Performance of the DVB-T2 System with MIMO Spatial Multiplexing

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***Abstract*—This paper presents the performance of the DVB-T2 broadcasting system including SISO, 2x1 MISO Alamouti and 2x2 MIMO Spatial Multiplexing. The DVB-T2 standard is now optionally using 2x1 MISO Alamouti system that is known to be optimal to achieve greater diversity gain. However in the future it is expected that the next generation of various broadcasting systems will take the MIMO system to obtain higher spectral efficiency as well as diversity gain. Thus we adapt a simply-adjusted DVB-T2 system as one application of MIMO system and provide its computer simulation results comparing the performance of conventional DVB-T2 to MIMO DVB-T2.**

Keywords-DVB-T2; MISO; MIMO; Channel Estimation; PACE

I. Introduction

DVB-T2 is one of the most advanced digital terrestrial transmission (DTT) system offering higher efficiency, robustness and flexibility developed upon the DVB-T system [2]. DVB-T2 uses orthogonal frequency division multiplexing (OFDM) modulation to deliver signal that is robust to multipath channel. The corresponding maximal throughput of DVB-T2 is 47.8Mbit/s, which is about a double of throughput with DVB–T, 29Mbit/s. Consequently, DVB-T2 system is available for HDTV-grade transmission [2],[5-6].

Besides of the increase with the flexibility of the system, an outstanding change, compared to the DVB-T system, is the addition of a multiple antenna technique, namely Multiple-Input Single-Output modified Alamouti processing. The principle of Alamouti coding is that the redundancy generated by the codification yields a transmitter diversity leading to improve link-reliability. As we see the recent wireless system standards starts obtaining better receiver reliability and spectral efficiency by using multiple antenna scheme, it seems to be a fact that the next generation of DVB standard, will be equipped with the MIMO technology according to [3].

Considering the upcoming generation of DVB standard is aiming higher system throughput by using the MIMO scheme, in order to foresee the effect of the MIMO technique, it is needed to have a modified DVB-T2 that is simply tuned to have two fluxes throughout the whole DVB-T2 transceiver chain.

The rest of this paper is organized as follows: In section II, basic principles of OFDM system, Maximum-likelihood detector and modified Alamouti MISO processing, based on the DVB-T2 standard, is presented. In the same section, the simple adjustment is explained, which is made to apply Spatial Multiplexing MIMO scheme on the DVB-T2 transceiver chain. The simulation results are shown in the section III and this paper is concluded in section IV.

II. DVB-T2 System

A. Basic OFDM System

In classical frequency division multiplexing (FDM), the total signal band is divided into multiple sub-channels allowing the system to transmit the data in parallel. Each sub-channel is modulated with a separate symbol and then all the sub-channels are frequency multiplexed. Sub-channels are not overlapped in frequency by inserting guard band between adjacent sub-channels. In this way, inter carrier interference (ICI) is avoided. However, the empty band within total signal band degrades the spectral efficiency. OFDM is an example of a multi-carrier technique that exploits orthogonality between subcarriers. Contrary to the conventional frequency division multiplexing, the orthogonal subcarriers are partly overlapped in the total signal band allowing greater number of subcarriers to be modulated simultaneously, and it follows a better spectral efficiency. When each sub-channel of OFDM occupies frequency band that is much less than the coherence bandwidth of the propagation channel, the frequency-selective fading channel turns into a set of flat fading sub-channels and it drastically reduces the complexity of the task of equalization. In time domain, sub-channels of OFDM that has a bandwidth less than the coherence bandwidth leads to a relatively long symbol duration, and it provides better circumstance to cope with inter symbol interference (ISI). Under the narrowband system environment, a portion of the last part of OFDM symbol, whose length is longer than the maximum channel delay spread, is appended at the beginning of the symbol to protect the symbol from interference between successive symbols.

The implementation of OFDM modulation and demodulation are performed by using a simple inverse fast Fourier transform (IFFT) and fast Fourier transform (FFT). Considering a sequence of discrete-time, QAM-modulated symbols, the N-point IFFT, operating as an N-subcarrier OFDM system, generates the time-domain data stream denoted by

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} s[k] e^{\left(j2\pi \frac{kn}{N}\right)}, \quad (1)$$

Where $s[k]$ is the QAM-modulated symbol of k-th subcarrier, $x[n]$ is the IFFD output at time n, and $1/\sqrt{N}$ is the scaling factor that normalizes the average power of the IFFT output.

The IFFT output is transmitted in the radio propagation environment that shows multipath fading. In order for the system to be robust to multipath fading channel, cyclic prefix (CP) and Pilot insertion blocks are added to the OFDM modulator and the demodulator consists of the complementary blocks.

B. *Alamouti MISO Processing*

The signal fading and interference is the major impairment of wireless transmission environment. It declines link reliability and spectral efficiency, which are generally required in a certain level to achieve target communication performance. Spatial diversity technique has been known as a multiple antenna technique that combats fading caused by multipath effects. The basic principle of diversity technique is to generate redundancy of information in time, frequency and/or space. Spatial diversity allows the system to experience less fading channel, and it leads to the improved link reliability, while conventional diversity schemes must be supported by additional time or frequency resource, spatial diversity has a meaningful advantage that it doesn't require any temporal or frequency expenditure [7]-[8].

The multiple-input single-output (MISO) processing of the DVB-T2 system is based on Alamouti space-time block coding (STBC). Instead of encoding symbols in time dimension, space-frequency block coding (SFBC) encodes QAM-modulated symbols of OFDM in frequency domain. Alamouti SFBC exploits transmit diversity gain to cope with multipath fading, which is obtained by encoding symbols on the adjacent subcarriers and by transmitting them over the independently fading channel through two transmit antennas.

We assume that the channel information is known only at the receiver, namely coherent detection. Under the assumption that the maximum delay spread of the channel is relatively shorter than the symbol duration, we can model the channel fading over sub-channels as attenuation with phase distortion. If the difference of fading across two consecutive sub-channels is very small, then it is permitted to regard two successive fading as identical.

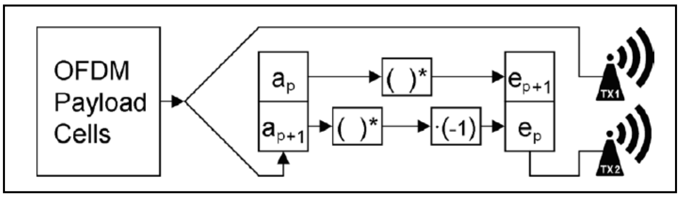

Figure 1. MISO Alamouti encoding of DVB-T2 system

TABLE I. MODIFIED ALAMOUTI SPACE FREQUENCY BLOCK CODING

$\alpha + \beta = \chi.$ (1) (1)

	Antenna1	*Antenna2*
Subcarrier i	s_i	$-s_{i+1}^*$
Subcarrier i+1	s_{i+1}	s_i^*

* denotes the complex conjugation operator

The received signal is a linear combination of the transmitted signal affected by channel distortion. The received signal at the receive antenna is sent to a combining operator, and then, with the assistance of the channel information from a channel estimator, the properly combined symbols are sent to the decision algorithm.

The space frequency block coding of the DVB-T2 system (Fig. 1), allows the frequency domain coefficients to be processed by a modified Alamouti encoding [4], which allows the T2 signal to be split between two groups of transmitters on the same frequency [1].

The modified mapping scheme is shown in Table I. QAM-modulated symbols on two adjacent subcarriers are mapped and transmitted from two transmit antennas. The first flux connected to the Antenna1 in Fig. 1 shows that it is using the conventional DVB-T2 system. In this way, the MISO Alamouti scheme can be applied by simply adding an independent flux to the conventional SISO DVB-T2 system.

When the channel at time t is modeled for transmit antenna1 and transmit antenna 2 by h_1, h_2, under the assumption that the fading is constant across two consecutive subcarriers, the distortion can be written by

$$\begin{aligned} h_1(i) = h_1(i+1) = h_1 = \alpha_1 e^{j\theta} \\ h_2(i) = h_2(i+1) = h_2 = \alpha_2 e^{j\theta}, \end{aligned} \quad (2)$$

Where i denotes the i-th subcarrier index. And then the symbols which are demodulated from adjacent subcarriers with the additive noise and interference can be expressed as

$$\begin{aligned} r_0 = r(i) = h_0 s_0 - h_1 s_1^* + n_0 \\ r_1 = r(i+1) = h_0 s_1 + h_1 s_0^* + n_1. \end{aligned} \quad (3)$$

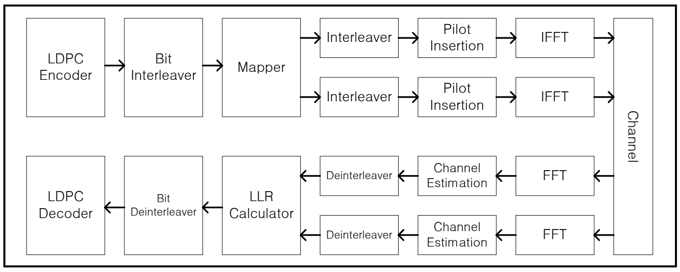

Figure 2. MIMO SM of DVB-T2 system

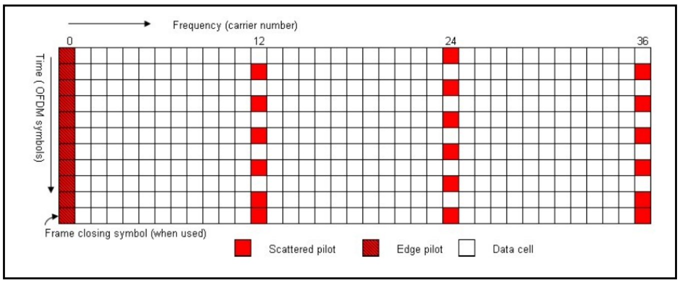

Figure 3. Scattered Pilot Pattern 4 (PP4)

C. MIMO Spatial Multiplexing

Spatial multiplexing is a multiple antenna technique that increases the capacity of the system linearly with the minimum of the number of transmit and receive antenna without any additional use of time or frequency resource. The capacity increase of the MIMO channel is achieved when it is assumed that the channel is known at the receiver. In addition to the perfect channel information assumption, the corresponding spatial multiplexing gain is boosted when the propagation environment is assumed to be richly-scattering. If the richly-scattering channel opens up multiple data pipes, then the independent data streams are conveyed over the data pipes resulting in increased spectral efficiency [7]-[8].

As it is depicted in Fig. 2, a bit stream is divided into two independent streams, and the data streams are transmitted over same frequency band after QAM-mapping, bit-to-cell interleaving, time interleaving, frequency interleaving, and OFDM modulation. In this paper, the QAM-mapping blocks at two independent fluxes of the system has different mapping rate; 4QAM and 16QAM, but the average power of each flux is normalized to be identical.

The reception antennas observe linear combinations of transmitted signals from different transmitter, which is distorted by channel fading. With the assistance of channel estimator, specifically pilot-aided channel estimation (PACE) method with OFDM, the digital signal processing blocks at the reception chain estimates the transmitted signal and maximum-likelihood (ML) decision algorithm yields the decision.

D. Channel Estimation

DVB-T2 system estimates the channel fading using the Pilot-Aided Channel Estimation method. Various cells within the OFDM frame are modulated with reference information whose transmitted value is known to the receiver. Cells containing reference information are transmitted at boosted power level. The information transmitted in these cells are scattered, continual, edge, P2 or frame-closing pilot cells.[1] There exists 8 pilot patterns in DVB-T2 system that determines the locations and values of pilot symbols, and Pilot Pattern 4, PP4, is chosen in this study (Fig. 3).

Since the flat-fading channel is represented as a complex constant over each subcarrier, channel can be easily estimated by dividing the distorted pilot symbols by original pilot symbol values. Thus, the channel estimation is expressed as

TABLE II. SIMULATION PARAMETERS

Parameters	
FFT size	4K
Guard Interval	1/4
Pilot Pattern	PP4
FEC Block	Short LDPC Block (16200 bits)
Code Rate	1/2
Modulation Depth	6 bit : 64QAM(SISO, MISO), 16QAM+QPSK(MIMO)
Channel Model	Rayleigh Fading Channel

$$y_k = h_k s_k + n_k$$
$$\hat{h}_k = \frac{y_k}{s_k} = h_k + \frac{n_k}{s_k}. \quad (4)$$

Where y, s, h, $\hat{h}$, and n is the received pilot symbol with noise, the original pilot symbol, channel distortion, the estimated channel distortion and Gaussian noise respectively. The subscript k denotes the symbol index, and the OFDM and antenna index is omitted. As we see in (4), the estimated channel is always impaired by noise. The remaining subcarriers that are not transmitting pilot symbols will have interpolated channel estimates from the subcarriers which the pilots are located.

E. Maximum-Likelihood Detector

The soft-decision output values for Maximum-Likelihood detector are generated based on the maximum a posteriori probability (MAP). We use log-likelihood ratio (LLR) as a measure that indicates the reliability of a bit. The LLR value of the estimated bit from the received vector **r** is expressed as

$$L(b_k) = \ln \frac{\sum_{s_i|b_k=1} \Pr(\mathbf{s}_i \mid \mathbf{r})}{\sum_{s_i|b_k=0} \Pr(\mathbf{s}_i \mid \mathbf{r})}. \quad (5)$$

Where b_k is the k-th bit of the transmitted vector, and $\boldsymbol{s}_\text{i}$ is the vector from the ensemble $\{\boldsymbol{s}_1, ..., \boldsymbol{s}_\text{I}\}$.

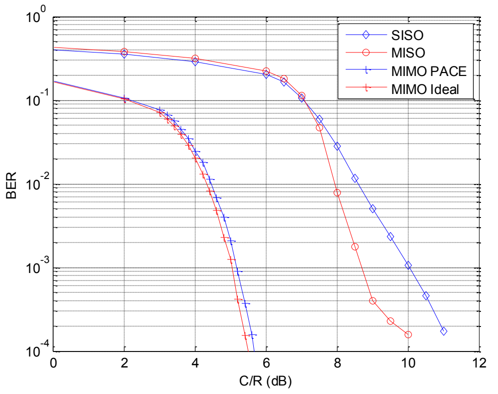

Figure 4. BER Performance of SISO, MISO system and Ideal channel estimation and PACE method on MIMO system

Simulation Results

In this section, the simulation parameters and the performance comparison between ideal channel estimation and PACE method in MIMO spatial multiplexing scheme is described. Rayleigh Fading channel is assumed in the simulation. Short forward error correction (FEC) blocks are generated from 1/2 code rate LDPC encoder. The modulation depth is fixed to 6 bits for all multiple antenna schemes. In particular, MIMO spatial multiplexing technique divides 6 bits codeword into 2 sub-words that have 2 bits and 4 bits yielding QPSK and 16QAM respectively.

Conventional DVB-T2 system BER performance with SISO and MISO antenna scheme is shown in Fig. 4. Assuming the channel information and noise power is known at the receiver in both SISO and MISO system, it is shown that the MISO system exhibits a 1.5 dB diversity gain over SISO system at 10^{-3} BER performance .

The same assumption that the knowledge of channel and noise power is provided to the receiver remains for MIMO system. As Fig. 4 shows, it is shown that the receiver quality of MIMO SM is better than conventional DVB-T2 SISO and MISO system. At 10^{-3} BER the SM MIMO system shows 4 dB and 5 dB gain over MISO and SISO system respectively. It also shows that the receiver quality is degraded when the channel estimation is achieved by PACE method.

III. Conclusion

In this paper, we investigated SISO, MISO Alamouti and MIMO Spatial Multiplexing schemes based on the DVB-T2 standard, and provided the corresponding simulation results under the Rayleigh fading channel. When the channel information is known at the receiver of the conventional MISO system shows a 1.5 dB diversity gain over SISO system, on the other hand MIMO Spatial Multiplexing scheme shows a 4 dB gain over MISO system. The simulation results also show that imperfect channel knowledge yields degradation less than 0.2 dB in terms of the receiver quality.

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