CIR-based Adaptive K-Best Sphere Decoder for DVB-T2

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***Abstract*—Multi–antenna processing first appeared in Digital Video Broadcasting in the 2nd generation terrestrial system DVB-T2 by defining an optional MISO processing based on modified version of Alamouti codes in frequency domain. Decoding methods recommended by the DVB-T2 is the linear methods ZF and MMSE. In this paper we propose to use a modified K-Best Sphere Decoder (SD), to enhance the system performance in a frequency selective time varying channel with some modification to target the reduction of the fixed K-Best SD complexity to be more suitable for hardware implementations over different platforms. The proposed modified K-Best SD that we name Adaptive K-Best SD (AKBSD) exploit the channel impulse response (CIR) to measure the channel selectivity as an indicator of the channel state.BER simulations show how the performance is enhanced when applying the AKBSD method rather than the linear methods defined by the DVB-T2 implementation guide with low extra added complexity.**

Keywords—Sphere Decoder; Alamouti code; SFBC; MISO and DVB-T2.

I. INTRODUCTION

The second-generation terrestrial transmission system for digital television broadcasting (DVB-T2) is the first television broadcasting system that exploit multiple antenna techniques as one of its key technologies used to increase its performance. DVB-T2 achieves better transmission capacity than its predecessor providing a capacity increase of at least 30% over the existing standard and enable a flexible and configurable robustness for each transmitted service [1][2][3].

Five key technologies were used in DVB-T2 to increase its performance [4]. First, *Error Protection Coding:* by combining Low Density Parity Check (LDPC) codes with BCH codes to achieve high performance (a target bit error rate (BER) on the order of $10^{-10}$for a 5 Mb/s service). Second, *Scheduling*: in order to offer service-specific robustness and optimize time-interleaving memory requirements, the DVB-T2 system can be described as a set of fully transparent Physical Layer Pipes (PLPs), each one performing independent mode adaptation, Forward Error Correction (FEC) encoding, bitmapping onto constellation points (cells), and time interleaving. Third, *Modulation Techniques*: where extending the range for payload data to 256-QAM offers increased throughput compared to a maximum of64-QAM in DVB-T and also it includes rotated constellation as an optional feature. Fourth, *Synchronization and Channel Estimation*: Including particular design solutions to ease the time and frequency synchronization of the receiver such as P1 and P2 symbols [1][2] and defining conventional Scattered Pilot (SP) sequences that modulate a set of equally spaced subcarriers. The main novelty introduced by DVB-T2 is that it supports eight different SP patterns with pilot reference sequence. Finally, *Multiple-Antenna Techniques*: providing an efficient means to exploit the presence of multiple transmitters i.e. obtaining a distributed 2x1 Multiple-Input Single-Output (MISO) system where the data on the two transmitters are not identical but closely related, avoiding destructive interference.

Multiple antenna techniques are classified according to the diversity techniques into transmit diversity (such as Space Time Block Codes (STBC) and Space Frequency Block Codes (SFBC) where related data are retransmitted over different space/antennas during different time slots or different frequency carriers respectively) and receive diversity (including Selection Combining (SC), Switch (or Switch and Stay)combining (SCC), Maximum Ratio Combining (MRC) and Equal Gain Combining (EGC) with tradeoff in complexity and performance) [5][6].

In this paper we focus on the Alamouti-based [7] SFBC transmit diversity technique over MISO channel as defined in the DVB-T2 standard and propose an algorithm to reduce the computational complexity of K-best SD (KBSD) and thereby the implementation complexity (which is an important issue in current sophisticated technologies and especially for battery-based devices) by adaptively change the number of paths that the KBSD considers in its searching method.

The rest of the paper is organized as follows: In Section II, we explore the SFBC MISO system and analyze how to exploit the sphere decoder in it. In Section III, we propose the new adaptive K-Best SD (AKBSD) method. Section IV shows the simulation results of the BER and complexity for KBSD with different K values along with the AKBSD method. Finally we conclude the paper in Section V.

II. SPHERE DECODER FOR 2X1 MISO SFBC SYSTEM

A. Encoding

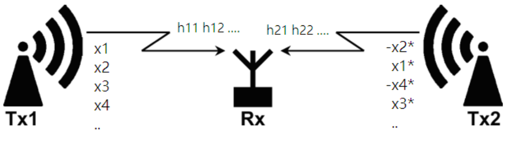

Fig. 1. MISO System Model [1].

DVB-T2 exploit MISO processing by defining a modified Alamouti encoding with a codeword equals the transpose of the original Alamouti codeword for backwards compatibility where the codeword rows represent the data carriers not the time intervals as in STBC. The 2x1 MISO system model is shown in fig.1 with the transmitter in MISO group 1 for transmitter 1 (Tx_1) remain unmodified regarding frequency order or arithmetic operations, while the transmitter group 2 for transmitter 2 (Tx_2) perform pairwise modification according to the modified Alamouti codeword which used to produce the two sets of data cells as [2]:

$$X = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \tag{1}$$

where (.)* denote conjugate operation.

B. Linear Decoding

The received pair of cells are given by

$$y_1 = h_{11}x_1 - h_{21}x_2^* + n_1$$
$$\text{and } y_2 = h_{12}x_2 + h_{22}x_1^* + n_2 \tag{2}$$

where n_1 and n_2 are additive white Gaussian noise and h_{ij} is the channel coefficient for i^{th} transmit antenna at the j^{th} payload cell. Simplifying the above equation by taking the complex conjugate of the second received signal and putting it in a matrix form ($y = H\,x + n$) we have:

$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} h_{11} & -h_{21} \\ h_{22}^* & h_{12}^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2^* \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \tag{3}$$

To get the estimated signal we can use Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) linear decoding [1] as:

$$\hat{x} = H^+ y \tag{4}$$

where H^+ is the pseudo inverse of the channel matrix i.e. $H^+=(H^H H)^{-1}H^H$ for ZF detection method with conjugate transpose H^H and $H^+= (H^H H+ \alpha^2 I)^{-1}H^H$ for MMSE one and α is the noise standard deviation.

Although these linear methods are simple in implementation, they give low performance in frequency selective time varying channels. On the other hand, the optimum Maximum Likelihood (ML) solution comes with high complexity. Sphere Decoding (SD) provide a sub-optimal solution that achieves near ML performance with lower complexity and therefore can be considered a suitable solution for MIMO decoding especially for the case of varying channel [8].

C. Sphere Decoding

The main idea of the SD is to consider only a small set of vectors within a given sphere to find the ML solution vector rather than searching all possible transmitted signal vectors, it adjusts the sphere radius until there exists a single vector within a sphere and this vector is the ML solution vector [9].

For a 2x1 complex MISO system, the SD method can be employed as follows. First we note that the 2x1 MISO channel is H= [h_1 h_2], while if SFBC is applied, the equivalent channel becomes as described in equations 3 and the complex system model is represented as:

$$\begin{bmatrix} y_{1R} + jy_{1I} \\ y_{2R} - jy_{2I} \end{bmatrix} = \begin{bmatrix} h_{11R} + jh_{11I} & -h_{21R} - jh_{21I} \\ h_{22R} - jh_{22I} & h_{12R} - jh_{12I} \end{bmatrix} \begin{bmatrix} x_{1R} + jx_{1I} \\ x_{2R} - jx_{2I} \end{bmatrix} + \begin{bmatrix} n_{1R} + jn_{1I} \\ n_{2R} - jn_{2I} \end{bmatrix} \tag{5}$$

where A_R = Re{A} and A_I = Im{A} and A represent y, h_{ij}, x or n. The underlying complex system is converted into an equivalent real one as:

$$\underbrace{\begin{bmatrix} y_{1R} \\ y_{2R} \\ y_{1I} \\ y_{2I} \end{bmatrix}}_{\bar{y}} = \underbrace{\begin{bmatrix} h_{11R} & -h_{21R} & -h_{11I} & -h_{21I} \\ h_{22R} & h_{12R} & h_{22I} & -h_{12I} \\ h_{11I} & -h_{21I} & h_{11R} & h_{21R} \\ h_{22I} & h_{12I} & -h_{22R} & h_{12R} \end{bmatrix}}_{\bar{H}} \underbrace{\begin{bmatrix} x_{1R} \\ x_{2R} \\ x_{1I} \\ x_{2I} \end{bmatrix}}_{\bar{x}} + \underbrace{\begin{bmatrix} n_{1R} \\ n_{2R} \\ n_{1I} \\ n_{2I} \end{bmatrix}}_{\bar{n}} \tag{6}$$

and the equivalent system can now be written as $\bar{y} = \bar{H}\bar{x} + \bar{n}$. The SD considers only the vectors inside a sphere with radius R_{SD} with upper limit of:

$$\arg\min_{\bar{x}\in C} \|\bar{y} - \bar{H}\bar{x}\|^2 \le R_{SD}^2 \tag{7}$$

Generally the SD search method is represented as a tree search and there are two common search strategies, i.e. Fincke–Pohst (FP) [10] which considered a breadth-first algorithm making search in the forward direction only and Schnorr–Euchner (SE) [11] which considered a depth-first algorithm making search in the forward and backward directions [12].

III. New Adaptive K-Best Sphere Decoder

K-Best SD [13] is based on the FP method. The K-Best SD follows the following tree search procedure in decoding:

1- Starting from the tree root sublatice of the transmitted signal constellation, it first initialize one zero metric path between the root and the first tree level nodes.
2- Then extend the survivor paths and update their accumulated metrics.
3- Then sorting them and select the K-Best ones and discard the others.
4- If it arrives at the end sublattice it finishes otherwise it go back to survivor paths again (step 2) and so on.

The advantage of K-Best SD is its fixed throughput which enables parallel and pipelined implementation [12].

Proposed Adaptive K-Best Sphere Decoder

There is a tradeoff between complexity and performance of the K-Best method depending on the number K of the paths that the decoder will concern while exploring the tree i.e. for small K we get a lower complexity in the cost of degradation in the performance and vice versa for large K. In the AKBSD method here, we want to compromise the effect of the K by defining a sub-optimum K suitable for different channel states. Channel Impulse Response method as one type of the Channel

Quality Estimation (CQE) [14] is performed for the sake of measuring the selectivity of the channel as follows:

- For two consecutive channel coefficients h_1 and h_2, we can measure the channel selectivity by defining C_1 parameter as the ratio between the two coefficients $\frac{|h_1|^2}{|h_2|^2}$
- If $C_1>$ threshold value Γ, the channel is most likely a high frequency selective channel which will badly affect the transmitted signals and if $C_1<\Gamma$, the channel is somehow a frequency selective while if $|h_1|^2=|h_2|^2$, the channel is non-frequency selective.
- Now if $C_1>\Gamma$, we can enter Mode1 of adaptation by defining a small K and vice versa at $C_1<\Gamma$ where Mode 2 defines a higher K.

Since for the 2x1 varying channel Matrix in SFBC MISO environment is as defined above H= $\begin{bmatrix} h_{11} & -h_{21} \\ h_{22}{}^{*} & h_{12}{}^{*} \end{bmatrix}$.We have two varying channels for the two transmitted antennas and therefore we have two C parameters as

$$C_1=\frac{h_{1,j}}{h_{1,j+1}}\ \&\ C_2=\frac{h_{2,j}}{h_{2,j+1}} \tag{8}$$

where $h_{i,j}$ is the channel coefficient for i^{th} transmit antenna at the j^{th} payload cell and therefore we have four different modes as described in table I. Actually Mode 2 and Mode 3 have a similar effect here and can be merged in one mode for simplicity, and therefore we can work on only three modes M_1, M_2 and M_3 defining different values of K_1, K_2 and K_3.

TABLE I. DIFFERENT ADAPTATION MODES OF OPERATION

Mode #	Conditions	Actual K
Mode 1	$C_1>\Gamma\ \&\ C_2>\Gamma$	K_1
Mode 2	$C_1<\Gamma\ \&\ C_2>\Gamma$	K_2
Mode 3	$C_1>\Gamma\ \&\ C_2<\Gamma$	
Mode 4	$C_1<\Gamma\ \&\ C_2<\Gamma$	K_3

IV. SIMULATION RESULTS

The 2x1 MISO system model shown in fig.1 is simulated for SFBC over a frequency selective Rayleigh fading channel with perfect CSI at the receiver using the new DVB-T2 defined 256-QAM modulation scheme for different K values and the BER performance results are shown in fig.2, where increasing the K value enhance the performance of the KBSD in the cost of the increased complexity i.e. increasing the K value increases the complexity of the decoder. Figure3 shows the complexity of the different K decoders in terms of execution time normalized to approximated ML execution time.

Applying the AKBSD methods (with threshold Γ=0.8 and small K_1= 2 and high K_3=16 and in between K_2= 8 for the different adaptation modes as described in table. I) shows performance enhancement rather than the ZF linear method and approaching the ML BER as shown in fig.4 with small increase in complexity as shown in fig.5. AKBSD idea is applicable for MIMO systems as for MISO, and therefore can be considered a sub-optimum decoding method that suits the DVB-T2 and DVB-NGH broadcasting systems.

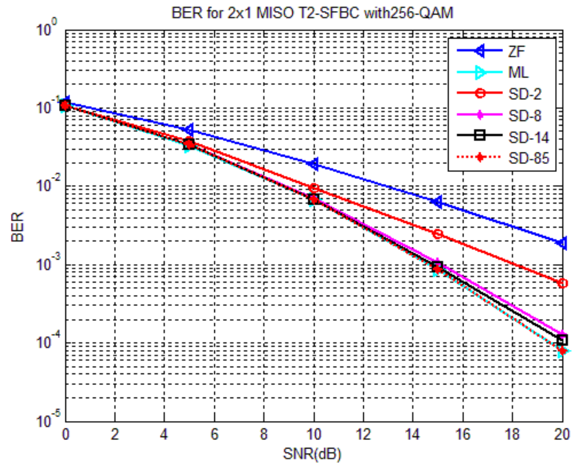

Fig. 2. BER Performance for different K values versus ZF and ML decoding methods.

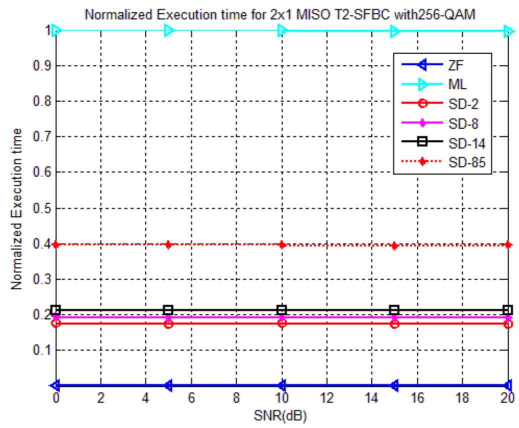

Fig. 3. Complexity in terms of normalized execution time for different K values versus ZF and ML decoding methods.

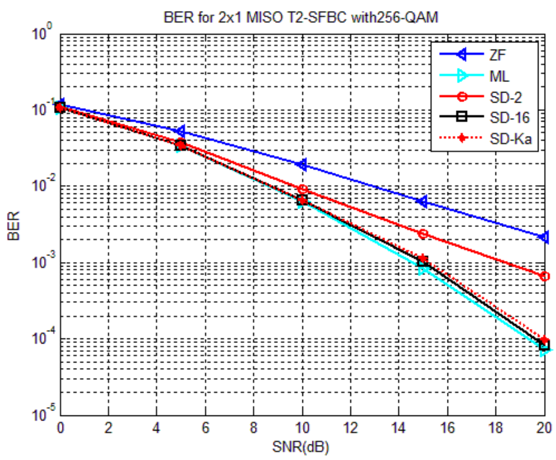

Fig. 4. BER Performance for AKBSD (SD-Ka legend) versus ZF, ML and different K-SD.

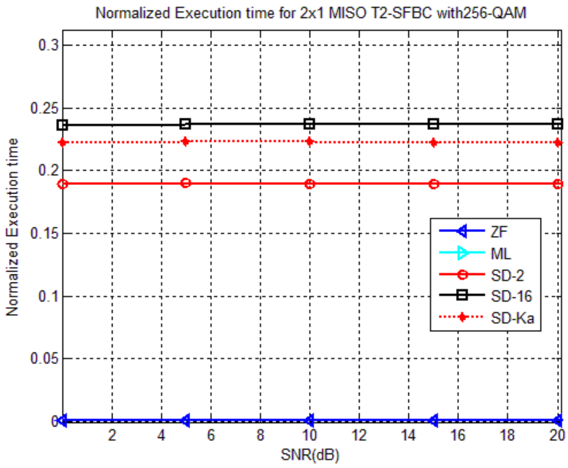

Fig. 5. Complexity in terms of normalized execution time (to ML time) for AKBSD (SD-Ka legend) versus ZF and different K-SD decoding methods.

V. CONCLOUSION

In this paper we proposed a new AKBSD as an alternative method of linear MISO decoding methods defined by the DVB-T2 implementation guide with improved performance in case of frequency selective time varying channels. The new AKBSD employ the CIR as one of the CQE methods to measure the selectivity of the channel and according to the channel selectivity/quality, it specifies a suitable K paths that the KBSD will concern in decoding and therefore gives a better performance with acceptable complexity that enable the decoder to be implemented via flexible engines such as ASIP and can be applied in DVB-T2 and next generation broadcasting standards such as DVB-NGH to increase the system performance and hence capacity.

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