

PERFORMANCE IMPROVEMENTS OF OFDM-CDMA SYSTEM

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Abstract: In this paper, MIMO OFDM-CDMA downlink scheme is proposed as a solution for performance improvement of the OFDM-CDMA downlink system with pilot tone and threshold detection combining (optimum TDC). The new presented system with MIMO included uses space-time block coding applied to two, three and four transmit antennas. BER (Bit Error Rate) performance in the case of Ricean frequency selective fading is evaluated for the original system as well as for the one with MIMO included. For that reason an adequate simulation model is developed. The results show that for the same data rate the proposed system with two times less subcarriers, i.e. narrower occupied frequency band provides better BER performance than the OFDM-CDMA system with pilot tone.

1. INTRODUCTION

Future mobile-radio systems should be able to cope with continuously increasing user demands for high bandwidth services and applications. Multi-carrier (MC) techniques represent an attractive solution for achieving high speed data transmissions. Additionally, increased downlink capacities can be accomplished by the combination of MC and code division multiple access (CDMA), [1]-[2]. If orthogonal subcarriers are used, this MC-CDMA scheme is known as orthogonal frequency division multiplexing (OFDM-CDMA), [3]-[4]. In the case of frequency-selective fading channel, received signals suffer from frequency distortion and thus orthogonality destruction occurs, thereby producing large multi-user interference (MUI). Frequency-domain equalization is necessary at the receiver to restore orthogonality among different users. In [1], OFDM-CDMA downlink scheme with pilot tone and threshold detection combining (optimum TDC) as a combining technique at the receiver is presented. It has been shown that optimum TDC outperforms orthogonal restoring combining (ORC) and controlled equalization combining (CEC). However, implementation of optimum TDC requires computation of optimum weighting coefficients for each SNR, and it is more complex than ORC and CEC.

In the case of high subcarriers offsets due to Doppler spreading system in [1] shows very poor BER performance. Scheme in [2] was proposed for improving BER performance of

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the OFDM-CDMA system with pilot tone and optimum TDC, in the case of propagation conditions characterized with high Doppler spread. It was shown that the model presented in [2] noticeably outperforms the scheme in [1]. However, in the scheme from [2], BER performance is dependent on the available frequency bandwidth, e.g. BER increases when the number of subcarriers used for transmitting single data symbol decreases. Since radio spectrum available for mobile communications is a scarce resource, one of the main targets in the design of radio access technologies is to optimize their spectrum efficiency.

In this paper, multiple-input multiple-output (MIMO) OFDM-CDMA system with space-time block coding (STBC) is proposed as a solution for improving the BER performance and spectrum efficiency of the OFDM-CDMA scheme from [2]. It is shown that for the same data rate the proposed system even with less number of subcarriers provides lower BER, i.e. proposed system provides more efficient use of the frequency resources. Besides better spectrum efficiency and reliability, the presented solution has another advantage since the implementation of a very complex optimum TDC equalization technique is avoided.

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. A single cell system with N users is assumed, with binary transmitted data mapped at the base station according to a chosen modulation scheme. After serial to parallel (S/P) conversion, at the each parallel branch ($p=1, \dots, F$; F -number of parallel branches) space-time block coder collects a block of M successive symbols and maps them into a sequence of L consecutive vectors $\mathbf{a}^p [l] = [a_1^p [l] \dots a_{M_t}^p [l]]^T$, $0 \leq l < L$. The code rate is $R_c = M / L$. It is assumed that channel remains constant during one code block, [6]. A sequence of pilot tones is implemented at each output of the every space-time block coder and multiplexed with coded data symbols.

After spreading in frequency domain using K -length orthogonal spreading sequence $C_k^n = \{-1, 1\}$, $k=1, \dots, K$, $K \geq N$, signals originated from different users are summed.

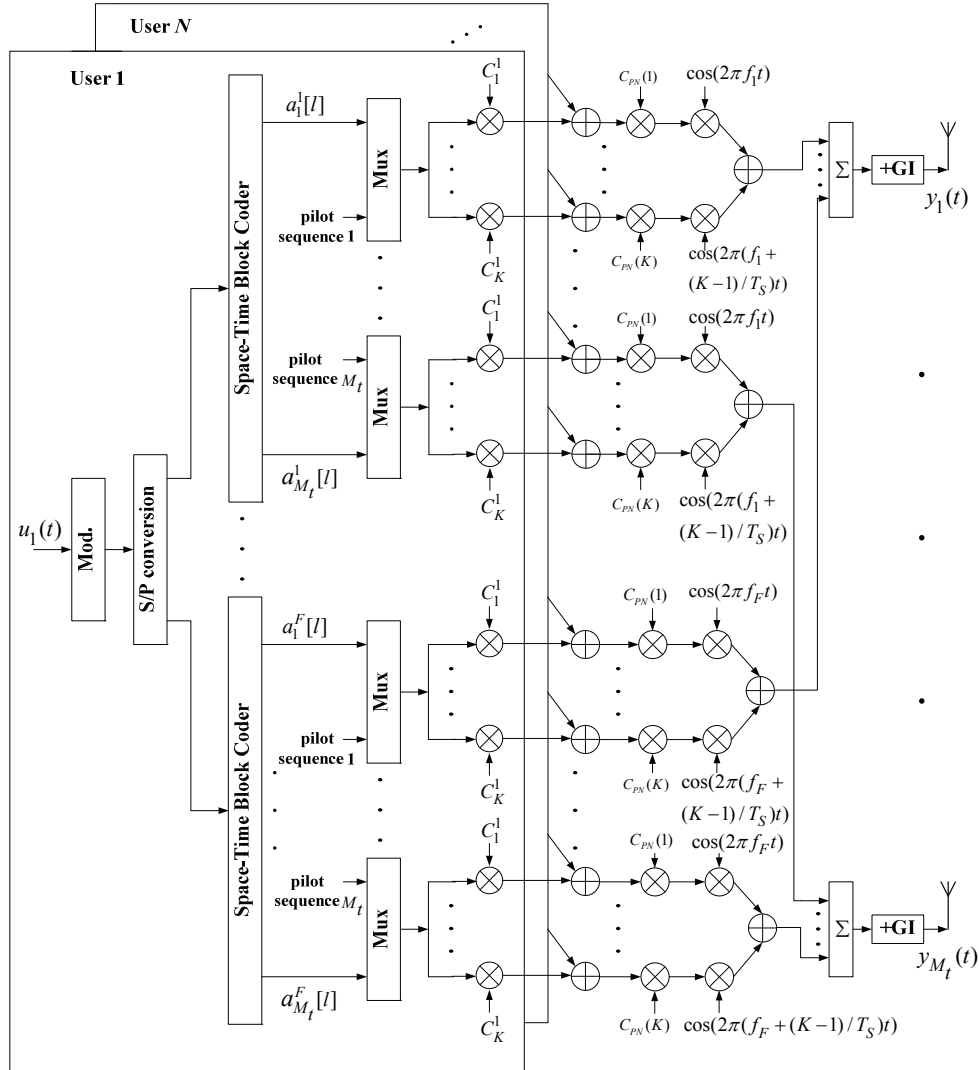


Fig. 1 Transmitter of the MIMO OFDM-CDMA downlink transmission system

Then, they are multiplied by a long pseudo noise (PN) sequence $c_{PN}(j) = \{-1, 1\}$, $j=1, 2, \dots, R$, $R \gg K$, used to randomize the multi-user interference produced by partial destruction of orthogonality due to imperfect frequency equalization. At the output stage of the transmitter, orthogonal subcarriers are organized in F groups, each having K subcarriers mutually separated by $1/T_S$ (T_S - effective length of a data symbol). Frequency separation between the subcarriers f_p ($p=1, \dots, F$) belonging to different groups is $1/FT_S$. Fig. 2 shows subcarriers distribution in frequency domain. The sum of FK modulated subcarrier

components forms the OFDM-CDMA waveform of length FT_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 $T = FT_S + T_{guard}$.

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

$$\begin{bmatrix} r_1(k) \\ r_2(k) \\ \vdots \\ r_{M_r}(k) \end{bmatrix} = \begin{bmatrix} h_{1,1}(k) & h_{1,2}(k) & \cdots & h_{1,M_t}(k) \\ h_{2,1}(k) & h_{2,2}(k) & \cdots & h_{2,M_t}(k) \\ \vdots & \vdots & \ddots & \vdots \\ h_{M_r,1}(k) & h_{M_r,2}(k) & \cdots & h_{M_r,M_t}(k) \end{bmatrix} \begin{bmatrix} y_1(k) \\ y_2(k) \\ \vdots \\ y_{M_t}(k) \end{bmatrix} + \begin{bmatrix} n_1(k) \\ n_2(k) \\ \vdots \\ n_{M_r}(k) \end{bmatrix} \quad (1)$$

$y_j(k)$ and $r_i(k)$ represent symbol transmitted from antenna $j, j=1, \dots, M_t$, and received symbol from antenna $i, i=1, \dots, M_r$, respectively. Parameter $h_{i,j}(k)$ represents the channel coefficient between j -th transmit antenna and i -th receive antenna. $n_i(k)$ is additive white Gaussian noise (AWGN).

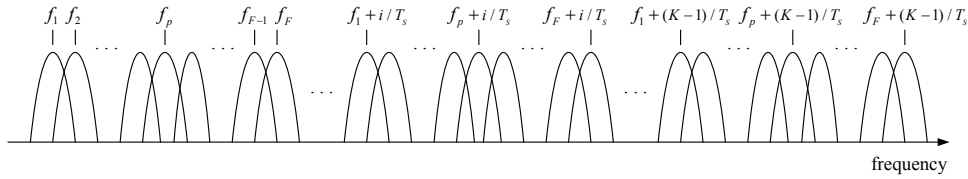


Fig. 2 Distribution of subcarriers in frequency domain

3. SIMULATION MODEL AND RESULTS

In order to analyze performance of the proposed MIMO OFDM-CDMA system, we have developed an original simulation model. It is based on the assumption that channels between the j -th transmit antenna and the i -th receive antenna are uncorrelated. In that case MIMO channel is modeled with $M_t M_r$ Single-Input Single-Output (SISO) wireless channels. Propagation conditions are defined with Ricean fading statistics. For the given Ricean channel parameter (K_{dB}), the maximum delay spread (T_{max}), and the rms delay spread (T_{rms}), the simulation model generates one direct and many reflected waves for each channel.

Subcarriers from Fig. 1 are realized using the IFFT. In the simulation we have used QPSK modulation, Walsh Hadamard matrix whose rows represent orthogonal spreading sequences for every user, $T_{max}=150$ ns, $T_{rms}=150/7$ ns.

As it was said in Sect. 2, space-time block coding is implemented in the proposed system. For the purpose of simulation we have used STBC that can be applied to two, three and four transmit antennas.

The space-time codewords arranged in space and time can be described using vector notations, [7]:

$$\mathbf{X}_2 = \begin{bmatrix} a_1 & -a_2^* \\ a_2 & a_1^* \end{bmatrix} \quad (2)$$

$$\mathbf{X}_3 = \frac{1}{\sqrt{12}} \begin{bmatrix} 2a_1 & -2a_2 & \sqrt{2}a_3^* & \sqrt{2}a_3^* \\ 2a_2 & 2a_1^* & \sqrt{2}a_3^* & -\sqrt{2}a_3^* \\ \sqrt{2}a_3 & \sqrt{2}a_3 & -a_1 - a_1^* + a_2 - a_2^* & a_1 - a_1^* + a_2 + a_2^* \end{bmatrix} \quad (3)$$

$$\mathbf{X}_4 = \frac{1}{\sqrt{16}} \begin{bmatrix} 2a_1 & -2a_2 & \sqrt{2}a_3^* & \sqrt{2}a_3^* \\ 2a_2 & 2a_1^* & \sqrt{2}a_3^* & -\sqrt{2}a_3^* \\ \sqrt{2}a_3 & \sqrt{2}a_3 & -a_1 - a_1^* + a_2 - a_2^* & a_1 - a_1^* + a_2 + a_2^* \\ \sqrt{2}a_3 & -\sqrt{2}a_3 & -a_1 - a_1^* - a_2 - a_2^* & -a_1 - a_1^* - a_2 - a_2^* \end{bmatrix} \quad (4)$$

\mathbf{X}_2 , \mathbf{X}_3 and \mathbf{X}_4 are codewords for systems with two, three and four transmit antennas, respectively. The columns comprise symbols transmitted at a certain time instant, while the rows represent symbols transmitted over a certain antenna.

In the proposed scheme, the instantaneous channel estimation at the k -th subcarrier frequency position for p -th parallel branch, between transmit antenna j and receive antenna i , for the n -th user is $\tilde{H}_{n,i,j}^p(k)$. Thus, after space-time block decoding, frequency equalization weight for the n -th user at the k -th subcarrier frequency position, for p -th parallel branch becomes:

$$w_n^p(k) = \frac{1}{\sum_{j=1}^{M_t} \sum_{i=1}^{M_r} |\tilde{h}_{n,i,j}^p(k)|^2} \quad (5)$$

Other simulation parameters are given in Table I.

Table 1 SIMULATION PARAMETERS

Modulation	QPSK
System capacity	200 Mb/s
Number of users	64
Number of parallel branch (F)	4
Subcarrier separation	$1/(4T_s)$
Rice channel parameter (K_{dB})	4 dB

BER performance of the proposed MIMO OFDM-CDMA system is analyzed and compared with OFDM-CDMA system from [2] in different conditions, described with two simulation scenarios. In the first scenario it is assumed that the Doppler spreading is negligible, while in the second scenario frequency shifts were taken into account.

Fig. 3 shows BER performance of the proposed system ($M_t=M_r=2, 3$ and 4) and of the original scheme from [2]. It is assumed that 64 subcarriers per parallel branch are used in the proposed system, while the number of subcarriers per parallel branch in the original scheme from [2] is 128. Here, it is assumed that the Doppler spreading is negligible. From Fig. 3, it's clear that despite the using two times less subcarriers, the proposed system for the same data rate has better BER performance. For example, for the BER value of 10^{-4} , the proposed system with $M_t=M_r=2$, attains the SNR gain of around 1dB in comparison with the original scheme, while in the case of $M_t=M_r=4$ this SNR gain amounts 2dB.

For various values of the normalized fading maximum Doppler frequency ($f_d T = 0.0001, 0.001, 0.0015$ and 0.002) BER performance of the proposed scheme with $M_t = M_r = 2, M_t = M_r = 4$ and the original scheme from [2] are shown in Fig. 4 and Fig. 5, respectively. The number of subcarriers per parallel branch for the proposed system is 64 while the original system from [2] uses 128.

Original scheme from [2] was proposed for improving BER performance of the OFDM-CDMA system with pilot tone and optimum TDC, in the case of propagation conditions characterized with high frequency shifts. It can be seen from Fig 4 and 5 that the proposed scheme obviously outperforms the original scheme from [2]. For the same data rate the proposed system provides decreased BER, while the use of frequency resources is more efficient. Also, with increasing frequency shifts, BER increases more rapidly in the original scheme from [2].

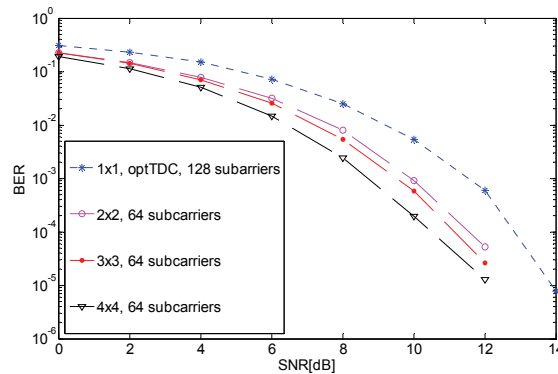


Fig. 3 BER performance of the proposed system ($M_t = M_r = 2, 3$ and 4) with 64 subcarriers and of the original scheme from [2] with 128 subcarriers

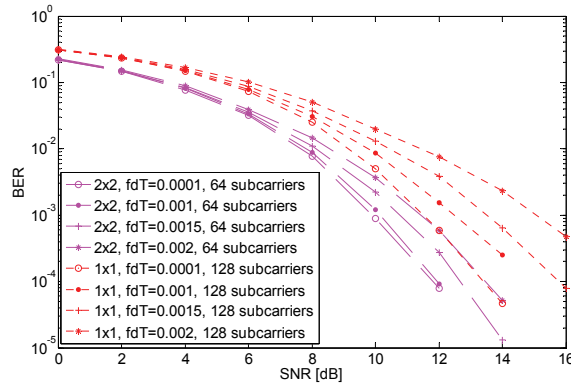


Fig. 4 BER performance of the proposed system ($M_t = M_r = 2$) with 64 subcarriers and of the original scheme from [2] with 128 subcarriers, in the case of Doppler spreading

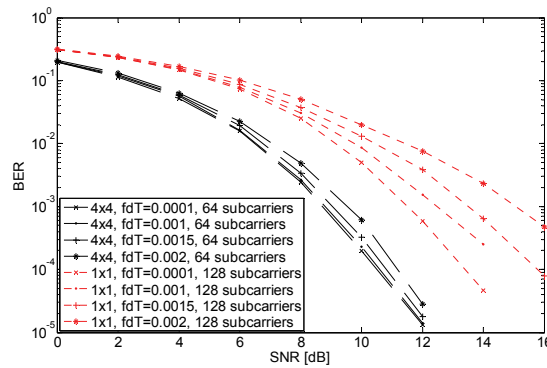


Fig. 5 BER performance of the proposed system ($M_t = M_r = 4$) with 64 subcarriers and of the original scheme from [2] with 128 subcarriers, in the case of Doppler spreading.

4. CONCLUSION

In this paper, MIMO OFDM-CDMA scheme was proposed as a solution for improving BER performance and the spectrum efficiency of the OFDM-CDMA system with pilot tone and optimum TDC combining. Evaluations and comparisons between the proposed and the original system were performed using the originally developed simulation model. Two scenarios were analyzed, one where it was assumed that frequency shifts due to Doppler spreading are negligible, and the second where these frequency shifts were taken into account. In the both scenarios it was assumed that proposed system uses two times less subcarriers than the original scheme. Regarding to the obtained results it is evident that the proposed system can be considered as a good solution for BER performance and spectrum efficiency improvements of the OFDM-CDMA system with pilot tone. As it was shown, significantly lower BERs can be achieved while at the same time providing more efficient use of the frequency resources. Besides these improvements, another advantage of the

proposed system is in avoiding implementation of the very complex optimum TDC equalization technique.

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