Low Complex Standard Conformable Transceiver based on Doppler Spread for DVB-T2 Systems

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Abstract

This paper addresses a novel Alamouti space-frequency block decoding scheme with discontinuous Doppler diversity (DDoD) and cyclic delay diversity (CDD). We investigate different antenna diversity concepts, which can be applied to orthogonal frequency division multiplexing (OFDM) systems over highly frequency selective channels. The main object of this research is standard compatibility and the effect of simple diversity techniques on the channel fading properties. Therefore, we analyze a receiver in terms of the effective channel transfer function, which leads to the possibility of optimizing diversity. Besides, a novel transceiver using DDoD is proposed, which increases the Doppler spread of the multipath fading channel without causing additional Intercarrier Interference (ICI). Moreover, an efficient Alamouti encoder and decoder based on CDD is proposed, which allows a high reliability and capacity enhancement. In order to evaluate the capability of that, we have implemented this scheme for the second-generation terrestrial video broadcasting (DVB-T2) system over different channels. Furthermore, mathematical analysis and simulation results show the bit error performance of the modified encoding method with these diversity techniques, performs mostly better than the other forms of encoding Alamouti over highly frequency-selective channels such as single frequency networks (SFN). The other advantages of the proposed method are simplicity, flexibility, and standard compatibility.

Keywords: SFBC; Transceivers; Diversity; MIMO; OFDM.

1- Introduction

The orthogonal frequency division multiplexing (OFDM) is known as an attractive modulation scheme for high-rate for transforming a frequency selective channel into multiple flat-fading channels [1], [2]. Moreover, multiple-input multiple-output (MIMO) is a very popular technology to increase communication reliability. Combining OFDM modulation with MIMO technology can be used to overcome the multipath distortion and increasing robustness over wireless fading channels [3]–[7] For this propose, the authors in [8] and [9] surveyed Space-time block codes (STBC) as a suitable multiple antenna technology. However, it needs processing at both transmitter and receiver.

To provide reliable transmission, some technologies like space-time coding are constrained with various designs such as the STBC transmission [10], [11]. Also, the Alamouti method with transmit antenna selection in flat Rayleigh fading channels is investigated in [5], [12], [13]. In [14], an improvement in the Alamouti method has been proposed by the combination of the Alamouti scheme and Bell Laboratories layered space-time (BLAST) methods based on using minimum mean square error (MMSE) detection. However, the results in [14] are valid only when the channel frequency response does not change over the entire Alamouti block code. It has also been shown in [15] that an SFBC-OFDM scheme and a finite-impulse response minimum-mean-square-error (FIR-MMSE) ICI cancellation algorithm can be used together for doubly-selective channels. It must be noted that the proposed solutions are not fully satisfactory due to incompatibility and inflexibility with standard systems such as digital system broadcasting. Also, the complexity of the equalizer will be increased to provide the satisfactory performance of the system for highly selective fading channels. In [16], the authors concentrated on turbo equalization receivers for frequency preceded collaborative spatial multiplexing (CSM) MIMO in the uplink of long term evolution advanced (LTE-A) system.

1-1- Motivation and Related Works

In recent years, different comparisons between theoretical and practical planning methods for DVB-T2 are presented

in [17]–[20]. For instance, the authors in [17] proposed a new timing detection metric for frequency-selective fading. The symbol timing synchronization scheme was investigated to improve the estimation accuracy. Also, a rotated and cyclic Q-delayed (RCQD) quadrature amplitude modulation was proposed for DVB-T2 systems. Therefore, this system needs a sphere damping algorithm for fading channels, and the sphere-decoder is used for multiple input multiple output detection. As a result, the performance over fading channels can be improved. However, these methods improve the performance of the system with the considerable cost of complexity and time of the process, which makes critical problems for online broadcasting [21], [22]. Generally, the simple Alamouti decoding suffers from the time-variation of the channel, which is not necessarily flat over the entire Alamouti block code [19]. As a result, using the simple Alamouti decoding will cause performance degradation in such channels [23], [24]. Moreover, many multiple antenna technologies require processing at both transmitter and receiver [25], [26]. In practice, the delay diversity (DD) method, which is known as a simple method for increasing diversity, has been attracted as a simple and efficient method in the past few years [27], [28]. Other diversity techniques are cyclic delay diversity (CDD) and Discontinuous Doppler diversity (DDoD) [29], [30]. In fact, the idea of increasing diversity by using multiple transmit (Tx) antennas is not new. However, there is a lack of exploiting temporal diversity for DVB systems [31]. Therefore, the application of DDoD for DVB-T2 becomes attractive. Hence, there is still room for a much better decoding algorithm, increasing diversity, and exploiting standard compatibility methods.

1-2- Contributions and Organization

In a recent publication [32], we have used the conventional Alamouti scheme with CDD. To combat the performance degradation of the conventional Alamouti scheme, in this paper some methods of Alamouti encoding and decoding using CDD and DDoD are proposed. The other objective of this work is to analyze the performance of the CDD in different forms of Alamouti encoding scheme with two transmit antennas on the DVB-T2 systems [33] in highly frequency-selective channels. Also, in DDoD method, partially shifts each spectrum of an OFDM symbol at the transmitter using different phase shifts in the time domain at different antennas after the OFDM modulation. In this research, we modify the form of Alamouti encoding to obtain a significant performance enhancement in a bit error rate (BER) without increasing the number of antennas. The other advantages of the proposed scheme are its simplicity, flexibility, compatibility, high reliability, and tolerability with respect to the standard Alamouti scheme. This means that a receiver does not need to be aware of their implementations at the transmitter. The

experimental results show that the proposed scheme in this paper can obtain a significant performance enhancement in the BER criterion without increasing the number of antennas.

This paper is organized as follows: in Section 2, the model system is presented which are included CDD, DDoD, and standard Alamouti code, channel properties, and determination of cyclic delay value. In Section 3, we present our proposed scheme which is an efficient coding-decoding Alamouti with CDD and DDoD. Section 4 provides simulation results including different delays with respect to two types of delay diversity techniques and presenting the property compatibility of the MIMO-OFDM with the CDD and DDoD schemes. In addition, the proposed scheme is compared with other well-known methods. Finally, the conclusion results of this research are presented in Section 5.

2- Model System

In DVB-T2 systems, in order to enhance bandwidth efficiency, multiple antenna technologies are used [33]–[36]. In other words, the DVB-T2 system output is typically a single signal to be transmitted. There is assumed that all DVB-T2 receivers shall be able to process the encoding Alamouti signals [37], [38]. Also, we do not require the transmitter to use a different frequency when distributing the same program since the guard interval features [27]. Therefore, we develop a single frequency network (SFN), where all transmitters use identical signals. We will have substantial improvements in the frequency economy and improve coverage for mobile reception due to diversity gain [1]. Figure 1 shows the front end of the DVB-T2 transmitter which is introduced in [33]. The system input may be one or more MPEG-2 transport streams that are built as a frame after, processing, interleaving and modulation. In the next step, after error protection, mapping, and interleaving, the MIMO coding is performed [33]. Then each independent data stream together pilots and transmission parameter signaling (TPS) data are arranged in an OFDM frame. After IFFT transformation, peak to average power ratio (PAPR) reduction, and guard interval (GI) addition, P1 symbol insertion is performed which can be used for signaling and detection purposes.

2-1- Diversity Techniques

Transmit antenna diversity plays an important role to increase the robustness and reliability of wireless fading channels. The DD scheme is a simple diversity scheme that was proposed by Witteneben in 1993 [28]. The DD scheme
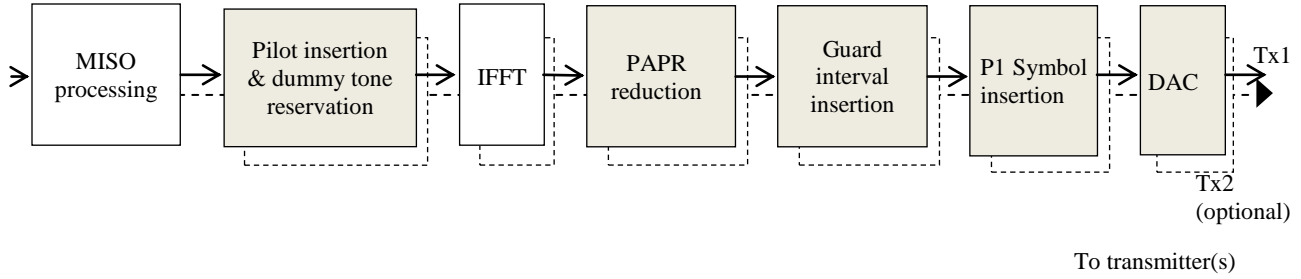
Fig. 1 The front end of the DVB-T2 transmitter [33]

has regained attraction recently as a transmit antenna diversity method for establishing a reliable link in fading channels. In principle, in the DD scheme, delay diversity of a signal over further TX-antenna is transmitted. To avoid ISI, the guard interval length NG should be longer than $L_{max}+d_i$ (maximum channel delay and delay diversity). The linearity features allow us to implement the DD scheme at the receiver side. However, the channel delay spread increment is imposed on the system. In order to solve this problem, the CDD method is applied in which the TX-antenna specific delays are replaced by cyclic shifts [33]. The frequency selectivity of the channel transfer function can be improved without increasing the observable time-domain channel delay spread at the receiver with the CDD scheme (Table. 1).

In the DDoD method, partially shift each spectrum of an OFDM symbol at the transmitter is applied by using different phase shifts in the time domain at different antennas after the OFDM modulation. In order to perform this operation, signals $\gamma_i(m)$ ($i= 0,.., N_T$-1, m=-N_G, …, N_{FFT}-1) are determined as sampled exponential function to perform a specific spectral shift of the signal $s(m)$ for specific frequency shift (f_i) and subcarrier spacing (Δf_{sc}). In fact, the main role of Doppler diversity (DoD) is to broaden the Doppler spectrum which results in a decreased channel coherence time such as CDD [39]. According to the results of [39], a specific frequency shift choose based on the value of Doppler width (f_D).

2-2- Standard SFBC Using Alamouti Code

The Alamouti STBC, which was primarily proposed for the MIMO system contained 2 transmit and 2 receive antennas. Since individual subcarriers can be considered as independent flat fading channels; applying the STBC for OFDM is a straightforward procedure [37], [40], [41].

Two adjacent data-carriers S_k and S^*_{k+1} for subcarriers k and $k + 1$, are considered, that the Alamouti coder outputs two pairs,[S_k $-S^*_{k+1}$] for the first antenna, and [S_{k+1} S^*_k] for the second antenna.

3- The Proposed Scheme for Transceivers

In the latest wireless broadcast systems, such as DVB-T2, in order to increase bandwidth efficiency, multiple antenna technologies are used [21]. The proposed scheme is implemented at both the transmitter and receiver sides, which will be explained in the following.

3-1- Transmitter

Our proposed scheme, as shown in figure 2, is a genetic MIMO-OFDM based on using the CDD scheme in the DVB-T2 system. The new proposed system provides additional propagation paths and is inserted into the system. Figure 2 shows the Front end of the proposed transmitter side, which has 2 data streams. In the first data stream, after the N_{FFT} point IFFT, a cyclic prefix (CP) is added to each symbol by repeating the end of the same symbol. In this case, the obtained signal $s_0(m)$, which is a sequence of N_{FFT} data symbols of S_l , for $l=0,…,N_{FFT}$-1, is transformed into time-domain and transmitted via the first TX-antenna without delay. In the other data stream, for providing additional diversity and as a result, improvement of system performance, the CDD scheme is implemented.

The average transmission power is kept normalized and independent of the number of related TX-antennas (N_T) by $(N_T -1)^{0.5}$ factor. Based on the block diagram, before inserting the CP with the length of N_G, the symbol is shifted cyclically and then the CP is inserted. Therefore, results in the antenna specific TX-signal can be express as bellow:

$$s_i(m) = \frac{1}{(N_T - 1)^{0.5}} \widetilde{s}(m - d_i^{cyc} \mod N_{FFT}) \qquad (1)$$

$$for \qquad i = 0,...,N_T - 1, m = -N_G,...,N_{FFT} - 1$$

where k and i denote the numbers of data symbol and TX-antenna, respectively.

Table 1: Simple diversity techniques

Diversity Technique	Key technology	Condition (to avoid ISI)	More information	Ref.
Delay Diversity (DD)	The simple method to increase diversity. (delay diversity schemes are based on signal shifts in the time domain,)	$N_G \geq L_{max} \, d_{i\,max}$	causes the channel delay spread increment	[8], [9]
Cyclic Delay Diversity (CDD)	CDD scheme enhances the frequency selectivity of the channel transfer function	$N_G \geq L_{max}$	Involved channel estimation	[19], [22]
Doppler Diversity (DoD)	Shift the antenna specific signals in the frequency domain.	$\gamma_i(m) = e^{j2\pi \cdot f_i \cdot T \cdot m}$ $T = 1/(N_{FFT} \cdot \Delta f_{sc})$	Increasing the Doppler with DoD in OFDM systems in principle enlarges ICI	[23]
Discontinuous Doppler Diversity (DDoD)	The DoD Signal is constant for the duration of an OFDM symbol.	$\gamma_i(m) = e^{j2\pi \cdot f_i \cdot T \cdot (N_{OFDM} \cdot (m \div N_{OFDM}))}$	Needs further investigation	[24], [30]

Also, $s(k)$ is considered as a sample of k_{th} Alamouti symbol, which is modulated in the time domain and then the signal is shifted cyclically by d_i^{cyc} before the CP is added.

After removing the CP at the receiver side, as long as TX - antenna certain delays, d_i, is equal to cyclic shifts, d_i^{cyc}, both CDD and DD schemes yield the same signal. The OFDM symbols of the DD signal partly overlap with the CP of the subsequent OFDM symbol at about delay which is a restriction in the choice of d_i. Therefore, the ISI part of the received signal at k^{th} subcarrier can also be expressed as:

$$R_{ISI}(k) = \frac{1}{\sqrt{N_{FFT}}}$$

$$\sum_{l=N_G+1}^{L_{max}+d_{max}} h(l) \sum_{k=0}^{l-N_G} s(m-l) . e^{j2\pi km/N_{FFT}}$$

(2)

where $h_i(l)$ is the channel impulse response from TX-antenna i to the RX-antenna with delays of $l > N_G$ samples and the signal part $s(k)$, $k < -N_G$, since these terms cause ISI [30]. Also, the minimum length of CP should be $N_G \geq L_{max}$ in the system based on the CDD and this length does not depend on the cyclic delays, d_i^{cyc}. Therefore, a shorter CP can be chosen and there is an advantage of CDD with respect to the DD that the CDD scheme does not depend on the number of TX-antenna and there is no overlapping of OFDM symbols in it. However, in the case of free-ISI, the DD scheme performs the same as CDD.

To avoid ISI interference, the guard interval length N_G must be $N_G > L_{max} + \max D_i$ for $i = 0, \ldots, N_{T-1}$, where L_{max} is the maximum channel delay samples. Also, we can choose the maximum possible cyclic delays according to:

$$d_i^{cyc} = \frac{N_{FFT}(i-1)}{N_T} = \frac{N_{FFT}}{N_T} + d_{i-1}^{cyc}$$

(3)

and

$$d_i^{cyc} = N_G + 1 + d_{i-1}^{cyc}$$

(4)

where N_T and N_{FFT} denote the number of TX-antenna and data symbol respectively [30].

3-2- Receiver

In the DVB-T2 system, standard Alamouti code is used in the transmitter for enhancing spectral efficiency and link reliability. This is done for maximizing the diversity in the receiver while using low complexity equalization based on the maximal ratio combining (MRC) method [10].

In this paper, we have utilized the Alamouti code, which was primarily introduced for MIMO systems with two transmit and two receive antennas. Assume S_k, S_{k+1} are the two successive subcarriers, $[S_k, -S_{k+1}^*]$ and $[S_{k+1}, S_k^*]$ are two pairs of MIMO encoder outputs for the first and the second data streams, respectively. On the receiver side, we use a decoding method [1], which is called "Δh-Alamouti decoding" in this paper. In this method, the first MIMO-OFDM symbol in (2) is the $S_0(k)$, which is transmitted as an un-shifted signal ($d_0^{cyc} = 0$) over the first TX-antenna. The other TX-antenna signal is shifted cyclically by d_i^{cyc} before adding the CP as shown in Figure 2. On the receiver side, after removing the CP, the remaining OFDM time domain symbol is transformed into the frequency domain by an FFT in the receiver side, as shown in Figure 3. The received data can be written in a compact form as follow:

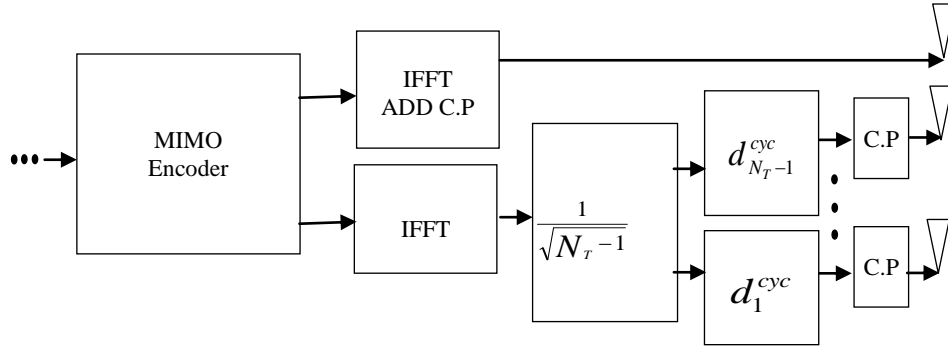$$\mathbf{Y} = \mathbf{S}\widetilde{\mathbf{H}} + \mathbf{N}$$

(5)

Fig. 2 The front end of the proposed scheme using CDD at the transmitter side

where $\tilde{\mathbf{H}}$ denotes an equivalent channel transfer function and is defined as bellow:

$$\tilde{\mathbf{H}} = \frac{1}{\sqrt{N_T}} \tag{6}$$

$$\sum_{i=0}^{N_T-1} \sum_{m=0}^{N_{FFT}-1} h_i(\text{m}) e^{\frac{j2\pi.mk}{N_{FFT}}} e^{\frac{-j2\pi.d_i^{cyc}.k}{N_{FFT}}} + \mathbf{N}$$

where $\mathbf{N}$ is a complex Gaussian noise, which is mutually uncorrelated between different subcarriers, h_i is the ith tap of the channel impulse response [30].

Equation (6) means that a receiver cannot distinguish whether a propagation path results from the CDD scheme or the channel itself [4]. After FFT transformation and pilot extraction at the receiver side, we have the following equations:

$$\begin{cases} Y_1^K = S_k H_{1,1}^k - S_{k+1}^* H_{1,2}^k + N_1^k \\ Y_2^K = S_k H_{2,1}^k - S_{k+1}^* H_{2,2}^k + N_2^k \\ Y_1^{K+1} = S_{k+1} H_{1,1}^{k+1} - S_k^* H_{1,2}^{k+1} + N_1^{k+1} \\ Y_2^{K+1} = S_{k+1} H_{2,1}^{k+1} - S_k^* H_{2,2}^{k+1} + N_2^{k+1} \end{cases} \tag{7}$$

where $\tilde{H}_{i,j}^k$ is the channel frequency response at carrier k^{th}, between i^{th} receive antenna and j^{th} transmit antenna, N_i^k is AWGN noise at the kth carrier of ith receive antenna, and * denotes conjugate operator.

In the standard Alamouti decoding should be assumed that the channel frequency response is constant over two consecutive carriers, i.e. $\tilde{H}_{i,j}^k = \tilde{H}_{i,j}^{k+1}$. However, the performance of the standard Alamouti decoding will be degraded over highly frequency-selective channels.

Since there should be quasi-static fading for adjacent subcarriers. In order to overcome this problem, an efficient Alamouti decoding scheme using the CDD scheme is proposed. By considering the changes in the

channel matrix over adjacent OFDM carriers, we can write:

$$\Delta\mathbf{H}^T = \begin{bmatrix} 0 & 0 & (H_{1,2}^{k+1} - H_{1,2}^k)^* & (H_{2,2}^{k+1} - H_{2,2}^k)^* \\ 0 & 0 & -(H_{1,1}^{k+1} - H_{1,1}^k)^* & -(H_{2,1}^{k+1} - H_{2,1}^k)^* \end{bmatrix} \tag{8}$$

where T refers to conjugate transpose operation. Equation (8) confirms that the variation of two consecutive carriers is considered. In other words, if the difference between two consecutive carriers is 0, the channel frequency response is flat over the Alamouti block. Therefore, there is not any necessity to consider the channel constant over

two consecutive subcarriers. In multiuser detection, optimal error-rate performance is achieved by the joint Maximum Likelihood (ML) detector, which its computational complexity increases exponentially. However, for the last part of detection, we use the results of [42] and [1], which have lower complexity than ordinary methods. For recovering the signal at the receiver side, ΔH is applied in a detection scheme by the MMSE criterion. Therefore, the estimated transmitted symbol can be expressed as [1]:

$$\tilde{\mathbf{S}} = \frac{1}{\det(\mathbf{I}_2 + \mathbf{B}\Delta\mathbf{H})} adj(\mathbf{I}_2 + \mathbf{B}\Delta\mathbf{H}).\mathbf{B}.\mathbf{Y} \tag{9}$$

where,

$$\mathbf{B} = (\mathbf{H}^T\mathbf{H})^{-1}\mathbf{H}^T \tag{10}$$

where det and adj denote determinant and adjoint operations, respectively and $\mathbf{I}_2$ is the identity matrix of order two.

The transmitted data can be recovered at the receiver side using Eq. (9). It is noticeable that the new scheme has a lower complexity since Eq. (9) does not consist of the

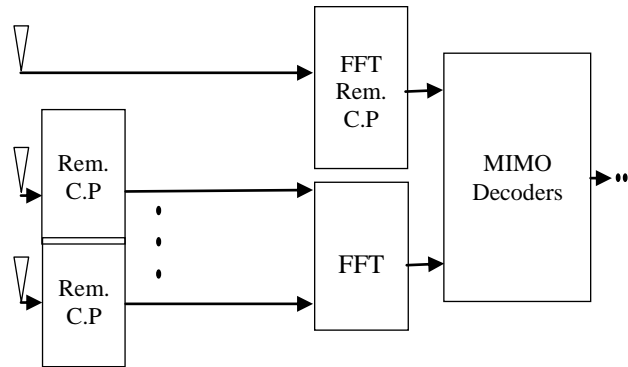direct inverse of the matrix $(\mathbf{I}_2+\mathbf{B}\Delta\mathbf{H})$

Fig. 3 The proposed scheme using CDD at the receiver side
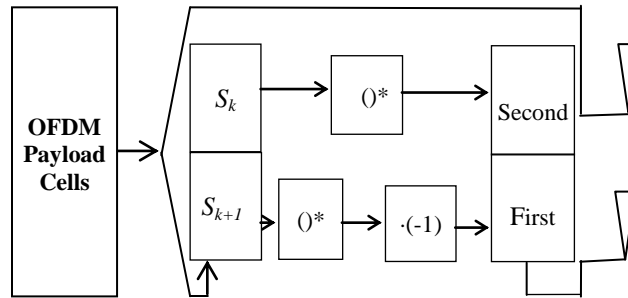

Fig. 4 Multiple Input, Encoder processing of OFDM payload cells [33]

3-3- An Efficient Alamouti coding and decoding using CDD

An optional initial stage, known as MISO processing in the DVB-T2 standard, provides the initial frequency domain coefficient, which is processed by a modified Alamouti [33]. Then, the DVB-T2 signal to be split between two groups of transmitters on the same frequency without the interference of signals [17].

Figure 4 shows that the MISO processing for transmitters in the MISO group1 copies the unmodified input cells to the output. Also, N data will be an even number, even in the frame closing symbol, even though value CFC (number of active cells in one frame closing symbol) might not be even. Hence we can use it in the proposed strategies.

In this section, we investigated Δh-Alamouti decoding using CDD. In other words, we have proposed an efficient scheme, which exploits the modified Alamouti using CDD. On the other hand, the core idea concerns the improvement of the transmitter and receiver sides. On the transmitter side, we use the CDD as an antenna diversity technique and improved Alamouti encoding (Fig. 3). The DVB-T2 standard using a modified form of

Alamouti encoding, which is the respective payload cells are processed in the frequency direction.

In the MIMO encoder module, $[S_k, S_{k+1}]$ is transmitted as the first data stream; without any modification regarding frequency order. In the second data stream, we have pairwise modification $[S_{k+1}{}^*, S_k{}^*]$. At the receiver side, the MIMO decoder module consists of MMSE criterion and a channel matrix equation as bellow:

$$\Delta\mathbf{H}^{\mathrm{T}}{}_{Effiicent} =$$
$$\begin{bmatrix} 0 & 0 & 0 & 0 \\ (H_{1,2}^{k+1}-H_{1,2}^{k})^* & (H_{2,2}^{k+1}-H_{2,2}^{k})^* & -(H_{1,1}^{k+1}-H_{1,1}^{k})^* & -(H_{2,1}^{k+1}-H_{2,1}^{k})^* \end{bmatrix}$$
(11)

Then, by applying equations (9) and (10), when the MIMO channel is estimated using the known pilot, the receiver can recover the transmitted data.

3-4- An Efficient Alamouti coding using DDoD

In this section, we investigate the use of Doppler diversity (DoD), which schemes shift the antenna-specific signals in the frequency domain [43], [44]. This type of scheme is used in studies such as [31]. Figure 5 shows the front end of the proposed scheme using

Doppler diversity at the transmitter side. After OFDM modulation using an IFFT and guard interval insertion as a cyclic prefix, the signal $s(m)$ is split (copied) into N_T

TX-branches. After normalization by the factor, the time domain signal in each TX-branch is multiplied by a TX-antenna specific signal
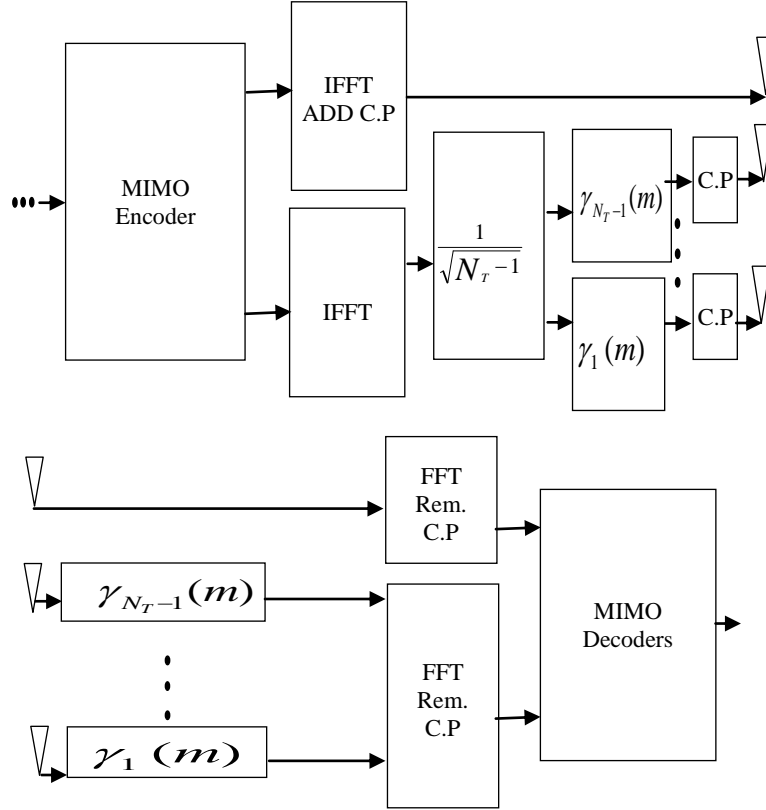

Fig. 5. The proposed scheme using DDoD (transmitter and receiver)

$\gamma_i(m)$. Therefore, results in the TX-antenna specific transmission signals can be expressed as [44] :

$$s_i(m) = \frac{1}{\sqrt{N_T}} s(m). - \gamma_i(m)$$

$$\text{for} \quad i = 0,\ldots,N_T - 1 \qquad (12)$$

$$m = -N_G,\ldots,N_{FFT} - 1$$

According to Fig. 5 (receiver side), the time domain signal for n^{th} OFDM symbol after removal guard interval can be written as follows [31]:

$$r_n(m) = \frac{1}{\sqrt{N_T}}$$

$$\sum_{i=0}^{N_T-1}\sum_{l=0}^{N_{\max}} s_n(m-l)h_i(m+n \cdot N_{OFDM},l) \cdot \gamma_i(m+n \cdot N_{OFDM}) \qquad (13)$$

where $h_i(m+n.N_{FFT}, l)$ denotes the time-variant Rayleigh fading process with a delay of l samples observed from Tx antenna i. After that, the received time-domain signal

is transformed into the frequency domain and this processing can be described by the following equation [31]:

$$R_n(k) = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} r_n(m) \cdot e^{-j\frac{2\pi}{N} \cdot k \cdot m} =$$

$$\frac{1}{\sqrt{N \cdot N_T}} \sum_{q=0}^{N} S_n(q) \cdot \sum_{i=0}^{N_T}\sum_{l=0}^{N_{\max}} \bar{\gamma}_{i \cdot n} \cdot H_{i,l,n}(q) \cdot e^{-j\frac{2\pi}{N} \cdot l \cdot q} \qquad (14)$$

Where $S(q)$ denotes the DFT of $s(m)$ and,

$$H_{i,l,n}(q) = \frac{1}{\sqrt{N}} \cdot \sum_{m=0}^{N-1} h_{i,n}(m,l) \cdot e^{-j\frac{2\pi}{N} k \cdot q} \qquad (15)$$

Equation (14) confirms that the effects of DDoD can be assigned to the channel. Also, this simplifies the parallel transmission (ICI-free) over subcarriers if there are constants channel fading $h_i(m,l)$ for the duration of an OFDM symbol. Otherwise, we mitigate the system performance degradation by using the proposed method

i.e. Δh-Alamouti in the third strategy. Therefore, we witness a considerable performance improvement. at the receiver side, and as a result, the transmitted data can be recovered at the receiver side using Eq. (9).

In table 1, the signals $\gamma i(m)$for DDoD is mentioned. In order to achieve a TX-antenna specific spectral, these signals are chosen as exponential functions shift of the signal $s(m)$, before adding the cyclic prefix.

However, the effects of DDoD can be assigned to the channel. These effects are shown in Fig. 6. We applied DDoD with different f_D/f_{SC} to the MISO systems (2×1). We used the 2k mode (2048 points IFFT) with 4-QAM modulation. The guard interval length is N_G =1/4. For our investigations, we used 9-path multipath Rayleigh channel models which is similar to indoor commercial-channel B models in 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. This result of simulation and mathematical analyses in [23] could be considered to provide design criteria for the choice of TX-antenna parameters for DDoD.

4- Simulation Results

In this Section, three strategies have been performed to demonstrate the advantages of our proposed scheme. A Δh-Alamouti decoding scheme introduced in [1] is used in this simulation. According to [25], the performance of the DD and CDD schemes is equal if the transmission is ISI free. However, by increasing the CP length using the MISO-DD method, noticeable performance degradation will occur at the receiver side. There is a fact to take into account that if the CP length is increased for the DD scheme, the amount of interference will be huge. It should be mentioned that the channel estimation is assumed to be perfect. Also, for better comparison, Table 2 list the parameters and reason for its selection.

4-1- The Δh-Alamouti Decoding using CDD (strategy 1)

We have set up the first strategy to verify the better performance of the proposed Δh-Alamouti decoder using the CDD scheme with respect to Δh-Alamouti. In the first strategy, the MIMO-OFDM system has been applied to the DVB-T2 standard, in which 8k modes, i.e. 8192 sub-carriers with 4-QAM modulation, are used. We have applied 10000 OFDM symbols with a CP length of ¼ to a 2×2 MIMO DVB-T2 system. We have used the P1 multipath Rayleigh fading channel model [6], which has 20 taps without any Doppler effects. In this simulation,

d_i^{cyc} = 2, this is because the SNR does not increase further when d_i^{cyc}>1.5µs, as shown in [4]. The performance of the un-coded strategy is also evaluated; thus the coding and interleaving blocks are bypassed in our system simulation. Four different profiles are used as MIMO channels with identity power and different phases. In order to make the uncorrelated channel, which is applied in [1], phases are randomly chosen between 0 and 2π.

In order to simulate highly frequency selective channels, random phase with different values for *a* and *b* parameters are used, where a and b are the power of the delayed channel and the delayed spread, respectively [26]. In principle, increment in the delay spread and the power of the delay channel convert the channel to a highly frequency-selective channel [1]. Figure 7 shows the results of different methods consisting of the efficient Alamouti decoding scheme using the CDD scheme, Δh-Alamouti, and the standard one, when, channel estimation is assumed to be perfect.

From the simulation result, it can be observed that for *a*=0.5, the proposed scheme performs approximately the same as the Δh-Alamouti scheme. However, the performance of the standard decoder degrades. Also, for a = 0.9, the performance of our proposed scheme is better than the Δh-Alamouti scheme.

Table 2:Parameters for simulations

Fig	Parameter	describe	References
6,10	Indoor commercial-channel B models	N_{tap}=20 Channel tap number length	[6]
10	2k mode (2048 points IFFT) with 4-QAM modulation. The guard interval length is NG =1/4	Mode selection	DVBT-2 standards model [33]
6-9, 11-13	8k modes, i.e. 8192 sub-carriers with 4-QAM modulation Nfft=8192	FFT size	[33],[6]

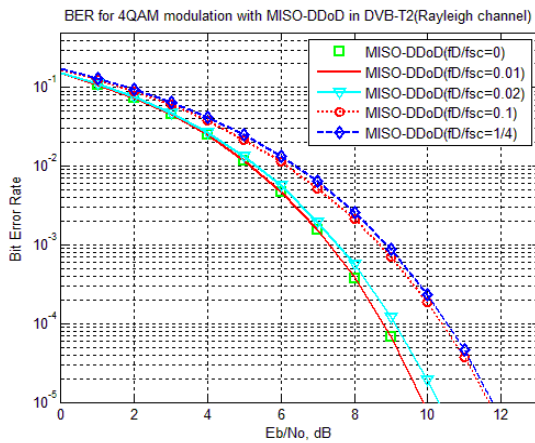| 6-13	nRX=2; nTX=2;	Number of antennas	DVBT-2 standards model [33]
6-9,11-13	$d_i^{cyc} = 2$	Delay (CDD)	[4]
7-9, 11-13	DVBT-2 channel model a, b	the power of the delayed channel and the delayed spread	DVBT-2 standards model [33] and [1]

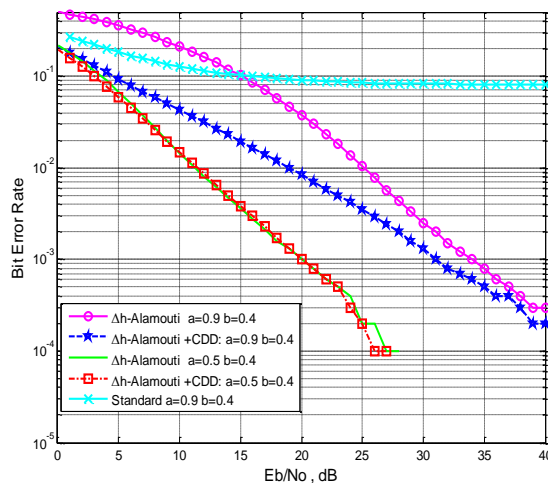Fig. 6 The effect of discontinues Doppler diversity delay

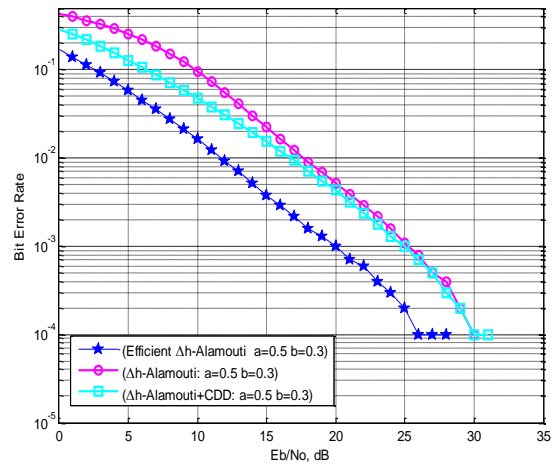Fig.7 The performance of Δh-Alamouti using CDD schemes in BER vs. SNR.

Fig. 8 A comparison of different schemes (a=0.5, b=0.3) in BER vs. SNR.

This improvement is due to the increased degree of diversity of the proposed method, which allows a significant performance enhancement that can be achieved without increasing the number of antennas. Besides, BER is also decreased by using this scheme and the performance of the proposed scheme is still much better than the other schemes. This is because the CDD scheme is capable of offering a larger degree of diversity to improve the performance, which is achieved through the reception of data signals from more than one path. For instance, Figure 7 shows that this scheme outperforms the scheme in [1] by 3.2 dB at an average BER of 10e-3.

4-2- The Efficient Δh-Alamouti Coding and Decoding Using CDD (strategy 2)

In this section, we investigate the efficient Δh-Alamouti coding and decoding using CDD, which is introduced in section 3. We consider the MIMO-OFDM system based on the DVB-T2 standard with 8k mode (8192 sub-carriers with 4-QAM modulation) and similar conditions of the previous strategy. The three schemes are compared in different channels.

In Figure 8, we observe that when *a*=0.5, two strategies of Δh-Alamouti with and without CDD perform a little convergence in the high SNR. However, the efficient Δh-Alamouti coding and decoding using CDD are much better than the other schemes. For instance, at BER= 10e-3, the efficient Δh-Alamouti coding and decoding using CDD get about 5dB gain than the other schemes.

For relatively high values of *a*=0.9 and *b*=0.4, the performance of the efficient Δh-Alamouti coding and decoding using CDD outperforms the previous schemes (Fig. 9). For example, at BER 10e-3, the modified encoding form with CDD gets about 9.8dB gain than the

standard encoding form with CDD. Due to the fact that, when channels are highly frequency-selective (with decreasing *a* and *b*), the efficient Δh-Alamouti coding and decoding using CDD can conserve its performance. But, the method of Δh-Alamouti with CDD has a minor performance improvement. In the proposed scheme, allows the high tolerability of the system to highly selective channels. Therefore, we gain better performance by using a new modified version of Alamouti encoding with CDD. Because, the efficient Δh-Alamouti coding using CDD provides additional diversity in channels and therefore, improves the system performance.

4-3- The Efficient Δh-Alamouti Decoding Using DDoD (strategy 3)
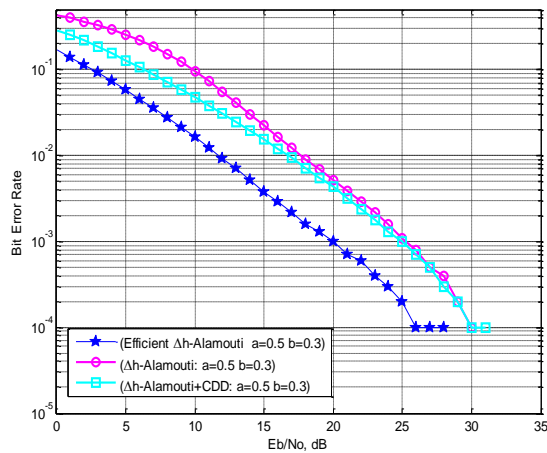
For an investigation of DDoD, we applied Alamouti

Fig. 8 A comparison of different schemes (a=0.5, b=0.3) in BER vs. SNR.

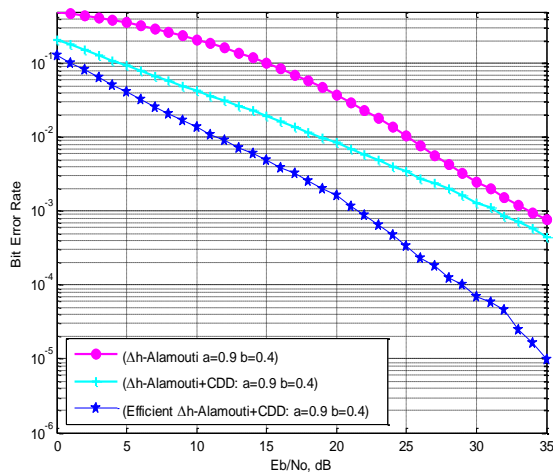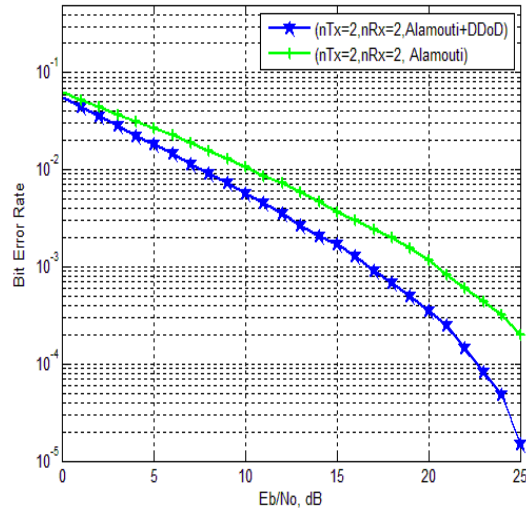Fig. 9 A comparison of different schemes (a=0.9, b=0.4) in BER vs. SNR.

Fig. 10 The effect of discontinues DDoD

enhanced with DDoD and Alamouti standard. We used the 2k mode (2048 points IFFT) with 4-QAM modulation. The guard interval length is N_G =1/4. At the receiver sides, we assumed that the channel estimation was perfect. For our investigations, we used indoor commercial-channel B models (used in Fig.6). Compared to the Alamouti standard which required an SNR of 21 dB at BER=10e-3, an Alamouti enhanced using DDoD requires 16.5 dB, which provides a gain of 4.5 dB for the considered DVB-T2 parameter set (Fig. 10).

In the next experiment, we compared different systems based on multiple antenna techniques; Alamouti, DD, CDD with different *di* to the MISO systems (2×1), and DDoD in Rayleigh fading channel. The previous channel, which was constant over two adjacent OFDM carriers (non-highly selective fading), was applied for this experiment (Fig. 11).

All MISO methods are based on standard Alamouti and the combination of that with other simple diversity techniques was compared. After removing the CP at the receiver side, as long as TX-antenna certain delays, d_i, is equal to cyclic shifts, d_i^{cyc}, both CDD and DD schemes yield the same signal. In this simulation condition, the DD scheme performs the same as CDD. However, there is a fact to take into account that if the CP length is increased for the DD scheme, the amount of interference will be huge. [32]. The OFDM symbols of the DD signal partly overlap with the CP of the subsequent OFDM symbol at about delay which is a restriction in the choice of d_i. As a result, Figure 11 shows that the DDoD combination is better than the other methods.

We have set up the third strategy to verify the better performance of the proposed Δh-Alamouti decoder using

the CDD scheme and DDoD with respect to Δh-Alamouti, which was introduced in [1]. we observe a comprehensive comparison between Δh-Alamouti, efficient Δh-Alamouti using CDD, and Δh-Alamouti using DDoD in Fig. 12 and 13. The performance is evaluated using simulations in different channels that include the presence of high selective fading. The last experiment is applied in two different channels, which are introduced in [1] (also, is based on [26]).

In the first type of channel, we witness that efficient Δh-Alamouti using CDD and Δh-Alamouti using DDoD have a better performance than Δh-Alamouti. Because, in two methods based on DDoD and CDD, diversity is exploited without the need for additional complexity at the receiver. This a considerable advantage of these types of methods. Also, these two proposed methods are driven great benefit from efficient encoding and decoding, which is explained in previous sections. However, in Fig.13, the Δh-Alamouti
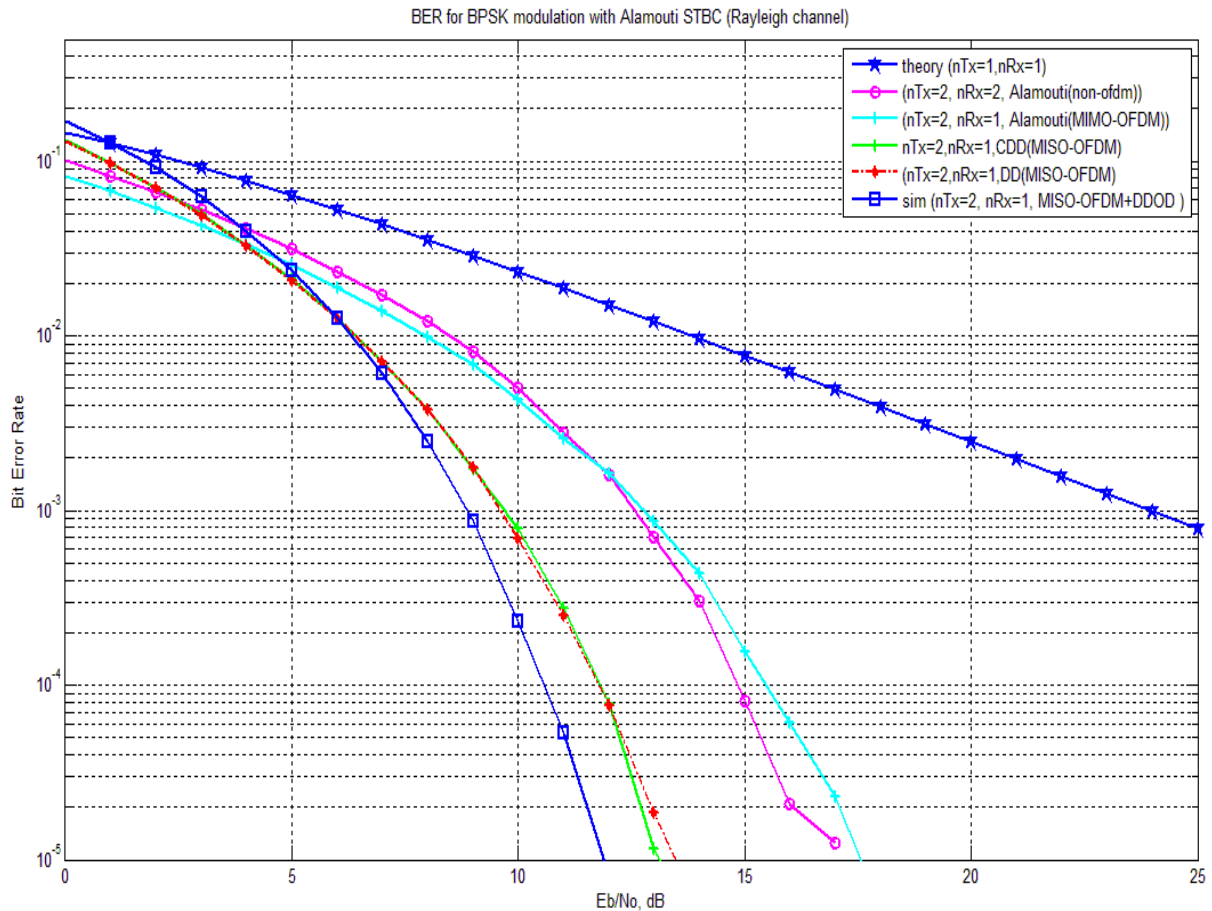

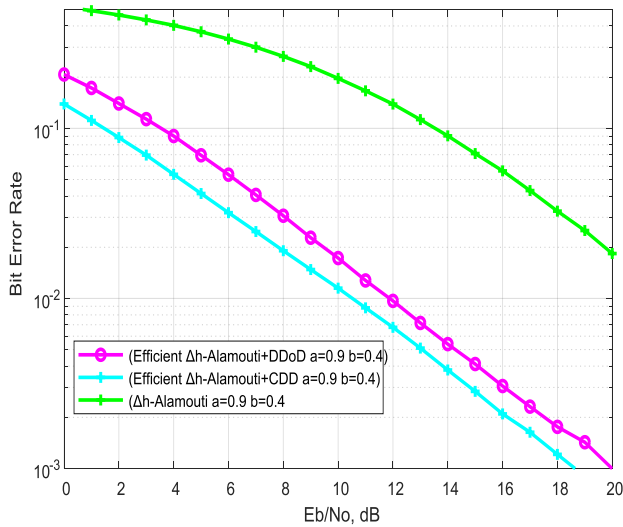Fig. 11 A comparison of different schemes (theory, Alamouti, DD, CDD, and DDoD)

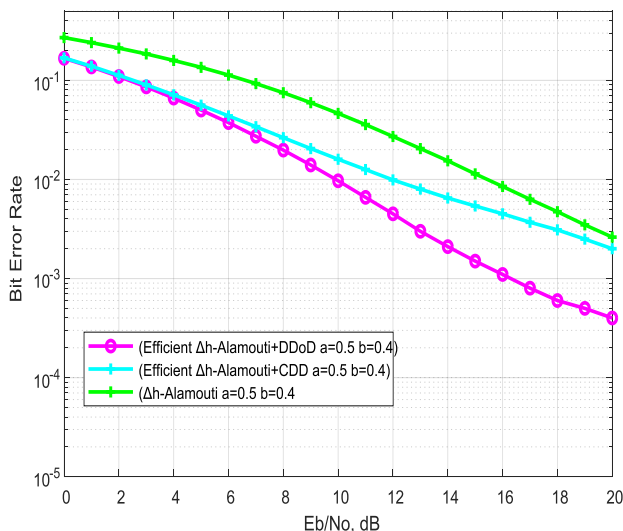Fig. 12 A comparison of different schemes (Efficient Δh-Alamouti,CDD, and DDoD for a=0.9, b=0.4)

Fig. 13 A comparison of different schemes(Efficient Δh-Alamouti,CDD, and DDoD for a=0.5, b=0.4)

5- Conclusion

In this paper, it was shown that the performance of well-known Alamouti decoding degrades in the highly frequency selective channels. To tackle this problem, we proposed an efficient decoder using the CDD and DDoD scheme, which enhanced the standard Alamouti decoding and allowed high tolerability of the system in the frequency-selective channels by increasing the diversity.

Due to standard compatibility, a receiver does not need to be aware of their CDD and DDoD implementation. Also, the effect of the DDoD scheme is well noticeable

on the receiver side. Analysis and simulation results demonstrated that the proposed scheme has significant performance improvement. Therefore, the new scheme is useful in MIMO-OFDM systems such as the DVB-T2 standard, which allows a high reliability and capacity enhancement. Due to all these features and as a future work, many wireless systems could take advantage of these schemes, explored with a low complexity implementation.

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