AN IMPROVED CHANNEL ESTIMATION SCHEME IN CDD OFDM

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ABSTRACT

A low-complexity transmit diversity scheme for coded orthogonal frequency division multiplexing (OFDM) systems is cyclic delay diversity (CDD). As the cyclic delay value increases the diversity effect also increases. However the channel estimation becomes more difficult due to the increased frequency selectivity as the increased cyclic delay value. In this paper various channel estimation schemes are discussed and a novel pilot-aided channel estimation scheme is proposed, where the pilot code words are made orthogonal to estimate the channel in an improved manner.

KEYWORDS: cyclic delay diversity, frequency selectivity, channel estimation.

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I. INTRODUCTION

Recently, OFDM has been used as one of the core technologies for communication systems. Especially, OFDM has been adapted for various wireless communication systems such as wireless local area networks (WLANs), wireless metropolitan area networks (WMANs), digital audio broadcasting (DAB) and digital video broadcasting (DVB). OFDM is an attractive technique for achieving high data rate in wireless communication systems and is robust to the frequency selective fading channel.

In wireless communications, transmit diversity techniques can be used to increase the reliability of communication in a fading environment. Diversity refers to the various ways of transmitting the signal. There are three major diversity techniques in OFDM. They are, frequency diversity, time diversity, and spatial diversity. In spatial diversity we have transmitter diversity and receiver diversity. A simple transmit diversity scheme is 'delay diversity' (DD) where the same signal is transmitted from different antennas with different time delays. This helps the system to achieve diversity at reception. The DD technique converts the multiple-input-single-output (MISO) channel into single-input-single-output (SISO) channel with an increased number of paths. However introducing additional delay requires a long guard interval and it results in a reduction in bandwidth efficiency (Kaiser 2000). If the guard interval is not sufficiently long, the additional delay will cause inter-symbol interference (ISI).

To avoid these disadvantages of the delay diversity, cyclic delay diversity (CDD) is proposed (Kaiser 2000) where time delay is replaced by the cyclic delays. Therefore, multipath diversity is obtained. Hence it exploits the increased frequency selectivity at the receiver and frequency diversity is achieved by an appropriate channel coding. CDD does not suffer from rate loss for large number of antennas. The important thing is that, the cyclic delay value should be carefully chosen such that it would be larger than the maximum delay spread in order to eliminate the correlation between signals transmitted through each of the transmit antennas if the channel estimation is perfect. However, when the channel estimation is not perfect, the increased frequency selectivity of a channel due to cyclic delay value would cause more channel estimation errors.

One channel estimation approach for CDD-OFDM is direct estimation of the SISO-equivalent channel. But in a CDD-OFDM system, due to the increased frequency selectivity, the frequency response of the SISO-equivalent channel can vary significantly across adjacent subcarriers. Hence it is very difficult to obtain an accurate interpolation between the pilot subcarriers.

An alternate channel estimation approach for CDD-OFDM is based on the MISO model. Here each channel is estimated individually and then combined to obtain the equivalent estimated SISO channel. Here the Bayesian channel estimator is used at the pilot locations which results in an irreducible channel estimation mean square error as SNR is increased. These considerations motivated to design a new CDD-OFDM scheme where the pilot code words can be made orthogonal to achieve Cramer-Rao bound on the channel estimation error variance. And it is further improved by considering spatially correlated channel.

The rest of this paper is organized as follows. The system model is described in section II and the existing methods of CDD-OFDM channel estimation are discussed in

section III. And the new scheme for CDD-OFDM channel estimation and its performance over spatially correlated channel for two antennas is given in section IV. Simulation results are presented in section V and the conclusion is given in section VI.

II. SYSTEM MODEL

Consider a conventional CDD-OFDM with N_T transmit antennas each antenna introduces a different cyclic delay $\Delta_n, n = 1, \dots, N_T$ resulting in the following transmitted time domain signal from the nth antenna

$$x_t^{(n)} = x_{(t-\Delta_n)N} \; ; 0 \le t \le N-1 \qquad (1)$$

where, N is the FFT size. A cyclic delay by Δ_n samples in the time domain corresponds to the following phase shift at the ith subcarrier

$$\varphi_i^{(n)} = \frac{2\pi i \Delta_n}{N} \quad (2)$$

Hence, the ith frequency domain subcarrier is

$$x_t^{(n)} = \frac{1}{N} \sum_{i=0}^{N-1} X_i^{(n)} e^{\frac{j2\pi ti}{N}},$$

$$= \frac{1}{N} \sum_{i=0}^{N-1} X_i e^{-j\varphi_i^{(n)}} e^{\frac{j2\pi ti}{N}}. \qquad (3)$$

The frequency domain input-output relation for a MISO-OFDM system at the i-th subcarrier is $Y_i = \sum_{n=1}^{N_T} H_i^{(n)} X_i^{(n)} + N_i$. Where, Y_i , H_i and N_i are the received signal, the channel frequency response and noise at the i-

th subcarrier. The received symbol of the *i*-th can be expressed as,

$$Y_i = X_i \left(\sum_{n=1}^{N_T} H_i^{(n)} e^{-j\varphi_i^{(n)}} \right) + N_i ,$$

$$= X_i H_i^{equ} + N_i ; 0 \leq i \leq N - 1. \quad (4)$$

Where we define $H_i^{equ} = \sum_{n=1}^{N_T} H_i^{(n)} e^{-j\varphi_i^{(n)}}$ to be the SISO equivalent channel frequency response at the *i*-th subcarrier.

The corresponding time domain SISO equivalent channel of CDD-OFDM is (Auer 2004),

$$h^{equ}(\tau) = \sum_{n=1}^{N_T} \sum_{q=0}^{v} h_q^{(n)} . \delta \left(\tau - \tau_q^{(n)} \Delta_n T_{spl} \right)$$

(5)

Where $h_q^{(n)}$ and $\tau_q^{(n)}$ are the gain and time delay for the *q*-th tap of the CIR from the *n*-th transmit antenna and *v* is the channel memory normalized to the OFDM sampling period T_{spl}.

III. CONVENTIONAL CDD-OFDM CHANNEL ESTIMATION

Here we are considering the pilot assisted channel estimation scheme. We assume that each OFDM symbol has *P* equally spaced unit magnitude pilots at subcarriers $p(0), \dots, p(P-1)$, then by using equivalent model in (4), we calculate the SISO equivalent channel frequency response (CFR) at the pilot subcarrier location as follows

$$\hat{H}_{p(i)} = \frac{Y_{p(i)}}{X_{p(i)}} \quad 0 \leq i \leq P - 1. \quad (6)$$

These estimates are interpolated to obtain an estimate of entire equivalent CFR. Since the channel is highly frequency selective due to CDD effects, it is very difficult to obtain exact channel.

An alternative approach is based on the original MISO channel model. Assume that we have 2 antennas. 1st antenna transmitting the original version of the signal (Δ_1=0). The 2nd antenna transmitting the cyclically shifted version ($\Delta_2 \neq 0$) of the same signal. Consider *k*-th and *k+1*-th OFDM symbols as follows,

$$Y_i^k = X_i^k \left(H_i^{(1),k} + H_i^{(2),k} e^{-\frac{j2\pi i \Delta_2}{N}} \right) + N_i^k . \quad (7)$$

$$(Y_i^{k+1} = X_i^{k+1} \left(H_i^{(1),k+1} + H_i^{(2),k+1} e^{-\frac{j2\pi i \Delta_2}{N}} \right)$$

$$+ N_i^{k+1} . \quad (8)$$

Assume that the channel is fixed over 2 adjacent OFDM symbols. We have

$$H_i^{(n),k} = H_i^{(n),k+1} = H_i^{(n)} \, for \, n = 1,2.$$

Under this assumption we can write,

$$\begin{bmatrix} Y_i^k \\ Y_i^{k+1} \end{bmatrix} = \begin{bmatrix} X_i^k & X_i^k e^{-\frac{j2\pi i \Delta_2}{N}} \\ X_i^{k+1} & X_i^{k+1} e^{-\frac{j2\pi i \Delta_2}{N}} \end{bmatrix} \begin{bmatrix} H_i^k \\ H_i^{k+1} \end{bmatrix} +$$

$$\begin{bmatrix} N_i^k \\ N_i^{k+1} \end{bmatrix} . \quad (9)$$

In matrix form as

$$Y_i = X_i H_i + N_i . \quad (10)$$

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If the covariance matrix of H_i and N_i are known we can calculate the Bayesian minimum mean square error estimator of $H_i$as (Kay 1993),

$$\hat{H}_{i,BMMSE} = R_H X_i^H (X_i R_H X_i^H + R_N)^{-1} Y_i \quad (11)$$

where$R_N = \sigma_N^2 I_2$ is the noise covariance matrix and $R_H = I_2$ is the covariance matrix of unknown H_i. The error covariance matrix is given by (Kay 1993)

$$C_e = (R_H^{-1} + X_i^H R_N^{-1} X_i)^{-1} . \quad (12)$$

The MSE is given by,

$$MSE\left(\hat{H}_i^{(m)}\right) = [C_e]_{m,m} = \frac{\gamma+1}{2\gamma+1} . \quad (13)$$

where, $\gamma = |X_i^k|^2 + |X_i^{k+1}|^2 / \sigma_N^2$.The MSE of this channel estimator is lower bounded by ½ as SNR goes to infinity.

IV. THE NEW METHOD OF CHANNEL ESTIMATION

Consider the original MISO channel. Assume that we have 2 antennas.

1st antenna transmitting the original version of the signal ($\Delta_1 = 0$) and the 2nd antenna transmitting a cyclically shifted version of the signal by providing shift of Δ_2 for kth symbol andΔ_2' for $k+1$-th symbol. Thus

$$Y_i^k = X_i^k \left(H_i^{(1),k} + H_i^{(2),k} e^{-\frac{j2\pi i\Delta_2}{N}}\right) + N_i^k$$

$$Y_i^{k+1} =$$

$$X_i^{k+1} \left(H_i^{(1),k+1} + H_i^{(2),k+1} e^{-\frac{j2\pi i\Delta_2'}{N}}\right) +$$
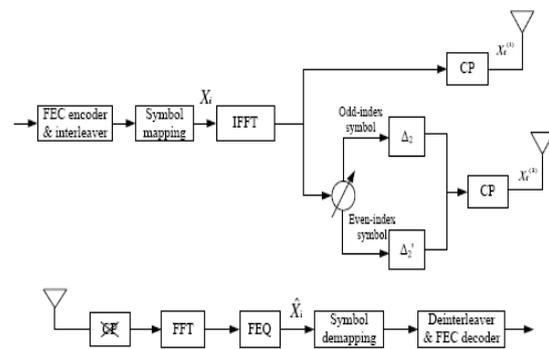
$$N_i^{k+1} \quad (14)$$

Fig 1.CDD OFDM transmitter and receiver with improved channel estimation.

The pilot codeword can be replaced by

$$X_i = \begin{bmatrix} X_i^k & X_i^k e^{-\frac{j2\pi i\Delta_2}{N}} \\ X_i^{k+1} & X_i^{k+1} e^{-\frac{j2\pi i\Delta_2'}{N}} \end{bmatrix} \quad (15)$$

The optimal choice for X_i is to make it orthogonal at pilot locations. That is, $X_i^H X_i = 2E_s I_2$. If this can be achieved, the efficient channel estimator is given by (Kay 1993),

$$\hat{H}_i = (X_i^H R_N^{-1} X_i)^{-1} X_i^H R_N^{-1} = \frac{1}{2E_s} X_i^H Y_i \quad (16)$$

It further reduce the channel estimation MSE to, $\frac{1}{\gamma+1}$. From (15) the orthogonality condition implies that,

$$E_s e^{-\frac{j2\pi p(i)\Delta_2}{N}} + E_s e^{-\frac{j2\pi p(i)\Delta_2'}{N}} = 0 \quad (17)$$

Hence the delay values must be set to satisfy the following $\Delta_2' - \Delta_2 = N/2\delta_0$ we must set $\Delta_2 \geq \Delta_1 + v$. And set Δ_2' as $d/2r$. r can be any range from 1 and $d/2$. And d must be selected such that $d \leq 1/K\tau_{max}\Delta_f$. where $\tau_{max} = vT_{spl}$ and Δ_f is subcarrier spacing in frequency domain. Where, K is constant.

V. SIMULATION RESULTS

We evaluate the performance of the new channel estimation scheme by taking N=64 subcarriers. We first compare the performance of MISO channel using conventional and proposed channel estimation methods. The simulation was conducted under the following conditions.

Table.1. Simulation parameters

No of carriers	64
No of OFDM symbols	100
No of pilot carriers	8
Coder	Convolutional coder
Interleaver	Matrix interleaver
Mapping	QPSK
Channel Estimation	Pilot Assisted Channel Estimation
No of Transmit Antennas	2

We first compare the MSE performance of channel estimation using conventional CDD OFDM and proposed CDD OFDM. The MSE is based on the estimated coefficients at pilot carrier locations. From Fig 2 we can conclude that, the channel estimation MSE of the proposed method is better than the conventional method using LS estimation.

It can be seen from the Fig 3 that, the MSE of the Bayesian estimator for the conventional CDD OFDM has a floor of ½. By making the pilot code words orthogonal, our proposed scheme eliminates this MSE floor.
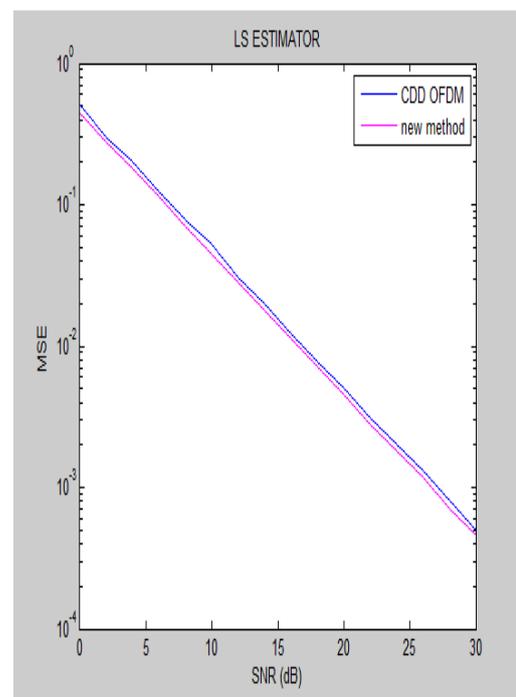

Fig 2.MSE performance of 2 TX CDD OFDM and the proposed method with estimated channel (LS) information.
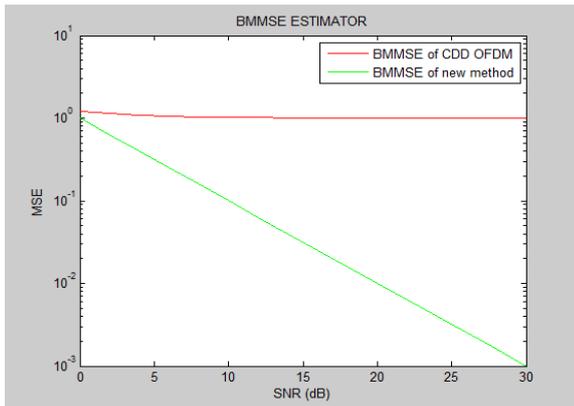
Fig 3. MSE performance of 2 TX CDD OFDM and the proposed method with estimated channel (BMMSE) information.

Fig 4 compares the BER performance of the original OFDM, conventional CDD OFDM and the proposed CDD OFDM. It can be seen that, our proposed scheme has improved performance than the other two methods.
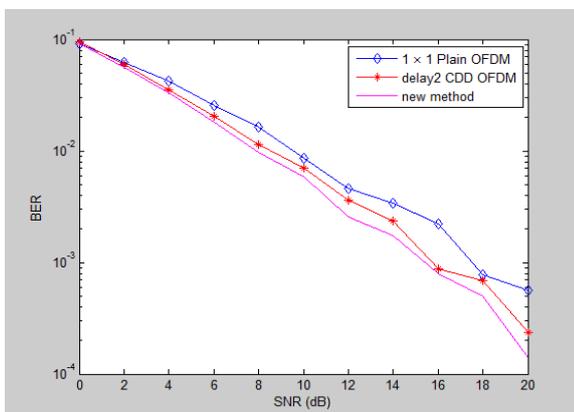

Fig 4.BER comparison between CDD OFDM and single transmitter OFDM & the proposed CDD OFDM.

VI. CONCLUSION

In this paper, various channel estimation methods are analyzed and a novel pilot-aided channel estimation scheme is proposed for CDD-OFDM which guarantees that the space-time pilot matrix is orthogonal to achieve the lowest channel estimation error variance for any number of transmit antennas. Based on the original MISO model, our scheme estimates each channel individually and achieves significant performance improvement compared to the schemes that estimate the equivalent SISO channel which exhibits more severe frequency selectivity

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