Simple Channel Estimation Techniques Based on Pilot-Assistance for STBC-Based MIMO-OFDM Systems

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***Abstract*: With equipping multiple antennas at both transmitter and receiver ends, the signals in the wireless OFDM systems could be transmitted over multipath fading channels for achieving benefits and high flexibility. In this paper, we focus on MIMO-OFDM systems that simultaneously perform channel estimation in order to combat additive noise, and multipath fading. The performance improvement is confirmed by simulations. Results show that the proposed MIMO-OFDM scheme is quite robust in practical environments.**

Keywords: Space–time block coder (STBC), MIMO-OFDM systems, channel estimation

I. INTRODUCTION

Wireless systems have many advantages over its wired counterpart. However, the main difficulty of the wireless channel is multipath fading. Fading is interference caused by sum of two or more form of the transmitted signal. The combined signal arrives at the receiver antenna at slightly different times. This signal can vary widely in amplitude and phase. OFDM (Orthogonal Frequency Division Multiplexing) is a multi-carrier modulation scheme that has gained considerable popularity over the past decade because of its ability to combat frequency-selective fading normally encountered in a multi-path wireless environment. OFDM converts the frequency selective channel into flat-fading sub-channels, there by significantly reducing the receiver complexity by eliminating the need for using equalization at the receiver [1]. MIMO (Multiple Input Multiple Output) systems were introduced in [2, 3]. Under certain conditions [3], the capacity of MIMO systems is shown to increase linearly with min$\{N_T , N_R\}$ where N_T and N_R are the number of antennas at the transmitter and the receiver, respectively.

MIMO-OFDM systems provide performance gains because they combine the diversity and multiplexing gains of MIMO with the resilience of OFDM against multi-path fading. In order to achieve these performance improvements, accurate CSI (Channel State Information) is required at the receiver which is obtained via channel estimation. A number of different pilot assisted methods have been proposed in the literature to estimate the channel, such as [4-6].

This paper proposes a pilot-symbol-assisted channel estimation technique for MIMO 2×2 architecture by assigning on-off pilot symbols between different transmitting antennas. The mixed transmitted signals could be completely separated at the receiver end. Results from simulation shows that the overall system performance is able to be further enhanced.

The paper is organized as follows: firstly, a brief description of the system is provided in Section II. The direct inserted and extracted pilot method is shown in section III. Simulation results are presented in section IV. Finally section V provides a short discussion and conclusions.

II. SYSTEM DESCRIPTION

Fig. 1 shows the model of STBC MIMO-OFDM system. The input of the system is a serial of binary data, mapped onto the *M-ary* QAM signal constellation to give a stream of complex symbols assumed statistically independent. This complex symbol stream came to the STBC encoder to be separated into two independence signals, assume $t_1(t)$ and $t_2(t)$. Each $t_i(t)$ signal is applied to OFDM modulation block. In the OFDM block, the stream is serial-to-parallel converted to produce a^n sequence $c_{i,k}$ with i=1,2. $c_{i,k}$ is transformed by a inverse fast Fourier transform (IFFT) unit. A guard interval called cyclic prefix (CP) with length T_g is added to this signal, yielding a T-spaced discrete-time representation of the transmitted signal. The n^{th} transmitted OFDM block is given by:

$$s_{i,n}(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} c_{i,k} \phi_n (t - nT) \quad (1)$$

Where

$$\phi_{i,k}(t) = \begin{cases} \exp(j \cdot 2\pi \cdot f_k \cdot t), & \forall t \in [-T_g, T] \\ 0 & \text{othersiwe} \end{cases} \quad (2)$$

Where N is the number of the subcarriers. $f_k = f_0 + \frac{k}{T_u}$ and $f_0 = 0$,i=1,2 .

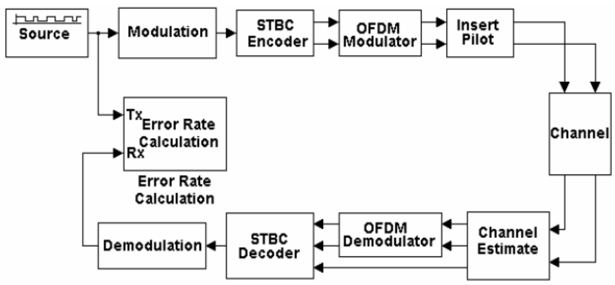

Figure. 1. STBC MIMO-OFDM system with pilot-aided method

If the signal $s(t) = A\cos 2\pi f_c t$ is transmitted over a multipath fading channel, the output is given by:

$$y(t) = A\sum_{i=1}^{N} a_i \cos(2\pi f_c t + \theta_i) + n(t) \quad (3)$$

Where a_i is the attenuation and θ_i is the phase shift of the i^{th} multipath component. We know that a_i and θ_i are random variable. $n(t)$ is complex additive white Gaussian noise with two-sided spectral density $N_0 / 2$.

If N is large, the received signal can be rewritten as:

$$y(t) = AR(t)\cos(2\pi f_c t + \theta(t)) + n(t) \quad (4)$$

where $R(t)$ has a Rayleigh distribution.

The amplitude distortion R(t) can severely degrade performance of wireless systems operating in a fading channel. The relation between the Signal to Noise Ratio (SNR) and Bit Error Rate (BER) in the cases that the channel affected by Additive White Gaussian Noise (AWGN) and fading plus AWGN show clearly how the BER be degraded by fading distortion.

At the receiver, the received signal is passed through a receiver filter and then sampled. The data samples are serial to parallel converted, and applied to the remove guard and FFT processor. The guard interval is removed and only the data in the time interval $[0, T]$ is employed and the output signal is converted back to a serial data sequence and demodulated.

III. CHANNEL ESTIMATION

For a 2×2 STBC system, the channel at time t can be modelled with assumption that fading is constant across two consecutive symbols as:

$$h_i(t) = h_i(t+T) = \alpha_i e^{j\theta_i} \quad i = 0,1,2,3 \quad (5)$$

where T is the symbol duration.

STC proposed by Alamouti [7] can be expressed as shown in Table 1:

TABLE 1. Transmitted and received signal at antennas

	Antenna 0	Antenna 1	Antenna Rx 0	Antenna Rx 1
Time t	s_0	s_1	r_0	r_2
Time $t+T$	$-s_1^*$	s_0^*	r_1	r_3

The received signal at the two receives antennas can be expressed as:

$$
\begin{aligned}
r_0 &= h_0 s_0 + h_1 s_1 + n_0 \\
r_1 &= -h_0 s_1^* + h_1 s_0^* + n_1 \\
r_2 &= h_2 s_0 + h_3 s_1 + n_2 \\
r_3 &= -h_2 s_1^* + h_3 s_0^* + n_3
\end{aligned} \tag{6}
$$

where n_i (i=0, 1, 2, 3) are AWGN noises.

The principle of our channel estimation technique using on-off pilot is shown in Fig. 2. In the OFDM modulation, at first, a fixed number of pilots are introduced into the data frame. In first branch, two on-off pilot symbols [p 0] were inserted in pilot frame. Similarly, we have the pilot [0 -p*] in the second branch. The on-off condition shows that there is only one channel parameter can be received at receiver at one time. The ratio between the numbers of pilot and numbers of data symbol depend on the channel conditional. In our work, we used two pilots per eight data symbols in transmitted frame. At the ODFM demodulation block, this noisy pilot bit is spitted and fed to channel estimation block in order to determine the information about the channel characteristics.

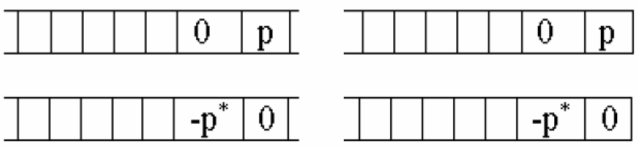

Figure. 2. Channel estimation using on-off pilot

In the receiver, we can obtain the signal at the two antennas as:

$$
\begin{aligned}
p_0 &= h_1 p + n_0 \\
p_1 &= -h_0 p^* + n_1 \\
p_2 &= h_3 p + n_2 \\
p_3 &= -h_2 p^* + n_3
\end{aligned} \tag{7}
$$

Thus, we can simply estimate the channel parameters as:

$$
\widehat{h}_0 \approx -\frac{p_1}{p^*} \quad \widehat{h}_1 \approx \frac{p_0}{p} \quad \widehat{h}_2 \approx -\frac{p_3}{p^*} \quad \widehat{h}_3 \approx \frac{p_2}{p} \tag{8}
$$

In the simplest case, we choose $p = 1+0i$, we can rewrite the Equ. (8) as:

$$
\widehat{h}_0 = -p_1 \quad \widehat{h}_1 = p_0 \quad \widehat{h}_2 = -p_3 \quad \widehat{h}_3 = p_2 \tag{9}
$$

with assumption that noise and pilots are not correlative.

Consequently, we have the channel state information to be used in Space–time block decoder.

IV. SIMULATION RESULTS

The simulations are carried out for a OFDM system with 144 subscribers and 16-ary QAM constellation on each sub-carrier. The bandwidth of the system is 18 MHz and the FFT-length is 64. The fading channel is characterized by the maximum Doppler shift of 113 Hz, five paths with the delay vector [0 1e^{-9} 2e^{-9} 1.2e^{-9} 4e^{-9}] (in seconds) and with the vector gain [0 -5 -3 -2 -3.5] (in dB) [8]. Perfect time synchronization is assumed.

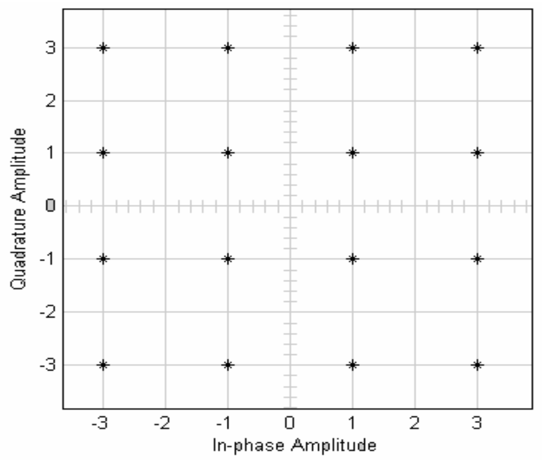

Figure 3. Received 16-ary QAM constellation without any impairment

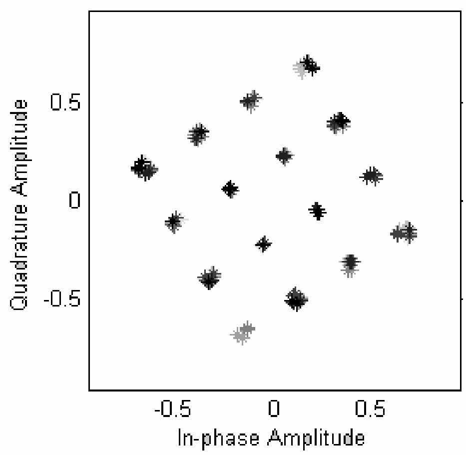

Figure 4. A snap shot of the received 16- QAM constellation with multipath fading

The effects of impairments on the received 16-ary QAM constellations are illustrated in Figs. 3, 4 and 5, which correspond to the ideal situation (noiseless and without ISI), fading plus AWGN, and fading plus AWGN with pilot assistance. In the ideal case, there are 16 well-defined points. In presence of impairments, the received cloud is due to AWGN and the fading phenomenon.

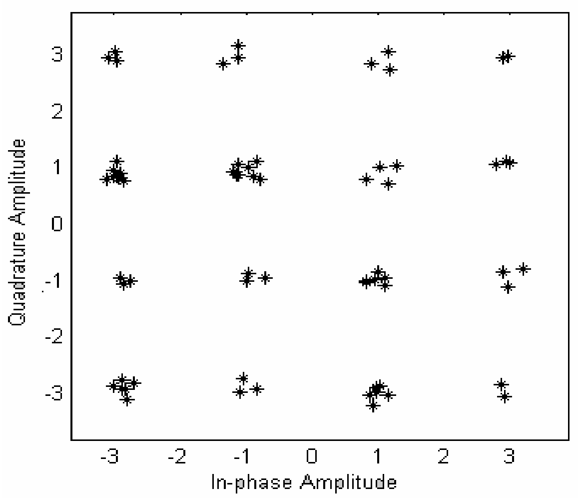

Figure. 5. Received 16-ary QAM constellation with AWGN plus multipath fading after the Equalizer block

The BER in term of SNR, varying between 0 and 10 dB of this model is shown in Fig. 6 within 4 cases listed in Table 2. The BER performance of the proposed system is evaluated using the Monte-Carlo method.

TABLE 2. Four schemes in the proposed OFDM system

Scheme No.	Impairments	Compensation method
1	Rayleigh + AWGN noise	No- EQ in SISO system
2	Rayleigh + AWGN noise	EQ in SISO system
3	Rayleigh + AWGN noise	No- EQ in MIMO system
4	Rayleigh + AWGN noise	EQ in MIMO system

The curves show the connection between BER and SNR in four scenarios respectively. Comparing the results of the 1st scenario versus the 2nd, the serious influence of the fading is evidenced. By using the pilot-assisted channel estimation, the scheme (2) had over 6 dB higher SNR gain at the BER of 10^{-2} than the existing schemes (4).

Comparing the results between the SISO and MIMO systems, it is evidenced that MIMO-OFDM systems can improve the BER performance in both two cases: with pilot-assistance or without pilot-assistance. With the pilot insertion method, MIMO OFDM system had over 3 dB higher SNR gain at the BER of 10^{-5} than the existing SISO system.

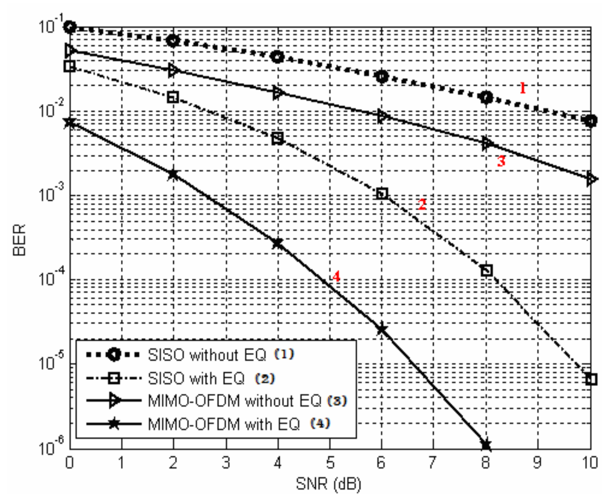

Figure. 6. The plot of BER vs SNR of four scenarios

V. CONCLUSIONS

Wireless communication networks often require high quality of sound and the high rate. Moreover, the physical size of mobile devices becomes smaller and their performance needs to be robust in various environments. The inherent problem of fading is always a major impairment of the wireless communication channel. In this paper, the simple and effective method are proposed to estimate CSI over multipath fading channel. Results show that this simple technique tremendously enhances the performance of the compensated system. The scheme proposed in this paper in shown to enjoy the effect.

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