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# Impact of STBC Scheme on BER Performance Assessment of a Single Amplify and Forward Relaying Protocol Based Cooperative MIMO-OFDM System

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### Abstract

*Cooperative communication is a novel class of wireless communication technique which wireless nodes help each other relay information to the intended destination. Orthogonal frequency division multiplexing (OFDM) has become a popular technique for the high data rate and performance. The integration of OFDM and cooperative communication in next generation wireless leads to the design of an efficient and reliable wireless network. A mathematical model for cooperative MIMO-OFDM system has been developed in the present study. Simulation results are provided to evaluate the BER and Text message performance of proposed system. It is observed that a quite satisfactory system performance is achieved in cooperative MIMO-OFDM with STBC under AAF relay for the MMSE detection scheme. It has been estimated from the simulation study that the performance of the cooperative MIMO-OFDM communication system improves with the increasing of SNR.*

**Keywords:** *Cooperative Communication, Orthogonal Frequency Division Multiplexing, Amplify and Forward, Minimum Mean Square Error and Zero Forcing*

## 1. Introduction

During a wireless data transmission, the transmitted signals suffer from fading. Cooperative Communication is a technique which could be employed to mitigate the effects of channel fading by exploiting diversity gain achieved via cooperation among the relays [1]. There are two main advantages of this technology: (i) the low transmit RF power requirements, and (ii) the spatial diversity gain [2].

Different types of relaying strategies, *e.g.*, amplify and forward (AF), decode and forward (DF), fixed relaying (FR), selection relaying (SR), coded cooperation (CC) and compress and forward (CF) were introduced in [3-6] respectively. M. M. Hossain *et al.* comprehended study elucidating the performance of a single relay cooperative OFDM system under AF and DF relaying strategies on Text message transmission. The results of BER simulation in AWGN and Raleigh fading channels show that the AF relaying protocol supported cooperative OFDM system outperforms in ERC signal combining scheme as compared to others (FRC, SNRC and ESNRC) under BPSK digital modulation [7]. S. Vorkoeper *et al.*, investigated the performance of cooperative OFDM and distributed interleave division multiplexing space time coding in a DF two hop multiple relay networks [8]. Distributed

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space time coding for cooperative systems were proposed in [9, 10], where a number of nodes transmit the different columns of a space time coding matrix simultaneously to the destination. D. Sreedhar *et al.*, proposed an interference cancellation algorithm for cooperative SFBC-OFDM networks with AF and DF system at the destination node and showed that the proposed algorithm effectively mitigated the ISI and ICI effects [11].

In this paper, we have established an analytical model for cooperative MIMO-OFDM with single relay implementation of AF scheme. The revolutionary concept of space time block coding (STBC) introduced in the last decade that the deployment of multiple antennas at the transceiver has been included cooperative MIMO-OFDM scheme. The performance of the system for the zero-forcing (ZF) and minimum mean square error (MMSE) has been evaluated in terms of BER and Text message.

## 2. System Model

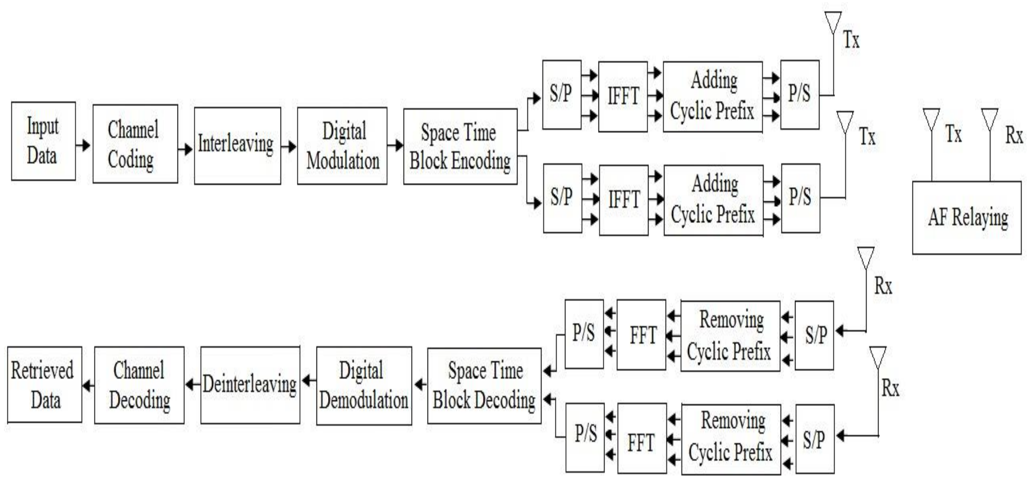


**Figure 1. Block diagram of Single Amplify and Forward Relayed Cooperative STBC encoded MIMO-OFDM system**

A cooperative MIMO-OFDM wireless communication system with single relay is shown in Figure 1. It consists of two users, one user acts as the source while the other user serves as the relay and the two users may interchange their message/information as source and relay at different instants of time. A redundant data source is also provided to transmit data with original signal and thereby protecting data error in the simulated system. To meet up such requirement, a simple convolution encoder of rate 1/2 is used in channel coding scheme. The binary data extracted from text and audio signal are channel coded subsequently interleaved. The interleaved binary data are converted into digitally modulated signal using BPSK. After digital modulation, data are rearranged according to the Space Time Block code. On the first antenna the original data and the negative second conjugate data are transmitted, while on the second antenna the conjugate original data and second data are transmitted [12, 13]. For each transmitting antenna section, the data are passed through serial to parallel converter (S/P) and the data are transformed into time domain signal using inverse fast Fourier transform (IFFT). A cyclic prefix is then added to the last elements of the frame. After parallel to serial convertion (P/S), information symbols are simultaneously transmitted from each transmitting antenna. In receiving end, signals are received in two phases (phase I-direct link and phase II-relay link). In phase I, the data are transferred from source to destination and source to relay directly. On the other hand, in phase II data are transferred from relay to destination. Each cooperative relay has to amplify its received signal and forward its amplified signal through a wireless channel to the destination. In the destination section, the received signals are subsequently passed through OFDM demodulator, digital demodulation, deinteleaver and channel decoder sections. Finally, the original signal either in binary or text forms are retrieved.

## 3. Theoretical Analysis of Single Relay

We assume an input binary data stream d of length $L_d$ with elements $d_i \in \{0,1\}$ for $i = 0, 1, 2, \ldots\ldots\ldots, L_d$ extracted from text/audio signals are fed into a Convolutional encoder. After convolutional encoding with redundant binary bit addition, the length of the channel encoded binary data is $2L_d$. The channel encoded binary data are digitally modulated using BPSK and the data are rearranged using STBC [12, 13] for the first antenna, $X_k^{Tx1} = [X_0, (-X_1)^*, X_2, (-X_3)^* \ldots\ldots\ldots (-X_{K-1})^*]$ and for the second antenna, $X_k^{Tx2} = [X_1, (X_0)^*, X_3, (X_2)^* \ldots\ldots\ldots X_{K-1}]$. Then the data are sent into serial to parallel converter (S/P) with 1024 symbols (K=1024) are processed in each OFDM block to transform into time domain signal using inverse fast Fourier transform (IFFT).

The inverse fast Fourier transformed signal for each transmitting antenna is defined as,

$$x^{Tx}(n) = \sum_{k=0}^{N_c-1} X_k^{Tx} e^{j(\frac{2\pi}{N_c})kn} \tag{1}$$

Where, $j = \sqrt{-1}$ , $T_x$ is the transmitter identifier, $N_c$ is the number of subcarriers, Each integer $n$ and $k$ ranges its values from $0$ to $N_c$-$1$. A cyclic prefix (CP) of length $N_{cp}$ is appended to the end of time domain discrete signal $x(n)$ and the cyclically prefixed extended information signal is defined as,

$$x^{Tx}(m) = \sum_{k=0}^{N_c+N_{cp}-1} X_k^{Tx} e^{j(\frac{2\pi}{N_c+N_{cp}})km}$$

$$x^{Tx}(m) = \sum_{k=0}^{N-1} X_k^{Tx} e^{j(\frac{2\pi}{N})km} \tag{2}$$

Where, $m = n + N_{cp}$ and $N = N_{cp} + N_c$. The signal is passed through a discrete-time baseband channel with response $h(m)$ and additive white Gaussian noise (AWGN) $w(m)$ is added. In amplify-and-forward (AF) relay scheme, the relay receives a signal from the source; the received signal is amplified and forwarded to the destination in spite of the source-relay link quality. In Phase I, the source-destination and the source-relay received signals are given by

$$r_{s,d}(m) = \sqrt{P_s}\{x^{Tx}(m) \otimes h_{s,d}(m) + w_d^1(m)\} \tag{3}$$

$$r_{s,r}(m) = \sqrt{P_s}\{x^{Tx}(m) \otimes h_{s,r}(m) + w_r(m)\} \tag{4}$$

Where $P_s$ is the transmission power of the source, $w_d^1(m)$ and $w_r(m)$ are the AWGN at the destination and relay in Phase I respectively.

In Phase II, the relay employs a linear precoder **F** on the received signal vector $r_{s,r}(m)$. The $M_r \times M_r$ precoding matrix F is given by [14, 15, 16]

$$F = \sqrt{\frac{1}{tr(H_{s,r}^H H_{s,r}(\sigma_r^2 I_{M_r} + \frac{P_s}{M_s} H_{s,r}^H H_{s,r}) H_{r,d} H_{r,d}^H)}} H_{s,r}^H H_{r,d}^H \tag{5}$$

Where, $H_{s,r}$ and $H_{r,d}$ are source to relay and relay to destination channel matrices; $\sigma_r^2$, $M_r$ and $M_s$ are noise variance at relay, no of receiving antenna at relay and no of transmitting antenna at sender respectively. Therefore, the signal transmitted by the relay is given by

$$x_r(m) = F.r_{s,r}(m) \tag{6}$$

and the signal received at destination from relay in phase II is given by

$$r_{r,d}(m) = [\sqrt{P_r P_s} F x^{Tx}(m) h_{s,r}(m)] h_{r,d}(m) + [\sqrt{P_r} F w_r(m)] h_{r,d}(m) + w_d^2(m)$$

$$= [\sqrt{P_r P_s} F x^{Tx}(m) h_{s,r}(m)] h_{r,d}(m) + \tilde{w}_d^2 \tag{7}$$

Where, $P_r$ is the relayed signal power, $w_d^2(m)$, $w_r$ and $\tilde{w}_d^2$ are the AWGN at the destination and relay and effective noise in Phase II respectively.

By combining the signals received at the destination in both phases, we obtain

$$r_{d-combined}(m) = [\sqrt{P_r P_s} F x^{Tx}(m) h_{s,r_1}(m)] h_{r_1,d}(m) + \tilde{w}_d^2 + \sqrt{P_s}\{x^{Tx}(m) h_{s,d}(m)\} + w_d^1(m) \tag{8}$$

In matrix form, Equation (8) can be written as

$$r_{d-combined}(m) = \begin{bmatrix} r_{s,d}(m) \\ r_{r,d}(m) \end{bmatrix} = \sqrt{P_s} \begin{bmatrix} h_{s,d}(m) \\ \sqrt{P_r} h_{r,d}(m) F h_{s,r}(m) \end{bmatrix} x^{Tx}(m) + \begin{bmatrix} w_d^1(m) \\ \tilde{w}_d^2(m) \end{bmatrix}$$

$$= \sqrt{P_s}\{x^{Tx}(m) H(m)\} + w(m) \tag{9}$$

Where, $H(m)=\begin{bmatrix} h_{s,d}(m) \\ \sqrt{P_r}\, h_{r,d}(m)Fh_{s,r}(m) \end{bmatrix}$ is the effective channel between source and destination and $w(m)=\begin{bmatrix} w_d^1(m) \\ \tilde{w}_d^2(m) \end{bmatrix}$ is the effective noise. With implementation of channel equalization and subsequent removal of cyclic prefixing schemes, the detected signal $r_d(n)$ is fed into fast Fourier transform (FFT) section with FFT size N and its output is given by

$$Y_{FFT}(k) = \frac{1}{N}\sum_{n=0}^{N-1} r_d(n) e^{-j(\frac{2\pi}{N})kn} \tag{10}$$

### 3.1. ZF Signal Detection

ZF detectors reverse the channel matrix. The Zero Forcing technique nullifies the interference by the following weight matrix [17, 18]

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

Where $(.)^{H_l}$ denotes the Hermitian transpose operation. In other words, it inverts the effect of channel as

$$x_{ZF} = W_{ZF} Y(k) \tag{12}$$

### 3.2 MMSE Signal Detection

The MMSE detector employs a linear filter that can take into account the noise. The MMSE filter is found by minimizing the mean-square error (MSE) as [17, 18]

$$W_{MMSE} = \left(H^H H + \sigma_{N_k}^2 I\right)^{-1} H^H \tag{13}$$

With a high SNIR, the MMSE detection becomes the ZF detection. Using the MMSE weight in equation (12), we obtain the following relationship

$$x_{MMSE} = W_{MMSE} Y(k) \tag{14}$$

## 4. Results and Discussion

This section presents and discusses on the results obtained by the computer simulation program written in MATLAB. Computer simulation works have been performed to estimate the BER on *Text message* transmission. The Channel Coding, Digital modulation, FFT/IFFT size and CP length have been set to be $1/2$-rated Convolutional Encoder, BPSK, 1024 and 103 symbols respectively.

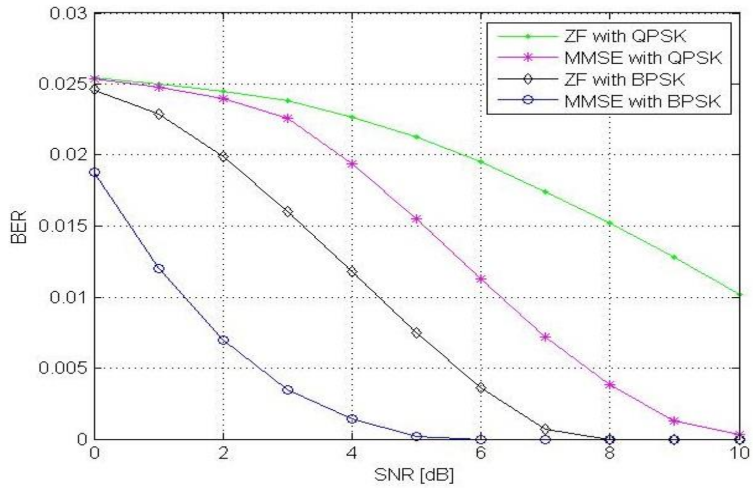


**Figure 2. BER performance of a convolutionally encoded and single relayed MIMO Cooperative OFDM wireless communication system with ZF and MMSE aided signal detection and various digital modulation schemes**

In Figure 2, it is demonstrated that the simulated system shows better performance in low order digital modulation scheme (BPSK) and MMSE signal detection technique. In case of higher order digital modulation schemes with ZF detection technique, the system performance is quite unsatisfactory.

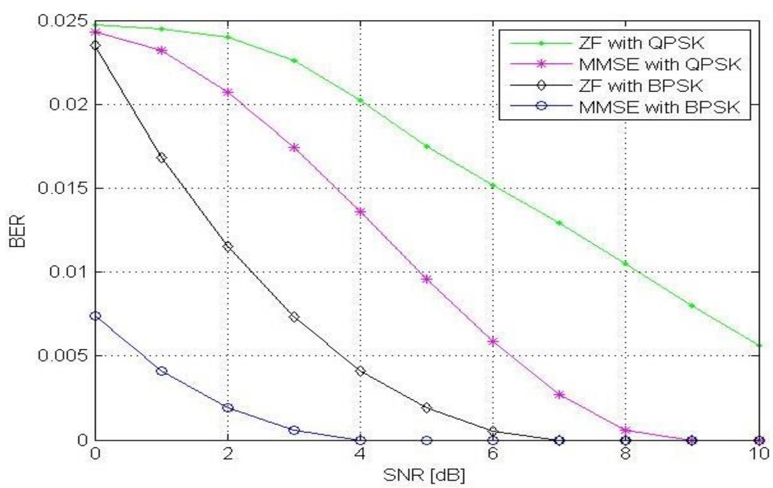


**Figure 3. BER performance of a convolutionally encoded and single relayed STBC based MIMO Cooperative OFDM wireless communication system with ZF and MMSE aided signal detection and various digital modulation schemes**

The BER performance results are presented in Figure 3 with various digital modulations, ZF and MMSE signal detection techniques. The simulated system is found to have shown most satisfactory performance in BPSK digital modulation as compared to other modulations. At a typically assumed SNR value of 3dB, the BERs of BPSK and QPSK for MMSE signal detection are 0.0006 and 0.0174 respectively which implies a system performance improvement of 14.62 dB.

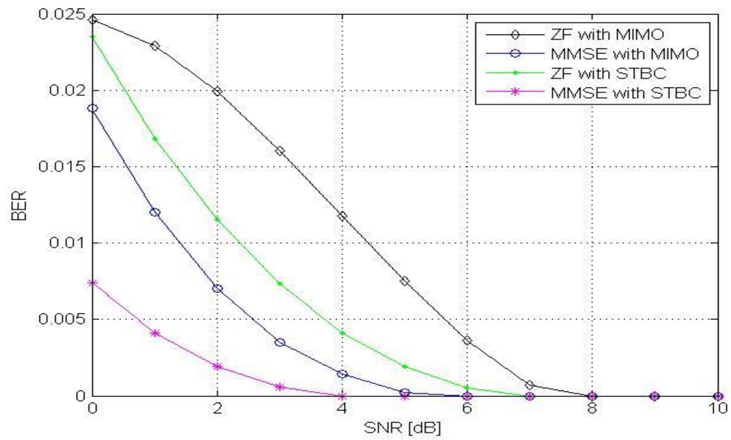


**Figure 4. Plots BER vs. SNR of ZF and MMSE**

In Figure 4, we have compared two Cooperative MIMO-OFDM schemes, one with Spatial multiplexing (MIMO) and another with STBC. We have also compared the system performance with ZF and MMSE channel equalization schemes. In ZF signal detection with a typically assumed SNR value of 2 dB, the BER values of the cooperative STBC encoded MIMO-OFDM and spatially multiplexed MIMO-OFDM are 0.0115 and 0.0199 and respectively and it implies a system performance improvement of 2 dB. In MMSE signal detection with a typically assumed SNR value of 2 dB, the BER values of the cooperative STBC encoded MIMO-OFDM and spatially multiplexed MIMO-OFDM are 0.0019 and 0.0070 and respectively and it implies a system performance improvement of 5.66 dB.

From the graph, it is observed that MMSE based receiver performs better than ZF based receiver and the performance of STBC encoded MIMO-OFDM system is better than Spatially multiplexed MIMO-OFDM system.

<table>
<tr><td>Transmitted Message</td><td>The integration of Cooperative communication with OFDM has the potential to largely increase the capacity of wireless communication and represents one of the most attractive air-interface solutions for next wireless generation system.</td><td>BER</td></tr>
<tr><td>Received Message (ZF with MIMO )</td><td>Thd Itegra|qc- of Cooperative Oommunication with OFDM has the 0n{e.tiAl to largely increase the(caPagipy of wkreless communication and rePresents gGe of |he most attraaXive air-interface solutions for next wireles[ generath l system.</td><td>0.0260</td></tr>
<tr><td>Received Message (MMSE with MIMO )</td><td>Dhe i?tegration of Cooperative wommunication qith OFDm has the potential to largely increase the capacity of wireless communiiation cnd rgpresent[@ond of"the most `ttractive air-interface solweions for next wireless!gkvyation system.</td><td>0.0176</td></tr>
<tr><td>Received Message (ZF with STBC)</td><td>The integration of Cooperative communication with OFDM bas the potential to largely increase the capacity {f wireless communication and repResents one of the mgst attractive air-interface solutions for next wireless generation system.</td><td>0.0065</td></tr>
<tr><td>Received Message (MMSE with STBC)</td><td>The integration of Cooperative communication with OFDM has the potential to largely increase the capacAty of wireless cnmmunication and represents one of the most attractive air-interface solutions for next wireless generation system.</td><td>0.0020</td></tr>
</table>

**Figure 5. Transmitted and Received Text messages for ZF and MMSE**

The transmitted and received text messages at typically assumed SNR value of 6 dB are presented in Figure 5. It is observable that the MMSE with STBC outperforms than other methods adopted. The received message is contaminated with noise at low SNR values. At higher SNR values, the performance is improved in support of all address methods.

## 5. Conclusion

In this paper, we have presented theoretical derivation and computer simulation for the cooperative MIMO-OFDM system with STBC, ZF and MMSE signal detection schemes. In the context of system performance, it can be concluded that the implementation of BPSK digital modulation technique in AF single relaying protocol with MMSE provides satisfactory result for cooperative STBC encoded MIMO-OFDM wireless communication system on text message transmission. Simulation results have also justified a lossless reproduction of transmitted text message at the receiving ends via possible relay station.

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