Performance Improving of Digital Video Broadcasting-terrestrial (DVB-T2) Using Alamouti Scheme with Cyclic Delay Diversity

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Abstract

The goal of the future terrestrial digital video broadcasting (DVB-T) standard is to employ diversity and spatial multiplexing in order to achieve the fully multiple-input multiple-output (MIMO) channel capacity. The DVB-T2 standard targets an improved system performance throughput by at least 30% over the DVB-T. The DVB-T2 enhances the performance using improved coding methods, modulation techniques and multiple antenna technologies. After a brief presentation of the antenna diversity technique and its properties, we introduce the fact of the well-known Alamouti decoding scheme cannot be simply used over the frequency selective channels. In other words, the Alamouti Space-Frequency coding in DVB-T2 provides additional diversity. However, the performance degrades in highly frequency-selective channels, because the channel frequency response is not necessarily flat over the entire Alamouti block code. The objective of this work is to present an enhanced Alamouti space frequency block decoding scheme for MIMO and orthogonal frequency-division multiplexing (OFDM) systems using the delay diversity techniques over highly frequency selective channels. Also, we investigate the properties of the proposed scheme over different channels. Specifically, we show that the Alamouti scheme with using Cyclic Delay Diversity (CDD) over some particular channels has the better performance. Then, we exemplarity implement this scheme to the DVB-T2 system. Simulation results confirm that the proposed scheme has lower bit error rate (BER), especially for high SNRs, with respect to the standard Alamouti decoder over highly frequency-selective channels such as single frequency networks (SFN). Furthermore, the new scheme allows a high reliability and tolerability. The other advantages of the proposed method are its simplicity, flexibility and standard compatibility with respect to the conventional methods.

Keywords: Alamouti Coding; DVB-T2; MIMO; OFDM.

1. Introduction

OFDM is known as an attractive modulation scheme because of its robustness to frequency selective fading channels [1], [2]. Moreover, the MIMO is considerable to achieve diversity for combating the channel fading. Combining OFDM with MIMO technology is vital to overcome the multipath distortion, to simplify equalization and to increase the data rate [3], [4]. Thus, the Alamouti space–frequency coded was offered as a suitable multiple antenna technology. However, it requires processing at both transmitter and receiver [5], [6]. Further, some technologies like space-time coding, are constrained in the choice of number of antennas or the applicable code rate [7], [8]. The Delay Diversity (DD) is known as simple method. However, CDD is more efficient. The Alamouti method with transmit antenna selection in flat Rayleigh fading channels is presented in [9]. However, this result is valid only when the channel does not change within the same Alamouti pair [10]. Correspondingly, this means that the simple Alamouti decoding suffers from time-variation of the channel, which is not necessarily flat over the entire Alamouti

block code. Therefore, using the simple Alamouti decoding will cause performance degradation in such channels [1], [11]. On the other hand, many of the multiple antenna technologies require processing at both transmitter and receiver [12], [13]. In practice, the delay DD methods have attracted as a simple and efficient method in the past few years [14], [15]. The other diversity technique is CDD, which is a special cyclic delay diversity diversity scheme [16].

To combat the performance degradation of the conventional Alamouti scheme, we introduce an enhanced Alamouti standard Alamouti space-frequency block code (SFBC) using CDD which is compatible with the DVB-T2 [17] system. In the proposed method we obtain a significant performance enhancement in BER without increasing the number of antenna. The other advantages of the proposed method are its simplicity, flexibility, compatibility, high reliability and tolerability with respect to the standard Alamouti scheme.

This paper is organized as follow. In Section 2, antenna diversity techniques which are included cyclic delay diversity, channel properties and determination of cyclic delay value is described. In Section 3, combination

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of the enhanced Alamouti decoding scheme and CDD is investigated. Section 4 provides simulation results for the proposed scheme with respect to two types of delay diversity techniques for MIMO-OFDM with CDD. Section 5 concludes the paper and mentioned the possible future work.

2. Antenna Diversity Techniques

Transmit antenna diversity play an important role to increase the robustness and reliability over wireless fading channels. There are simple approaches to achieve diversity, such as Delay Diversity which is used in our research.

2.1 Cyclic Delay Diversity

The Delay Diversity is a simple diversity scheme which was proposed by Witteneben in 1993 [12]. The DD techniques have regained attraction recently as simple transmit antenna diversity methods for establishing a reliable link in fading environments. In principle, the DD transmits delay diversity of a signal over further TX-antenna. Because of linearity, implementing the DD at the receiver side is possible, but it causes the channel delay spread increment. In order to overcome this drawback, the CDD method is used in which the TX-antenna specific delays are replaced with cyclic shifts [18]. The CDD scheme enhances the frequency selectivity of the channel transfer function without increasing the observable time domain channel delay spread at the receiver. Figure 1 shows the front-end of a generic MIMO-OFDM transmitter using the CDD [19],[20]. In this figure we have two data streams.

Alamouti space-time block code, was primarily proposed for MIMO system using two transmit and two receive antennas. Using STBC to the OFDM is very straightforward because individual subcarriers can be considered as independent flat fading channels. Alamouti space-time code can be represented by the following matrix:

$$s = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \tag{1}$$

Each row indicates the transmiting antenna and each column indicates a time interval. Thus, in the first time interval s_1 symbol will be transmitted from the first antenna and s_2 from the second one, while in the second time interval $-s_2^*$ will be transmitted from the first antenna and $-s_2^*$ from the second one.

In the DVB-T2 case, simple Alamouti code is used in the transmitter which enhances spectral efficiency and link reliability by maximizing the diversity in the receiver while using low complexity equalization based on maximal ratio combining (MRC) [10]. In the first data stream, after the IFFT transform, cyclic prefix (CP) is added to each symbol by repeating the end of the same symbol. Therefore, the obtained signal $S_0(k)$, which is a sequence of N_{FFT} data symbols of S_l, for $l=0,…,N_{FFT}-1$, is

transmitted via TX-antenna zero without delay. In the other data stream, the CDD scheme is implemented for providing additional diversity; therefore the system performance will be improved. In order to keep the average transmission power independent of the number of related TX-antennas (N_T), the data stream is normalized by $(N_T-1)^{0.5}$ factor. Before inserting the CP, the symbol is shifted cyclically, which results in the antenna specific TX-signal as bellow

$$S_i(k) = \frac{1}{\sqrt{N_T - 1}} \widetilde{S}(K - D_i^{cyc} \mod N_{FFT}) \tag{2}$$

for $i=0,…,N_T-1$ and $k=-N_G,…,N_{FFT}-1,$, where N_G denotes the length of the CP. Also, Š(k) is the sample of an Alamouti symbol, which is modulated in time domain and then the signal is shifted cyclically by D_i^{cyc} before the CP is added. After guard interval removing at the receiver, as long as TX-antenna specific delays D_i is equal to cyclic shifts D_i^{cyc}, both CDD and DD yield the same signal. The OFDM symbols of the DD signal partly overlap the guard interval of the subsequent OFDM symbol at about D which is a restriction in the choice of D. To avoid inter symbol interference (ISI), the N_G must be

$$N_G \geq \begin{cases} L_{\max} + \max_i D_i & for\,DD \\ L_{\max} & for\,CDD \end{cases} \tag{3}$$

where L_{max} is the maximum channel delay samples. Based on (2) the minimum length of the CDD guard interval does not depend on the cyclic delays D_i^{cyc}, and we can choose shorter guard interval [4].In other words, the CDD scheme does not depend on the number of TX-antenna and there is no overlapping of OFDM symbols. However, when the received signal is free of the ISI, the DD has the same performance as the CDD. Note that, the MIMO channel is changed to a single-input multiple-output (SIMO) channel via CDD method, i.e. the spatial diversity is transformed into frequency diversity [4].
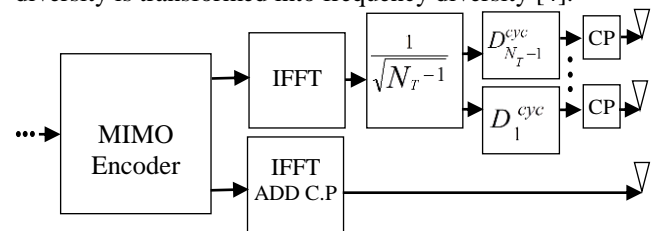

Fig. 1. Front- end of a generic MIMO-OFDM transmitter using CDD

2.2 Channel Properties of Cyclic Delay Diversity

In order to analyze the properties of CDD, we consider the received time domain signal as

$$r(k) = \frac{1}{\sqrt{N_T}} \sum_{i=0}^{N_T-1} \sum_{p=0}^{N_{\max}} s(k - p - D_i^{cyc} \mod N).h_i(k,p) \tag{4}$$

where $k = 0 , . . . , N - 1$ and $h_i(k,p)$ denotes the time domain fading process (time index is k) for TX-antenna i and path delay p (in samples) [21]. Note that, to simplify the equation (3), we neglect additive white Gaussian noise (AWGN). We desired to obtain effective channel transfer function subcarrier fading correlation. Thus, equation (3) is transformed into the frequency domain and is given by …

$$R(l) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} r(k) e^{-j2\pi kl/N} = \frac{1}{\sqrt{N.N_T}} \sum_{v=0}^{N} S(v).$$

(5)

$$\sum_{i=0}^{N_T-1} \sum_{p=0}^{N_{max}} H_i(l-v \mod N, p).e^{-j2\pi(p+D_i^{cyc}).v/N}$$

Where

$$H_i(q,p) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} h_i(k,p).e^{-j2\pi kq/N}$$

(6)

is the $N \times N$ discrete Fourier transform (DFT) of the time variant channel fading process $h_i(k,l)$ with respect to time index k. We can use this expression as the transferred channel at the receiver and it can help us to analyze the properties of channel in order to modify it. Note that, if the fading processes $h_i(k,p) = h_i(p)$ are constant for the duration of an OFDM symbol we have ICI-free transmission over subcarriers [16]. Then if we consider a quasi-static fading, the received signal will be

$$R(l) = S(l).\frac{1}{\sqrt{N_T}}.\sum_{i=0}^{N_T-1} e^{-j2\pi.D_i^{cyc}.l/N}.\sum_{p=0}^{N_{max}} h_i(p).e^{-j2\pi pl/N}$$

(7)

Then, we rewrite equation (6) and simplify as

$$\tilde{H}(l) = \sqrt{\frac{N}{N_T}} \sum_{i=0}^{N_T-1} H_i(l).e^{-j2\pi.D_i^{cyc}.l/N}$$

(8)

which is the equivalent channel transfer function and it can clearly specify the CDD effects. Also, $H_i(l)$ are the frequency domain channel fading coefficients for subcarrier l of the OFDM symbol from TX-antenna i to the receiver [21]. Note that, $H_i(l)$ is the DFT of $h_i(k,p)$ with respect to the path delay p and the quasi-static fading assumption *(i.e. $h_i(k,p) = h_i(p)$)*. Finally, $H_i(q,p)$ is the DFT of $h_i(k,p)$ with respect to the time variable k and path delay p as a parameter.

2.2.1 Correlation Properties

The expectation $E\{H^*(l)\cdot \tilde{H}(l+v \bmod N)\}$ yields the correlation properties of the frequency domain channel fading, where $(\cdot)^*$ means complex conjugate. We assume these processes are stationary. In other word, identical statistical channel properties from TX-antenna i to the receiver, σ_p does not depend on TX-antenna index i. Then, we obtain the fading correlation as

$$\Phi(v) = E.\left\{\tilde{H}^*(l).\tilde{H}(l+v \bmod N)\right\}$$

(9)

$$= \frac{1}{N_T} \sum_{i=0}^{N_T-1} e^{-j2\pi.D_i^{cyc}/N} \sum_{p=0}^{N-1} \sigma_p^2.e^{-j2\pi.p.v/N}$$

That means, $\sigma_p^2 = E\{|h_i(p)|^2\}.\phi^{Ch}(v)$ is the fading correlation function in frequency direction for the component channels, *i.e.* the channel observed from the TX-antenna i to the receiver antenna. Therefore, equation (8) allows the design of roots for the correlation function which leads to find the value v independent of the multipath channel properties $\phi^{Ch}(v)$ [16].

2.3 Determination of Cyclic Delay Value

In this section we investigate the impact of the value of D_i^{cyc}. By increasing cyclic delays with a constant increment *(D)* as

$$D_i^{cyc} = D.i, \qquad i = 0,...,N_T - 1$$

(10)

we get

$$\phi^{CDD}(v) = \frac{1}{N_T}.e^{-j\frac{\pi\delta(N_T-1)v}{N}}.\frac{\sin(\frac{\pi\delta N_T}{N}.v)}{\sin(\frac{\pi\delta}{N}.v)}$$

(11)

Then, it can be considered for two cases:
i) N_T is a divider of N:
we set $\delta = N/N_T$ and (10) simplifies to

$$\phi^{CDD}(v) = \delta(v \bmod N_T)$$

(12)

Thus, a subcarrier fading process is uncorrelated to its $N_T - 1$ neighbors.
ii) we choose δ such that $\delta.N_T$ is a divider of N:
with $\eta = N/\delta.N_T$

$$\phi^{CDD}(v) = \frac{1}{N_T}.e^{\frac{-j\pi(N_T-1).v}{\eta.N_T}}.\frac{\sin(\pi v/\eta)}{\sin(\pi v/\eta N_T)}$$

(13)

3. Combination of Enhanced Alamouti Decoding Scheme and CDD

In the latest wireless broadcast systems, such as DVB-T2, in order to increase bandwidth efficiency, multiple antenna technologies are used [17]. The block diagram in Figure.2 illustrates the proposed scheme which is a genetic MIMO-OFDM DVB-T2 system using CDD. At the DVB-T2 transmitter side, after error protection, mapping and interleaving, the MIMO coding is performed [17]. Then each independent data stream together pilots and transmission parameter signaling (TPS) data are arranged in an OFDM frame. In this paper, we focus on using of Alamouti STBC, that was primarily introduced for MIMO scenario with two transmit and two receive antennas. With assumption of S_k, S_{k+1} as two successive subcarriers, the MIMO encoder outputs two pairs, $[S_k, -S_{k+1}^*]$ for the first data stream, and $[S_{k+1}, S_k^*]$ for the second data stream. In this paper, we combine the enhanced Alamouti decoding and the CDD scheme. For this propose, considering one MIMO-OFDM symbol in (1), the $S_0(k)$ is transmitted as un-shifted ($D_0^{cyc} = 0$) signal over TX-antenna 0. The other

TX-antenna signal is shifted cyclically by D_i^{cyc} before CP is added due to Fig. 2. In the receiver side, after removing the CP, the remaining OFDM time domain symbol is transformed into frequency domain by an FFT which yields to

$$Y = S\tilde{H} + N$$

(14)

where

$$\tilde{H} = \frac{1}{\sqrt{N_T}} \sum_{i=0}^{N_T-1} \sum_{k=0}^{N_{FFT}-1} h_i e^{\frac{j2\pi.kl}{N_{FFT}}} e^{\frac{-j2\pi.D_i^{cyc}.l}{N_{FFT}}} + N \tag{15}$$

where N is complex Gaussian noise which is mutually uncorrelated between different subcarriers. Also, h_i are the taps of the channel impulse response and $\tilde{H}$ denotes an equivalent channel transfer function. It means that a receiver cannot distinguish whether a propagation path results from CDD or the channel itself [4]. In the channel estimation, known pilots are used for estimation of the complex valued channel fading coefficients for each subcarrier. After FFT transformation and pilot extraction, the received signal will be:

$$\begin{cases} Y_1^K = S_k h_{1,1}^k + S_{k+1} h_{1,2}^k + N_1^k \\ Y_2^K = S_k h_{2,1}^k + S_{k+1} h_{2,2}^k + N_2^k \\ Y_1^{K+1} = -S_{k+1}^* h_{1,1}^{k+1} + S_k^* h_{1,2}^{k+1} + N_1^{k+1} \\ Y_2^{K+1} = -S_{k+1}^* h_{2,1}^{k+1} + S_k^* h_{2,2}^{k+1} + N_2^{k+1} \end{cases} \tag{16}$$

where $h_{i,j}^k$ is the channel frequency response at the carrier kth, between the ith receive antenna and jth transmit antenna, and N_i^k is AWGN noise at the kth carrier of the ith receive antenna. Also, * denotes conjugate operator. In the standard Alamouti algorithm, it is assumed that the channel frequency response is constant over two consecutive carriers, i.e. $h_{i,j}^k = h_{i,j}^{k+1}$. However, the performance of the standard Alamouti decoding degrades in highly frequency-selective channels since quasi static fading for adjacent subcarriers is required. To tackle this drawback, we propose an efficient Alamouti decoding scheme using CDD. Let us consider the changes in the channel matrix over adjacent OFDM carriers which are described as:
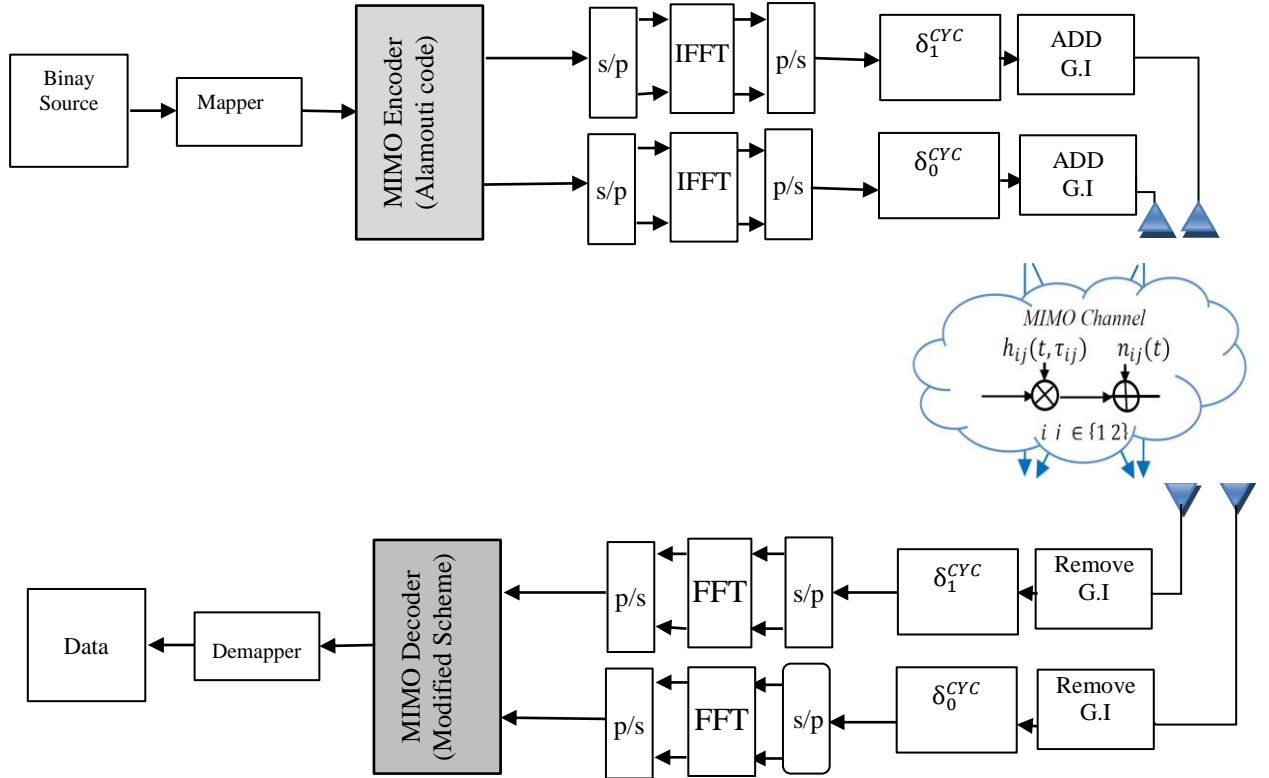

Fig. 2. Transmitter and receiver sides of proposed scheme

$$\Delta h^T = \begin{bmatrix} 0 & 0 & (h_{1,2}^{k+1} - h_{1,2}^k)^* & (h_{2,2}^{k+1} - h_{2,2}^k)^* \\ 0 & 0 & -(h_{1,1}^{k+1} - h_{1,1}^k)^* & -(h_{2,1}^{k+1} - h_{2,1}^k)^* \end{bmatrix} \tag{17}$$

Where, the T refers to the conjugate transpose. Thus, there is not any necessity to consider the channel constant over two consecutive subcarriers [1]. Then, the estimated transmitted symbol in minimum mean square error (MMSE) criterion will be:

$$\tilde{S} = \frac{1}{\det(I_2 + B\Delta h)} adj(I_2 + B\Delta h).B.Y \tag{18}$$

where,

$$B = (h^T h)^{-1} h^T \tag{19}$$

Where det() and adj() denote the determinant and the adjoint of matrix of $(I_2 + B\Delta h)$, respectively. Then, the transmitted data can be recovered at the receiver through (9). It is considerable that the new scheme has a lower complexity since in (9) does not consist of direct inverse of the matrix $(I_2 + B\Delta h)$.

4. Simulation Results

In this paper, we applied DD and CDD with different D_i to the MISO systems (2×1). We use the *2k* mode (2048 points IFFT) with 4-QAM modulation. The guard interval length is N_G =1/4. At the receiver sides we assume that the channel estimation is perfect. For our investigations, we use 9-path multipath Rayliegh channel models which is similar to Indoor Commercial-channel B models large open centers, such as shopping malls and airports. Its power-delay profile is [0-8-17-19-21-23-25]$_{dB}$. The fading processes for the several propagation paths are statistically independent. Figure 3 compares the performance of MISO with DD and CDD. As can be seen for short guard interval, DD and CDD perform the same such as D_i =5 samples. In other word, the performance of DD and CDD is equal if the transmission is ISI free. However, by increasing guard interval, using the MISO-DD method, causes noticeable performance degradation at the receiver. For instance, at BER= 10e -4 a MIMO-CDD system with D_i =1 requires an SNR of 17.2. But, D_i =3 and D_i =5 require SNRs of 23.5 and 24.5 respectively. There is a fact to take into account that if the guard interval is increased for DD, we obtain a huge amount of interference.

To study the property compatibility of MIMO scheme (Fig.2) with the DVB-T2 system, a MIMO-OFDM system is compared to a MIMO-OFDM with CDD system. For this purpose, we implement the proposed scheme (Fig.2). It worth mentioning that in [22] both methods of CDD and Alamouti are used separately for the channel DRM+ system at a velocity. In [22], the author shows that the CDD performs better than simple Alamouti in fast fading channels [22]. We use 15-path multipath Rayleigh fading channel model which is similar to the pervious channel model. We applied 4-QAM, 8k length with a guard interval of ¼. Channel estimation is assumed to be perfect.

We observe that the performance of the proposed method is much better that the Alamouti scheme in DVB-T2 system (Fig. 4). In this simulation, we use enhanced decoding Alamouti which is introduced in [1]. Compared to a MIMO-OFDM system which requires an SNR of 21 dB at BER=10e-3, a MIMO-OFDM system using CDD requires 16.5 dB, which provides a gain of 4.5 dB for the considered DVB-T2 parameter set (Fig. 4).

In order to verify the better performance of the proposed enhanced Alamouti decoder using CDD with respect to the Alamouti decoder in [1], we consider the MIMO-OFDM system based on the DVB-T2 standard. An 8k mode where 8192 sub-carriers with 4-QAM are used .We applied 10000 OFDM symbols with a guard interval of ¼ in a MIMO DVB-T2 system (2×2). We used the P1 multipath Rayleigh fading channel model, which is described in [5]. The channel has 20 taps without any Doppler effects. We also evaluate the performance of un-coded scenario; thus the coding and interleaving are bypassed in the system simulation. We applied four profiles as MIMO channels with the same power and different phase, i.e. they are randomly chosen between 0

and 2π in order to make the uncorrelated channel. In order to simulate highly frequency selective channels, random phase with different values for *a* and *b*, as the power of the delayed channel and the delayed spread respectively, are used. In principle, increment in the delay spread and the power of delay channel converts the channel to a highly frequency-selective channel [1]. Fig. 5 shows the results of the efficient Alamouti decoding scheme using CDD versus the introduced method in [1] and the standard one. We chose D_i^{cyc} =2, because as shown in [4], the SNR does not increase further when D_i^{cyc}>1.5μs . In this simulation channel estimation is assumed to be perfect. Fig. 5 shows that for *a*=0.5, the proposed scheme performs approximately the same as the scheme in [1]. On the other hand, the performance of standard decoder degrades. For *a*=0.9, we observe that the performance of the proposed scheme is better than the scheme in [1]. This improvement is a fact because the proposed scheme increases the degree of diversity. The proposed scheme allows a significant performance enhancement that can be achieved without increasing the number of antenna. However, we decrease BER by using an enhanced Alamouti-CDD. In other word, even for such channels the performance of the proposed scheme is still much better than the other schemes. For instance, this figure shows that the proposed scheme outperforms the scheme in [1] by 3.2dB at an average BER of 10-3.

5. Conclusions

In this paper, we have shown that the performance of well-known Alamouti decoding degrades in the highly frequency selective channel. To tackle this problem, we proposed an enhanced Alamouti decoder using CDD scheme. The proposed modification in the standard Alamouti decoding caused a high tolerability of the system in the frequency selective channels such as the SFN channels. Simulation results confirm that the new introduced scheme has significant performance improvement. Therefore, the new scheme is useful in MIMO-OFDM systems such as the DVB-T2standard which allows a high reliability and capacity enhancement.
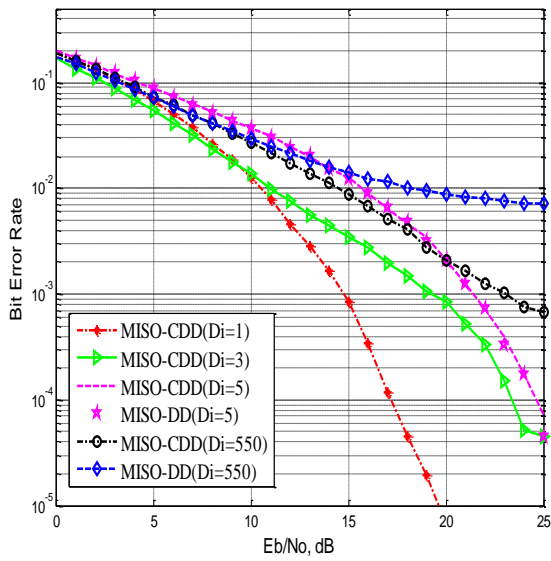
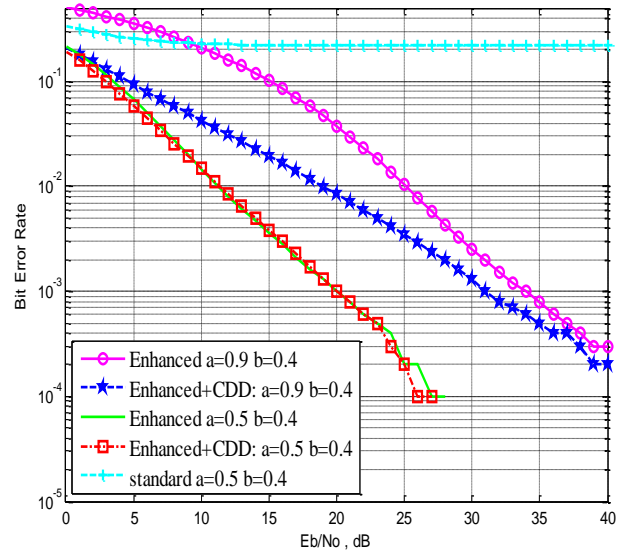Fig. 3. a comparison of SNR in CDD and DD respect to D_i

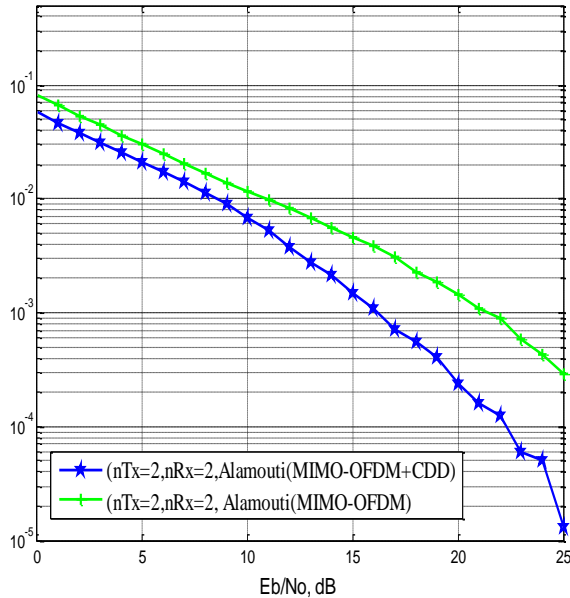Fig. 5. The performance of different schemes in BER vs. SNR.

Fig. 4. The performance of DVB-T2 system by using Alamouti scheme and CDD.

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