MIMO MODEL FOR IMPROVING SPECTRUM EFFICIENCY OF OFDM-CDMA SYSTEM WITH PILOT TONE

Uglješa Urošević, Zoran Veljović***

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Abstract: In this paper, the model for improving spectrum efficiency of the pilot aided OFDM-CDMA downlink system with threshold detection combining (optimum TDC), is presented. The proposed MIMO OFDM-CDMA system uses space-time block coding applied to two and four transmit antennas and has arbitrary number of receive antennas. Bit error rate (BER) performance of the two competitive systems, in the case of Ricean frequency selective fading, is evaluated using originally developed computer simulation. The results show that besides smaller frequency bandwidth, the presented system provides lower BER, in comparison with its competitive solution.

1. INTRODUCTION

Mobile radio systems of the next generation should be able to meet increasing user demand for high bandwidth services. Multi-carrier (MC) approach is an attractive technique for achieving high speed data transmissions. Increased downlink capacity may be accomplished by the combination of MC and code division multiple access (CDMA), [1], [2]. MC CDMA using orthogonal subcarriers is called orthogonal frequency division multiplexing (OFDM)-CDMA, [3], [4]. In the case of frequency-selective fading channel, the received signal suffers from frequency distortion and thus, orthogonality destruction occurs, thereby producing large multi-user interference. Frequency-domain equalization is necessary at the receiver to restore orthogonality among different users. In [1], pilot-aided threshold detection combining (optimum TDC) is presented as a very efficient combining technique at the receiver. It is shown that optimum TDC outperforms orthogonal restoring combining (ORC) and controlled equalization combining (CEC). There exists an optimal threshold that can minimize the bit error rate (BER), for a given received signal energy per information bit-to-additive white Gaussian noise power spectrum density ratio (SNR).

* Mr Uglješa Urošević, Faculty of Electrical Engineering, University of Montenegro, Podgorica

** Doc. Dr Zoran Veljović, Faculty of Electrical Engineering, University of Montenegro, Podgorica

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However, implementation of optimum TDC requires computation of optimum weighting coefficients for each SNR, which assumes considerable processing time. Also, in model from [1], BER performance is dependent on the available frequency bandwidth, e.g. BER decreases with increasing the number of subcarriers that are used for transmitting single data symbol.

Radio spectrum available for mobile communications is a scarce resource and hence one of the main targets in the design of the radio access technologies is to optimize spectrum efficiency. In this paper, MIMO OFDM-CDMA system is proposed as a solution for improving spectrum efficiency of the system from [1]. It is shown that, even when less subcarriers are used, the presented scheme provides lower BER. Another advantage of the considered system is shorter processing time than in the competitive system, due to smaller complexity of space-time block coding implementation compared to realization of the optimum TDC.

This paper is composed in the following order. In Sect. 2 the proposed MIMO OFDM-CDMA system is described. Simulation model and results are presented in Sect. 3. Conclusions are drawn in Sect. 4.

2. SYSTEM MODEL

The transmitter of the MIMO OFDM-CDMA downlink transmission system is shown in Fig. 1, [5]. N users in a single cell system are assumed to be in communication. At the base station, a binary transmission data are transformed into quaternary phase shift keying (QPSK) symbol sequence. Next, the space–time block coder collects a block of K successive symbols and maps them onto a sequence of L consecutive vectors $\mathbf{a}[l]=\left[a_1[l]\ ...\ a_{M_t}[l]\right]^{\mathrm{T}}$, $0\leq l<L$, [6], [7]. The code rate is $R_c = K / L$. It is assumed that channel remains constant during one code block. Sequence of pilot tones is implemented at each output of the space–time block coder and multiplexed with coded data symbols. In that way, at each output of the coder, slot with N_{slot} symbols (N_p pilot symbols and N_d coded data symbols) is formed. It has duration equal to T_{slot}. The m-th coded data symbol of the n-th user (n = 1, 2, ..., N) in q_r-th slot at the r-th output of the coder, $d_n(q_r N_{slot}+m)$, is spread in frequency domain using F-length orthogonal spreading sequence $c_k^n=\{-1,\ 1\}$, k=1,…, F. q_r is the q-th slot at the r-th output of the coder, and F is chosen to be greater than or equal to the number of users N. After that, signals originated from different users are summed. Then, they are multiplied by a long pseudo noise (PN) sequence $c_{PN}(i)=\{-1,\ 1\}$, i=1, 2,..., R, R>>F, used to randomize the multi-user interference produced by partial destruction of orthogonality due to imperfect frequency equalization. In the case of multi-cell systems, it is also used to randomize multi-user interference produced by users in other cells.

The sum of F modulated subcarrier components forms the OFDM-CDMA waveform of length T_S. This process can be performed using the inverse fast Fourier transform (IFFT). Finally, a guard interval (GI) of length T_{guard}, is added to OFDM-CDMA symbol, to form a resultant OFDM-CDMA symbol of length $T = T_S + T_{guard}$. F orthogonal subcarriers are used with frequency separation of $1/T_S$, where T_S denotes the effective length of the OFDM-CDMA symbol.

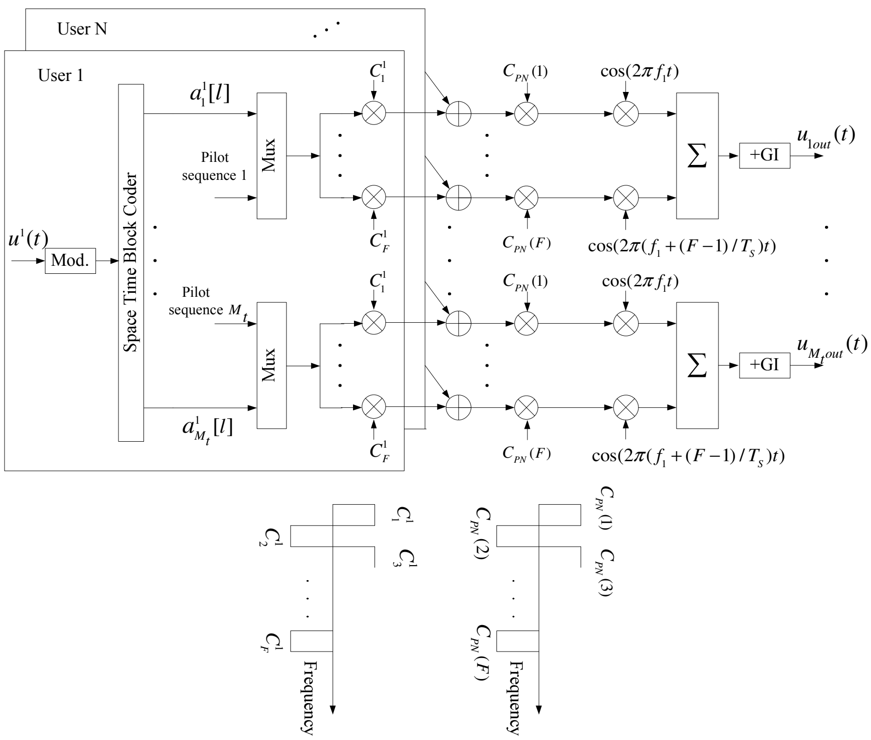

Fig. 1 Transmitter of the MIMO OFDM-CDMA downlink transmission system

MIMO channel (for the k-th subcarrier) can be represented by the following discrete time model, [8]:

$$\begin{bmatrix} y_1^k \\ y_2^k \\ \vdots \\ y_{M_r}^k \end{bmatrix} = \begin{bmatrix} h_{1,1}^k & h_{1,2}^k & \cdots & h_{1,M_t}^k \\ h_{2,1}^k & h_{2,2}^k & \cdots & h_{2,M_t}^k \\ \vdots & \vdots & \ddots & \vdots \\ h_{M_r,1}^k & h_{M_r,2}^k & \cdots & h_{M_r,M_t}^k \end{bmatrix} \begin{bmatrix} x_1^k \\ x_2^k \\ \vdots \\ x_{M_t}^k \end{bmatrix} + \begin{bmatrix} n_1^k \\ n_2^k \\ \vdots \\ n_{M_r}^k \end{bmatrix} \tag{1}$$

x_j^k and y_i^k represents symbol transmitted from antenna j ($j = 1, ..., M_t$; M_t - number of transmit antennas) and symbol received by antenna i ($i = 1, ..., M_r$; M_r - number of receive antennas), respectively. $h_{i,j}^k$ represents the channel coefficient between transmit antenna j and receive antenna i. n_i^k is additive white Gaussian noise (AWGN).

The receiver of the MIMO OFDM-CDMA downlink transmission system is shown in Fig. 2.

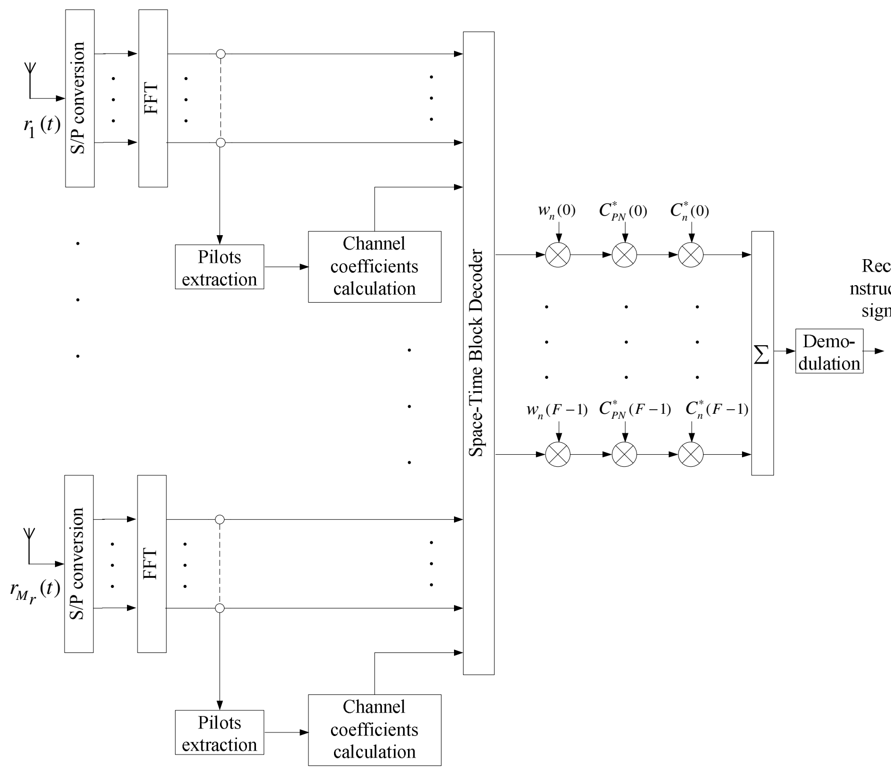

Fig. 2 Receiver of the MIMO OFDM-CDMA downlink transmission system

At each receive antenna, received signal is converted into F parallel streams. Subcarriers demodulation is performed by using fast Fourier transform (FFT). In the case of frequency-selective fading channel, the received signal suffers from frequency distortion and thus, orthogonality destruction occurs, thereby producing large multi-user interference. Frequency-domain equalization is necessary at the receiver for subcarriers' orthogonality restoration. Calculation of the channel coefficients is performed after extraction of pilot sequence. Calculated channel coefficients are necessary for space-time block decoding and subcarriers' orthogonality restoration, which are followed by decoding long PN sequence, decoding orthogonal spreading sequence and symbol demodulation.

3. SIMULATION MODEL AND RESULTS

We developed original simulation model to obtain BER performance of the analyzed MIMO OFDM-CDMA system. $M_t M_r$ single-input single-output (SISO) wireless communications channels with Ricean fading and AWGN are assumed. For the given Rice channel parameter (K_{dB}), maximum delay spread (T_{max}) and rms delay spread (T_{rms}), the simulation model generates one direct and many reflected waves. We assumed that subcarriers' frequency shifts due to Doppler spreading are negligible. Subcarriers from Fig. 1 are realized using IFFT. In the system model we used QPSK modulation, Walsh Hadamard code, $T_{max} = 150$ ns, $T_{rms} = 150/7$ ns. The algorithm for generating Walsh Hadamard code is:

$$\mathbf{H}_w = \begin{bmatrix} \mathbf{H}_{w-1} & \mathbf{H}_{w-1} \\ \mathbf{H}_{w-1} & -\mathbf{H}_{w-1} \end{bmatrix}, \ \mathbf{H}_0 = [1] \tag{2}$$

Space-time block coding that can be applied to two and four transmit antennas and to arbitrary number of receive antennas, is used in simulation. The codewords arranged in space and time can be described using vector notations, [9]:

$$\mathbf{X}_2 = \begin{bmatrix} a_1 & -a_2^* \\ a_2 & a_1^* \end{bmatrix} \tag{3}$$

$$\mathbf{X}_4 = \begin{bmatrix} a_1 & -a_2 & -a_3 & -a_4 & a_1^* & -a_2^* & -a_3^* & -a_4^* \\ a_2 & a_1 & a_4 & -a_3 & a_2^* & a_1^* & a_4^* & -a_3^* \\ a_3 & -a_4 & a_1 & a_2 & a_3^* & -a_4^* & a_1^* & a_2^* \\ a_4 & a_3 & -a_2 & a_1 & a_4^* & a_3^* & -a_2^* & a_1^* \end{bmatrix} \tag{4}$$

$\mathbf{X}_2$ and $\mathbf{X}_4$ are codewords for systems with two and four transmit antennas, respectively. The columns comprise the symbols transmitted at a certain time instant, while the rows represent the symbols transmitted over a certain antenna. In (3) code rate amounts to 1, while in (4) it amounts to 1/2. In order to draw a fair comparison among codes $\mathbf{X}_2$, and $\mathbf{X}_4$, we can fix the average power spent per data symbol. This leads to a scaling factor of $1/\sqrt{2}$ for $\mathbf{X}_2$ and $1/\sqrt{8}$ for $\mathbf{X}_4$.

In the proposed scheme, the instantaneous channel estimation at the *k*-th subcarrier frequency position, between transmit antenna *j* and receive antenna *i*, is $\tilde{H}_{i,j}\left(k/T_S, qT_{slot}\right)$. After space-time block decoding, frequency equalization weight at the *k*-th subcarrier frequency position, for every *m*-th data symbol in *q*-th slot is:

$$w\left(k, q\left(N_p + N_d\right) + m\right) = \frac{1}{\sum_{i=1}^{M_r}\sum_{j=1}^{M_t}\left|\tilde{H}_{i,j}\left(k/T_S, qT_{slot} + mT\right)\right|^2} \qquad (5)$$

Simulation parameters are given in Table 1.

Table 1. Simulation Parameters

Modulation	QPSK
System capacity	50 Mb/s
Number of users	64
Subcarrier separation	$1/T_S$
Rice channel parameter (K_{dB})	4 dB
T_{max}	150 ns
T_{rms}	150/7 ns
T_S/T_{guard}	5

Fig. 3 depicts BER performance of the presented model (with $M_t = 2$ transmit antennas and $M_r = 1$, 2 and 4 receive antennas) and of the system from [1]. The results are given as a function of average received SNR. Fig. 4 shows BER performance of the considered scheme (with $M_t = 4$ transmit antennas and $M_r = 1$, 2 and 4 receive antennas) and of the competitive system. It is assumed that 64 subcarriers are used in the considered model, while the number of subcarriers for the competitive system is 128.

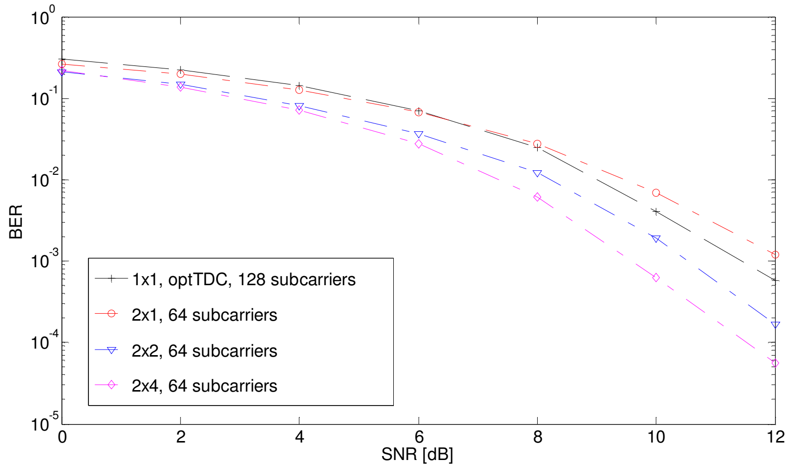

Fig. 3 BER performance of the analyzed system ($M_t = 2$, M_r = 1, 2 and 4) with 64 subcarriers and of the competitive system with 128 subcarriers

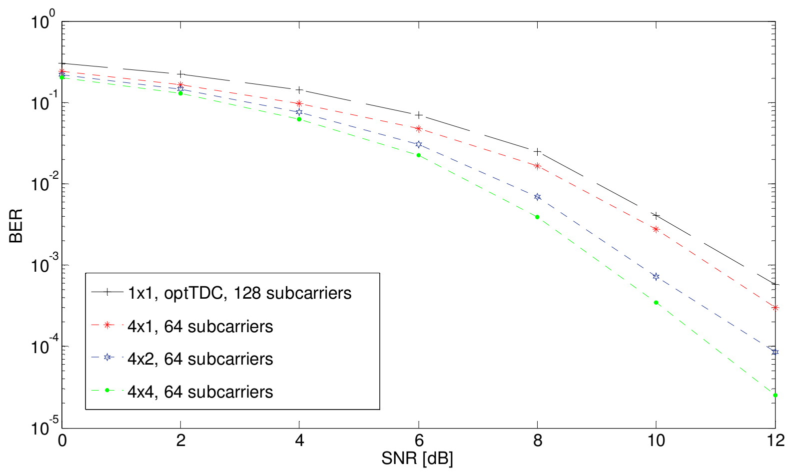

Fig. 4 BER performance of the analyzed system ($M_t = 4$, M_r = 1, 2 and 4) with 64 subcarriers and of the competitive system with 128 subcarriers

From Fig. 3, it's clear that despite the using smaller number of subcarriers, the proposed scheme with $M_t = 2$ transmit antennas and $M_r = 2$ and 4 receive antennas, has better BER performance than the system from [1]. Only model with $M_t = 2$ transmit antennas and

$M_r = 1$ receive antenna has slightly worse BER performance. It can be seen from Fig. 4 that analyzed model with $M_t = 2$ transmit antennas and $M_r = 1$, 2 and 4 receive antennas, outperforms concurrent system.

The assumed system uses two time less subcarriers than competitive system. Besides better spectrum efficiency, proposed model shows significantly better BER performance than its competitive solution.

Another advantage of the presented model is shorter processing time than in the system from [1], due to smaller complexity of space-time block coding implementation compared to realization of the optimal TDC.

4. CONCLUSION

In this paper, MIMO OFDM-CDMA scheme was proposed as a solution for improving spectrum efficiency of the OFDM-CDMA system with pilot tone and optimum TDC combining. BER performance was evaluated through originally developed simulation model. It is shown that, in spite of using smaller number of subcarriers, the presented system achieves significantly better BER performance, than its competitive model. In the considered case of two times less subcarriers, assumed system with $M_t = 2$ transmit antennas and $M_r = 2$ and 4 receive antennas, and model with $M_t = 4$ transmit antennas and $M_r = 1$, 2 and 4 receive antennas, performs better than concurrent scheme. Another advantage of the analyzed scheme is shorter processing time, than in the concurrent model, because optimal TDC has a significant impact on it.

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