MIMO-OFDM with Pilot-Aided Channel Estimation for WiMax Systems

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Abstract— **This paper describes a channel estimation scheme for Multiple Input Multiple Output (MIMO)-Orthogonal Frequency Division Multiplexing (OFDM) systems based on training sequence. We first develop an approach to channel estimation which is crucial for the decoding of the transmitted data. We then discuss the implementation of the proposed method for WiMax systems under various channel conditions. The efficiency of the new algorithm is demonstrated through the simulation of the MIMO-OFDM system for two and four transmit antennas and different number of receive antennas. The Space-Time Coding with 192 information subcarriers per codeword is used as defined in the WiMax standard. Through simulations, it is shown that the proposed method has between 1.5 dB and 2dB loss compared to the ideal case where the channel coefficients are known at the receiver. In summary, with the proposed channel estimation technique, combining diversity using Space-Time Codes with OFDM is proved to be a promising technique for the present and future wireless communications.**

Keywords- Othogonal Frequency Division Multiplexing (OFDM); Multiple Input Multiple Output (MIMO); WiMax; channel estimation; Space-Time Codes.

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a technique that has attracted a lot of attention to achieve higher data rate over wireless channels. The principal reasons that OFDM is widely studied, is its design simplicity and its particularity to resist against frequency selective channels by dividing the entire channel into many narrow parallel subchannels which thereby reduce Inter-Symbol Interference (ISI). Combination of Multiple Input Multiple Output (MIMO) wireless communication systems with OFDM has gained considerable interest and seems to be a promising technique for future wireless communications [1, 2]. However, such systems require the knowledge of the Channel State Information (CSI) at the receiver.

CSI must be known at the receiver side in order to recover the transmitted data. CSI can be obtained in different ways; one is called pilot-aided channel estimation [3] and is based on training symbols which are known at the receiver and transmitted as a preamble at the beginning of each data frame, whereas the other is blind and relies on the exploitation of the statistical information of the received symbols [4]. Compared to pilot-aided channel estimation, blind technique is limited to slow time varying channel and generates higher complexity at the receiver. As a result, this paper is mainly focused on pilot-aided channel estimation.

In the previous literature many techniques have been proposed to estimate the channel parameters of MIMO-OFDM systems [5-8]. In such systems, a complete OFDM frame composed of training symbols is first sent in order to estimate the channel parameters. The channel is therefore assumed constant for the next OFDM blocks until a new estimation is performed. In fast fading environment, performances degradation would be noticed due to the outdated channel estimation. As a matter of fact, estimation performed in time domain would be more appropriate as impulse response contains fewer parameters than frequency response.

In an OFDM system such as WiMax, the training data has to be sent on selected tones called pilot tones, which are defined in the WiMax standard [9]. The question then arises that which tone is used in order to have simple and accurate channel estimation at the receiver.

In this paper, a separated channel estimation technique is presented, where first, CSI is estimated and used to recover an entire OFDM frame. Based on the previous work done in [10] for MIMO-STBC system, the algorithm has been improved in order for the channel to be estimated and used to decode data of a MIMO-OFDM system. One of the pilot tone defined in [9] is used in order to estimate the channel. Simulations were realised for two and four transmit antennas and a different number of receive antennas. In addition, the algorithm has been simulated for different positions of the training data in the pilot tones according to the definition of 802.16 standard, and under different channel conditions defined in the Stanford University Interim (SUI) channels models.

The rest of the paper is organised as follows. Section II describes the simulated system. Section III provides a simple estimator that uses pilot sequence to estimate the channel coefficients. Section IV evaluates the performances of the systems achieved through spatial diversity at the receiver with two and four antennas at the transmitter under different SUI channel models. Section V introduces a discussion of the results and future work is presented. Finally, section VI summarizes the paper.

II. SYSTEM MODEL

The system under consideration can be found in Figure 1, which is a simplified block diagram for two transmit and one receive antenna. In this paper, derivations of the channel estimation technique are given assuming two transmit and one receive antenna, however, the algorithm given in section III can

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easily be extended to higher number of transmit and receive antenna.

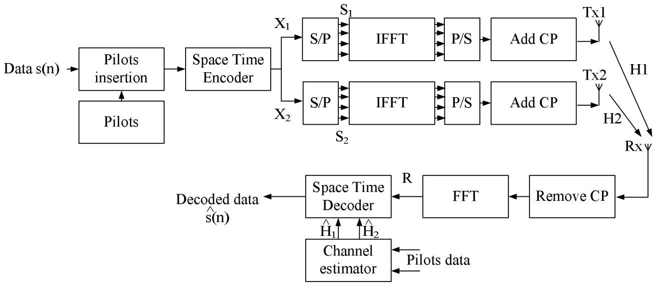

Figure 1. A block diagram of the MIMO-OFDM system

Random modulated data symbols are generated and pilot sequence known at the receiver is first added to the original frame which is then encoded with the help of the space-time encoder. Next, data are modulated by an Inverse Fast Fourier Transform (IFFT) and the output of the modulator can be expressed as:

$$x^t_{i,n} = \frac{1}{\sqrt{K}} \sum_{k=1}^{K} X^t_{i,k} e^{j2\pi kn/K} \quad ,i = 1,2,...,n_t \tag{1}$$

where, n_t is the number of transmit antennas, i and t represent the signal at the i-th antenna and at the t-th symbol period. K denotes the number of subcarrier used and defined as 192 in [9]. Moreover, $X^t_{i,k}$ and $x^t_{i,n}$ represent the coded symbol at the k-th subcarrier and the corresponding time-domain sample at the n-th moment, respectively.

The last operation before transmitting is the addition of the cyclic prefix which will be assumed longer than the delay spread of the channel in order to avoid any Inter Symbol Interference (ISI).

By assuming quasi-static fading during the transmission of an OFDM frame and the cyclic prefix longer than the largest delay spread of the multipath channel, the FFT output at the receiver can be expressed as:

$$R^t_{j,k} = \sum_{i=1}^{n_t} H^{t,j}_{i,k} X^t_{i,k} + W^t_{j,k} \tag{2}$$

where $H^{t,j}_{i,k}$ is the channel frequency response for the path from the i-th transmit antenna to the j-th receive antenna on the k-th OFDM sub-channel, and $W^t_{j,k}$ represents the OFDM demodulation output for the noise sample at the j-th receive antenna and at the k-th sub-channel with variance W_0.

Finally, the demodulated data signal is decoded by a space time decoder, which in presence of CSI applies the maximum likelihood (ML) decision such as given in equation (3).

$$\tilde{s}_t = \underset{\hat{X}}{\arg\min} \sum_{j=1}^{n_R} \sum_{k=1}^{K} \left| R^t_{j,k} - \sum_{i=1}^{n_t} H^{t,j}_{i,k} X^t_{i,k} \right|^2 \tag{3}$$

where n_r is the number of receive antennas and the minimization is performed over all possible space-time codewords of the transmission. Since channel estimation is the main concern in this paper, and because the following derivations are for two transmit and one receive antenna, that is, n_t=2 and n_r=1, index j will be omitted for the rest of the paper for clarity convenience.

III. PROPOSED ALGORITHM

As described in the previous section, data are encoded through space and time with the help of the space time encoder. Therefore, each antenna is fed with a stream including guard intervals (g), pilots (p) and data (s) as defined in [9] and shown in Fig.2. The stream can be expressed as:

$$X_1 = [g_1,...,g_{27}, s_1, -s^*_2, s_3, -s^*_4,..., p_1, -p^*_2,..., s_{2N-1}, -s^*_{2N}, g_{28},..., g_{56}] \tag{4}$$

$$X_2 = [g_1,...,g_{27}, s_2, s^*_1, s_4, s^*_3,..., p_2, p^*_1,..., s_{2N}, s^*_{2N-1}, g_{28},..., g_{56}] \tag{5}$$

where X_i is representing the data frame at antenna i=1, 2 before the IFFT operation and N is representing the total number of subcarrier transmitted at a time t by one antenna. This number N includes the number of nonpilot subcarrier (data) only which therefore, as defined in the standard [9], is equal to 192. Then, cyclic prefix larger than the delay spread of the channel is added to each stream.

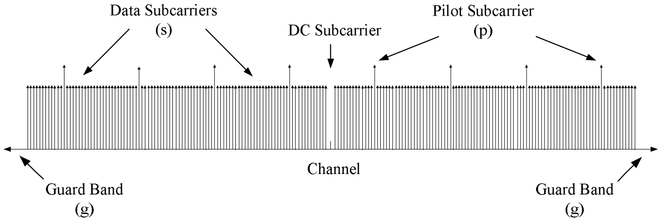

Figure 2. OFDM frame description

Data are encoded according to space, time and subcarrier, therefore by looking at the frame transmission at antenna 1, encoded data can be found as in Table I for antenna 1.

TABLE I
ENCODED DATA ACCORDING TO TIME AND SUBCARRIER

Subcarrier / Time	1	2	K
t	s_1	s_3	s_{2K-1}
t+T	$-s^*_2$	$-s^*_4$	$-s^*_{2K}$

Given Table 1 and assuming $H^t_{i,k} = H^{t+T}_{i,k}$ the received equation at the FFT output, for the simple case of two transmit and one receive antenna can be expressed as:

$$R^t_k = H^t_{1,k} S^t_{1,k} + H^t_{2,k} S^t_{2,k} + W^t_k \tag{6}$$

where R^t_k , $S^t_{i,k}$ and W^t_k are the received symbols, transmitted vector symbols and the Gaussian noise sample respectively; t refers to the t-th symbol period and k to the k-th subcarrier as stated previously.

In addition, $S^t_{1,k}$ and $S^t_{2,k}$ are the vector given after the serial to parallel operation at the transmit antennas 1 and 2 respectively and given for the time t and t+T by the following equations:

$$S^t_{1,k} = [s_1 \;\; s_3, \ldots, s_{21}, p_1, \ldots, s_{2K-1}] \tag{7}$$

$$S^{t+T}_{1,k} = [-s_2^* - s_4^*, \ldots, -s_{22}^*, -p_2^*, \ldots, -s_{2K}^*] \tag{8}$$

$$S^t_{2,k} = [s_2 \;\; s_4, \ldots, s_{22}, p_2, \ldots, s_{2K}] \tag{9}$$

$$S^{t+T}_{2,k} = [s_1^* \;\; s_3^*, \ldots, s_{21}^*, p_1^*, \ldots, s_{2K-1}^*] \tag{10}$$

where p_i represent the training signal from the i-th transmit antenna. As only one tone of the pilot subcarrier is used, others are filled with zeros in order to respect the frame format presented in Fig. 2. In the standard, pilots positions are defined as subcarriers 13, 38, 63 88,114, 139, 164 and 189. Moreover, the total number of subcarrier used including pilot tones is 200.

At the receiver, the signal is first demodulated by an FFT and then data are recovered by the space time decoder. For an ideal transmission where the channel is known at the receiver and according to the equations given in [11] for single carrier system, it can be derived for multicarrier:

$$\tilde{S}_{i,k} = H^*_{1,k} r^t_k + H_{2,k} (r^{t+T}_k)^* \tag{11}$$

$$\tilde{S}_{i+1,k} = H^*_{2,k} r^t_k - H_{1,k} (r^{t+T}_k)^* \tag{12}$$

with k=1, 2, ...,K, representing the symbol number, i represent the i-th transmit antenna and $\tilde{S}$ is the decoded signal.

In pilot aided channel estimation, pilots are first transmitted in order to estimate the channel. Here, we propose a new method where channel is first estimated using pilots inserted in the frame. Once the channel is estimated, equations (11) and (12) are used to decode the transmitted symbol by replacing H_1 and H_2 by the estimated ones. Thus, the two received pilot symbols and the corresponding training symbol of each antenna are used to estimate H_1 and H_2.

In order to estimate the channel, pilot symbols are extracted from the received frame. Therefore, assuming $H^t_{i,n} = H^{t+1}_{i,n}$, two vectors results of this extraction, one receive data vector and one receive training symbols vector described as R^t_k and Rp^t_n given by equations (6) and (13) respectively.

$$Rp^t_n = H^t_{1,n} P^t_{1,n} + H^t_{2,n} P^t_{2,n} + W^t_n \tag{13}$$

where $P^t_{i,n}$ corresponds to the transmitted pilot vector from i-th antenna and n=1,…8 corresponds to the pilot subcarrier number in the pilot vector. The value of n is limited to 8 as 8 pilot subcarriers have been defined in the standard. Pilot vectors for antennas, 1 and 2 are given below for time t and t+1.

$$P^t_{1,n} = [p_1 \;\; p_3, \ldots, p_{15}] \tag{14}$$

$$P^{t+T}_{1,n} = [-p_2^* - p_4^*, \ldots, -p_{16}^*] \tag{15}$$

$$P^t_{2,n} = [p_2 \;\; p_4, \ldots, p_{16}] \tag{16}$$

$$P^{t+T}_{2,n} = [p_1^* \;\; p_3^*, \ldots, p_{15}^*] \tag{17}$$

The proposed equations for channel estimation can be found in equations (18) and (19).

$$\hat{H}^t_{1,n} = \frac{Rp^t_n P^*_{1,n} - Rp^{t+T}_n P_{2,n}}{\left|P_{1,n}\right|^2 + \left|P_{2,n}\right|^2} \tag{18}$$

$$\hat{H}^t_{2,n} = \frac{Rp^t_n P^*_{2,n} + Rp^{t+T}_n P_{1,n}}{\left|P_{1,n}\right|^2 + \left|P_{2,n}\right|^2} \tag{19}$$

Therefore, as mentioned above, the estimated channel coefficients are used in equations (11) and (12) to recover the transmitted data.

By replacing H_1 and H_2 equations (11) and (12) by $\hat{H}_1$ and $\hat{H}_2$ in equations (18) and (19), it can be deduced:

$$\tilde{S}_{i,k} = \hat{H}^*_{1,k} r^t_k + \hat{H}_{2,k} (r^{t+T}_k)^* \tag{20}$$

$$\tilde{S}_{i+1,k} = \hat{H}^*_{2,k} r^t_k - \hat{H}_{1,k} (r^{t+T}_k)^* \tag{21}$$

As the equations (20) and (21) describe, the estimation of the channel $\hat{H}_1$ and $\hat{H}_2$ is used in order to recover all the data of the transmitted OFDM block.

As it can be noticed from the previous derivations, this method is very simple and therefore is cost and computation effective. Indeed, it is computation effective because the channel is only estimated once to decode the entire OFDM block and because, at the receiver, the proposed technique does not require any matrix inversion in order for the channel to be estimated. The proposed algorithm is also cost effective as only the modulated pilot needs to be added to the transmitted frame.

IV. SIMULATION RESULTS

The performances of the proposed channel estimation technique for WiMax are evaluated by computer simulation for fixed wireless communications. Simulations were realized for two and four transmit antennas and different numbers of receive antennas.

According to the SUI channel definition, 3 taps have been simulated for the cases of SUI1 and SUI3. The number of subcarriers used was 192 for the data and one of the pilot tones per OFDM block was used for the training parameter. Indeed, according to the WiMax standard, 8 pilot tones are available but for the proposed algorithm, only one is required; therefore, simulations were made for each pilot tone position defined in the standard.

To make the tones orthogonal to each other, symbol duration of 186 µs was used with an addition of 46µs for the guard interval. Finally, a channel bandwidth of 1.5MHz was defined. Simulations presented in this paper were realized with a 64-QAM modulation but the proposed method can be used for any modulation such as M-PSK or M-QAM.

Simulation results are presented in the following in term of Bit Error Rate (BER) versus Signal to Noise Ratio (SNR).

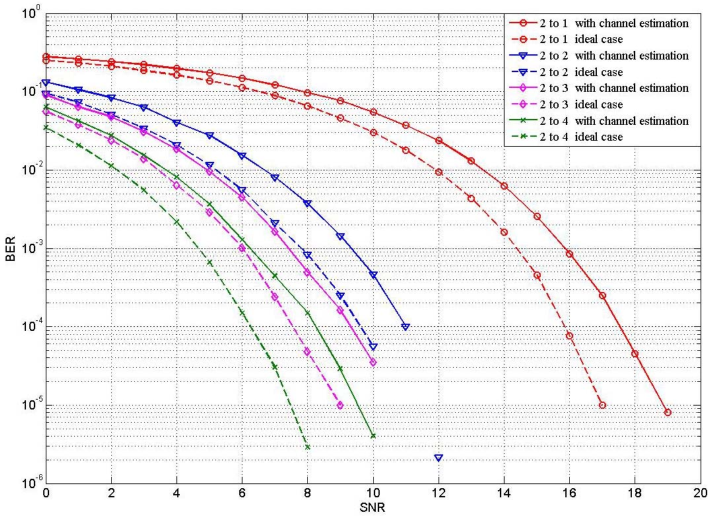

Figure 2. Results of the MIMO-OFDM system with two transmit antennas and 64-QAM under SUI1channel

From Figures 3 and 4, it can be seen that higher number of receive antenna gives better BER for the same value of SNR. Moreover, performances under SUI1 channel are better than the corresponding ones under SUI3 channel which is due to the difference in the delay spread of the channel.

It can be noticed from the two figures that, a loss of 1.5dB to 2dB occurred between the ideal case where the channel is known at the receiver and the proposed channel estimation algorithm.

Figures 5 and 6 show the performances of the proposed channel estimation technique for four transmit antennas and one to four receive antennas under SUI1 and SUI3 channel for 64-QAM. Conclusions similar to the two transmit antenna cases can be drawn. Indeed, from Figures 5 and 6 we can see that the BER difference at the same SNR is between 1.5dB and 2dB and the performances are better under SUI1 than SUI3. Moreover, as always for MIMO systems, higher number of antennas provides better results; performances for four transmit antenna are better than those for two transmit antennas.

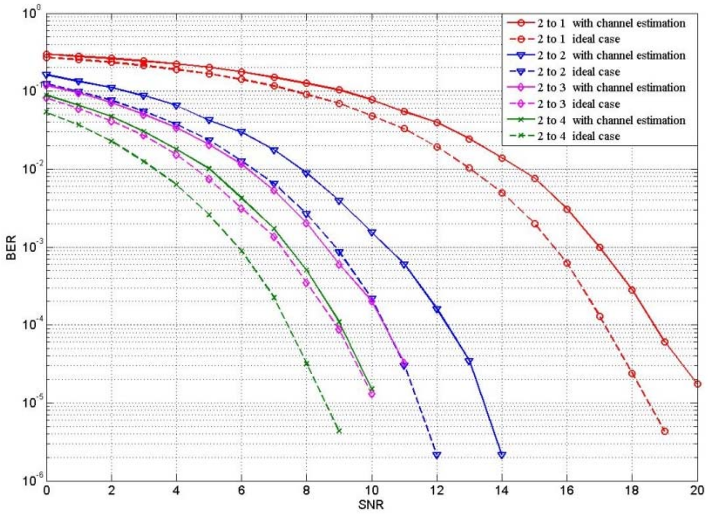

Figure 2. Results of the MIMO-OFDM system with two transmit antennas and 64-QAM under SUI3channel

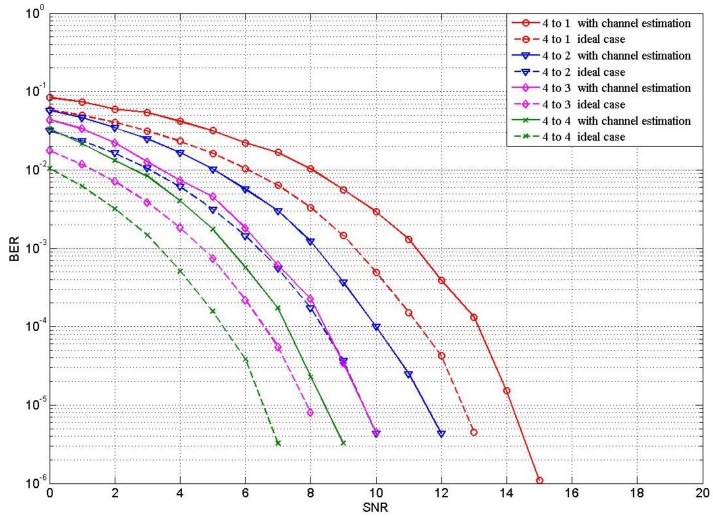

Figure 3. Results of the MIMO-OFDM system with four transmit antennas and 64-QAM under SUI1channel

More simulations have been conducted for different modulation schemes but are not presented here. It has been observed through different simulations for two and four transmit antennas that the error between the ideal case and the proposed technique reduces for lower order modulation and increases for higher order modulation, as expected.

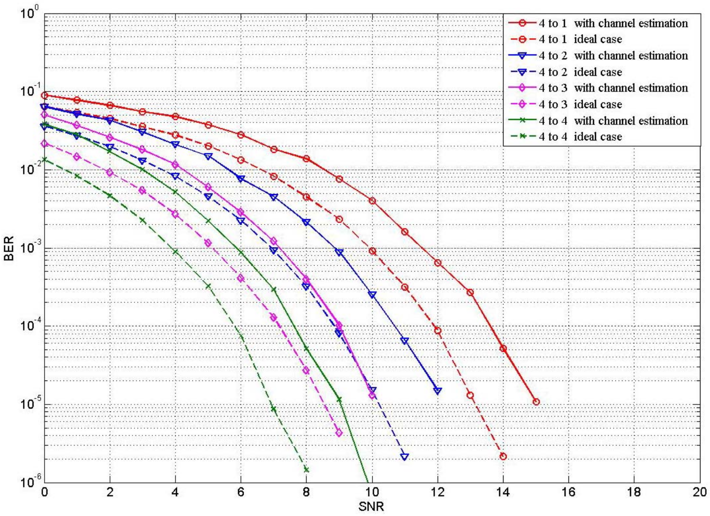

Figure 3. Results of the MIMO-OFDM system with four transmit antennas and 64-QAM under SUI3channel

We have also carried out simulations for different positions, the training symbols were assigned on the 8 defined pilot tones of the 802.16 standard, but found that the obtained results were similar.

V. ANALYSIS AND DISCUSSION

In Section IV, simulation results were proposed for different case scenarios. Higher order modulation and higher number of antenna at either the transmitter or the receiver can be used to enhance the system performances. However, these would increase the algorithm complexity and computation.

The proposed channel estimation technique has been simulated in this paper for WiMax system, but it can be applied to any MIMO-OFDM system. Indeed, the algorithm can also be for other MIMO systems and under other channel models. The method has been proven to be very simple and of low computation as matrix inversion is not required at the receiver as other methods normally do. Our investigation has now turned to systems under mobile wireless channel, such as mobile WiMax and LTE.

VI. CONCLUSION

In this paper, a channel estimation technique for MIMO-OFDM system and particularly for WiMax system has been proposed, which is crucial to decode the space time codes. The technique is simple and requires low computation as no matrix inversion is required at the receiver. The overall performance of the algorithm has been evaluated by computer simulations. For MIMO-OFDM systems using two or four transmit antennas, an error of only 1.5dB to 2dB has been noticed under different SUI channel conditions. Through simulations, we have found that the technique has achieved good performance for all SUI channels and for any pilot position in the data frame.

REFERENCES

[1] A. Ghosh, D. R. Wolter, J. G. Andrews, and R. Chen, "Broadband wireless access with WiMax/802.16: current performance benchmarks and future potential," *IEEE Communications Magazine ,* vol. 43, pp. 129-136, 2005.

[2] W. Fan, A. Ghosh, C. Sankaran, P. Fleming, F. Hsieh, and S. Benes, "Mobile WiMAX systems: performance and evolution," *IEEE Communications Magazine,* vol. 46, pp. 41-49, 2008.

[3] L. Ye, "Pilot-symbol-aided channel estimation for OFDM in wireless systems," *IEEE Transactions on Vehicular Technology,* vol. 49, pp. 1207-1215, 2000.

[4] H. Bolcskei, R. W. Heath, Jr., and A. J. Paulraj, "Blind equalization in OFDM-based multi-antenna systems," in *The IEEE 2000 Adaptive Systems for Signal Processing, Communications, and Control Symposium*, pp. 58-63, 2000.

[5] J. Won Gi, P. Kyung Hyun, and C. Yong Soo, "An efficient channel estimation technique for OFDM systems with transmitter diversity," in *The 11th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications,* vol.2*,* pp. 1246-1250 *2000.*

[6] G. L. Stuber, J. R. Barry, S. W. McLaughlin, L. Ye, M. A. Ingram, and T. G. Pratt, "Broadband MIMO-OFDM wireless communications," *Proceedings of the IEEE,* vol. 92, pp. 271-294, 2004.

[7] L. Ye, N. Seshadri, and S. Ariyavisitakul, "Channel estimation for OFDM systems with transmitter diversity in mobile wireless channels," *IEEE Journal on Selected Areas in Communications,* vol. 17, pp. 461-471, 1999.

[8] L. Ye, "Simplified channel estimation for OFDM systems with multiple transmit antennas," *IEEE Transactions on Wireless Communications,* vol. 1, pp. 67-75, 2002.

[9] "IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Broadband Wireless Access Systems," *IEEE Std 802.16-2009 (Revision of IEEE Std 802.16-2004),* pp. C1-2004, 2009.

[10] F. Delestre, E. Masoud, Y. Sun, and A. Slaney, "Detection scheme for space-time block codes wireless communications without channel state information," in *11th IEEE International Conference on Communication Systems*, pp. 77-81*, 2008.*

[11] S. M. Alamouti, "A simple transmit diversity technique for wireless communications," *IEEE Journal on Selected Areas in Communications,* vol. 16, pp. 1451-1458, 1998.