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Performance Comparison of Coded OFDM System with Cooperative Diversity and Multi-Antenna Receiver Diversity using QAM Modulation

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Abstract— Orthogonal Frequency Division Multiplexing (OFDM) is recognized recently to be one of the major cooperative techniques for wireless local area network (WLAN). In this paper, a comparative performance of OFDM utilizing relay cooperative diversity and antenna diversity is examined. The performance evaluation is carried out by comparing Bit Error Rate (BER) values for different schemes such as Decode and Forward (DF) and different relay positions of coded cooperative relay over multipath Rayleigh fading channel using BPSK and QAM modulation techniques; and convolution code is used as channel coding. Also, the performance of relay cooperative diversity schemes is compared with OFDM using Single Input Single Out put System (SISO). The Monte Carlo simulation results confirmed that coded OFDM cooperative relay system provides better performance than OFDM coded system with antenna diversity in most scenarios. The analytic expression for error probability and effective SNR correlated to (BPSK) modulation for cooperative coded relay and multi-antenna diversity has been presented and derived for different schemes as Decode and Forward and Amplify and Forward (AF) for multi branches combining schemes.

Keywords— OFDM system, Rayleigh fading, BPSK, QAM, coded cooperative relay diversity, multi antenna receiver diversity, Convolution Code, combining schemes, MRC, EGC, BER, PEP.

I. INTRODUCTION

Designing an advanced reliable communication system that provides the demands of recent high technology wireless communication such as high data rate and best quality of service (QoS) is the main concern. Antenna diversity and cooperative diversity techniques are considered so effective to reduce the multipath effects and improve the performance of wireless communication over Single Input Single Output (SISO) [1], [2]. These diversity techniques can exploit the spatial diversity by offering a new dimension, which can be used to enhance the performance of the communication system [3]. Multiple Input Multiple Output (MIMO) is one of the main antenna diversity schemes in which two antenna transmitters and single receiver antenna can provide the same diversity of a single antenna transmitter and two receiving antennas [4] .

The cooperative diversity is investigated in literature as in [5]-[9] and cooperative multiuser protocols are proposed in [7]. In this paper, cooperative diversity is integrated with OFDM. The development of OFDM has allowed the transmission of audio signals and several 4G multimedia applications [10]. Also, OFDM is considered a wide band modulation scheme which is specially designed to cope with multipath reception. Therefore, integrating OFDM with cooperative diversity by employing a relay between source and destination is a promising alternative to SISO transmission [11] because that relay improves the coverage and performance of communication systems at the expense of complexity. In this paper, a comparison between a coded OFDM cooperative relay diversity system and a multi-antenna receiver system is achieved. Convolution code is used as channel coding; and guard interval is inserted with OFDM system in all paths to reduce Inert Symbol Interference (ISI) effect. This

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paper deals with BER evaluation for BPSK, 4 QAM, 16 QAM, and 64 QAM modulation schemes over multipath Rayleigh fading channels. The performance of OFDM system with different modulation schemes over different positions of relay and two receiving antennas is analyzed in terms of Bit Error Rate (BER) and Signal to Noise Ratio (SNR) using Monte Carlo simulation.

II. SYSTEM MODEL

In this paper, multi tone system (MTS) technique is considered to achieve a high rate wireless communication system. The Fast Fourier Transform (FFT) enables efficient generation and demodulation of MTS [12]. The block diagram of an OFDM system for SISO link is shown in Fig. 1. The binary input sequence is applied to convolutional encoder then to QAM modulator. For the simulation where coherent demodulation is being investigated, the QAM modulator generates a complex symbol sequence which is formed into parallel blocks by the serial to parallel convertor (S/P) before applying it to the Inverse Fast Fourier Transform (IFFT). The IFFT generates Multi Carrier (MC) signal. The resulting output of IFFT consists of blocks of N complex samples that can be written as in [13]:

$$x(n) = \sum_{k=0}^{N-1} X(k)\, exp\left(\frac{j2\pi kn}{N}\right), \quad 0 \le n \le N-1 \tag{1}$$

where *N* is the number of sub-carrier, *X(k)* is the data symbol in each sub-carrier, k shows the subcarrier index $k = (0,1,\cdots,N-1)$ and n is the time domain sample index of an OFDM signal.

This output is converted into a serial format by parallel to serial (P/S) convertor which is applied to guard add circuit before quadrature up conversion to radio frequency (RF), then the signal is ready for transmission. This signal is sent through a frequency selective multi-path fading (FSH) channel [14] with Additive Gaussian Noise (AWGN). In this kind of channel, the components of transmitted signal are received in different delays due to different propagation paths. The received signal can be written as:

$$r(n) = x(n) * h(n) \oplus w(n), \quad 0 \le n \le N-1 \tag{2}$$

Rayleigh fading is assumed in this paper. The received signal at destination is converted down before applying it to guard band remove circuit. The output of guard band remove circuit is a complex baseband received signal. This complex signal is formed into blocks of length *N* samples by (S/P) convertor before applying it to FFT to generate a block of *N* received complex symbols in a frequency domain that can be written as in [13]:

$$Y(k) = \frac{1}{N}\sum_{k=0}^{N-1} r(n)\, exp\left(\frac{-j2\pi kn}{N}\right) = X(k)H(k) + w(k), \quad 0 \le k \le N-1 \tag{3}$$

where $w(k)$ is the noise in time domain and $H(k)$ is the channel frequency response. These symbols are then converted back to serial binary sequence format by (P/S) convertor before they are applied to QAM demodulator. The output of demodulator is binary serial sequence which is applied to convolution decoder. In a channel with delay, spread guard band or cyclic prefix must be added to reduce inter symbol interference effects. The guard band size is chosen as to be 25%.

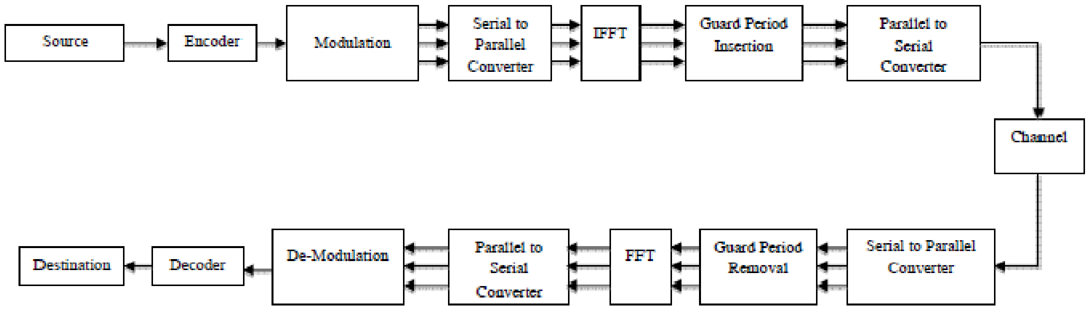

Fig. 1. Block diagram of OFDM system for SISO link

A. Cooperative Relay System

As mentioned before, this paper presents a comparison between OFDM cooperative relay model and OFDM multi antenna receiver diversity. As shown in Fig. 2, the cooperative relay system consists of three nodes: source (S), relay (R) and destination (D) as in [8] [9].

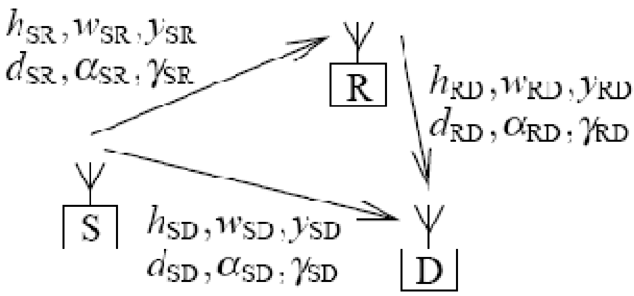

Fig. 2. Cooperative relay system among the network nodes: source (S), relay (R) and destination (D)

All nodes are equipped with a single transmitter and receiver. The channels between all nodes are assumed to be FSH channel for multi path fading with AWGN. For cooperative system the following notations are used as in [5]-[8] to describe the transmission from a node:

$X \in (S, R)$ to a node $Y \in (R, D)$
$d_{XY} > 0$ Distance between X and Y
$\alpha_{XY} > 0$ Path-loss coefficient
$h_{XY} \in C$ Channel fading coefficient
$w_{XY} \in C$ AWGN
$r_{XY} \in C$ Received signal at node Y

where C denotes the set of complex numbers. For the cooperative diversity, that assumes the AF relaying, the received signals at different paths are written as in [8]:

$$r_{SD} = \alpha_{SD} h_{SD} x + w_{SD} \tag{4}$$

$$r_{SR} = \alpha_{SR} h_{SR} x + w_{SR} \tag{5}$$

$$r_{RD} = \alpha_{RD} h_{RD} \beta_{AF} x + w_{RD} \tag{6}$$

where β_{AF} is the amplification factor at the relay, and α is defined as path-loss at distance d from the transmitter which can be expressed as:

$$\alpha_{XY} = \left(\frac{d_{XY}}{do}\right)^{-\mu}$$

where μ is the path loss exponent and d_0 is denoted as the reference distance assuming the path-loss between S and D is unity, i.e., $d_0 = d_{SD}$ as in [8]. So, the path-loss at distances greater (smaller) than the reference distance d_0 is smaller (larger) than unity. For the DF relaying, the received signal between relay and receiver is

$$r_{RD} = \alpha_{RD} h_{RD} \acute{x} + w_{RD} \quad (7)$$

where $\acute{x}$ is a re-encoded symbol at the relay, i.e., $\acute{x}$ is from the same modulation constellation as the symbol x. If $\acute{x} \neq x$, then there is a decoding error at the relay.

B. Multi antenna receiver diversity

For a single transmitter multi-antenna receiver diversity system, the receiver antenna is $\mathrm{i} = 1,2,3 \cdots \mathrm{I}$ as it is shown in Fig. 3. The following notations are used as in [8]: $d > 0$ is defined as the distance between S and D, $\alpha > 0$ is defined as the path-loss coefficient, $h_i \in C$ is the channel fading coefficient, $w_i \in C$ is the AWGN, and $r_i \in C$ is the received signal at node D.

Fig. 3. Single transmitter multi antenna reviver diversity

For the receiver diversity, the received signals at the multi receiver antennas are written as:

$$r = \sum_{i=1}^{I} h_i \, x(n) \oplus w(n)_i \quad (8)$$

Two diversity reception methods are used in this paper: Maximum Ratio Combining (MRC) and Equal Gain Combining (EGC). In EGC, all the received paths are weighted equally and summed to produce the decision statistics. On the i_{th} receive antenna, equalization is performed at the receiver by dividing the received symbol r_i by the priori known phase of h_i. The decoded symbol is the sum of the phase compensated channel from all the receive antennas. The EGC combination for cooperative relay and multi antenna diversity is respectively written as [15]:

$$r = \frac{|h_{SR}| e^{j\theta_{SR}} x(n)}{e^{j\theta_{SR}}} + \frac{|h_{RD}| e^{j\theta_{RD}} \acute{x}(n)}{e^{j\theta_{RD}}}$$

$$r = \sum_i \frac{y_i}{e^{j\theta_i}} = \sum_i \frac{|h_i| e^{\theta_i} x(n) + w(n)_i}{e^{\theta_i}}$$

$$= \sum_i |h_i| \, x(n) + \widehat{w_i} \quad (9)$$

where $\widehat{w_i} = \frac{w_i}{e^{j\theta i}}$ is the additive noise scaled by the phase of the channel coefficient. In MRC, the signals received from multiple paths are weighted according to their individual signal voltage to noise power ratios and then summed. The MRC combination for cooperative relay and multi antenna diversity is respectively written as in [8]:

$$r = \frac{\beta \alpha_{RD} \alpha_{SR} h_{RD} h_{SR}}{\beta^2 \alpha^2{}_{RD} \, |h_{RD}|^2 + 1} r_{RD} + \alpha_{SD} h_{SD} r_{SD} \tag{10}$$

$$r = \sum_i^I h_{SD}{}^*{}_i \; r_{SD}{}_i \tag{11}$$

C. Rayleigh Channel Description

In this paper, Rayleigh fading frequency selective channel is assumed in all paths (S-R, R-D, and S-D). So, the effects of multipath, interference, and phase shifting of the signal are considered. No line of sight (NLOS) path means there is no direct path between transmitter and receiver in Rayleigh fading channel. The received signal is written as:

$$r(n) = h(n)x(n) \oplus w(n) \tag{12}$$

where $w(n)$ is AWGN noise with zero mean and unit variance, $h(n)$ is channel impulse response random variables. The Rayleigh distribution is basically the magnitude of the sum of two equal independent orthogonal Gaussian random variables and the probability density function (pdf) given by:

$$p(z) = \frac{z}{\sigma^2} \, e^{\frac{-z^2}{2\sigma^2}}, z \geq 0 \tag{13}$$

where $\sigma^2 = E[z^2]$ is the variance of complex Gaussian random variable.

III. Analysis of Cooperative Transmission of OFDM Convolutional Coded System

In this section, performance analysis for (DF) relaying protocol is presented for OFDM convolution coded system in terms of probabilities. In the following subsections these results are compared with simulation results for a specific convolution coded OFDM system.

A. Direct Transmission of OFDM-Coded System

An expression for BER over Rayleigh distribution for BPSK is provided by [16] as:

$$Pb = \frac{1}{2}\left(1 - \sqrt{\frac{E_b/_{No}}{E_b/_{N_o}+1}}\right) \tag{14}$$

where E_b is the energy per bit. For OFDM system, each subcarrier is experiencing a flat fading channel and independent relay fading. So, assuming that cyclic prefix eliminates the Inter Symbol Interference (ISI), the BER for BPSK with OFDM in Rayleigh fading channel will be the same as BER for BPSK un-coded in Rayleigh fading channel [16]. Consequently, the BER for BPSK with OFDM can be expressed as in [16]:

$$Pb = \frac{1}{2}\left(1 - \sqrt{\frac{E_s/_{No}}{E_s/_{N_o}+1}}\right) \quad (15)$$

where the relation between symbol energy and bit energy is given as:

$$\frac{E_s}{N_o} = \frac{E_b}{N_o}\left(\frac{nDSC}{nFTT}\right)\left(\frac{T_d}{T_d+T_{cp}}\right) \quad (16)$$

where *nDSC* is the number of subcarrier, *nFTT* is the size of *FTT*, T_d is the data symbol duration, and T_{cp} is the cyclic prefix duration.
The application of convolution code with code rate $R = \frac{k}{n}$ to OFDM system with Viterbi decoding algorithm the coded bit error probability is like in [17]:

$$Pcoded = \frac{1}{k}\sum_{d=d_f}^{\infty} W(d)P(d) \quad (17)$$

where d_f is the free distance between the coded word of the encoder and the characteristics coefficient of the encoder $W(d)$, $P(d)$ is the probability of decoding algorithm *P (d)* and *W (d)* can be expressed respectively as in [17]:

$$P(d) = [4Pb(1 - 4Pb)]^{\frac{1}{2}} \quad (18)$$

$$W(d) = \sum_{i=1}^{\infty} ia\,(di) \quad (19)$$

where $ia(di)$ is the number of paths at distance d from the correct decoder path.

B. Cooperative Relay Transmission of OFDM-Coded System

In this paper, the probability of error analysis is carried for OFDM –convolution coded cooperative relay system. The analysis of DF and AF protocols is carried at the relay. The resultant message at destination side is a combination of the received signal from the relay and the source in the direct link.
Analysis of DF Cooperative Relay using Pair Wise Error Probability (PEP): PEP for a coded system is defined as deciding in favor of codeword $e = (e_1, e_2, \dots, e_M)$ when a codeword $c = (c_1, c_2, \dots, c_M)$ is transmitted. For a binary code with BPSK modulation, coherent detection, and maximum likelihood (ML), the PEP condition on the set of fading coefficient magnitudes $\delta = (\delta_1, \delta_2, \dots, \delta_M)$ can be written as [18]:

$$P\left(C \rightarrow \frac{e_0}{\delta}\right) = Q\left(\sqrt{2\sum_{n\in\eta} y_n}\right) \quad (20)$$

where $Q(X)$ denotes the Gaussian Q function and y_n is the instantaneous (SNR) of received bit *n* as:

$$y_n = \frac{\delta_n E_n}{N_{0,n}} \quad (21)$$

The set η is the set of all n for which $C_n \neq e_n$ and the criteria of η is the hamming distance d between *c* and *e*. So the conditioned PEP is typically denoted as $P(d/\delta)$ or $P(d/r)$.
Firstly, for one relay cooperative diversity when a relay successfully decodes the source message, the conditioned PEP for fast fading channel for SR link is obtained as:

$$P(d/r) = Q\left(\sqrt{2\sum_{n\in\eta} y_n}\right) \tag{22}$$

To obtain un-conditional PEP for SR link, the above equation over fading Rayleigh distribution is averaged as:

$$P(d_{SR}) = \int_0^{\infty} P(d_{SR}/r_{SR})\, P(r_{SR}) \tag{23}$$

where $P(r_{SR})$ is the probability density function (pdf) of the Rayleigh fading distribution. The exact solution for above equation can be obtained as in [15]:

$$Q(x) = \frac{1}{\pi}\int_0^{2\pi} exp\left(\frac{-x^2}{2\sin\theta^2}\right) d\theta,\ x \geq 0 \tag{24}$$

Now substituting (24) in (23) gives:

$$P(r_{SR}) = \frac{1}{\pi}\int_0^{2\pi}\int_0^{\infty} P(r_{SR})\, dr_{SR} \cdot d\theta \tag{25}$$

Using results in [15], the integral in (25) can be evaluated as in (26):

$$P(d_{SR}) = \frac{1}{\pi}\int_0^{\frac{\pi}{2}}\left(\int_0^{\frac{\pi}{2}} 1 + \frac{\overline{y_{SR}}}{sin\,\theta^2}^{-1}\right) d\theta \tag{26}$$

where $\overline{y_{SR}}$ is the average SNR for S-R link. PEP is determined as in [8] [9] at the destination for the two received links R-D and S-D, assuming that the new codeword transmitted from relay after detection and decoding is b.

$$P(C \rightarrow e/r_{SD}, r_{SR}, r_{RD}) = \sum_{b\in c} P(C \rightarrow b/r_{SD}, r_{RD})\, P(C \rightarrow r_{SR}) \tag{27}$$

If $P(C \rightarrow b/r_{SD}, r_{RD}) = P\big(W(d)_{e,r} > W(d)_{r,C}\big)$ where *r* is the hard decisions of the two combined received links at destination either MRC or EGC. So (27) can be expressed as in (28):

$$P(C \rightarrow b/r_{SD}, r_{RD}) = Q\left(\sqrt{2\sum_{n\in\eta} y_{MRC} OR\ y_{EGC}}\right) \tag{28}$$

According to the previous equation, the overall PEP for cooperative relay transmission will be as:

$$P(C \rightarrow e/r_{SD}, r_{SR}, r_{RD}) = P(d/r_{SD}, r_{RD}, r_{SR})$$

$$Q\left(\sqrt{2\sum_{n\in\eta} y_{MRC\ OR\ EGC}}\right) Q\left(\sqrt{2\sum_{n\in\eta} y_{SR}}\right) \tag{29}$$

To obtain the un-conditional PEP, (29) is averaged over the fading distribution as:

$$P(d) = \iiint_0^{\infty} P(\,d/r_{SD} r_{RD} r_{SR}) P(r_{SD})\, P(r_{RD}) P(r_{SR}) \tag{30}$$

In this paper the pair wise error probability analysis is utilized to locate the most suitable position for relay to obtain the best performance. Table 1 shows that the best location for cooperative relay coded OFDM system is the midway between source and destination.

TABLE 1
PEP FOR CODED OFDM COOPERATIVE DF RELAY SYSTEM FOR DIFFERENT POSITIONS OF RELAY AT 5dB

$\left(\frac{d_{SR}}{d_{SD}},\frac{d_{RD}}{d_{SD}}\right)$	(0.1,0.9)	(0.2,0.8)	(0.3,0.7)	(0.4,0.6)	(0.5,0.5)	(0.6,0.4)	(0.8,0.2)
$\mathrm{PEP_{DF}}$	0.001	0.00085	0.0007	0.0001	0.00001	0.001	0.1

C. Multi Antenna Receiver Diversity of OFDM Convolutional Coded System

EGC and MRC multi-antenna diversity for OFDM convolution code system: there is no closed form solution for the BER in EGC for general *N*, though several researchers have investigated the BER performance in several kinds of fading channels [8], [10]. There are several other papers that have addressed this issue. In particular, the effective $\frac{E_n}{N0,n}$ For BPSK with EGC, MRC and probability of error is discussed deeply in [15]. The expression for EGC is mentioned here as an example:

$$E(y_i) = \frac{E_n}{N0,n}\frac{1}{I}\left[1 + I(I-1)\sqrt{\frac{\pi}{4}}\right]$$

$$P_e = \frac{1}{2}\left[1 - \frac{\sqrt{\frac{E_n}{N_{0,n}}\left(\frac{E_n}{N_{0,n}}+2\right)}}{\frac{E_n}{N_0}+1}\right] \quad , \qquad \text{for } I = 2$$

IV. SIMULATION AND RESULTS

In order to compare the performance of all diversity protocols analyzed above for different combining schemes and different modulation schemes for convolution coded OFDM system over a Rayleigh fading channel, we deal with MATLAB simulation using the parameters listed in Table 2.

TABLE 2
SIMULATION PARAMETERS FOR CODED OFDM SYSTEM

Parameters	Values
Modulation	BPSK,16 QAM, 64 QAM
Channel model	Rayleigh Fading
Noise model	i.i.d AWGN
FFT and IFFT samples	64
OFDM symbol length (*Ts*)	4μS
Number of used subcarrier (*nDSC*)	48
CP length and duration (*Tcp*)	16,0.8 μsec
Data symbol duration (*Td*)	3.2 μsec
Used sub-carrier index	$\{-26 \text{ to } -1, 1 \text{ to } 26\}$
Convolution Code	1/2, 2/3

Fig. 4 shows that the results of the simulation model are exactly the same as the theoretical model obtained by mathematical analysis. It shows that the performance of BPSK with OFDM multi-receiver antenna system is much better than OFDM with SISO, which is identical to simulation results for the same scenario. Fig. 5 shows the bit error rate vs. the SNR for different diversity techniques, applied to convolution coded OFDM system with BPSK-modulation and code rate 1/2. A single-antenna-system SISO-OFDM with single antenna at source and single antenna at destination with direct link and no path loss is given. No spatial diversity is implemented for this system. As it can be seen from Fig. 5, the coded OFDM cooperative relay system performance improves as the relay position stands in the midway between source and destination which agrees with PEP theoretical analysis. This scenario outperforms the coded SISO-OFDM-Coded single-antenna system of 11dB in SNR at a BER of 10^{-6}. The same cooperative relay scenario outperforms the multi antenna receiver diversity OFDM-1Tx-2Rx-EGC with 3dB in SNR at a BER of 10^{-6}. Therefore, the second receiver antenna provides the receiver with additional signal power though it is not enough to compete the relay process. Furthermore, the two antenna receiver diversity outperforms the coded OFDM cooperative relay system as the antenna position moves away from the midway position

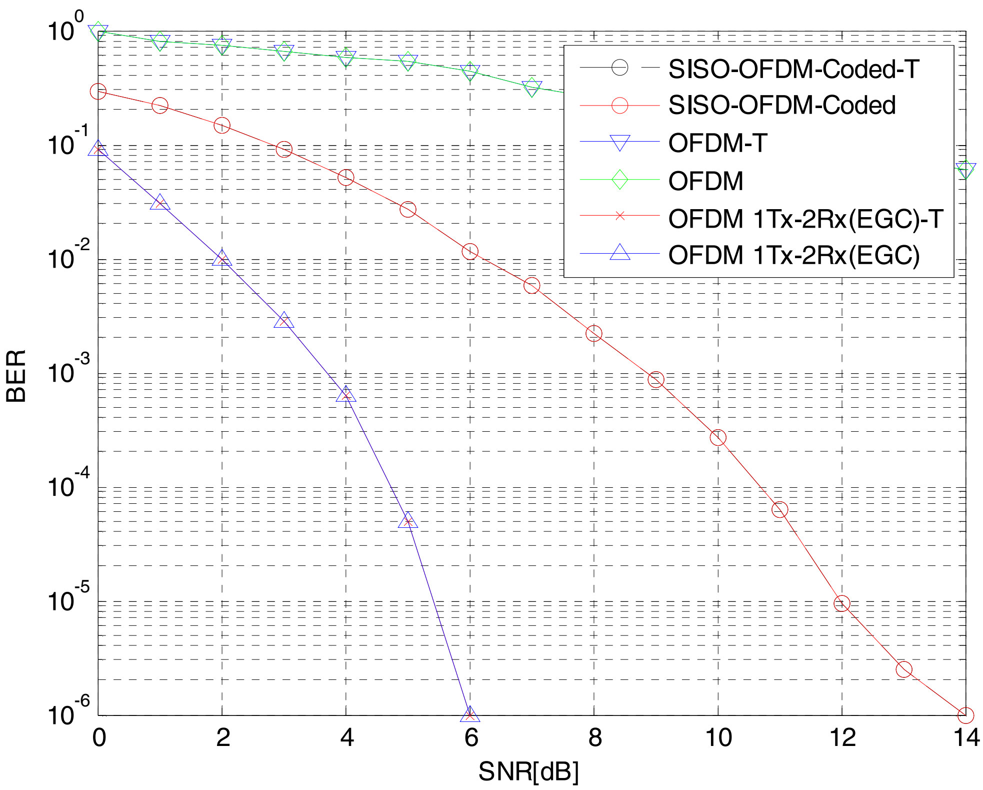

Fig. 4. Theoretical and simulated BER of un-Coded and Coded OFDM convolution coded with *R*=1/2, BPSK modulation with SISO and multi antenna diversity with EGC at the destination

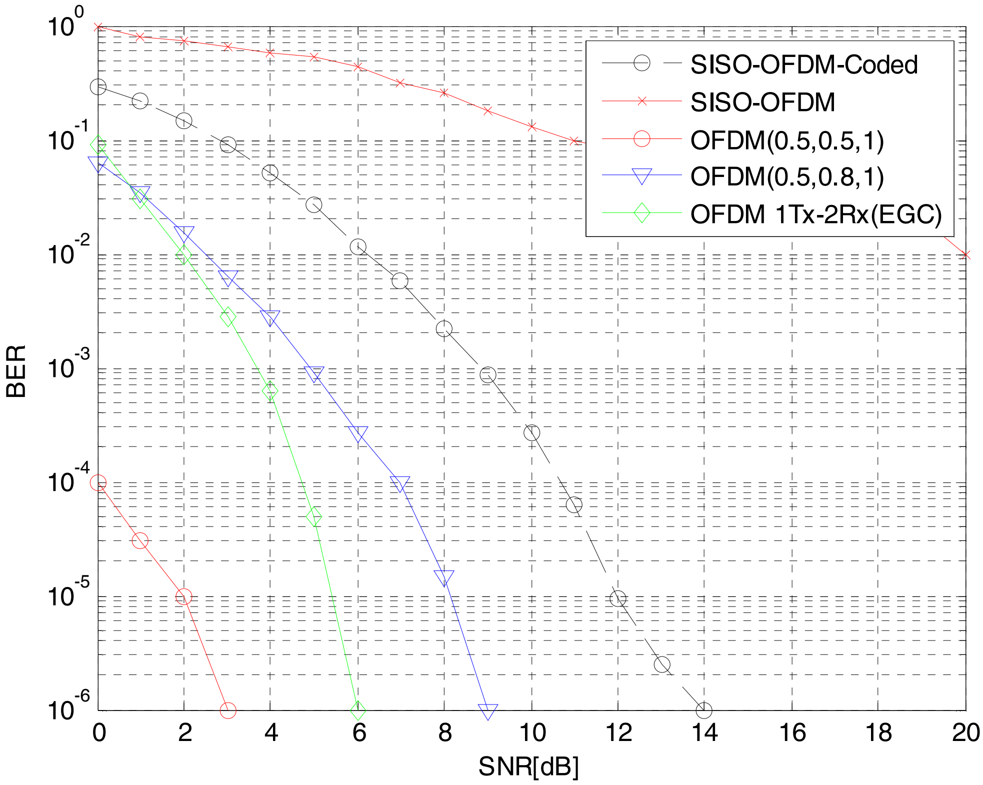

Fig. 5. The BER of OFDM convolution coded with *R*=1/2, BPSK modulation and DF cooperative relay and multi antenna diversity with EGC at the destination for different relay positions

Fig. 6 and Fig. 7 represent the bit error rate vs. the SNR for different diversity techniques as in Fig. 5 but for different modulation schemes. Fig. 6 is applied to convolution coded OFDM system with 16 QAM-modulation and code rate 1/2. A single-antenna-system SISO-OFDM with one antenna at source and one antenna at destination with direct link and no path loss is also given here as a reference. As it can be seen from Fig. 6, the coded OFDM cooperative relay system performance improves as the relay position stands in the midway between source and destination. This scenario with 16 QAM modulation outperforms the coded SISO-OFDM-Coded single-antenna system of 12dB in SNR at a BER of 10^{-6}. The multi antenna receiver diversity is carried for two combining schemes at the destination. We can notice here that coded OFDM-1Tx-1Rx–MRC outperforms the coded OFDM-1Tx-2Rx-EGC under the same conditions of transmission with about 2dB in SNR at a BER of 10^{-6}. However, the cooperative relay scenario still outperforms the multi-antenna receiver diversity scenarios OFDM-1Tx-2Rx-MRC and OFDM-1Tx-2Rx-EGC with about 3dB and 5dB in SNR at a BER of 10^{-6} respectively. It is important to notice that coded OFDM cooperative relay system performance is much better than multi-antenna diversity for complex modulation schemes. This can be clearly seen in Fig. 7 where the coded OFDM cooperative relay system shows an improvement in performance with about 6dB and 8dB in SNR at a BER of 10^{-6} compared to different combining schemes of multi antenna receiver diversity either MRC or EGC respectively. Furthermore, the two antenna receiver diversity outperforms the coded OFDM cooperative relay system as the antenna position moves away from the midway position.

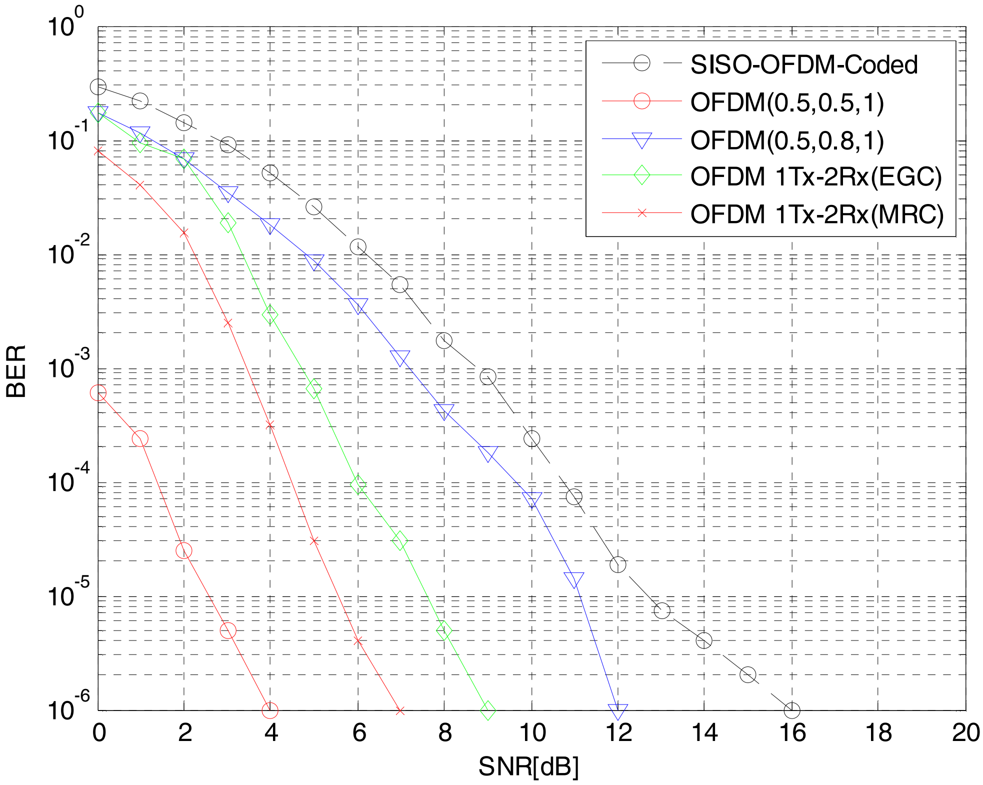

Fig. 6. The BER of OFDM convolution coded R=1/2, 16 QAM modulation and DF cooperative relay and multi antenna diversity with MRC and EGC at the destination for different relay positions

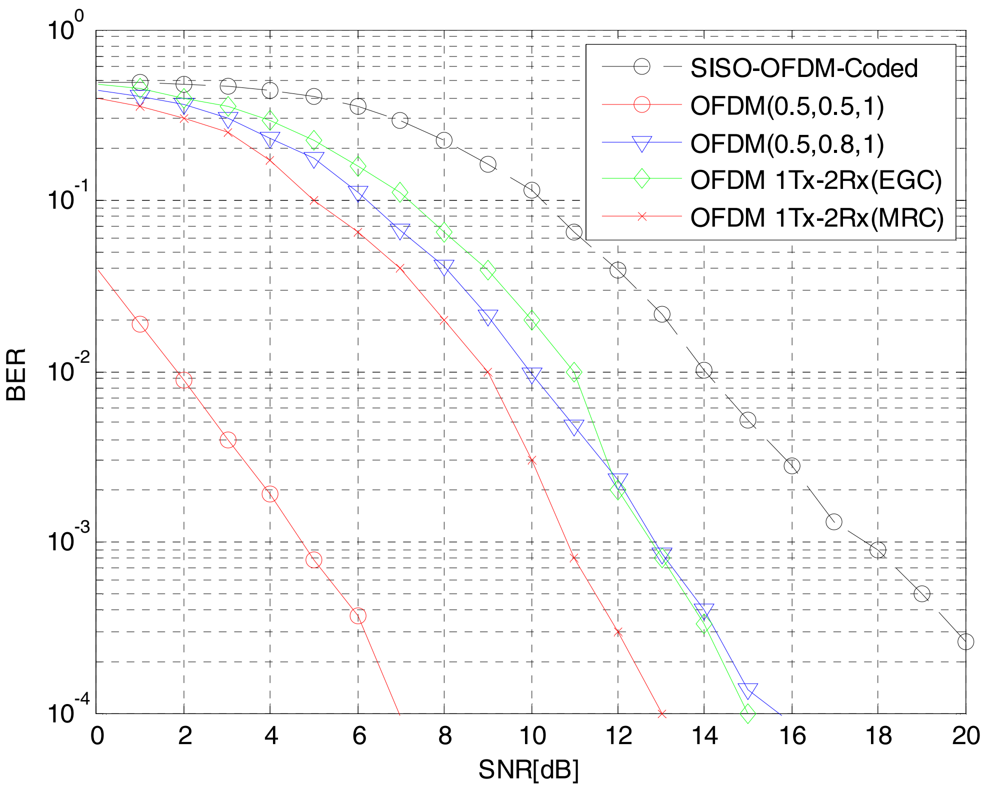

Fig. 7. The BER of OFDM convolution coded with R=2/3, 64 QAM modulation and DF cooperative relay and multi antenna diversity with MRC and EGC at the destination for different relay positions

V. CONCLUSION

In this paper, the BER performance of BPSK, 16 QAM, and 64 QAM modulation for convolution coded OFDM system employing cooperative relay system and multi antenna receiver diversity for different combining schemes has been analyzed and compared over Rayleigh fading channel. The performances of the diversity techniques are compared in terms of SNR. Based on the simulation results, it is clear that the best performance is for the coded OFDM cooperative relay system which provides much better SNR performance with minimum BER compared with multi-antenna receiver diversity when the relay is located at the midway between source and destination. Also, results prove that coded OFDM cooperative system is more efficient in performance especially for complex modulation schemes as the number of constellation points increases. Also, simulations and analytic results demonstrate that the performance of the coded OFDM cooperative diversity wireless communication system over fading channels can be significantly improved with convolutional coding. The analytic expression for error probability and effective SNR correlated to (BPSK) modulation for cooperative coded relay and multi antenna diversity is presented and derived for different schemes as DF and AF for multi branches EGC, MRC schemes.

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