature on the decrease in overhead of these techniques. In future systems where MIMO-OFDM will be playing a key role, overheads for channel tracking will present a severe bottleneck in achieving high throughput for systems involving higher number of transmit/receive antennas.

In this paper ML technique for MIMO-OFDM channel estimation is presented. Preamble is code division multiplexed, for different transmit antennas, within one OFDM symbol duration. ML technique is proposed for channel estimation. In the next section, preamble design is proposed.

IV. PROPOSED PREAMBLE DESIGN AND CHANNEL ESTIMATION ALGORITHM

1. *Novel Preamble Design*

Proposed preamble design for channel estimation for MIMO-OFDM system is code multiplexed. Let M be the total number of transmit/receive antenna channels that are to be estimated in one OFDM symbol. Channels that can be estimated in one OFDM symbol at maximum are,

$$M_{\max} = \frac{N}{N_g} \tag{6}$$

where N_g will be kept twice of maximum delay spread. In this case, preamble from i_{th} transmit antenna without cyclic prefix is,

$$s_i[m + (j-1)M] = hdm[i, j]x_i[m] \tag{7}$$

where j=1 to M, m=0 to N_g-1 and hdm[i,j] is the i_{th}, j_{th} element of M^2 hadamard matrix . $x_i[m]$ represents complex baseband data samples in time domain. Data sequence, which is different for different transmit antennas (as shown in Fig.1 and Fig.2 with different colors), must obey the condition of optimal channel estimation [16].

Complete preamble that includes cyclic prefix is formed by copying last N_g samples to the beginning of the OFDM symbol. If M is lesser than total number of transmit antennas, more than one OFDM symbol will be required in preamble.

Preamble design for 2x2 MIMO-OFDM system is shown in Fig.1. Preamble design for 4x4 MIMO-OFDM shown in Fig.2 in which it is assumed that

$$N_g = 2L \tag{8}$$

with

$$M = 4 \tag{9}$$

and

$$N = 4N_g \tag{10}$$

2. *Channel Estimation using Proposed Preamble*

In proposed preamble design, data transmission is made from all transmit antennas simultaneously for the whole OFDM symbol duration. Time orthogonal training sequence causes back off in maximum transmission power as training sequence transmission is made from only one transmit antenna at a time.

Maximum likelihood channel estimation is proposed for this novel preamble. As the signal on a particular receiver antenna will be the sum of signals from all the transmit antennas, signal separation is required at every receiver antenna. Signal separation can be made by making use of the orthogonal coded preamble design. Each section of the preamble which is multiplied by a different element of hadamrad marix will be corrupted by its previous section.

Thus corrupted portion is cut to make the section orthogonal at the receiver as well. Separation will then be possible as shown in (11).

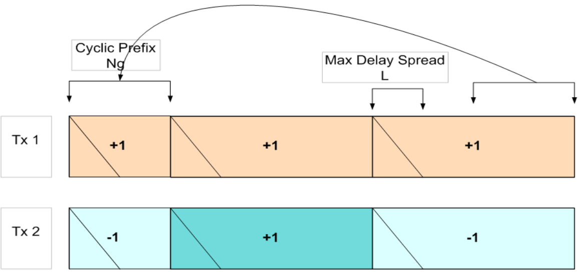

Figure 1. Preamble Design for 2x2 MIMO-OFDM System

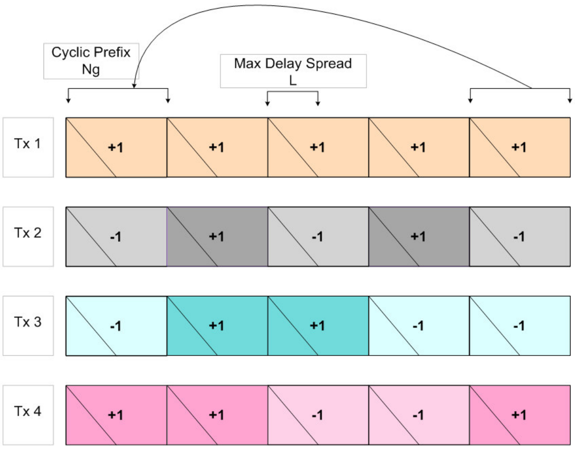

Figure 2. Preamble Design for 4x4 MIMO-OFDM System

$$h_{\text{int}}^{ji}[n] = \frac{\sum_{p=1}^{Nt} y_j[n + \frac{N_g}{2} + p\frac{N}{M}]hdm[i,p]}{N_t} \tag{11}$$

Where n= 0 to M- N_g/2 and $y_j[n]$ is the received sequence at j_{th} antenna after cyclic prefix has been removed. $h_{\text{int}}[n]$ is the intermediate sequence which is without mixing of signals and will be used in channel estimation between j_{th} receive antenna and i_{th} transmit antenna.

CIR can be found using (12).

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CIR can be found using (12).

$$h^{ji}[n] = (S_i^H S_i)^{-1} S_i^H h_{\text{int}}^{ji} \qquad (12)$$

Where S_i is;

$$S_i = \begin{bmatrix} x_i[\frac{N_g}{2}] & \ldots & \ldots & x_i[\frac{N_g}{2} - n] \\ . & & & . \\ . & & & . \\ x_i[\frac{N}{M}] & \ldots & \ldots & x_i[\frac{N}{M} - n] \end{bmatrix}, 0 \le n < \frac{N_g}{2} \qquad (13)$$

In (12) it is assumed that $(S_i^H S_i)$ is full rank. MSE of the channel estimation is

$$MSE = N_o tr\{(S_i^H S_i)^{-1}\} \qquad (14)$$

where N_o is the complex noise power spectral density and tr{ } is the transpose of matrix. Thus design of S_i is critical and conditions for optimal design are given in [16]. Channel can be estimated using (11), (12) and (13) among M transmit antennas and receive antenna using one OFDM symbol. Channel estimation is done in time domain. If N/M duration is made exactly equal to N_g duration in the preamble, there would be no margin for timing synchronization variance. If it is greater than that, more channel estimation samples will be available which will result into greater margin for timing synchronization.

V.SIMULATION RESULTS

The simulation parameters are shown in Table.1. Mean Square Error (MSE) is calculated for different cases. 2x2 system and 4x4 MIMO-OFDM system is simulated for different parameters and results are shown.

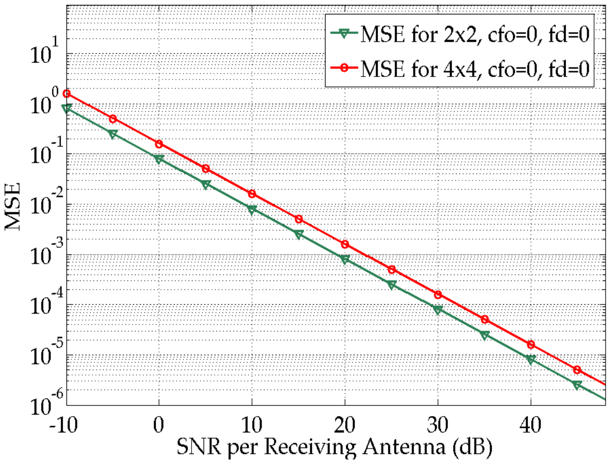
Channel taps assumed are 8. The number of samples used in channel estimation for 2x2 system is 32 and in case of 4x4 system, the number of samples used in channel estimation is 16. Under the parameters give in Table.1 4x4 system is the case, in which maximum number of channels ($M=M_{max}=4$) using one OFDM symbol can be estimated.

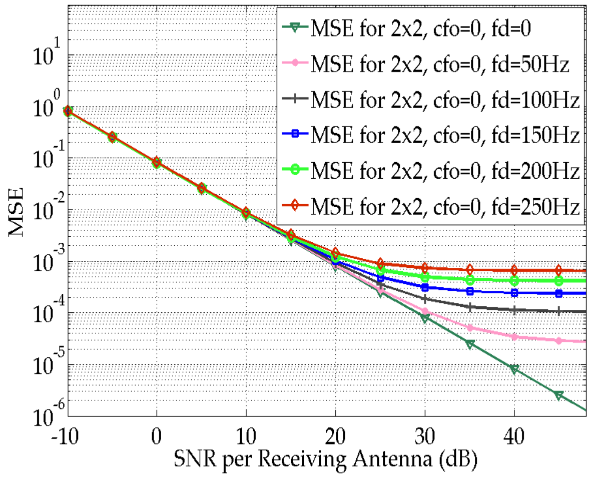
In case of 2x2 system, the margin for timing estimation variance is higher as compared to the 4x4 system where more channels are estimated using the same OFDM symbol. 32 samples are used for 2x2 system and 16 samples are used for 4x4 system, 2x2 system gives us 3dB performance gain as shown in Fig.3. However to achieve the same performance for 4x4 system, number of OFDM symbols for channel estimation must be doubled. For higher number of antennas, at higher signal to noise ratio (SNR) preamble overhead can be reduced considerably.

TABLE I. SIMULATION PARAMETERS

S.No	Parameter	Value
1.	RF frequency	2.4 GHz
2.	No. of Subcarriers	64
3.	Subcarrier Spacing	15.625 kHz
4.	Sampling Rate	1Mhz
5.	Cyclic Prefix Duration	16 µs (16 samples)
6.	Max Delay Spread	8 µs (8 samples)
7.	Max Doppler,f_d	0,50,100,150,200,250 Hz
8.	Carrier Frequency Offset,CFO	2%,5%,10% of subcarrier spacing
9.	No of Antennas	2x2,4x4

The simulation results for different fading rate or Doppler spread, f_d, are shown for 2x2 and 4x4 systems in Fig.4 and Fig.5 respectively. Simulation results for different carrier frequency offsets and Doppler spread for both 2x2 and 4x4 systems are shown in Fig.6 and Fig.7. The greater the carrier frequency offset (CFO) or the Doppler spread, the greater the MSE. CFO has been simulated as percentage of subcarrier spacing of 15.625 kHz.





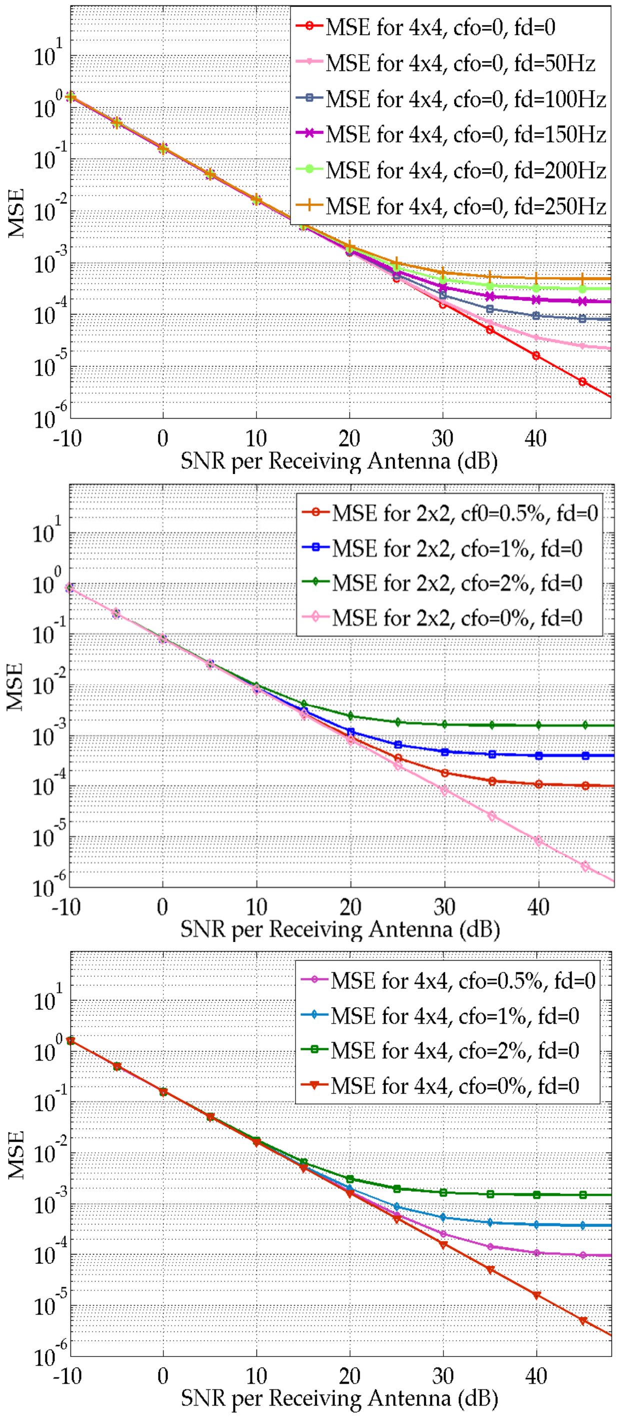


Figure 3. MSE Comparison of 2x2 and 4x4 MIMO-OFDM system

VI. CONCLUSION

The paper presents the technique for channel estimation for more than one transmit/receive antenna channels using one OFDM symbol. Proposed method provides the enhanced throughput capability with low overhead, especially with higher number of antennas. Simulation results show the performance of the algorithm. The performance can be improved further if M is kept lesser M_{max}. Performance improvement is achieved at the cost of throughput by increasing the number of OFDM symbols for estimation as more samples will then available for channel estimation.

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