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Performance of a Cognitive Cooperative Relay aided Downlink Multi-Carrier Code Division Multiple Access (MC-CDMA) System

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Abstract— With the advent of Internet of Things and 5G wireless services, the scarcity of radio resources is increasing. The Cognitive Radio Network can reduce spectrum scarcity problem by sharing licenced spectrum to the secondary users. The Quality of Experience (QoE) especially reliability and throughput are the major concern for the users. In this paper, a cooperative relay aided multi-carrier code division multiple access based cognitive radio network has been proposed which is expected to reduce interference and improve spectrum utilization efficiency. Here a primary transmitter utilized multiple inactive secondary relay nodes to send data to the primary receiver. At the receiving end, multi path transmission will be received and the received signals are combined through maximal ratio combining. The signal-to-interference-plus-noise ratio (SINR) of MC-CDMA system for Rayleigh fading channel with MRC technique and SINR of cooperative systems using Amplify and Forward or Decode and Forward relaying are derived. A closed form outage probability equation is also derived. Finally, we investigated the performance of the proposed system. The performance evaluation reveals that the performance is better.

Keywords— AF, CRN, Co- operative Relay, DF, MIMO, MC-CDMA, MRC, Rayleigh Fading, Outage Probability.

1 INTRODUCTION

Cognitive Radio Network (CRN) is an expedient technology which can be used to solve the scarcity of bandwidth by sharing the spectrum. The licensed or subscribed users are called Primary Users (PUs) while the unlicensed users are called Secondary Users (SUs). In CRN technology, the SUs can use the free or unused bandwidth of PUs by tracing free spectrum hole of PUs [1,2]. In addition, the SUs can share the bandwidth hole simultaneously with PUs without interference [3] or if the interference temperature is below the predefined value, I_{th} [4,5]. In [6], the authors investigate the capacity gains due to bandwidth sharing under Rayleigh fading channel.

Cooperative relay network is a new model involving transmission and distribution side which provides a significant increase of capacity and also increase transmit and receive diversity gain in wireless communications system [7-9]. When any SUs remain inactive, those can be used as relay for PUs to communicate with other PUs.

In wireless communication, the data transmission rate of PUs can be abridged due to shadowing as well as large scale and small scale fading. As a result, the rate cannot reach the minimum required level of primary transmitter (PT) and primary receiver (PR) using direct link (DL). In [10], the authors conduct research regarding the problem to increase the spectrum efficiency. MIMO based CR network outage capacity has been analyzed within interference temperature-limit [11].

A cellular architecture has been proposed for CRN using Direct Sequence Multi-Carrier CDMA (DS MC-CDMA) in [12]. In this study, the performance of the system is observed using Singular Value Decomposition (SVD) based Transmitter Pre-Processing (TP) technique which mitigates the influence of Co-Channel Interference (CCI) and Multiple Access Interference (MAI).

Outage probability is a very important characteristic in wireless network which affects many networks functionality. A CR based DS-MC-CDMA system has been designed for different narrowband networks under the same frequency band in [13], where the system can reduce the interference at the receiver and also make a comparison between MC-CDMA and CR based MC-CDMA, finally evaluates that CR based MC-CDMA systems has high performance with reliability.

In this paper, the performance of a cognitive cooperative relaying MC-CDMA system has been analysed under Rayleigh fading channel within interference limitation. Here, when only one ST is active, the inactive STs are used as relays to restrain data rate of PU high. So that, the performance of PUs can be increased. The prime objective in this paper is to derivate a closed form SNIR equation for MC-CDMA and also for the MIMO MC-CDMA systems. Finally, in order to improve the system performance, we derive a closed form equation of outage probability for MC-CDMA based cooperative cognitive radio network over Rayleigh fading channel. The numerical analysis of the system is also proved by simulations which are performed in MATLAB.

The paper is organized as follows, section 2 contains system model, section 3 is Performance Matris, section 4 shows Outage Probability, section 5 includes Simulation Results, and in section 6, work is concluded.

2 SYSTEM MODEL

2.1 System Secnario

Fig. 1 illustrates a scenario for cooperative relay based Cognitive Radio Network (CRN). It is assumed that there are M pairs of secondary transmitter and secondary receiver (ST and SR) where two types of secondary transmitters (STs) are considered- active ST and inactive ST. There are K (K$\in M$) numbers of active STs and the N number of inactive STs, where, $N = M - K$. The active ST group is marked as ST_x $(x = 1, 2, \ldots, K)$ and inactive ST group as ST_y $(y = 1, 2, \ldots, N)$. When the Primary Transmitter (PT) transmits data using direct link to the Primary Receiver (PR), if the data rate falls below R_{PT} then the N numbers of inactive STs are used as relay through which the PT can communicate with PR. This method is called AF or DF. While inactive STs are acting as relays, both relays and Primary Receivers (PR) are affected by the interference from active STs. If the interference is below the threshold level, I_{th} the inactive STs and PT can transmit data to PR simultaneously otherwise, the STs cannot be used as relay to communicate with PR.

2.2 Channel Model

When the transmitter transmits data through Rayleigh fading channel, the magnitude of transmitted signals varies randomly according to Rayleigh distribution. In case of long transmission, fading remains almost constant for Rayleigh flat fading with AWGN while it varies in case of short transmission. The fading channel coefficients for the link, PT to cooperative relay are assumed to be α_{PT-ST1} , α_{PT-ST2} ... α_{PT-STy} respectively for N number of inactive SUs. Similarly, those coefficients for the link cooperative relay to PRs and the interference link between active STs to inactive STs are considered as α_{ST1-PR}, , α_{ST2-PR} ... α_{STy-PR} and $\alpha_{STx-ST1}$, $\alpha_{STx-ST2}$ ... $\alpha_{STx-STy}$ for K number of active STs respectively. The channel coefficients for PT→ inactive STs are h_{PT-ST1} , h_{PT-ST2} ... h_{PT-STy} and for anactive STs → PR are h_{ST1-PR}, , h_{ST2-PR} ... h_{STy-PR} which are exponentially distributed with mean values λ_{PT-ST1} , λ_{PT-ST2} ... λ_{PT-STy}, λ_{ST1-PR}, , λ_{ST2-PR} ... λ_{STy-PR} [10].

At the receiver, a receive diversity is applied by using multiple antennas and each of them is equipped with MC-CDMA receivers. MRC combining technique is used to combine the outputs of MC-CDMA receivers. Finally, the outputs of all the receiving antennas are again combined with OFDM demodulator. The destination coherently combines the signals that are received from the source. All the relays use Maximal Ratio Combining (MRC).

3 Performance Matris

3.1 MC-CDMA

1) Primary Transmitter

According to the block diagram of MC-CDMA transmitter shown in Fig.1, the transmitted signals are modulated by BPSK modulation systems.

The proposed MC-CDMA transmitted signals can be expressed as,

$$S_{MC}^{J}(t)=\sum_{n=-\infty}^{\infty}\sum_{p=1}^{L}\sum_{l=1}^{L}\sqrt{2P_T}\; b_P^J(n)C_l^J(n)P(t-nT_s)\cos(\omega_l n+\theta_l) \quad (1)$$

Here, P_T, b_P^J , θ and Ts are defines the transmitted power per symbol, transmitted bit symbol of J[th] user in P[th] sub-channel being modulated by the L sub-carrier, the instantaneous phase angle of each sub-carrier which are assumed to

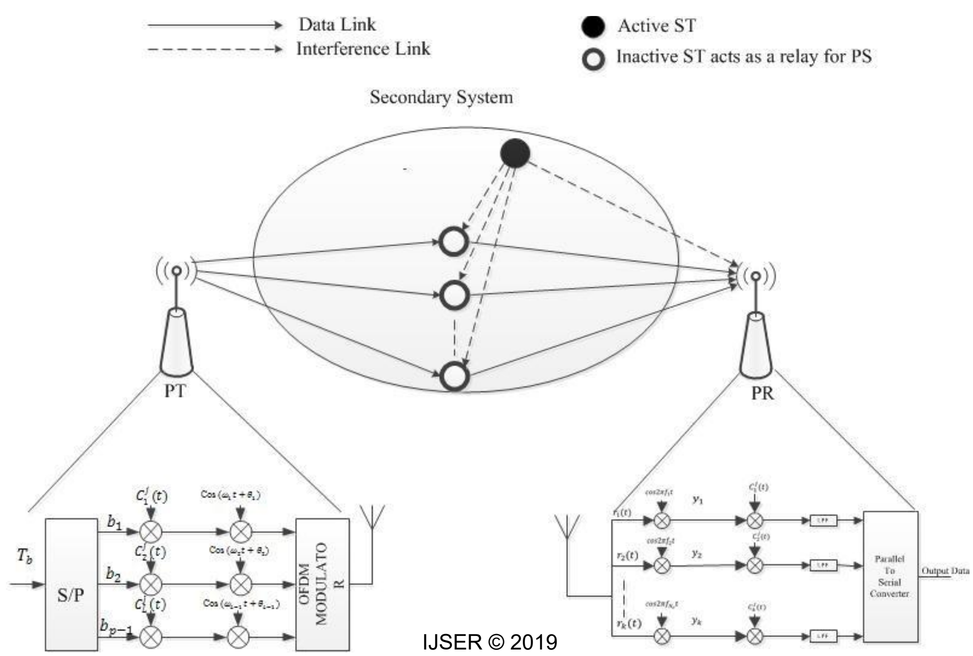

Fig. 1. Proposed scenario of MC-CDMA based Cooperative Relay Cognitive Radio Network

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be uniformly distributed over $[0{:}2\pi]$, the symbol duration for the projected MC-CDMA respectively.

2) Primary Reciever:

The signals transmitted by K number of user are received by the receiver of the J^{th} user. After combining all the transmitted signals at the receiver end and expressed as-

$$r(t)= \sum_{n=-\infty}^{\infty}\sum_{J=1}^{K}\sum_{l=1}^{L}\sqrt{2P_r}\,\beta_l^J b_l^J(n)c_l^J(n)P(t-nT_s)\cos(\omega_l n+\theta_l+\emptyset_l)+\eta(t) \quad (2)$$

Where, P_r is the received power, φ is the phase shift and β^J is the amplitude attenuation. We can derivate the received-signal at the output of the Coherent Demodulator corresponding to 1^{st} path is and so on.

$$y_1=\sum_{J=1}^{K}\sqrt{2P_r}\beta_l^J\, b_1^J c_1^J(n)P(t-nT_s)\cos(\omega_1 n+\theta_1+\varphi_1)\times c_1^J\alpha_1^J\cos(\omega_l n+\theta_l+\varphi_1) \quad (3)$$

$$y_2=\sum_{J=1}^{K}\sqrt{2P_r}\beta_l^J\, b_2^J c_2^J(n)P(t-nT_s)\cos(\omega_2 n+\theta_2+\varphi_2)\times c_2^J\alpha_2^J\cos(\omega_2 n+\theta_2+\varphi_2) \quad (4)$$

$$y_K=\sum_{J=K}^{K}\sqrt{2P_r}\beta_l^J\, b_L^J c_L^J(n)P(t-nT_s)\cos(\omega_L n+\theta_L+\varphi_L)\times c_L^J\alpha_L^J\cos(\omega_L n+\theta_L+\varphi_L) \quad (5)$$

After passing through the low pass filter of the MC-CDMA systems, the output signal can be written as-

$$Y=\sum_{J=1}^{K}\sum_{l=1}^{L}\sqrt{\frac{P_r}{2}}\beta_l^J\, b_L^J c_L^J(n)P(t-nT_s)\cos(\omega_L n+\theta_L+\varphi_L)\times c_L^J\alpha_L^J\cos(\omega_L n+\theta_L+\varphi_L)+\eta \quad (6)$$

Now, Signal power for the MC-CDMA systems is defined as-

$$P_s=\sqrt{\frac{P_r}{2}}\sum_{l=1}^{L-1}\alpha_l^2 \quad (7)$$

$$SINR=\frac{|H|^2\sum_{l=1}^{L-1}\alpha_l^2}{\sigma_n^2} \quad (8)$$

Where, σ_n^2 is the variance and η is the additive white Gaussian noise (AWGN).

3.2 MIMO MC-CDMA

Finally, a close form SINR equation of MIMO MC-CDMA systems is derved-

$$SINR=\frac{|H|^2\sum_{l=1}^{L-1}\alpha_l^2}{\sigma_n^2} \quad (9)$$

CAUSE: Consider the wireless communication scenario shown in Fig. 1. Here, MC-CDMA transmitter is communicating with MC-CDMA receiver through a cooperative relay network which is inactive ST for our designed system. Assume that MC-CDMA is transmitting a signal $S_{MC}^j(t)$ which has an average power normalized to one. The received signal at cooperative relay network can be written as,

$$r_{ST}=\alpha_{PT-ST_y}S_{MC}^j(t)+\eta_1 \quad (10)$$

The received signal at the end of the relay is then multiplied by the gain of the relay and then re-transmitted to the MC-CDMA receiver. The received signal at receiver can be written as,

$$r_{PT}=\alpha_{ST_y-PR}G\{\alpha_1 S_{MC}^j(t)+\eta_1\}+\eta_2 \quad (11)$$

Where, amplification gain,

$$G=\frac{1}{\frac{P_r}{2}\sum_{l=1}^{L-1}\alpha_l^2\left|h_{PT-ST_y}^2\right|d_{PT-ST_y}^{-\alpha}+\sigma_n^2} \quad (12)$$

The destination of our proposed system combines the received signals using a MRC and the overall SINR [14] for MC-CDMA cooperative relay network at the receiver end can be written as,

$$\gamma_{MRC}=\gamma_{PT-PR}+\gamma_{PT-ST_y-PR}$$

$$\gamma_{MRC}=\gamma_{PT-PR}+\frac{\gamma_{PT-ST_y}\gamma_{ST_y-PR}}{\gamma_{PT-ST_y}+\gamma_{ST_y-PR}+1} \quad (13)$$

$$\gamma_{MRC}=\frac{\sqrt{\frac{P_r}{2}}\sum_{l=1}^{L-1}\alpha_l^2}{\sqrt{\frac{P_r}{2}}\sum_{l=1}^{L-1}\alpha_l^2\sum_{j=2}^{J-1}\beta_l^j b_l^j+\sigma_n^2}+\frac{\left(\frac{\sqrt{\frac{P_r}{2}}\sum_{l=1}^{L-1}\alpha_l^2}{\sqrt{\frac{P_r}{2}}\sum_{l=1}^{L-1}\alpha_l^2\sum_{j=2}^{J-1}\beta_l^j b_l^j+\sigma_n^2}\right)^2\left|h_{PT-ST_y}^2\right|d_{PT-ST_y}^{-\alpha}\left|h_{ST_y-PR}^2\right|d_{ST_y-PR}^{-\alpha}}{\frac{\left|h_{PT-ST_y}^2\right|d_{PT-ST_y}^{-\alpha}\sqrt{\frac{P_r}{2}}\sum_{l=1}^{L-1}\alpha_l^2}{\sqrt{\frac{P_r}{2}}\sum_{l=1}^{L-1}\alpha_l^2\sum_{j=2}^{J-1}\beta_l^j b_l^j+\sigma_n^2}+\frac{\left|h_{ST_y-PR}^2\right|d_{ST_y-PR}^{-\alpha}\sqrt{\frac{P_r}{2}}\sum_{l=1}^{L-1}\alpha_l^2}{\sqrt{\frac{P_r}{2}}\sum_{l=1}^{L-1}\alpha_l^2\sum_{j=2}^{J-1}\beta_l^j b_l^j+\sigma_n^2}} \quad (14)$$

4 Outage Probability

Data rate corresponding the cooperative relay nodes are,

$$R_{PT-ST_y}=\frac{1}{2}log_2(1+SINR_{PT-ST_y}) \quad (15)$$

$$R_{ST_y-PR}=\frac{1}{2}log_2(1+SINR_{ST_y-PR}) \quad (16)$$

Where, SINR in equation of (14) and (15) approximated as follows:

$$SINR_{PT-ST_y}=\left|h_{PT-ST_y}^2\right|\frac{\sqrt{\frac{P_r}{2}}\sum_{l=1}^{L-1}\alpha_l^2}{\sqrt{\frac{P_r}{2}}\sum_{l=1}^{L-1}\alpha_l^2\sum_{j=2}^{J-1}\beta_l^j b_l^j+\sigma_n^2} \quad (17)$$

$$SINR_{PT-ST_y}=\frac{\rho_{PT-ST_y}P_S}{1+\sigma^2} \quad (18)$$

$$SINR_{ST_y-PR}=\frac{\rho_{ST_y-PR}P_S}{1+\sigma^2} \quad (19)$$

Where, I defines the interference of the MC-CDMA system. $\left|h_{PT-ST_y}\right|$, $\left|h_{ST_y-PR}\right|$ are assume that the channel coefficient and link path gain to the corresponding channels are $\rho_{PT-ST_y} = \left|h_{PT-ST_y}\right|^2$ and $\rho_{ST_y-PR} = \left|h_{ST_y-PR}\right|^2$. From equation (15) and (16),

$$R_{PT-ST_y} = \frac{1}{2}\log_2(1 + \frac{\rho_{PT-ST_y}P_S}{1+\sigma^2}) \quad (20)$$

$$\rho_{PT-ST_y} = \left(2^{2R_{PT-ST_y}} - 1\right)\frac{1+\sigma^2}{P_S} \quad (21)$$

Similarly,

$$\rho_{ST_y-PR} = \left(2^{2R_{ST_y-PR}} - 1\right)\frac{1+\sigma^2}{P_S} \quad (22)$$

Outage Probability can be expressed as [15],

$$P_{out} = \int_0^{\rho} \frac{4\lambda_S^2\lambda_P^2}{(\lambda_S^2+\lambda_P^2 z)^2} dz \quad (23)$$

Where, λ_s, λ_P are expected random variables and z is expressed as random variable of probability density function (PDF) for Rayleigh fading channel.

The outage probability follows equation (23) for the two links of $PT - ST_y$ and $ST_y - PR$ respectively.

$$P_r(R_{PT-ST_y} < R_{PT-PR}) = \frac{4\rho_{PT-ST_y}\lambda_{ST_x-ST_y}^2}{\lambda_{PT-ST_y}^2 + \rho_{PT-ST_y}\lambda_{ST_x-ST_y}^2} \quad (24)$$

$$P_r(R_{ST_y-PR} < R_{PT-PR}) = \frac{4\rho_{ST_y-PR}\lambda_{STx-PR}^2}{\lambda_{STj-PR}^2 + \rho_{SR}\lambda_{ST_x-PR}^2} \quad (25)$$

Where, λ is the exponential random variables with mean value. Dual hop cooperative relay link is a useful method in reducing channel scarcity where minimum one of the hop is involved to transmit end to end data. **S** is denoted as the set of relays that can be expressed for relay selection as,

$$S = x^{\min(R_{ST_y-PR}, R_{ST_y-PR})}$$

When, $|\boldsymbol{S} = 0|$, that is the inactive secondary users do not attain the data rate of R_{PT-ST_y} the Outage Probability is expressed as [16],

$$P_{out} = P_r\{\|s\| = 0\}$$

$$P_{out} = P_r\{max_{m\in N}\left(\min\{R_{PT-ST_m}, R_{ST_m-PR}\}\right) < R_{PT}\}$$

$$P_{out} = \prod_{m=1}^{N-1}\{P_r\left(\min\left\{R_{PT-ST_y}, R_{ST_y-PR}\right\}\right) < R_{PT}\}$$

$$P_{out} = \prod_{m=1}^{N-1}[1 - (1 - P_r\{R_{PT-ST_m} < R_{PT}\})(1 - P_r\{R_{ST_m-PR} < R_{PT}\})] \quad (26)$$

5 Simulation Results

The SINR performance results of a MC-CDMA cooperative relay system with diverse system parameters and order of Rayleigh fading with and without receive interference are evaluated. To end, the optimum values of system parameters like number of OFDM sub-carrier, spreading code, modulation system for a given SINR and the outage probability are determined from the simulation results. The parameters are used for the numerical simulations are shown in table below.

Parameter	Values
Spreading codes, C	Walsh-hadamard code (256)
Channel	Rayleigh fading
Modulation	BPSK
Antennas	SISO, SIMO, MISO, MIMO
Power	30 dB
Equalization technique	MRC

The channel capacities of OFDM and MC-CDMA for SISO and MIMO system are compared in fig. 2. For all systems, channel capacity increases with the increase of SINR. Moreover, MC-CDMA always provides higher channel capacity than OFDM irrespective of the number of received antennas.

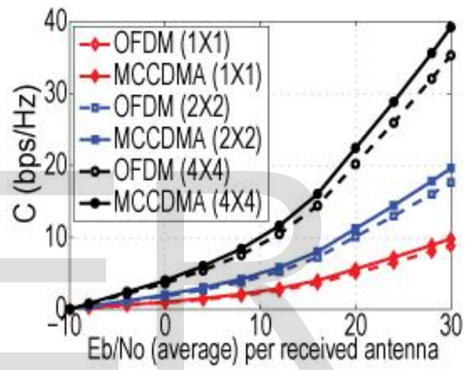

Fig. 2. SINR vs Outage capacity for SIMO and MISO systems without interference

From the analysis, it can be seen from fig. 3 that for 10 dB SINR per antenna channel capacity of OFDM and MC-CDMA are about 1.5 bps/Hz for SISO system. However, for MIMO system the performance of channel is improved with the increase of received antenna.

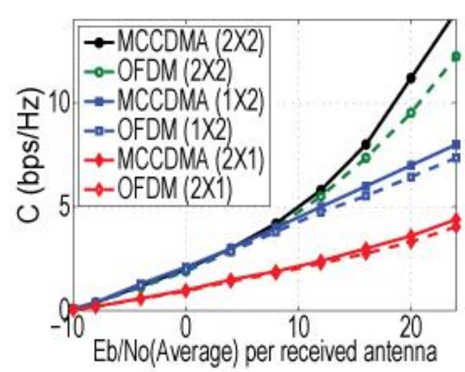

Fig. 3. SINR vs Outage capacity for MIMO systems without interference.

The best performance is observed for MC-CDMA, 4×4 MIMO system where channel capacity is 10 bps/Hz for the same value of SINR. Here, the comparison is shown for the channel capacity of MC-CDMA and OFDM for MISO, SIMO and MIMO multiplexing in fig. 4. For same SINR (10 dB), MC-CDMA shows the most improvement for MIMO (almost 4.8 bps/HZ) than all other multiplexing where OFDM with MISO multiplexing shows the least value of channel capacity (slightly more than 2 bps/Hz).

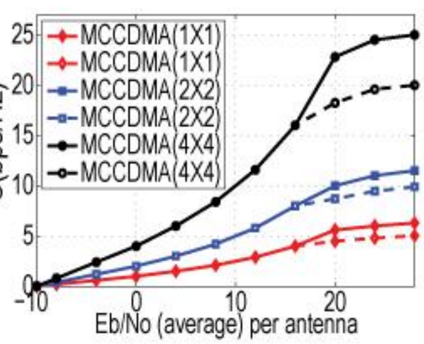

Fig. 4: Effect on SINR on the link capacity.

In fig. 5 and fig. 6, the SINR varies from -8 dB to 2 dB. In fig. 5, the outage probability is analysed with SINR for MIMO multiplexing. Here, for -2 dB SINR, the probability P_{out} for 4× 4 and for 2× 2 multiplexing is 10^{-4} and 10^{-2} rspectively which concludes that, P_{out} performance depends on MIMO antenna. The P_{out} imoroves for 4× 4 MIMO system compared to 2× 2 MIMO system.

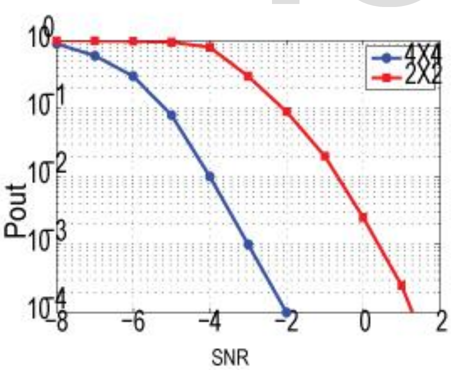

Fig. 5. The effect of SINR on the Outage probability for MIMO systems.

Fig. 6 shows the effect of interference temperature on the outage probability performance of transmission link. The outage probability improves for 4× 4 MIMO system than 2× 2 MIMO system with MRC at the receivers. The interference tenpeartire limit increases the Pout compared to no interference limit case.

Moreover, the probability dereases for all MIMO multiplexing with the rise of SINR. Hence, the outage probability of cooperative relay is better than that of non coopearive relay. Both the simulation result and numerical analysis clearly indicates that the proposed system provides better performance due to the increase of cooperative relays.

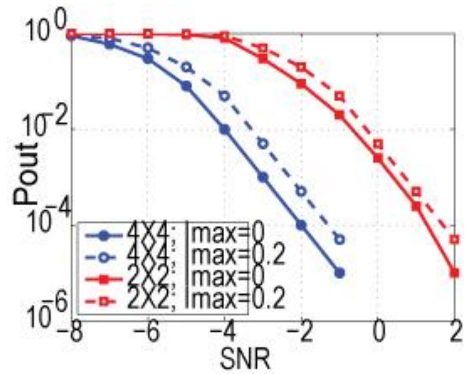

Fig. 6. The effect of SINR on the Outage Probability for MIMO systems with varing max values.

6 Conclusion

To share the spectrum of other mobile it is necessary to analyze the performance of our proposed MC-CDMA cooperative relay communication system. Using MATLAB simulation, the performance of SINR for Rayleigh fading channel with MRC technique for different systems like SIMO, MISO and MIMO with and without interference are determined and also the derived expression of outage probability matched with simulation result.

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