Performance Assessment of a Block Cipher Encryption based Channel Encoded Cooperative MIMO MCCDMA Wireless Communication System

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Abstract

In this paper, we made a comprehensive simulative study on the performance assessment of a MIMO MC CDMA wireless communication system. The proposed system under investigation consider a communication link between three multi antenna supported units such as a mobile user unit, base station and relaying node. The system incorporates four low-complexity channel equalization techniques, various digital modulations and Block cipher encryption based channel coding schemes. From MATLAB based simulated study on synthetic data transmission*, it is found a quite noticeable impact on deploying a single relaying node on performance enhancement of the presently considered MIMO MCCDMA system. The system is also capable of showing its robustness in retrieving transmitted data over hostile multipath fading channels in a scenario of thickly populated urban area.*

Keywords: MCCDMA**,** Relaying**,** Block cipher encryption based channel coding, Walsh-Hadamard code, Linear signal detection technique, Bit Error rate (BER), AWGN and Raleigh fading channels

1. Introduction

With development of physical layer techniques , the data rates of mobile communication services have increased by about 100 times every 6–7 years and it is predicted that in 2020, the required data rate will be as large as 100–1000 times the currently served data rate. The wireless transmission and networking technologies are the essential components of the mobile communication systems. Due to the recent breakthrough in transmission technologies with consideration of constraints of traditional cellular systems in terms of transmit power, complicacy in frequency of handover in high speed mobile environment (350km/h) and cell edge effect for transmission frequencies higher than 2 GHz, cellular communications have entered the era of cooperative communications. In Cooperative communication system, various types of cooperative schemes such as relay, DAS, multicellular coordination, Group Cell, Coordinated Multiple Point transmission and reception (CoMP) are used. [1]

Cooperative communications have recently been migrated to one of state-of-the-art features of the 3GPP LTE-Advanced (LTE-A) system. In LTE-Advanced system, single

carrier frequency division multiple access (SC-FDMA) has been adopted in the uplink communication and orthogonal frequency division multiple access (OFDMA) has been adopt in the downlink communication. In such system, base-station (BS) cooperative transmission under CoMP cooperative transmission scheme has been widely recognized as a promising technique to enhance throughput by avoiding intercell interference (ICI), particularly for cell-edge users. In January 2009, CoMP and Cooperative Relay based trial networks have been deployed in the campus of Beijing University of Posts and Telecommunication [2, 3].

In this paper, we have used MC-CDMA, a hybrid transmission technique employing an amalgam of Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) merely to assess the system performance under deployment of a single cooperative relaying node. The MC-CDMA is expected to combine the benefits of pure CDMA and OFDM techniques. The MC-CDMA is an attractive choice for high speed wireless communication as it mitigates the problem of inter-symbol interference (ISI) with exploitation of frequency diversity [4]. In Figure 1, a scenario of cooperative relaying network has been shown where it is seen that a mobile user is in a running car and making communication link with both base station and relaying node. The relaying node receives signal from the base station and retransmits it to the mobile user after proper amplification.
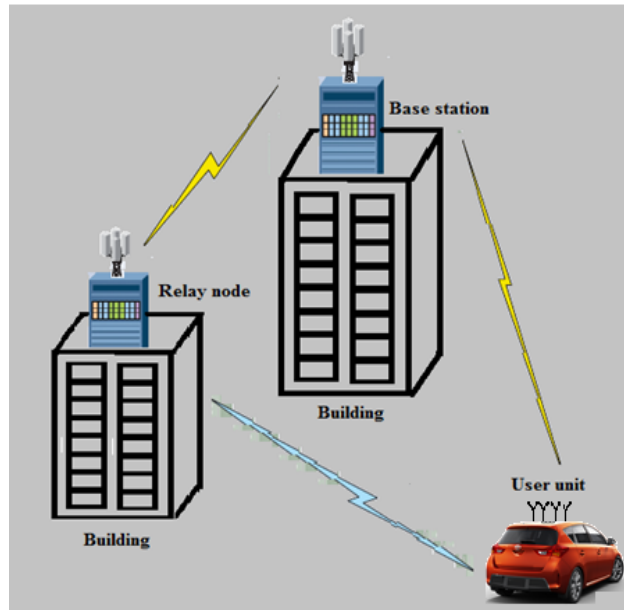

Figure 1. Scenario of Cooperative Relaying Network

2. Block Cipher Encrypted Channel Coding (BCECC)

In our presently considered single relayed MIMO MC-CDMA wireless communication system. Block cipher encryption based channel encoding scheme has been implemented A brief description is given below

In BCECC scheme, a symmetric block cipher process a data blocks of 256 bits at a time using a secret cryptographic key of 256 bits. The input source binary data are framed into 256 bit blockwise and processed in two channel. In one channel, data block is merely channel encoded using ½ -rated convolutional encoder. In another channel, data block is encrypted using symmetric block cipher and fed into another ½ -rated convolutional encoder (Figure

2).The output of both channel encoder are demultiplexed to produce Block cipher encrypted Channel encoded binary data [5, 6]
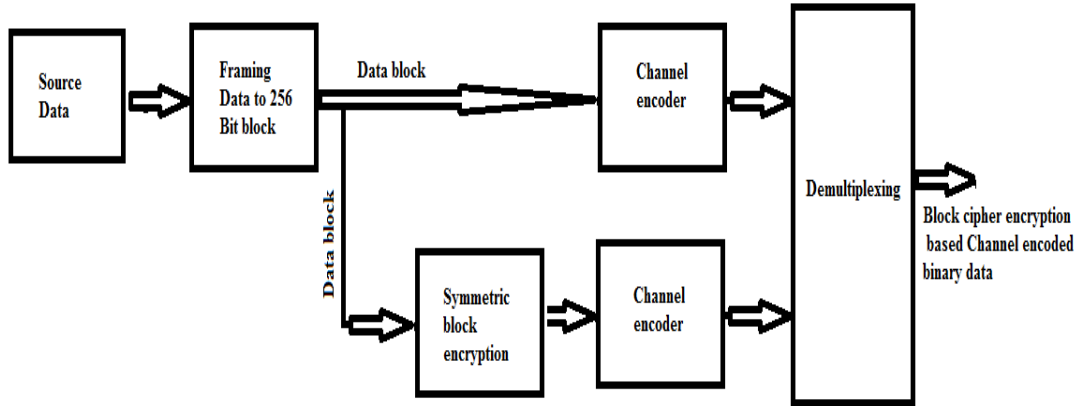

Figure 2. Block Cipher Encryption based Channel Coding System

3. Signal Models

We assume a communication link is established from a base station to a user unit considering transmission both directly and via a relaying unit. All of these three units are multi antenna supported. The relaying unit operates in half duplex mode viz. it is capable of making simultaneous reception and transmission. For simplicity, we have considered that a

binary data stream **d** with elements $d_i \in \{0,1\}$ for i = 0, 1, 2,……………., L is to be transmitted from base station. After block cipher encryption, its length is M (M=4L). The channel encoded binary data **dcn** is interleaved and mapped into digitally modulated symbol sequence **X0** with its size **N0** depending upon the order of modulation considered. Each symbol of the data sequence **X0** is repeated PG times and multiplied with orthogonal spreading code C of its factor value assigned to PG. The orthogonally spreaded data symbol vector X are spatially multiplexed into four complex data streams X1, X2, X3 and X4 .The data of each stream are rearranged into **Q** ((=N0*PG)/(4*Nc)) number of blocks with each block containing **Nc** number of symbols. In block wise processing for each of the four data streams X1, X2, X3 and X4, the discrete time domain OFDM signal xm,q[n] at the output of IFFT section for an input frequency-domain signal Xm,q[k] is given by-

$$x_{m,\,q}[n] = \sum_{k=0}^{N_c-1} X_{m,\,q}[k]e^{\,j\left(\frac{2\pi}{N_c}\right)kn} \tag{1}$$

Where, **m** and **q** are the transmitting antenna and block identifiers respectively; m=1,2,3,4 and q=1,2,3…..Q, n=0,1,2,3….N_c-1 and k=0,1,2,3….N_c-1

In cyclic prefixing, the OFDM signal $x_{m,q}[n]$ is extended by copying 10% of the total number of samples, **cp** from its last samples and placed into its front. The cyclically prefixed OFDM signal can be written in matrix form as-

$$\begin{bmatrix} \mathbf{xc}_{m,q}[\mathbf{n+cp}] \end{bmatrix} = \begin{bmatrix} \mathbf{x}_{m,q}[\mathbf{N_c - cp + 1 : N_c}] & \mathbf{x}_{m,q}[n] \end{bmatrix} \tag{2}$$

Considering all data, the transmitted signal vector Xs in terms of its four signal vector components $Xs_1, Xs_2 \ Xs_3$ and Xs_4 can be written as-

$$Xs = \begin{bmatrix} Xs_1 \\ Xs_2 \\ Xs_3 \\ Xs_4 \end{bmatrix} = \begin{bmatrix} \mathbf{xc}_{1,1}[\mathbf{n+cp}] & \mathbf{xc}_{1,2}[\mathbf{n+cp}] & \text{.......} & \mathbf{xc}_{1,q}[\mathbf{n+cp}] \\ \mathbf{xc}_{2,1}[\mathbf{n+cp}] & \mathbf{xc}_{2,2}[\mathbf{n+cp}] & \text{.......} & \mathbf{xc}_{2,q}[\mathbf{n+cp}] \\ \mathbf{xc}_{3,1}[\mathbf{n+cp}] & \mathbf{xc}_{3,2}[\mathbf{n+cp}] & \text{.......} & \mathbf{xc}_{3,q}[\mathbf{n+cp}] \\ \mathbf{xc}_{4,1}[\mathbf{n+cp}] & \mathbf{xc}_{4,2}[\mathbf{n+cp}] & \text{.......} & \mathbf{xc}_{4,q}[\mathbf{n+cp}] \end{bmatrix} \tag{3}$$

The transmitted signal is processed from base station (source) to the relay and user unit(destination) in first phase. If $H_{s,r}$, and $H_{r,d}$, and $H_{s,d}$ are considered to be the 4×4 channel matrices for the base station to relay and relay to user unit and base station to user unit links and $w_{s,r}$, $w_{r,d}$, and $w_{s,d}$ are the corresponding zero mean circularly symmetric complex Gaussian noise for the source-relay, relay-destination and source-destination links for transmitted signal Xs, the signals received at the relays and the destination can be written as

$$\mathbf{Y_r = H_{s,r} \ X_s + w_{s,r}} \tag{4}$$

$$\mathbf{Y^{(1)}_d = H_{s,d} \ X_s + w_{s,d}}$$

In second phase, the relay amplifies the received signal and transmits it to the user unit. The relaying amplification factor, G can be written as:

$$G = \sqrt{\frac{average \quad transmitte \ d \quad signal \quad power}{average \quad received \quad signal \quad power \quad at \quad relay}} \tag{5}$$

The signal received at the user unit from the relay is given by-

$$\mathbf{Y^{(2)}_d = H_{r,d} \ GY_r + w_{r,d} = H_{r,d} \ G \ H_{s,r} \ X_{s} + H_{r,d} \ G \ w_{s,r} + w_{r,d}} \tag{6}$$

Considering Equation (4) and Equation (6), the equivalent received signal Y at the user unit in two phases can be written as-

$$Y = \begin{bmatrix} Y^{(1)}_{\mathbf{d}} \\ Y^{(2)}_{\mathbf{d}} \end{bmatrix} = \begin{bmatrix} \mathbf{H}_{\mathbf{s,d}} \\ H_{r,d} GH_{s,r} \end{bmatrix} Xs + \begin{bmatrix} \mathbf{w}_{\mathbf{s,d}} \\ \mathbf{H}_{\mathbf{r,d}} Gw_{s,r} + w_{r,d} \end{bmatrix} \tag{7}$$

In concise form, Equation (7) can be written as in terms of equivalent channel matrix H and Equivalent noise N as-

Y=HXs+N (8)

In Minimum mean square error (MMSE) signal detection scheme, the MMSE weight matrix is given by-

$$\mathbf{W_{MMSE}} = (\mathbf{H^H H} + \sigma_n^2 \mathbf{I})^{-1} \mathbf{H^H} \tag{9}$$

and the detected desired signal from the transmitting antenna is given by-

$$\tilde{X}_{MMSE} = W_{MMSE} Y \tag{10}$$

In Zero-Forcing (ZF) scheme, the ZF weight matrix is given by

$$\mathbf{W_{ZF}} = (\mathbf{H^H H})^{-1} \mathbf{H^H} \tag{11}$$

and the detected desired signal from the transmitting antenna is given by [7]

$$\tilde{X}_{ZF} = W_{ZF} Y \tag{12}$$

In ZF-SIC channel equalization scheme, the channel matrix **H** undergoes QR factorization as-

$$H = QR = Q \begin{bmatrix} R_{1,1} & R_{1,2} & R_{1,3} & R_{1,4} \\ 0 & R_{2,2} & R_{2,3} & R_{2,4} \\ 0 & 0 & R_{3,3} & R_{3,4} \\ 0 & 0 & 0 & R_{4,4} \end{bmatrix} \tag{13}$$

where, Q and R are the unitary and upper triangular matrix respectively. Equation (8) can be rewritten on multiplying by $\mathbf{Q^H}$ as-

$$X = Q^H Y = RXs + Q^H N \tag{14}$$

where, $Q^H N$ is a zero-mean complex Gaussian random vector. Since $Q^H N$ and N have the same statistical properties, $Q^H N$ can be used to denote **N**. We get Equation **(14)** as

$$X = RXs + N$$

$$\Downarrow$$

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & r_{1,4} \\ 0 & r_{2,2} & r_{2,3} & r_{2,4} \\ 0 & 0 & r_{3,3} & r_{3,4} \\ 0 & 0 & 0 & r_{4,4} \end{bmatrix} \begin{bmatrix} \widetilde{x}_{s1} \\ \widetilde{x}_{s2} \\ \widetilde{x}_{s3} \\ \widetilde{x}_{s4} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix} \tag{15}$$

the detected desired signal $\widetilde{X}s$ from the four transmitting antennas can written on neglecting noise term from Equation **(15)** as-

$$\widetilde{x}_{s4} = \frac{x_4}{r_{4,4}}$$

$$\widetilde{x}_{s3} = \frac{(x_3 - r_{3,4} \widetilde{x}_{s4})}{r_{3,3}}$$

$$\widetilde{x}_{s2} = \frac{(x_2 - r_{2,3} \widetilde{x}_{s3} - r_{2,4} \widetilde{x}_{s4})}{r_{2,2}} \tag{16}$$

$$\widetilde{x}_{s1} = \frac{(x_1 - r_{1,2} \widetilde{x}_{s2} - r_{1,3} \widetilde{x}_{s3} - r_{1,4} \widetilde{x}_{s4})}{r_{1,1}}$$

In MMSE-SIC Scheme, the received signal, channel matrix and noise are extended

$$H_{ex} = \begin{bmatrix} H^T & \sqrt{\frac{\sigma_n^2}{\sigma_s^2}} I \end{bmatrix}^T, \quad Y_{ex} = \begin{bmatrix} Y^T & 0^T \end{bmatrix} \text{ and}$$

$$N_{ex} = \begin{bmatrix} N^T & -\sqrt{\frac{N_0}{E_s}} X_s^T \end{bmatrix}^T \tag{17}$$

Where, $\frac{\sigma_n^2}{\sigma_s^2}$ is the ratio of average noise power to average signal power(1/SNR). On QR factorization of extended channel matrix H_{ex}, we get

$$H_{ex} = Q_{ex} . R_{ex} \tag{18}$$

Where, Q_{ex} and R_{ex} represent a unitary matrix and an upper triangular matrix respectively. We assume that Y, H, N, Q and R are replaced by Y_{ex}, H_{ex}, N_{ex}, Q_{ex} and R_{ex} respectively and correspondingly the resulting system takes the following form-

$$x_{ex} = Q_{ex}^{H}.Y_{ex}$$
$$= R_{ex}.X_{s} + Q_{ex}^{H}.N_{ex}$$

(19)

Neglecting noise term in Equation (19) and using matrix inversion scheme, the transmitted signal can be detected [7-9].

4. Communication System Model

A simulated single -user 4 x 4 spatially multiplexed single relayed cooperative MCCDMA wireless communication system is depicted in Figure 3. In such a communication system, the synthetically generated binary bit stream is processed for Block cipher encryption based channel encoding and subsequently interleaved for minimization of burst errors. The interleaved and channel encoded bits are digitally modulated using QPSK, QAM,16QAM and 16PSK and the number of digitally modulated symbols is increased 256 times in copying section (as the processing gain of the Walsh Hadamard codes is 256) and subsequently multiplied with Walsh Hadamard codes. The complex digitally modulated symbols are fed into spatial Demultiplexer to produce four data streams. The complex data symbols of each of the four streams are serial to parallel (S/P) converted and fed into IFFT section (OFDM modulator) where modulation is performed utilizing all subcarriers in each OFDM block. The modulated complex symbols are cyclically prefixed for minimizing inter symbol interference (ISI) and converted from parallel to serial and eventually sent up from the transmitting antennas. In receiving section, the transmitted signals are detected using signal detection techniques the detected signals are processed for serial to parallel conversion and removal of cyclic prefixing, OFDM demodulation and parallel to serial conversion prior to Spatial multiplexing. The processed data are then digitally demodulated, deinterleaved and channel decoded for retrieval of transmitted binary data [10, 11].
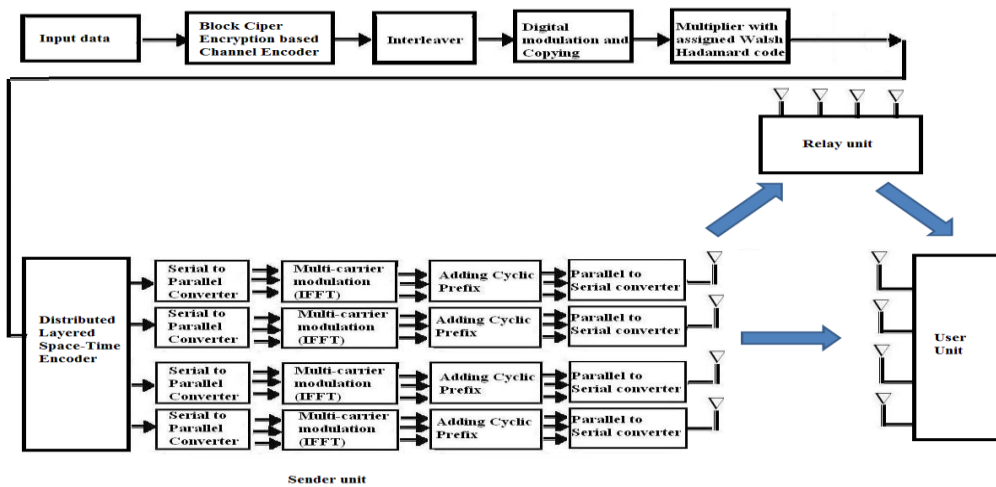

Figure 3. Conceptual Block Diagram of a Single Relayed Cooperative MIMO MCCDMA Wireless Communication System

5. Results and Discussion

Results presented in this section are obtained by the computer simulation programs written in MATLAB12 and discussion are made on the achievable BER performance of a secured single relayed cooperative MIMO MC CDMA system with spatial multiplexing/demultiplexing aided antenna diversity, AES encryption based channel coding and various channel equalization/signal detection schemes. The simulation study is made with the parameters presented in Table 1. We assume a frequency-non-selective fading channel with its channel state information (CSI) available at the transmitter side and consider the bandwidth of the wireless channel wider as compared to transmitted signal bandwidth to neglect Doppler frequency effect.

Table 1. Summary of the Simulated Model Parameters

no. of synthetically generated binary data	4096
Channel Coding	Block Cipher Encryption based
Digital modulation	QPSK, QAM,16QAM and 16PSK
No of subcarriers (FFT Size)	1024
CP length	103 symbols
Spreading Code	Walsh-Hadamard codes
Spreading-factor of Spreading Code(Processing gain, PG)	256
Antenna Configuration (User Equipment , Base station and Relay node)	(4,4)
Signal Detection Scheme	Minimum Mean square error(MMSE), Zero forcing (ZF), MMSE-SIC and ZF-SIC
Channel	AWGN and Rayleigh fading
Signal to noise ratio (SNR)	0 to10 dB

Graphical illustrations presented in Figure 4 through Figure 7 show the Bit error rate of the simulated system under consideration of transmission from both Base station and cooperative node to mobile user unit as a function of the average signal power to average noise power. In all cases, the system outperforms in QAM and shows worst performance in 16PSK digital modulations. In Figure 4, the simulation results are presented comparing the BER of the MMSE linear equalizer receiver for various type of digitally modulated (QAM, QPSK, 16QAM and 16PSK) symbols detection. With four receiver antenna, MMSE receiver has high performance penalty in 16PSK as compared to QAM, QPSK and 16QAM digital modulations. As the receiver has multiple antennas, the MMSE linear equalizer receiver is able to fully mitigate fading and intersymbol interference (ISI) at the expense of certain SNR loss. In Figure 4, it is observable that at a typically target $1\%(10^{-2})$ BER, the MMSE linear equalizer in QPSK,16QAM and 16PSK require approximately 0.6 dB, 5.7 dB and 7.8 dB higher SNR respectively as compared to QAM. At a typically assumed 1dB SNR value, system performance improvement of 3.69 dB and 11.31 dB are achieved in QAM as compared to QPSK and 16PSK digital modulations respectively. In low SNR value region, the fading channel is capable of providing rich amount of diversity and the MMSE linear equalizer exploits fully diversity gain in low order digital modulations. In Figure 5, the BER results are shown for ZF linear equalizer receiver. In such receiver, it is noticeable that the

noise enhancement is significant and the fading channel is incapable of providing rich amount of diversity for QAM and QPSK digital modulations at low SNR value region as compared to MMSE linear equalizer receiver. In higher SNR value region with 16QAM and 16PSK digital modulations, the simulation graphs show a significant reduction of BER. At 1dB low SNR value, system performance improvement of 5.22 dB and 9.43 dB are achieved in QAM as compared to QPSK and 16PSK digital modulations respectively. At 1% BER, the ZF linear equalizer in QPSK, 16QAM and 16PSK require approximately 1.3 dB, 6.3 dB and 8.6 dB higher SNR respectively as compared to QAM. In Figure 6, MMSE-SIC linear equalizer receiver shows peculiar BER performance. At identical signal and noise power (0dB SNR), the simulated system is found to have BER value less that 1% with QAM digital modulation. At low SNR regime with 16QAM and 16PSK digital modulations, the receiver shows almost identical system performance and the BER difference becomes prominent with increase in SNR value. At 1dB low SNR value, the simulated system is found to have performance improvement of 5.36 dB and 21.10 dB in QAM as compared to QPSK and 16PSK digital modulations respectively.In Figure 7, ZF-SIC linear equalizer receiver shows comparatively distinct BER performance. In low SNR value region with low order digital modulations, the fading channel is incapable of providing significant amount of diversity as compared to MMSE-SIC linear equalizer. At 0 dB SNR value, the simulated system is found to have BER value greater that 1% with QAM digital modulation. At 1dB low SNR value, the simulated system achieves performance improvement of 7.52 dB and 18.04 dB in QAM as compared to QPSK and 16PSK digital modulations respectively.
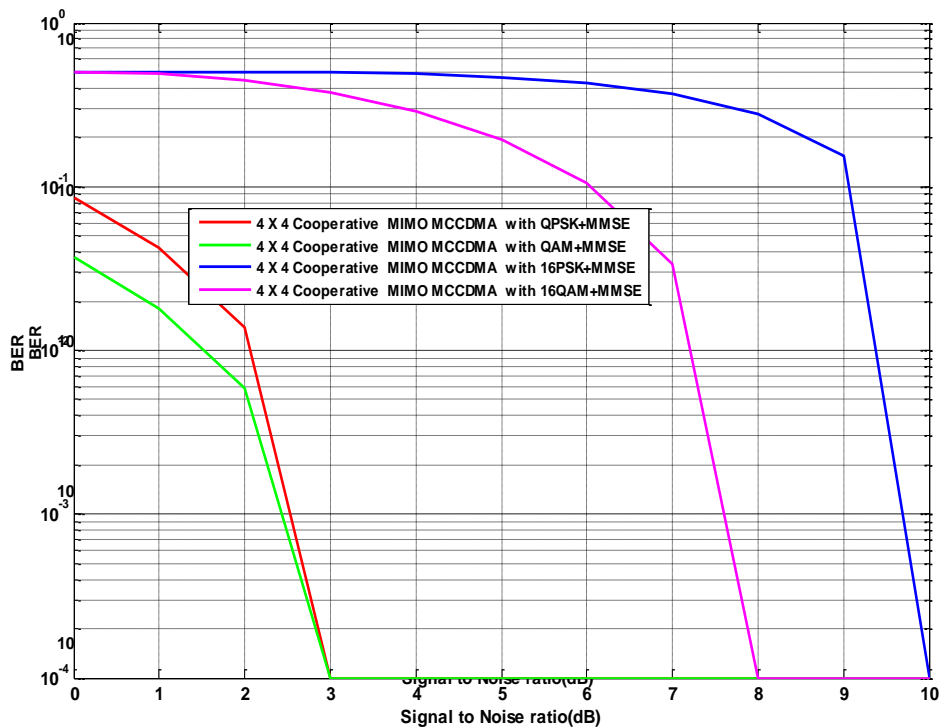

Figure 4. BER Performance of a Single Relayed Cooperative MIMO MC CDMA Wireless Communication System under Deployment of MMSE Channel Equalization, Distributed Layered Space-Time Coding and Various Digital Modulation Schemes
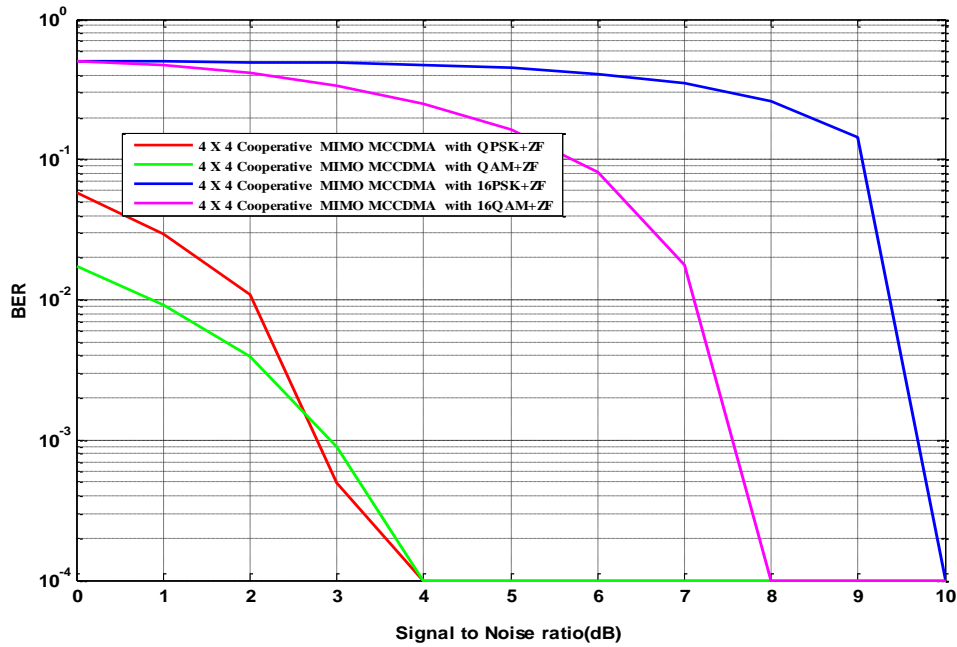
Figure 5. BER Performance of a Single Relayed Cooperative MIMO MC CDMA Wireless Communication System under Deployment of ZF Channel Equalization, Distributed Layered Space-Time Coding and Various Digital Modulation Schemes
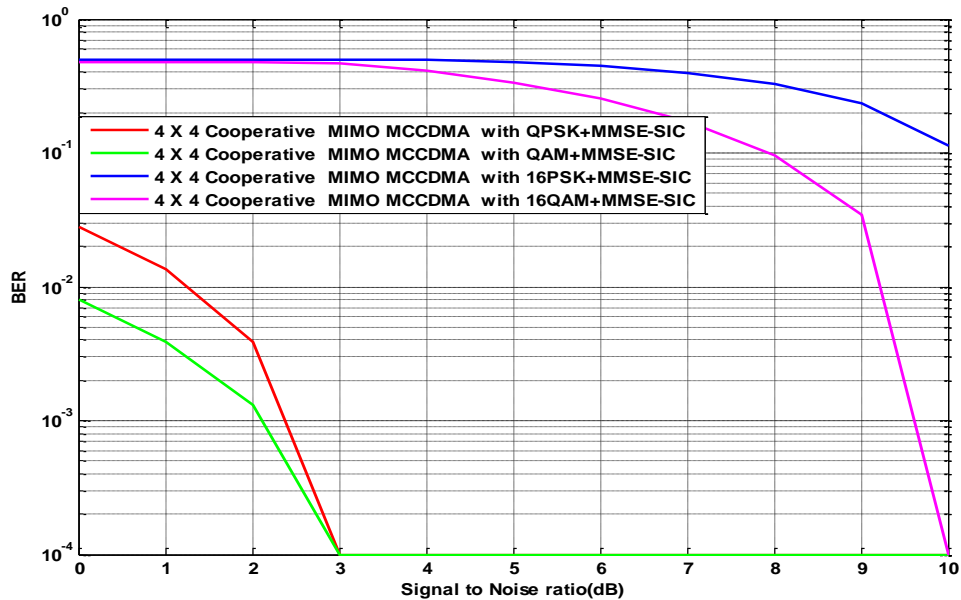

Figure 6. BER Performance of a Single Relayed Cooperative MIMO MCCDMA Wireless Communication System under Deployment of MMSE-SIC Channel Equalization, Distributed Layered Space-Time Coding and Various Digital Modulation Schemes
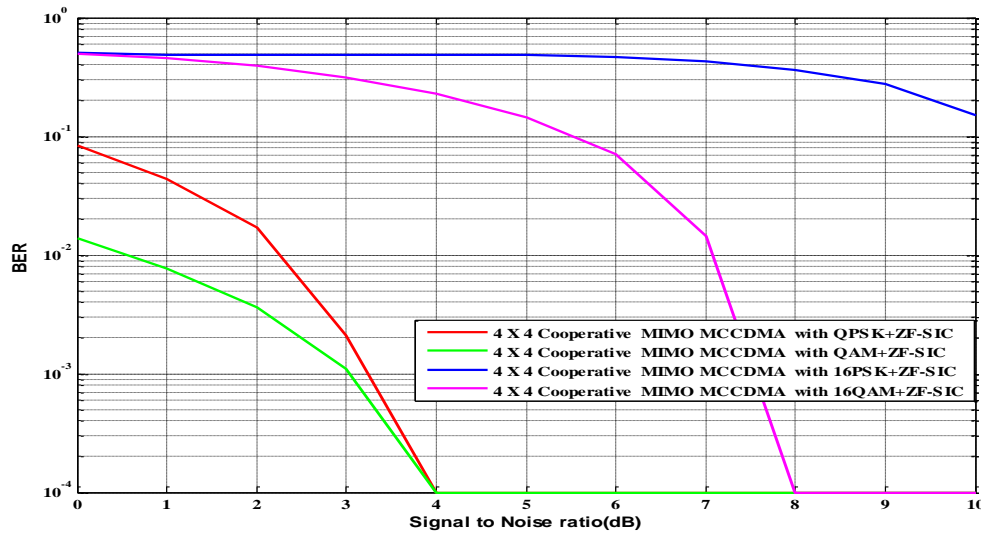
Figure 7. BER Performance of a Single Relayed Cooperative MIMO MC CDMA Wireless Communication System under Deployment of ZF-SIC Channel Equalization, Distributed Layered Space-Time Coding and Various Digital Modulation Schemes

6. Conclusion

Cooperative communications have recently been migrated to one of state-of-the-art features of 3GPP LTE-Advanced (LTE-A). Cooperative communications fundamentally change the abstraction of a wireless link and offer significant potential advantages for wireless communication networks. In this paper, we have presented a new co-operative scheme with deployment of a single relay station working as cooperative agency in a MIMO MCCDMA wireless communication system. The MCCDMA system can be used in future generation wireless communication networking. In context of system performance, it can be concluded that the MIMO MCCDMA wireless communication system provides robust and satisfactory performance with MMSE-SIC signal detection, QAM digital modulation and Block cipher encryption aided channel encoding schemes.

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