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Obtaining Diversity and Coding Gains for Digital Terrestrial Television by Using a Coded Cooperative MIMO Transmission Scheme

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Abstract Digital terrestrial television is a modern broadcasting technology that has permitted broadcasters to offer television service with excellent image and sound quality. Many countries have been assigned a new digital television standardization process and many studies are underway regarding digital multimedia broadcasting technology. This paper investigates the utilization of a coded cooperative multiple-input and multiple-output (MIMO) transmission scheme in modern digital broadcasting systems to achieve additional transmit diversity and coding gains. The main idea of this work is the implementation of a coded cooperative MIMO scheme based on a low-density parity check code. A coded cooperative transmission can obtain a robust forward error correction. In this way, it is possible to achieve more stable system performance and improved mobility for next generation handheld systems. In order to show the potential for practical implementation, the performance of the proposed method is evaluated on the basis of the Digital Video Broadcasting-Second Generation Terrestrial (DVB-T2) system. The simulation results show that the proposed scheme can be utilized for the development of future DVB broadcasting systems that should support high mobility handheld devices, such as the Digital Video Broadcasting–Next Generation Handheld (DVB–NGH) system.

Keywords Digital TV · Digital Video Broadcasting · MIMO · Cooperative communications · NGH

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1 Introduction

The development of high definition and advanced television systems has proceeded in parallel in the United States, Europe, and Japan. For various technical, organizational, and political reasons, this has resulted in multiple sets of DTV standards that are applicable in different regions of the world. These days, analog-to-digital conversion is required in many industrial fields [1,2]. Broadcasting systems are not an exception. Many countries have promoted the digitization of their broadcasting systems. The conversion of the terrestrial television platform from analog to digital technology has spurred increasing economic growth in the television market [3].

In a DTV system, the single frequency network (SFN) transmit scheme has significant advantages. By using an SFN system, a broadcasting system performs in an arbitrary large area with the same data within the same frequency block. In the SFN system, one station relays the same program to another station over the same frequency, or several stations broadcast the same program over the same frequency at the same time, in order to increase the spectral efficiency. In such cases, the transmission signal from each base station in the SFN operation needs to be time-synchronized. The most basic method of synchronization is through a global positioning system (GPS) [4,5]. In [6], the authors studied multi-station transmission based on a hierarchical cell structure. They proposed a transmission delay control scheme using GPS position information. A novel modulator design is proposed for Chinese Digital Terrestrial Multimedia Broadcasting in China. A modulator embedded with a GPS/Compass2 timing receiver is presented, which can be useful for the SFN timing redundancy and multiple frequency network (MFN) or SFN applications [7].

Recently, a lot of research has been in progress to apply MIMO technology into the DTV system in order to enhance the advantage of an SFN system. The characteristics of the MIMO radio channel on the UHF band were investigated by studying the basic channel parameters, cross-polarization ratios, spatial correlations with a 4-by-4 MIMO antenna configuration, and two different types of receiver antennas. A comparison between outdoor rooftop and indoor reception was given in [8]. In [9], a new SFN model was proposed for the diversity gain for a DTV system. The authors did not take the SFN signals with different delays as a multipath propagation, because multiple signals transmitted through independent paths that can be separated elegantly if their directions of arrival (DOA) are considered. To achieve spatial diversity, the authors employed a MIMO system. In addition, a three-dimensional (3D) MIMO scheme was proposed for a DTV broadcasting system in SFNs [10]. This is based on a double layer structure that is defined for inter- and intra-cell situations by adequately combining the performance of the Alamouti code and the Golden code. The authors showed that a 3D MIMO scheme is highly efficient for coping with equal and unequal received powers in SFN scenarios.

The DTT broadcasting system that includes MIMO and orthogonal frequency division multiplexing (OFDM) techniques has been studied in the context of the development of the next generation Digital Video Broadcasting-Terrestrial (DVB-T) system [11]. The propagation effects in DVB-T networks are analyzed and demonstrated by applying the developed software to mobile reception [12]. In order to evaluate the performance of a DVB-T2 system in realistic scenarios, a novel 2-by-2 MIMO test bed has been designed and implemented [13].

Many studies of DVB-T2 have been conducted since 2006. The mobile performance of DVB-T2 has been previously evaluated in [14], where certain parameters, such as the guard interval, the fast Fourier transform (FFT) size, or the utilization of rotated constellations were investigated by means of laboratory tests. The proposed codification technique for MISO in

DVB-T2 is based on the Alamouti space-time block code (STBC). The proposed method is a space-frequency block code (SFBC) that is derived from a modified coding matrix of the original Alamouti STBC, but MIMO techniques have not been applied to the DVB-T2 standard. According to the recommendations of the DVB–NGH, MIMO techniques are one of the included study areas on next generation broadcasting standards for increasing channel capacity.

The DVB–NGH specification should be designed for co-existence with other broadcasting and wireless/mobile telecommunication systems on the transmitter/base station side. Therefore, there is a need to look at ways of leveraging the advantages of DVB-T2 in developing a DVB–NGH system in the new paradigm of high rate media content delivery [15].

In this paper, we investigate the utilization of a coded cooperative MIMO transmission scheme in the DTT system to achieve transmit diversity. We refer to the DVB-T2 system parameters for physical layer simulation, because many countries are assigned the European standard, DVB-T, which specifies the framing structure, channel coding, and modulation for the DTT system. This standard also includes the SFN operation and OFDM techniques [16, 17]. We have utilized some methods of time-interleaving blocks to apply a coded cooperative transmission scheme for cooperation on a number of base stations. In the DVBT2 standard, the FEC code from the cell interleaving block for each physical layer pipe (PLP) shall be grouped into interleaving frames, and each interleaving frame is either mapped directly onto one T2 frame or spread out over several T2 frames. When the interleaving frame is mapped over several T2 frames, the time interval occurs between T2 frames. We have applied a cooperative communication transmission scheme between base stations through the time interval between several T2 frames.

2 DVB-T2 System

The inputs of the DVB-T2 system may be one or more MPEG-2 transport streams and/or one or more generic streams. The input pre-processor, which is not part of the T2 system, may include a service splitter or de-multiplexer for transport streams (TS) that separate the services into the T2 system inputs, which are one or more logical data streams. These are then carried in individual PLPs [18]. The DVB-T2 uses a novel technique, called “rotated constellations,” which offers the potential for a significant improvement in robustness, particularly in the case of terrestrial channels [19,20]. The system output is typically a single signal to be transmitted on a single RF channel. Optionally, the system can generate a second set of output signals, to be conveyed to a second set of antennas in what is called the “MISO transmission mode.”

The DVB-T2 standard has additional 16K and 32K carrier modes that enable larger SFNs without increasing the expected overhead in the guard interval. The maximum guard interval size in DVB-T2 is over 500, which is sufficient to implement a large national SFN. The DVB-T2 standard uses a flexible approach by defining eight patterns that can be selected depending on the FFT size and guard-interval fraction adopted for a particular transmission. This reduces pilot overhead while assuring sufficient channel-estimation quality. The interleaving concept is common in many digital signal transmission techniques. The goal of this concept is to spread the digital content in the time or frequency plane in such a way that neither impulsive noise nor frequency-selective fading would destroy long sequences of the original data stream. Table 1 shows the available parameters of the DVB-T2 system.

The DVB-T2 standard implements four types of interleaving stages. If the data symbols are interleaved by the frequency inter-leaver block before SFBC, then the data symbols are combined with space-frequency mapping, and thus are affected by the same fading coefficient.

Table 1 Comparison of available parameters in DVB-T and DVB-T2 systems

Parameters	DVB-T	DVB-T2
FEC	Convolutional code, Reed Solomon (code rate = 1/2, 2/3, 3/4, 5/6, 7/8)	LPDC, BCH (code rate = 1/2, 3/5. 2/3, 3/4. 4/5. 5/6)
Modes	QPSK, 16-QAM, 64-QAM	QPSK, 16-QAM, 64-QAM, 256-QAM
Guard interval	1/4, 1/8, 1/16, 1/32	1/4, 19/256, 1/8, 19/128, 1/16, 1/32,1/128
FFT size	2K, 8K	lK, 2K, 4K, 8K, 16K, 32K
Scattered pilots	8 % of total	1, 2, 4, 8 % of total
Continual pilots	2.6 % of total	0.35 % of total

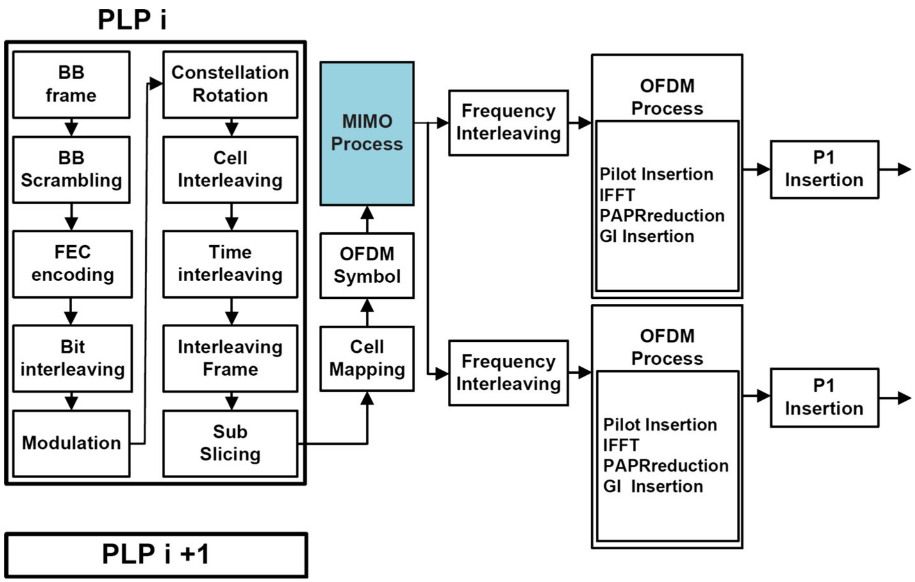

Fig. 1 The proposed DVB-T2 system transmitter block

However, as the data symbols are interleaved by the frequency inter-leaver block after the SFBC block, the data symbols experience different fading coefficients. These can be increased to gain transmission diversity. We propose a modified DVB-T2 system model that maintains the conventional DVB-T2 system with minimum changes and is shown in Fig. 1.

3 The Proposed Scheme

Cooperative diversity, a well-known scenario of the cooperative system in which multiple nodes cooperate to form a virtual multi-antenna array, has been intensively studied as a form of spatial and transport diversity [21]. Multiple antennas can greatly increase the capacity and reliability of a wireless communication link in a fading environment through the use of space-time coding. With the recent increasing interest in ad-hoc networks, researchers have been looking for methods to exploit spatial and transport diversity using the antennas of

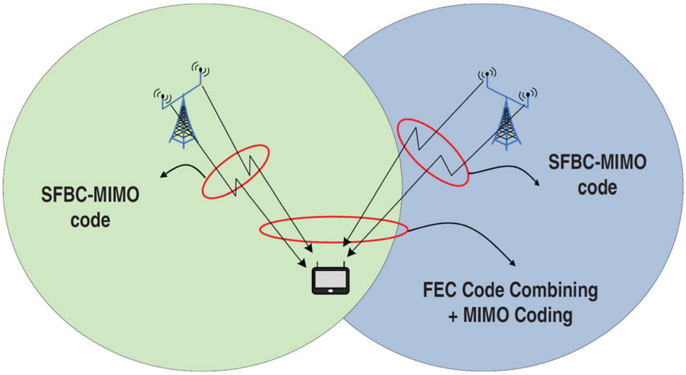

Fig. 2 Example of coded cooperative transmission scheme

different users in the network. Many studies improve the spatial diversity by using repetition and space-time algorithms. The mutual information and outage probability of the network are analyzed. Although current research on cooperative networks mainly focuses on SFN systems, relay networks can also be implemented for OFDM. Coded cooperation in SFN systems offers another scenario for cooperative diversity.

The DVB-T2 system includes many methods for obtaining diversity gains. Thus we focus on achieving the coding gain, and propose a coded cooperative transmission scheme for the DVB-T2 system. We add the FEC code combining method for cooperative transmission. This code combining method can reduce the coding rate and improve the coding gain for a mobile node. The proposed coded cooperative transmission scheme is shown in Fig. 2.

The main purpose of this work is to find a method that enables a new coding gain while maintaining the same transmission efficiency as the DVB-T2 system. Our proposed cooperative transmission scheme employs a 1/3 or 1/4 LDPC code rate. However, the DVB-T2 system does not implement these LDPC code rates. The LDPC encoder core of DVB-T2 is provided by the LDPC encoder block used in DVB-S2 systems. DVB-S2 is the second generation of satellite broadband applications, and was developed by the DVB Project in 2003. This is the first standard that uses the LDPC mechanism for error detection and correction. We used a DVB-S2 LDPC encoder block, as recommended by the DVB project.

An example of the coded cooperative transmission scheme for the 1/3 coding rate is shown in Fig. 3. Each base station generates a default 1/3 inner code $C = [S; P_1; P_2]$, where S is the symmetric data bit, and P_1 and P_2 are parity check bits 1 and 2, respectively. After the inner FEC process, each base station makes a 1/2 rate novel inner code for punching a parity bit depending on the proposed FEC type. For example, as shown in Fig. 3, Base station A generates the original inner code C and punches one parity bit, P_2, depending on the proposed FEC type. Eventually, Base station A has a new code word, $C_1 = [S; P_1]$, and will send it. Base station B punches one parity bit, P_1, depending on the proposed FEC type, and will transmit novel code words $C_2 = [S; P_2]$. Finally, each base station processes the MIMO block coding, SFBC or STBC, and can be used to send the changed code rate data.

Other base stations' signals usually create inter-cell interference in a wireless communication system. Since interference reduces the performance of the wireless system, we need a frame transmission scenario to prevent interference. The frames should be separated for transmitting completely different information. An example of our cooperative transmission scheme between two base stations is shown in Fig. 4a. Each base station has a different frame

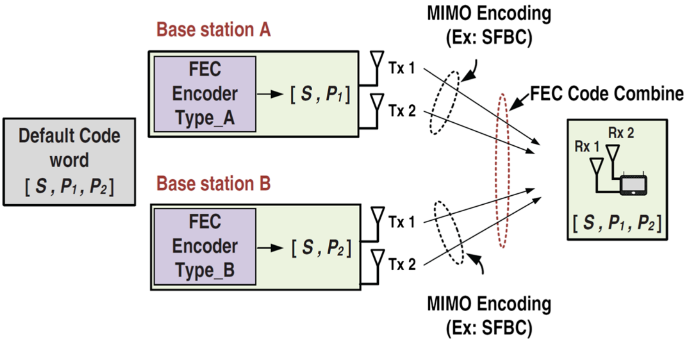

Fig. 3 Example of coded cooperation scenario—original code rate 1/3

start offset and frame hopping index. We assume that all base stations are perfectly time-synchronized using GPS, and that the transmission frame size is also the same. Base station A has a "0" frame start offset and a "2" frame hopping index. Base station A transmits the first frame during the frame duration, T_{FRAME}. When the transmission is finished, Base station A waits for the duration of a given T_{FRAME}. In Fig. 4a, we assign a frame hopping index for one T2 frame. When the transmission is started, Base station B waits for the duration of the given frame start offset. In Fig. 4a, we assign the value "1" to the frame start offset for Base station B. After waiting for a time of T_{FRAME}, Base station B can transmit the first frame. These frame mapping schemes are derived from the time inter-leaver mapping approach in the DVB-T2 standard. The transmission process shown in Fig. 4b utilizes the future extension frame (FEF). The FEF is the part of the super frame between two T2 frames. The FEF part process is similar to the frame mapping scheme. Each base station has its own FEF part offset and FEF parts hopping index. We also assume that each base station is perfectly frame-synchronized with the others. Their frame sizes and frame mapping schemes are the same.

In the interleaving stages, the greatest difference between DVB-T2 and DVB-T is the introduction of time interleaving in DVB-T2, which provides better protection against impulsive noise and time-selective fading. The time interleaver (TI) shall operate at the PLP level. The parameters of the time interleaving may be different for different PLPs within a DVB-T2 system. Each interleaving frame is either mapped directly onto one T2 frame or spread out over several T2 frames. Each interleaving frame is also divided into one or more TI blocks, where a TI block corresponds to one usage of the time inter-leaver memory. The TI blocks within an interleaving frame can contain a slightly different number of FEC blocks. If an interleaving frame is divided into multiple TI blocks, it shall be mapped to only one T2 frame. Figure 5 shows example options for time interleaving in a cooperative transmission scheme.

Each interleaving frame contains one TI block and is mapped to more than one T2 frame. In Fig. 5, one interleaving frame is mapped on two T2 frames. There are two frame intervals (I_{JUMP}) and T2 frames in one interleaving frame (P_I). This provides greater time diversity for low data-rate services. The length of the time interleaving period T_P shall not exceed the length of one super-frame. The time interleaving period is calculated as:

$$T_p = T_F \times P_I(i) \times I_{JUMP}(i), \tag{1}$$

where T_F is the T2 frame length in time, and I_{JUMP} (i) is the interval of the T2 frames for PLP i, if the PLP occurs in every third T2 frame, where I_{JUMP} $(i) = 3$. P_I (i) is the value of P_I for PLP i.

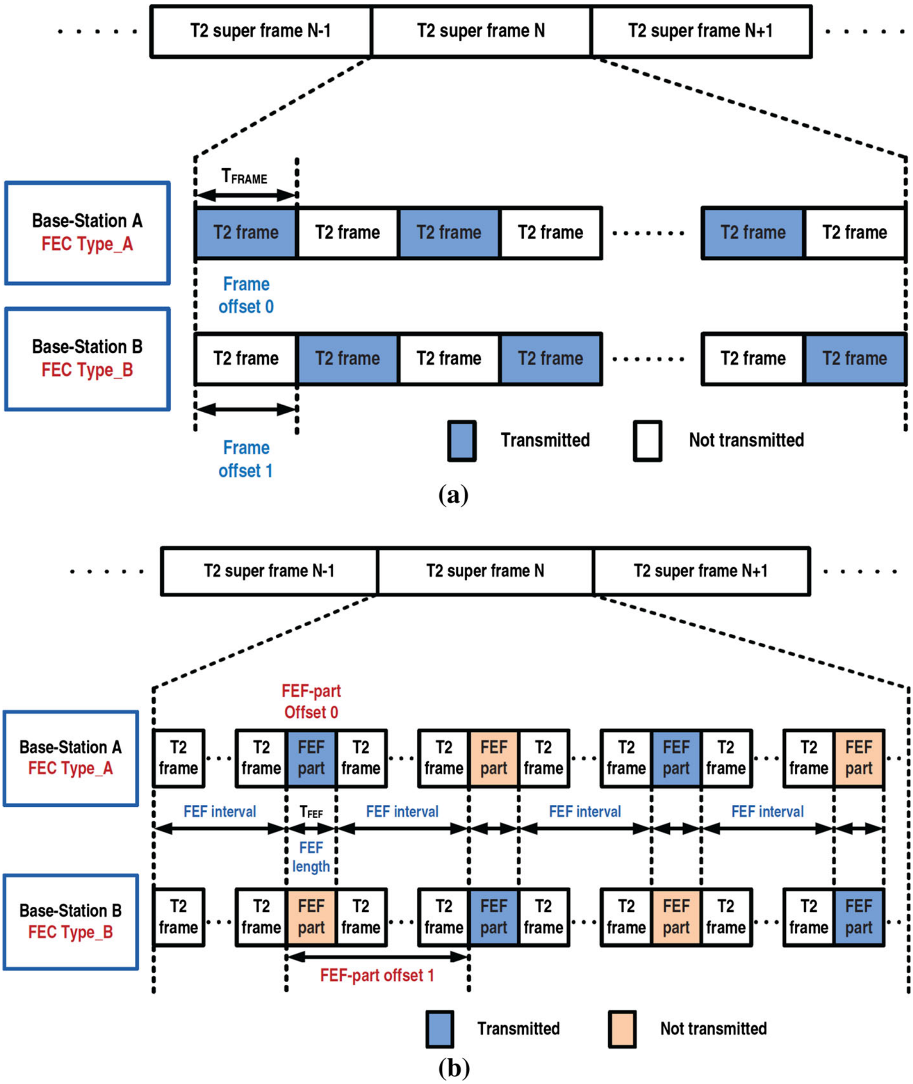

Fig. 4 Example of a cooperative transmission scenario with two base stations that utilizes **a** the T2-frame part and **b** the future extension frame part. Each base station transmits a 1 = 2-rate novel code word after the punching process

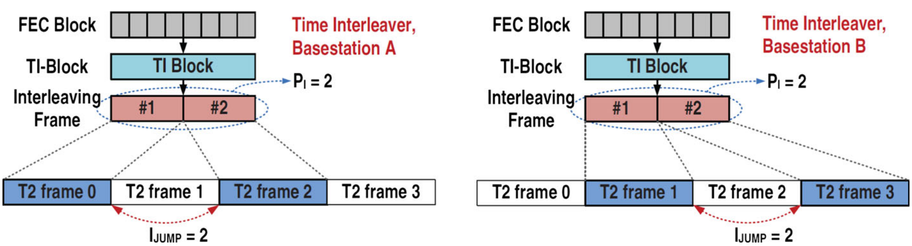

Fig. 5 Cooperative transmission scenario for two base stations using FEC types-A and -B, respectively

Table 2 Mapping with space frequency block codes and 2 Tx antennas

	Antenna 1	Antenna 2
Sub carrier i	S_i	$-S_{i+1}^*$
Subcarrier i + 1	S_{i+1}	S_i^*

We assume that two antennas are implemented at Base stations A and B and at the destination node. Base station A will transmit the punched code word $C_1 = [S;\ P_1]$, while the punched code word for Base station B will be $C_2 = [S;\ P_2]$. After the FEC process, each base station employs the SFBC scheme on each transmission antenna for the MIMO process when a T2 frame is transmitted, depending on the transmission scenarios using a frame mapping scheme. The bit stream to be transmitted is encoded by the space-frequency encoder into blocks of size N. The mapping scheme for the data symbols, S_i, for SFBC with two transmission antennas is shown in Table 2.

The conjugate complex value is denoted by (.)*. The mapping scheme for SFBC is chosen such that the original data is transmitted on the first antenna without any modification. Noise is added at the receiver side. The detected data symbols of the signals transmitted by the base station A are

$$\text{Rx } 1 = \begin{cases} \hat{S} = \left(\|h_{11}\|^2 + \|h_{12}\|^2\right) S + h_{11}n_{1,l} + h_{12}n_{1,l+1}^*, \\ \hat{P}_1 = \left(\|h_{11}\|^2 + \|h_{12}\|^2\right) P_1 + h_{11}^*n_{1,l} - h_{12}n_{1,l+1}^*, \end{cases} \tag{2}$$

$$\text{Rx } 2 = \begin{cases} \hat{S} = \left(\|h_{21}\|^2 + \|h_{22}\|^2\right) S + h_{21}n_{2,l} + h_{22}n_{2,l+1}^*, \\ \hat{P}_1 = \left(\|h_{21}\|^2 + \|h_{22}\|^2\right) P_1 + h_{21}^*n_{2,l} - h_{22}n_{2,l+1}^*, \end{cases} \tag{3}$$

and the detected data symbols of the signals transmitted by the base station B are

$$\text{Rx } 1 = \begin{cases} \hat{S} = \left(\|h_{13}\|^2 + \|h_{14}\|^2\right) S + h_{13}n_{1,l} + h_{14}n_{1,l+1}^*, \\ \hat{P}_2 = \left(\|h_{13}\|^2 + \|h_{14}\|^2\right) P_2 + h_{13}^*n_{1,l} - h_{14}n_{1,l+1}^*, \end{cases} \tag{4}$$

$$\text{Rx } 2 = \begin{cases} \hat{S} = \left(\|h_{23}\|^2 + \|h_{24}\|^2\right) S + h_{23}n_{2,l} + h_{24}n_{2,l+1}^*, \\ \hat{P}_2 = \left(\|h_{23}\|^2 + \|h_{24}\|^2\right) P_2 + h_{23}^*n_{2,l} - h_{24}n_{2,l+1}^*, \end{cases} \tag{5}$$

where l is the l-th subcarrier index.

The received signals are combined after being processed by a channel estimator and sent to the maximum likelihood (ML) detector. The received signals after the MIMO decoding process and combining are

$$\begin{aligned} \hat{S} = & \left(\|h_{11}\|^2 + \|h_{12}\|^2 + \|h_{21}\|^2 + \|h_{22}\|^2 + \|h_{13}\|^2 + \|h_{14}\|^2 + \|h_{23}\|^2 + \|h_{24}\|^2\right) S \\ & + h_{11}n_{1,l} + h_{12}n_{1,l+1}^* + h_{13}n_{1,l} + h_{14}n_{1,l+1}^* + h_{21}n_{2,l} \\ & + h_{22}n_{2,l+1}^* + h_{23}n_{2,l} + h_{24}n_{2,l+1}^*, \end{aligned} \tag{6}$$

$$\begin{aligned} \hat{P}_1 = & \left(\|h_{11}\|^2 + \|h_{12}\|^2 + \|h_{21}\|^2 + \|h_{22}\|^2\right) P_1 + h_{11}^*n_{1,l} - h_{12}n_{1,l+1}^* \\ & + h_{21}^*n_{2,l} - h_{22}n_{2,l+1}^*, \end{aligned} \tag{7}$$

$$\begin{aligned} \hat{P}_2 = & \left(\|h_{13}\|^2 + \|h_{14}\|^2 + \|h_{23}\|^2 + \|h_{24}\|^2\right) P_2 + h_{13}^*n_{1,l} - h_{14}n_{1,l+1}^* \\ & + h_{23}^*n_{2,l} - h_{24}n_{2,l+1}^*. \end{aligned} \tag{8}$$

Now we describe some examples of the proposed coded cooperation scenario for the 1/4 rate when implemented at two and three base stations. Each base station generates a default 1/4 inner code word $C' = [S;\ P_1;\ P_2;\ P_3]$, where S is a symmetric data bit, and P_1, P_2, and P_3

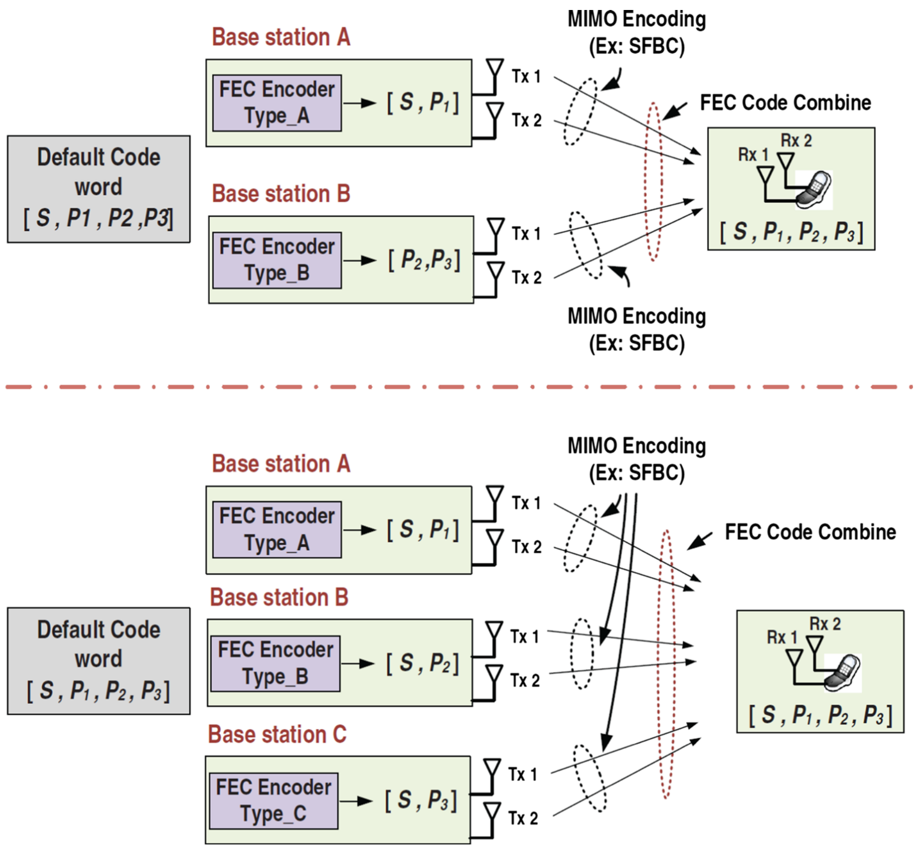

Fig. 6 Example of coded cooperation scenarios among two and three base stations—original code rate 1/4

are parity check bits 1, 2, and 3, respectively. After the FEC process, each base station divides one of the FEC blocks into two parts, followed by its own FEC type. As shown in Fig. 6, Base station A generates an original 1/4 inner code word C' and divides the FEC blocks into two parts, $C_1 = [S; P_1]$ and $C_2' = [P_2; P_3]$. Eventually, Base station A can select one of the divided FEC parts, C_1 or C_2', and will transmit the selected FEC part. Base station B goes through a similar process to Base station A. If Base station A selects FEC part C_1, Base station B should select C_2', and vice versa. If we implement the three base-station-based cooperative transmission scenarios, we can consider other code word types. Each base station generates a default 1/4 inner code word C', and then divides and recombines the default code word into $C_1 = [S; P_1]$, $C_2 = [S; P_2]$, and $C_3 = [S; P_3]$. Each base station selects one novel code word, not equal to that of the others, and processes the SFBC MIMO block coding. Finally, each base station should follow the cooperative transmission scenario to transmit data as shown in Fig. 4.

We explained the 1/3 and 1/4 coding schemes for the two- and three-base-station-based coded cooperation scenarios. In the previous cases, two and three cooperative base stations should transmit different information. The transmission frame should be separated when transmitting completely different information. However, in the case of the two base stations having implemented the 1/3 coding cooperative scenario, each cooperative base station con-

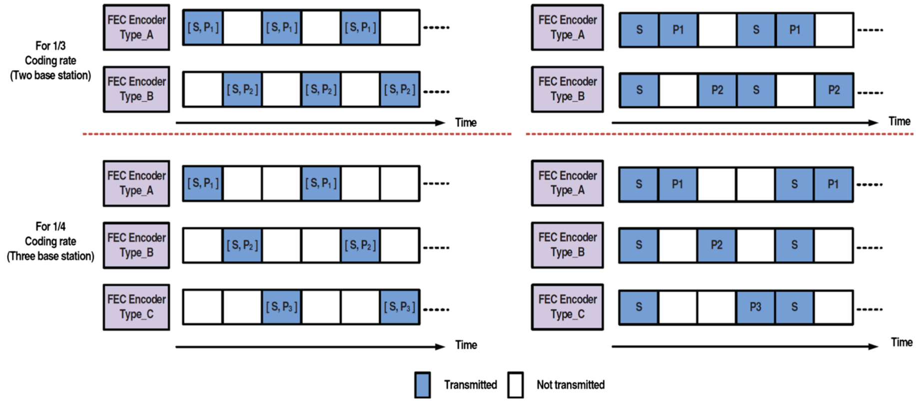

Fig. 7 The data mapping scenarios in the transmission frame

tains shared information, S. If each cooperative base station shares some information, another transmission method can be used. We can divide one of the novel FEC blocks C_n into two parts. One is the symmetric part S, and another is the parity check part P_i. We can transmit the symmetric part S simultaneously, because the symmetric part is included in all of the base stations. If we transmit the symmetric part S at the same time, we can obtain a diversity gain after combining processes at the receiver side. However, as the parity check part P_i is different in every base station, we should transmit the parity check part P_i at a different time. The case of three base stations having implemented the 1/4 coding cooperative scenario can also work in similar ways. The data mapping scenarios into the transmission frame are shown in Fig. 7.

4 Simulation Results

In this section, we describe the simulator parameters and demonstrate, through simulation results, that the performance of our proposed coded cooperative SFBC transmission scheme is better than that of the conventional system. Slow Rayleigh fading channel and ideal channel estimation are assumed in the simulation. In this paper, we simulated only the 1/3 coding rate. Quadrature phase-shift keying (QPSK) and 16-quadrature amplitude modulation (QAM) modulation are applied. As shown in Table 3, most of the simulation parameters follow the DVB-T2 standard. The pilot pattern for the MIMO transmission scheme was not applied. Instead, we used MISO transmission parameters for the MIMO process. We implemented an 8K FFT size and an 8 MHz channel bandwidth for the simulation. The number of carriers per symbol, the number of P2 symbols, and the extra carriers on each side in extra carrier mode are 6817, 2, and 48, respectively. We selected a transmission frame size of 250 ms, which is the maximum frame size as mentioned in the DVB-T2 standard. We selected a short LDPC block for the inner code type. The FEC block length is 16,200, and the 1/3 and 1/4 LDPC code rates are not applied in the DVB-T2 standard. Since the DVB-T2 standard's LDPC code is oriented from the DVB-S2 standard, we used the DVB-S2 standard's 1/3 and 1/4 LDPC to generate a matrix for the simulation. The number of inner decoder iterations is 50. The DVB-T P propagation scenario given in [22] is implemented for the Rayleigh channel model. The transmission power of the entire system is normalized as 1.

Table 3 Simulation parameters

Parameter	Value
FFT size	8K
Channel bandwidth	8 MHz
Frame size	250 ms
Guard interval	1/8
Pilot pattern	PP1
Outer code	BCH
Inner code	Short LDPC block (16,200)
Modulation order	QPSK, 16-QAM
Constellation rotation	QPSK: 29°, 16-QAM: 16.6°
Sub slice	270
Channel model	DVB-T P (Rayleigh)

4.1 Scenario 1: Cooperation Model Using 1/3 Rate Code

Simulation scenario 1 is a two-base-station-based coded cooperation model. As shown in Fig. 3, we implemented two base stations for coded cooperative transmission. After the inner FEC process, each base station creates a 1/2 rate novel inner code for punching a parity bit, depending on the proposed FEC type. Each base station will transmit its novel 1/2 coding rate data. The symmetric data are the same, and only the parity check data are different from each other. Each base station has a different frame start offset and frame hopping index. The destination nodes combine the 1/2 coding rate data after receiving the two base stations' data, and create a 1/3 code before sending the decoding block.

4.2 Scenario 2: Cooperation Model Using 1/4 Rate Code

Simulation scenario 2 is a three-base-station-based coded cooperation model. As shown in Fig. 6, we implemented three base stations for coded cooperative transmission. Each base station transmits 1/2 coding rate data. The symmetric data are the same, but the parity check data are different. Each base station has a different frame start offset and frame hopping index. The destination nodes also combine the 1/2 coding rate data after receiving the three base stations' data and make a 1/4 code before sending the decoding block.

4.3 Scenario 3: Double Layer Transmission Model

In the double layer transmission model scenario, code construction is based on the single layer results. We used two transmit (Tx) antennas and two receive (Rx) antennas in our study. We constructed the first layer with the Alamouti SFBC scheme, since it is the most resistant to different received powers. We constructed the second layer with the Golden code in a complementary manner. The Golden code is a Space-Time code for two transmitting and two receiving antennas, for the coherent MIMO channel. The code is constructed using a particular family of division algebras, called cyclic division algebras. The Golden code is

$$\mathbf{X} = \frac{1}{\sqrt{5}} \begin{pmatrix} \alpha(a + b\theta) & \alpha(c + d\theta) \\ j\sigma(c + d\sigma) & \sigma(a + b\sigma) \end{pmatrix}, \tag{9}$$

where a, b, c, and d are the information symbols that can be taken from any M-QAM constellation, $= \sqrt{-1}$, $\theta = (1 + \sqrt{5})/2$, $\quad \sigma = (1 - \sqrt{5})/2$, and $= 1 + j - j\theta$.

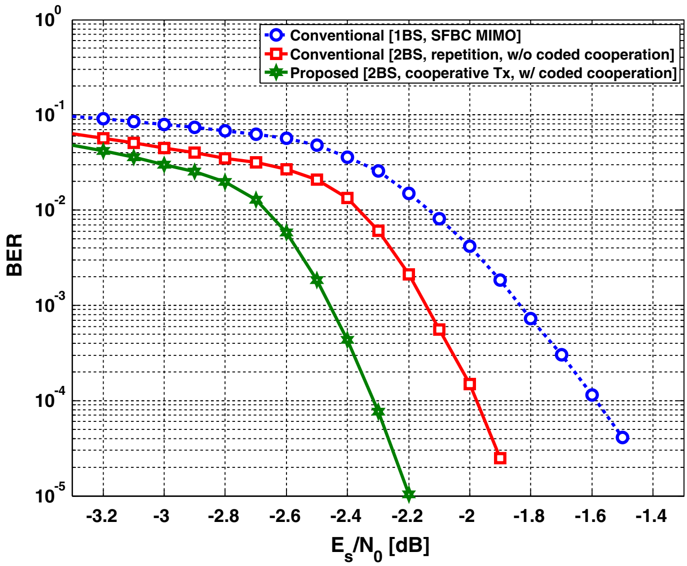

Fig. 8 Simulation result for scenario 1: 1/3 rate code cooperation model with QPSK

We measured the bit error rate (BER) performance versus the energy per symbol to noise power spectral density ratio (E_s/N_0) for the proposed schemes. Performance was evaluated in comparison with the conventional SFBC schemes without the cooperation. The SFBC cooperation corresponds to the coded cooperation scheme shown in Fig. 3. In Figs. 8 and 9, [1BS, SFBC MIMO] means using a 1/2 rate LDPC code and transmitting the Alamouti SFBC transmission scheme based on one base station, while [2BS, repetition, w/o coded cooperation] means the Alamouti SFBC transmission scheme based on two base stations without using the proposed coded-cooperation. In the scheme denoted by [2BS, repetition, w/o coded cooperation], each base station transmits the same data, and the destination node repeatedly receives the same data. [2BS, cooperative Tx, w/ coded cooperation] indicates the proposed scheme. In this case, the transmission data rate is the same as in the 2BS conventional scheme. Each base station shared the same symmetric data as in the 2BS conventional scheme, but the parity check data were different. Because of these differences, we expected combined coding gains at the destination node. As shown in Figs. 8 and 9, the proposed scheme shows improved performance over the two conventional schemes. At the 10e−4 BER point, the 2BS coded cooperation transmission scheme showed approximately a 0.6 dB gain over the 1BS SFBC, and a 0.3 dB gain over the 2BS conventional scheme.

In Figs. 10 and 11, [3BS, repetition, w/o coded cooperation] means the Alamouti SFBC transmission scheme based on three base stations. In this scheme, each base station transmits the same data, and the destination node repeatedly receives the same data. In these figures, [3BS, cooperative Tx, w/ coded cooperation] means the proposed scheme, where the transmission data rate is the same as that of the 3BS conventional scheme. In this scheme, each base station shares the same symmetric data as in the 3BS conventional scheme, and only the parity check data is different. Because of these differences, we can expect a combined coding gain at the destination node. As shown in Figs. 10 and 11, the proposed scheme also outperformed the conventional schemes. At the 10e-4 BER point, the 3BS coded cooperation

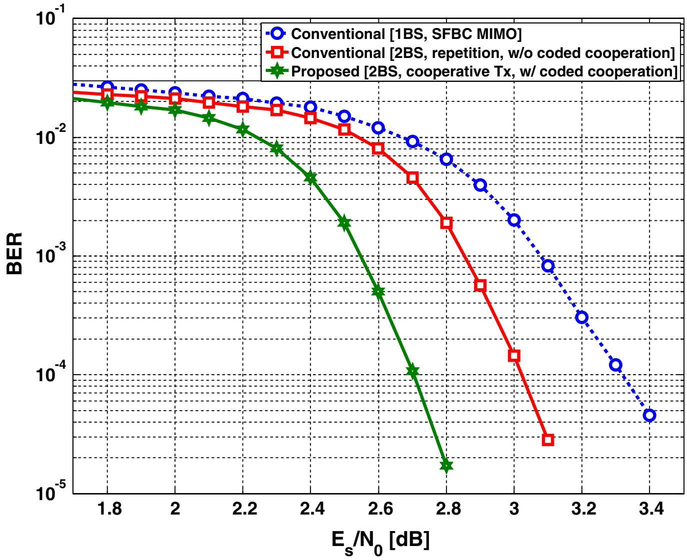

Fig. 9 Simulation result for scenario 1: 1/3 rate code cooperation model with 16-QAM

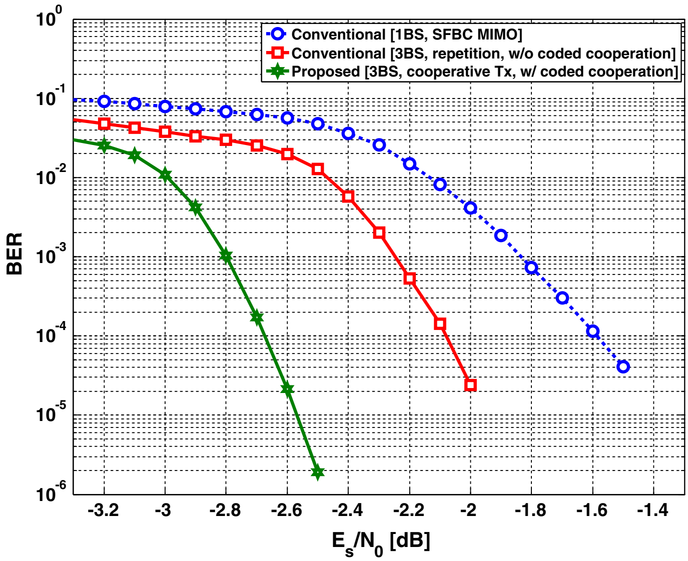

Fig. 10 Simulation result scenario 2: 1/4 rate code cooperation model with QPSK

transmission scheme shows approximately a 0.9 dB gain over the 1BS SFBC, and a 0.5 dB gain over the 3BS conventional scheme.

Finally, Fig. 12 shows the result of the double layer transmission model, taking into account the difference in received power. If a terminal is at an equal distance from two base stations, the 2BS-coded cooperation has the same power. In general, however, the distances between base stations and a terminal are different. In Fig. 12, "power x:y" indicates that the

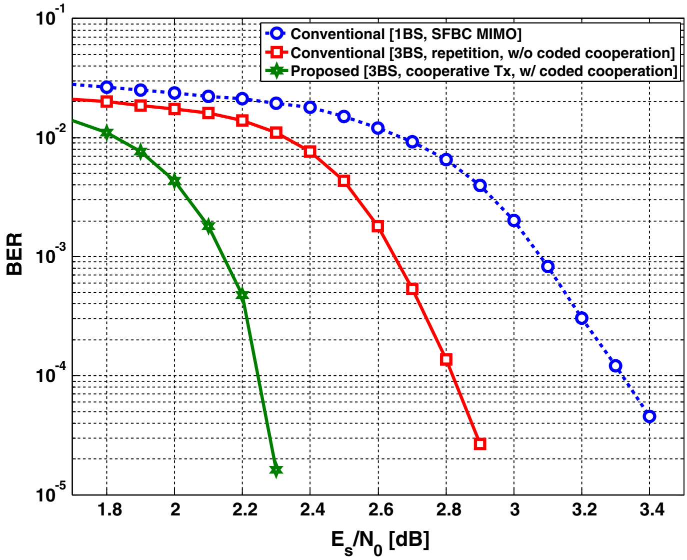

Fig. 11 Simulation result scenario 2: 1/4 rate code cooperation model with 16-QAM

ratio of power levels received from two base stations is x:y. This model is used to examine performance degradation due to the differences in power of the two base stations. In Fig. 12, [2BS, double layer transmission, power 3:7] means the proposed double layer transmission scheme which uses the Golden code and the Alamouti SFBC technique at the same time. According to other studies, the performance of the double layer transfer method is reported to be even better than the performance of 2BS-coded cooperation at the same power. However, in Fig. 12, the performance of the double layer transfer method looks similar to that of [2BS, cooperative Tx, w/ coded cooperation, power 1:1]. These results are due to the impact of the Constellation Rotation of the DVB-T2 standard.

The Golden code symbol is divided into real and imaginary parts, which allows for processing of the random rotation of the constellation. The Constellation Rotation caused by the Golden code appears to be simultaneously superimposed with the Constellation Rotation of the DVB-T2 standard techniques. The performance degradation is thought to have been caused by an overlap with the Constellation Rotation techniques. The error is increased in the ML detection process at the receiver side.

5 Conclusion

The DVB-T2 standard provides many transmitter configuration functions. This paper described the key technologies included within the DVB-T2 standard, and presented some performance results. In this paper, the coded cooperation transmission scheme of the DVBT2 system was studied with the help of computer simulations. We investigated the two- and three-base-station-based coded cooperative transmission schemes for the DVB-T2 system, and provided the corresponding simulated performance under the slow Rayleigh fading channel. The corresponding signal processing algorithms are given in this paper according to the realization of different scenarios. From the simulation results, we conclude that the coded

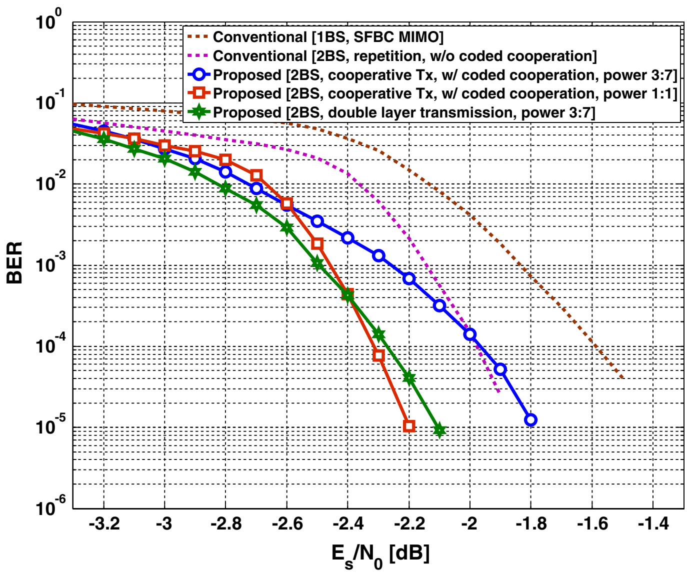

Fig. 12 Simulation result scenario 3: double layer transmission model using 1/3 rate code cooperation with QPSK

cooperative schemes have advantages in system performance and cooperative diversity compared to one- and two-base-station-based conventional transmission schemes. Improved system performance can be achieved through the optimal design of the cooperative scheme. Our research has shown remarkable results to increase the channel capacity of the DVB system. Therefore, this work has been carried out in the context of development of the DVB-NGH system. Our future work will focus on the efficient power allocation of coded cooperation and rate adaptation transmission schemes.

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