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Implementation of STBC-MC-CDMA Systems Employing Different Detection Techniques

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Abstract: In this paper, plain multicarrier-code division multiple access (MC-CDMA) system is implemented and the performance in terms of bit error rate (BER) is obtained. The theoretical performance of the MC-CDMA system is also calculated which is given by N. Yee et al. and compared with the simulated performance to verify the accuracy of the system. Then, the space-time block code (STBC) is implemented and passed through the MC-CDMA system with multiple input multiple output (MIMO) antenna diversity in the multi-path fading channel. The combination of STBC code and MC-CDMA system is named as STBC-MC-CDMA system.

At the receiver, the received signals of STBC-MC-CDMA systems are combined in the frequency domain in order to collect the overall received signal energy scattered on different subcarriers assuming perfect channel state information (CSI). The combining schemes used are the maximum ratio combining (MRC), equal gain combining (EGC), and minimum mean-squared error (MMSE) combining.

Keywords: MIMO; MMSE; MC-CDMA; STBC; EGC; MRC

I. Introduction

The multicarrier-code division multiple access (MC-CDMA) system has been proposed to achieve multiple accesses with high data rate applications to reduce the effect of inter symbol interference (ISI). The MC-CDMA technique also solves the inter-chip-interference (ICI) problem by transmitting the same data symbol over a large number of narrow band orthogonal carriers. By transmitting the same data symbol on different carriers, frequency diversity can be achieved. The number of carriers may be equal or exceed the pseudo-noise (PN) code length [1].

For achieving high bit rate, a MC-CDMA technology in combination with multi-input multi-output (MIMO) antennas is considered as one of the technique in the future generation systems. Orthogonal frequency division multiplexing (OFDM) is also a popular discrete Fourier transform (DFT) based technique. OFDM has gained popularity with the emergence of wireless communications and wideband systems because of its inherent ability to compensate for multipath. In 1993, N. Yee. et al. combined OFDM with code-division multiplexing (CDM) and proposed a new modulation scheme, MC-CDMA. MC-CDMA effectively mitigates multipath interference while providing multiple access capability [2]. MC-CDMA combines the benefits of CDMA in a multi-user environment with that of multi-carrier modulation for high rate data transmission over frequency selective fading channels. In MC-CDMA system, the data symbols are modulated on many subcarriers to introduce frequency diversity instead of using only one carrier like in CDMA. Thus, MC-CDMA is robust against deep frequency selective fading compared to direct sequence CDMA. Each user data is first spread using a given high rate spreading code in the frequency domain. A fraction of the symbol corresponding to a chip of the spreading code is transmitted through different subcarriers [3]-[5].

Space-time (S-T) coding techniques have been used to implement multiple input multiple output (MIMO) antenna systems, which minimizes the effect of multi-path fading and improves the performance and capacity of digital transmission over wireless radio channels. There are various approaches in S-T coding structures, which include Alamouti STC, S-T block code (STBC), S-T trellis code (STTC), S-T turbo code (STTuC), etc. Alamouti first introduced a simple code to provide diversity for two transmit antennas. This scheme is generalized to an arbitrary number of antennas and is named as STBC, which provides full diversity advantage with a very simple decoding scheme. In this paper, STBC code is generated and applied to the MC-CDMA system [6]-[9].

At the receiver, maximum ratio combining (MRC), equal gain combining (EGC), and minimum mean-squared error (MMSE) combining techniques are used to combine the received signal. The MRC and EGC are single-user detection schemes based on per-subcarrier combining, i.e., the signals at individual subcarrier are independently weighted and summed to generate decision variables while MMSE is joint weighting and combining on all subcarriers by utilizing the mean-squared error (MSE) criterion. The corresponding performances of STBC-MC-CDMA system are obtained through these combining techniques [10]-[12].

The organization of the rest of this paper is as follows. In Section II, description of MC-CDMA system model is presented. In Section III, combining techniques are given. The space-time block coded MC-CDMA system is presented in section IV. Simulation of the STBC-MC-CDMA system is discussed in Section V. The conclusions are described in Section VI.

II. Description of MC-CDMA System Model

In MC-CDMA systems, each data symbol is transmitted over N narrowband sub-carriers with symbol duration, T_b, which is much larger than the delay spread, T_d, hence MC-CDMA signal does not experience significant ISI. Multiple access is achieved due to the different users transmitting at the

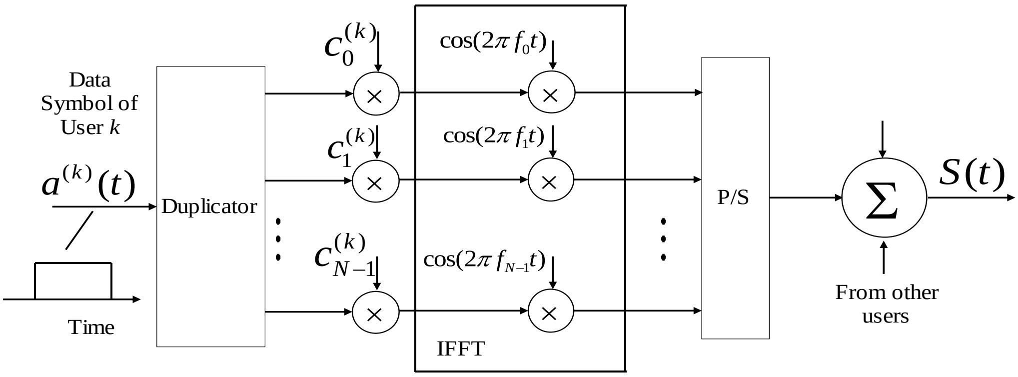

Fig. 1. A general MC-CDMA transmitter model.

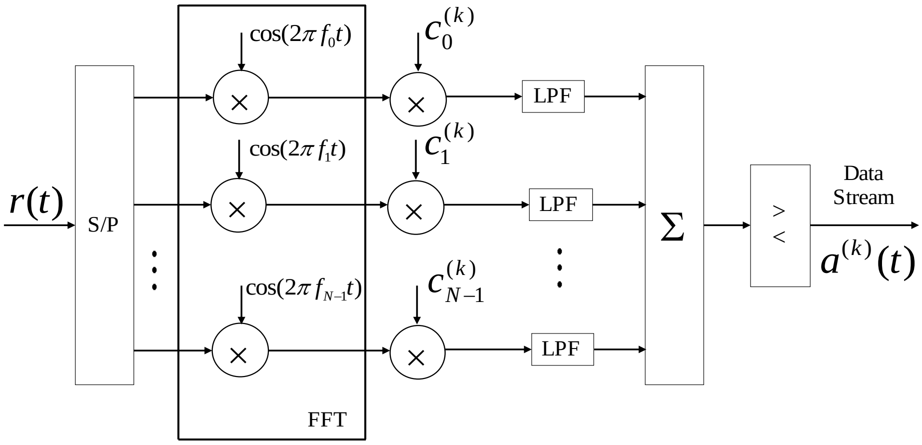

Fig. 2. A general diagram of MC-CDMA receiver.

same set of sub-carriers but with spreading codes that are different to the codes of different users.

The basic block diagram of downlink MC-CDMA transmitter configuration for the k^{th} user is shown in Fig. 1. The MC-CDMA system transmits the same symbol in parallel through several subcarriers whereas the OFDM systems transmit a different symbol, which is the main difference between MC-CDMA and OFDM systems. Let the spreading code sequence for k^{th} user in the frequency domain is represented in vector form as $\mathbf{c}^{(k)} = [c_0^{(k)}, c_1^{(k)}, ..., c_{N-1}^{(k)}]^T$ with $c_n^{(k)} = \pm 1$. The input data symbol is $a^{(k)}(t)$, which is multiplied by the spreading code of length N. Each chip of the spreading code modulates one subcarrier, so that the numbers of subcarriers are also N. The users are separated by different orthogonal spreading codes. All data corresponding to the total number of subcarriers are modulated in baseband by an inverse fast Fourier transform (IFFT) and converted back into serial data.

Then, the signals of all the users are added and transmitted through the channel by assuming that the duration of guard interval is more than the maximum channel delay spread to combat the inter-symbol interference (ISI) and the inter-channel interference (ICI) caused by multipath fading. The transmitted signal from the base station during the t^{th} period for the input data stream $\boldsymbol{a}^{(k)}(t) = [a^{(k)}(0), a^{(k)}(1), a^{(k)}(2), ...]$ through MC-CDMA system can be written as follows [8]:

$$s(t) = \sum_{k=0}^{K-1} \sum_{n=0}^{N-1} a^{(k)}(t) c_n^{(k)} \cos(2\pi f_n t + \phi_{k,n}) \qquad (1)$$

where f_n is the n^{th} carrier frequency given as $f_n = \left(f_c + \frac{n}{T_b} \right)$, $\phi_{k,n}$ is a random phase for each carrier, uniformly distributed in $(0, 2\pi)$ and independent, identically distributed (i.i.d.) for all k and n, $\boldsymbol{c}^k$ is the PN code sequence of user k which consist a periodic train of chips, f_c is the carrier frequency, T_b is the symbol duration. The transmitted signal propagates through a quasi static fading channel and the received signal by k^{th} user can be described as

$$r(t) = \sum_{k=0}^{K-1} \sum_{n=0}^{N-1} H^{(k)}(t,n) a^{(k)}(t) c_n^{(k)} \cos(2\pi f_n t + \phi_{k,n}) + v(t) \qquad (2)$$

where $r(t)$ is the complex baseband component of the received signal for K number of users. $H^{(k)}(t,n)$ denotes the channel frequency response of k^{th} user at n^{th} subcarrier during t^{th} symbol period, $v(t)$ is the additive white Gaussian noise (AWGN).

The MC-CDMA receiver configuration for the k^{th} user is shown in Fig. 2. At the receiver, received signals are first serial to parallel converted to obtain the N-subcarriers components, corresponding to the $a^k(t)$ data symbol. Then demodulated by a fast Fourier transform (FFT) and multiplied by the code sequence $\mathbf{c}^k$ to combine the received signal energy scattered in the frequency domain.

The theoretical bit error rate (BER) of plain MC-CDMA system for sufficiently large values of N on full load is given by N. Yee et al. and may be approximated as [2]

$$BER_{MC-CDMA} = \frac{1}{2} erfc \sqrt{\frac{0.5\left(N\ \mathrm{E}\{W_n\}\right)^2}{\left(N^2\sigma_{W_n}^2\right) + N\frac{N_0}{T_s}\ \mathrm{E}\{v_n^2\}}} \qquad (3)$$

where $W_n = \dfrac{h_n^2}{Nh_n^2 + \dfrac{N_0}{T_s}}$, $v_n = \dfrac{h_n}{Nh_n^2 + \dfrac{N_0}{T_s}}$,

$E\{.\}$ is the expected value, h_n is the channel amplitude and $(\hat{.})$ denote the estimated value. On full load mean all the combinations of orthogonal spreading code sequences are used by the users.

III. Combining Techniques

The performance of communication systems with diversity techniques depends on combining techniques, i.e., how multiple signal replicas are combined at the receiver to increase the overall received signal to noise ratio (SNR). Diversity reception reduces the probability of occurrence of communication failures caused due to fades by combining several copies of the same message received over different channels. The various techniques are known to combine the signals from multiple diversity branches. In this work, we consider three combining techniques (1) Maximal Ratio Combining (MRC) (2) Equal Gain Combining (EGC) (3) Minimum Mean Square Error (MMSE) combining [10].

a) Maximal Ratio Combining: Maximum ratio combining (MRC) is a linear combining method. In MRC each signal branch is multiplied by a weight factor that is proportional to the signal amplitude and added together to get an output signal. The output signal is a linear combination of a weighted replica of all of the received signals. It is given by

$$r = \sum_{j=1}^{n_R} w_j \,.\, r_j$$

where r_j is the received signal at receive antenna j, and w_j is the weighting factor for receive antenna j. In MRC the weighting factor of each receive antenna is chosen to be in proportion to its own signal to noise power ratio. In this scheme, each individual signal must be co-phased, weighted with its corresponding amplitude and then summed.

b) Equal Gain Combining: Equal gain combining is a simple linear combining method. It does not require estimation of the fading amplitude for each individual branch. In equal gain combining, each signal branch weighted with the same factor, irrespective of the signal amplitude. In this way all the received signals are co-phased and then added together with equal gain.

c) Minimum Mean Square Error Combining: The minimum mean square error (MMSE) combining is mainly designed for Multiuser Detection (MUD). MUD is the intelligent estimation/detection technique of transmitted bits in the presence of multiple access interference (MAI). MMSE detection scheme is also a linear process but it assumes a priori knowledge of noise variance and channel covariance. The aim of this method is to minimize the mean square error between the transmitted symbol vector $\boldsymbol{a}^{(k)}$ and estimated symbol vector $\hat{\boldsymbol{a}}^{(k)}$. Due to this, it is a more accurate detection scheme.

IV. Space-Time Block Coded MC-CDMA System

The space-time block code was introduced by Alamouti in 1998 [9]. It was the first code to provide full transmit diversity to systems with two transmit antennas. The Alamouti scheme achieves the full diversity with a very simple maximum–likelihood decoding algorithm. The key feature of the scheme is orthogonality between the sequences generated by the two transmit antennas. This scheme was generalized to an arbitrary number of transmit antennas by applying the theory of orthogonal designs. The generalized schemes are referred to as STBC. The STBC can achieve the full transmit diversity specified by the number of the transmit antennas n_T, while allowing a very simple maximum-likelihood decoding algorithm, based only on linear processing of the received signals [7].

A baseband system configuration of the STBC-MC-CMDA system employing the S-T block coding scheme at the transmitter is depicted in Fig. 3, which involves two transmit antennas, T_{X1} and T_{X2}, and one receive antenna, R_X. At the transmitter, K number of users transmit simultaneously STBC information symbols through MC-CDMA system with two transmit antennas. The flat fading channel between transmit and receive antennas is divided into N sub-channels such that each sub-channel is approximately flat. Let $\left\{\boldsymbol{X}^{(k)}(t)\right\}$ be the modulated output. For k[th] user, the output of modulator is given to the S-T block encoder that is represented by the following code matrix:

$$\boldsymbol{S}^{(k)}(t) = \begin{bmatrix} s^{(k)}(1) & s^{(k)}(2) \\ \bar{s}^{(k)}(1) & \bar{s}^{(k)}(2) \end{bmatrix} \qquad (4)$$

where $s^{(k)}(1) = x_t^{(k)}(1)$, $s^{(k)}(2) = -x_t^{(k)*}(2)$

$\bar{s}^{(k)}(1) = x_t^{(k)}(2)$, $\bar{s}^{(k)}(2) = x_t^{(k)*}(1)$

and $(.)^*$ denotes the complex conjugate. The two columns of $s^{(k)}(t)$ will be transmitted in two consecutive time slots, with

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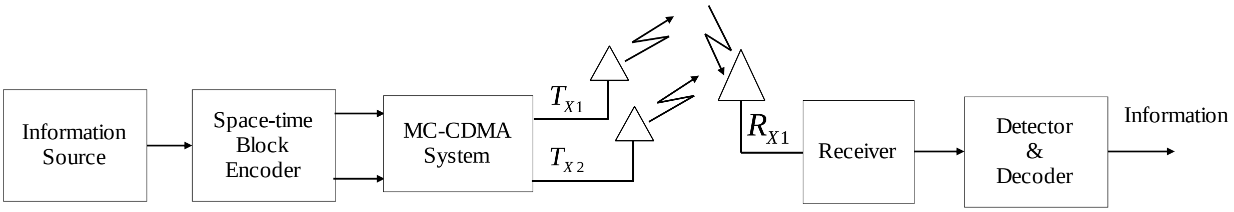

Fig. 3. Block diagram of STBC-MC-CDMA system.

the first element of each column transmitted from T_{X1} and the second element from T_{X2}, respectively. Throughout this work, $(\bar{\cdot})$ is used for quantities associated with T_{X2}. In the current system, each user is assigned two distinct spreading codes to spread symbols transmitted from the two antennas. Let $\boldsymbol{c}^{(k)} = \left[c_0^{(k)},....,c_{N-1}^{(k)}\right]^T$ and $\bar{\boldsymbol{c}}^{(k)} = \left[\bar{c}_0^{(k)},....,\bar{c}_{N-1}^{(k)}\right]^T$ are two spreading code sequences for k^th user with processing gain N which spread the symbols transmitted from antenna T_{X1} and T_{X2} respectively. The spreaded signal before IFFT is given as

$$u^{(k)}(t) = s^{(k)}(t)\boldsymbol{c}^{(k)} \qquad (5)$$

is the signal associated with T_{X1}. The OFDM modulation can be implemented via IFFT on $u^{(k)}(t)$:

$$y^{(k)}(t) = F^{-1}u^{(k)}(t) \qquad (6)$$

Similarly we obtain the signal associated with T_{X2} as $\bar{y}^{(k)}(t)$.

At the receiver, the received signal after demodulating via FFT and passing through deinterleaver is given as:

$$Y(t) = \sum_{k=1}^{K}\left[s^{(k)}(t)b\boldsymbol{c}^{(k)} + \bar{s}^{(k)}(t)\bar{b}\bar{\boldsymbol{c}}^{(k)}\right] + \boldsymbol{v}(t) \qquad (7)$$

where $b = F\boldsymbol{h} = \left[g(0),....,g(N-1)\right]^T$, $\boldsymbol{h} = \left[h(0),....,h(M-1),0_{N-M}^T\right]^T$ is channel between T_{X1} and R_X, and $\boldsymbol{v}(t) = \left[v_0(t),....,v_{N-1}(t)\right]^T$ contains samples of the channel noise with zero mean and variance σ_v^2. At the receiver, the received signal is combined and decoded employing MRC, EGC, and MMSE detection techniques.

V. SIMULATION RESULTS

In order to evaluate performance of MC-CDMA systems, the simulation results are obtained in quasi static flat fading channels with binary phase shift keying (BPSK) modulation scheme. The quasi static is a statistical model of the channel effect on a radio signal in wireless communication systems, which is generated by simply adding the two components of complex Gaussian Random variables of zero-mean and unity variance. The BER performance through simulation is compared with the theoretical performance in presence of perfect CSI to verify the result as shown in Fig. 4.

The STBC-MC-CDMA system is simulated with K = 5 and 16 users. The user symbols are drawn from a unit-energy BPSK constellation. Walsh-Hadamard codes with processing gain N = 16 are used for spreading. The signal after spreading is multiplied by the channel impulse gain. In Fig. 5 the performance of STBC-MC-CDMA system is compared with the plain MC-CDMA system using MMSE detection technique. The results are obtained by transmitting 1000 frames of frame length 130 bits at each value of SNR and the average of 10 independent trials is plotted. The SNR is defined as $SNR = 10\log_{10}\frac{1}{\sigma_v^2}$ in dB. In quasi static fading the channel impulse response changes at a rate much slower than the data rate, such channel is assumed to be static over a frame period. It is observed that STBC-MC-CDMA system performs better, i.e., around 6 dB improvement at 10^{-3} BER than plain MC-CDMA system, which reflect the advantage of S-T code system

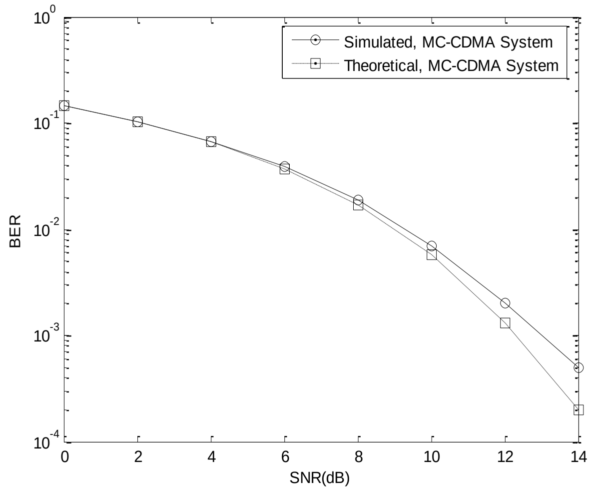

Fig. 4. Theoretical and simulated BER performance of plain BPSK MC-CDMA system.

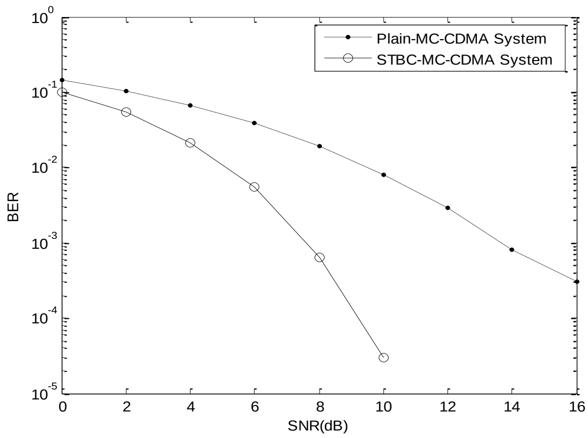

Fig. 5. BER performances of plain MC-CDMA system and STBC-MC-CDMA system.

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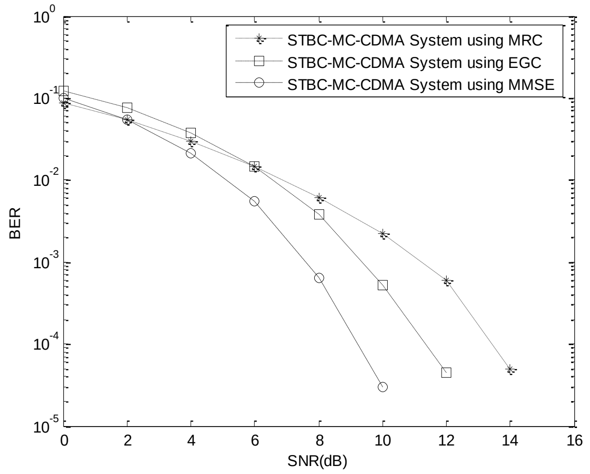

Fig. 6. BER performances of STBC-MC-CDMA system employing MRC, EGC, and MMSE detection techniques for K=5 of users.

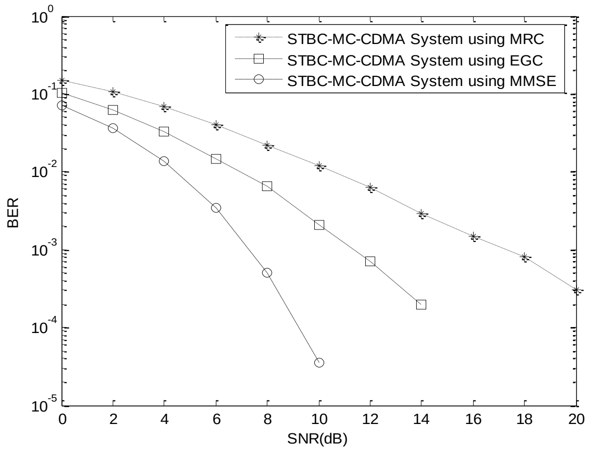

Fig. 7. BER performances of STBC-MC-CDMA system employing MRC, EGC, and MMSE detection techniques for K=16 no. of users.

In Fig. 6 the performance of STBC-MC-CDMA system using MRC, EGC, and MMSE detection techniques are presented for K = 5 users and in Fig. 7 the performance is presented for K = 16 users, respectively. It is noted from Fig. 6 that STBC-MC-CDMA system using MMSE detection technique achieves a BER level of 10^{-3} at the SNR value of around 8 dB whereas EGC detection technique achieves this level at SNR of around 10 dB and MRC detection technique at 12 dB.

Similarly, from Fig. 7, after increasing the number of users, BER level of 10^{-3} achieved by STBC-MC-CDMA system using MMSE detection technique at around 8.5 dB SNR, using EGC detection technique at around 12 dB, and using MRC detection technique at around 17 dB of SNR. These results show that the MMSE scheme outperforms the EGC and MRC schemes, and it is also seen that the performances using MRC and EGC detection techniques decreases rapidly with increasing the number of users.

VI. CONCLUSIONS

In this paper, initially a simple BPSK MC-CDMA system is implemented, and the performance is compared with the theoretical performance of the MC-CDMA system. It is observed that the simulated performance is in close agreement with theoretical performance which verifies the accuracy of the implementation of MC-CDMA system.

Next, STBC-MC-CDMA system is implemented in downlink and applied to MMSE criterion for signal detection in known flat fading channel environment. The performance results are obtained and compared with the performance of plain MC-CDMA system. It is observed that by employing S-T coding technique in plain MC-CDMA system the performance improves substantially.

The MRC and EGC detection techniques are also applied at the receiver to detect STBC-MC-CDMA system and the performances are compared with the MMSE detection technique, with perfect CSI. The performance results are obtained for the evaluation using these detection techniques with different number of users and it is noted that MMSE detector performs better compared to MRC or EGC detection techniques and the performances by MRC and ECG detection techniques degrade rapidly with increasing number of users.

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