Low Complexity Adaptive K-Best Sphere Decoder for 2x1 MISO DVB-T2

Ahmad A.Aziz El-Banna, Maha El-Sabrouty and Adel Abdelrahman
Electronics and communications department
Egypt-Japan University of Science and Technology (E-JUST)
{ahmad.elbanna, maha.elsabrouty, adel.bedair}@ejust.edu.eg

***Abstract*—The second-generation terrestrial transmission system for digital television broadcasting (DVB-T2) exploits Space Frequency Block Codes (SFBC) by defining a modified Alamouti code in the frequency domain in its optional Multi Input Single Output (MISO) processing transmission. Linear decoding methods such as Zero-Forcing (ZF) and Minimum Mean Square Error (MMSE) are recommended by the DVB-T2 implementation guidelines. This paper presents two modified K-Best Sphere Decoder methods to enhance the performance of the system along with low extra added complexity. The first method adapts the K-paths of the decoder according to a Channel Quality Estimation (CQE) using the Channel State In formation (CSI) of the channel while the second method utilizes the estimated Signal-to-Noise Ratio (SNR) in its adaptation process. Both methods outperform the linear ZF decoding method defined by the DVB-T2 standard in the case of selective channels.**

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

I. INTRODUCTION

Multiple Antennas can be exploited at the transmitter and/or the receiver and therefore there are a number of different MIMO configurations that can be used in wireless communication systems. Depending on the number of antennas at the transmitter/receiver sides there exist different configurations SISO, SIMO, MISO and MIMO (S, M stands for single and multi where I, O stand for Input and Output respectively). Transmit diversity is one type of the multiple antenna techniques. In practical systems, transmit diversity is usually achieved through coding the signal at the multiple transmit antenna as Space Time Block Codes (STBC) or Space Frequency Block Codes (SFBC). In these codes, data are retransmitted over different space/antennas during different time slots or different frequency carriers respectively [1], [2].

DVB-T2 is the second-generation terrestrial transmission system for digital television broadcasting. It makes use of innovations in the physical layer technology to revamp the physical layer of its preceding standard, i.e. DVB-T first generation. The second generation terrestrial standard aims at achieving a higher throughput as well as a more robust transmission in difficult wireless channel conditions. DVB-T2 exploits the same basic modulation technique as DVB-T and the same baseband framing and Forward Error Correction (FEC) mechanisms employed at the DVB-S2 [3]. On the other hand, it introduces some new/extended technologies in the terrestrial transmission such as the 256-QAM modulation scheme along with the new LDPC inner error correction coding and the optional features of the rotated constellation and the MISO transmission. By employing these featured technologies, the DVB-T2 system is capable of providing a capacity increase of thirty percent over the existing DVB-T specification and a flexible and configurable robustness for each transmitted service [4][5]. The key technologies behind the DVB-T2 are multiple antenna transmission, BCH/LDPC forward error correction scheme, OFDM with large block sizes, transmission scheduling and synchronization techniques [3].

Space time block code employing two- transmit antennas is first introduced by Alamouti [6]. The Alamouti-STBC code using 2x1 MISO system is proved to provide a similar diversity order as in the case of Maximum Ratio Combining (MRC) receive diversity technique using 1x2 SIMO system; and provides a diversity order of $2N_r$ in the system of two transmit antennas ($N_t = 2$) and N_r receive antennas 2xN_r MIMO system.

In this paper we focus on the Alamouti-based SFBC transmit diversity technique over a 2x1 MISO channel defined in the DVB-T2 standard and propose two methods to reduce the computational complexity of K-best SD (KBSD) and thereby the implementation complexity by adaptively change the number of paths that the KBSD considers in its searching method. The reduced complexity of the decoder is an important issue in current sophisticated technologies and especially if that technologies employing a battery-based devices such as the Digital Video Broadcasting for Next Generation broadcasting system to Handheld terminals DVB-NGH. It worth noting that the DVB-NGH defines four different transmitter networks profiles with the first one (named Base profile) requires only one antenna at the receiver as in the DVB-T2 [7].

The rest of the paper is organized as follows: In Section II, we explore the 2x1 MISO SFBC implemented by the DVB-T2 and analyzing how to exploit the sphere decoder in it. In Section III, we propose the two methods of the Adaptive K-Best SD (AKBSD). Section IV shows the BER and complexity simulation results for KBSD with different K values along with the AKBSD methods. Finally we conclude the paper in Section V.

II. 2X1 MISO SFBC SYSTEM

A. Encoding

DVB-T2 employs the MISO encoding process over a 2x1 system with SFBC on pairs of OFDM payload cells by taking the input data cells and produce two correlated sets of data cells at the output to be directed to the two groups of transmitters. It defines a modified Alamouti encoding (for backwards compatibility) with a codeword equals the transpose of the original Alamouti codeword to produce the two sets of data cells as:

ISBN 978-3-8007-3529-7

$$\mathbf{X} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \quad (1)$$

where (.)* denote conjugate operation. The transmitter in MISO group 1 remain unmodified regarding frequency order or arithmetic operations, while the transmitter group 2 perform pairwise modification according to the above codeword [2].

B. Linear Decoding

The received pair of cells are given by:

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

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 ($\boldsymbol{y} = \boldsymbol{H}\,\boldsymbol{x} + \boldsymbol{n}$) we have:

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

To get the estimated signal we can use ZF and MMSE linear decoding [1] as:

$$\hat{\boldsymbol{x}} = \boldsymbol{H}^{+}\boldsymbol{y} \quad (4)$$

where $\mathbf{H}^{+} = (\mathbf{H}^{H}\mathbf{H})^{-1}\mathbf{H}^{H}$ for Zero-Forcing (ZF) detection method and $\mathbf{H}^{+} = (\mathbf{H}^{H}\mathbf{H} + \alpha^2\mathbf{I})^{-1}\mathbf{H}^{H}$ for Minimum Mean Square Error (MMSE) one while $\mathbf{H}^{H}$ is the conjugate transpose of $\mathbf{H}$ and α is the noise standard deviation.

In general, the ZF solution provides an optimum performance in the quasi-static channel conditions. However, in the case of selective channels, the type of MISO decoding notably impacts the decoding performance. The ZF and MMSE are linear methods with simple implementation, but they give low performance in case of the more realistic selective channels. On the other hand, the Maximum Likelihood (ML) solution is an exhaustive search which gives the optimal performance but this comes with high complexity. Sphere Decoding (SD) provides a sub-optimal solution that achieves near ML performance with lower complexity and therefore can be considered a suitable solution for MIMO decoding [8].

C. Sphere Decodeing

Sphere Decoding finds a suboptimal selection through searching the ML conditions over a small area around the received vector. The searched area is a sphere with a radius that defines the order of complexity of algorithm. Having this radius large enough to certain all possible constellation points renders SD to the original ML solution [9].

For a 2x1 complex MISO system, the SD method can be employed as follows. First noting that the 2x1 MISO channel is $\mathbf{H} = [h_1\ h_2]$ where h_i is the channel coefficient for i^{th} transmit antenna, while if SFBC is applied, the equivalent channel becomes as described in equations 3 and the complex system model is represented as:

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

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

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

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

$$arg\ min_{\bar{x} \in C} \|\bar{\boldsymbol{y}} - \bar{\boldsymbol{H}}\bar{\boldsymbol{x}}\|^2 \leq R_{SD}^2 \quad (7)$$

where C is the constellation points that x can take a value from it.

SD search method generally represented as a tree search with 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. Adaptive K-Best Sphere Decoder

K-Best SD [13] is based on the FP method. The K-Best SD follows the steps in fig. 1 in the decoding process. The advantage of K-Best SD is its fixed throughput which enables parallel and pipelined implementation [12].

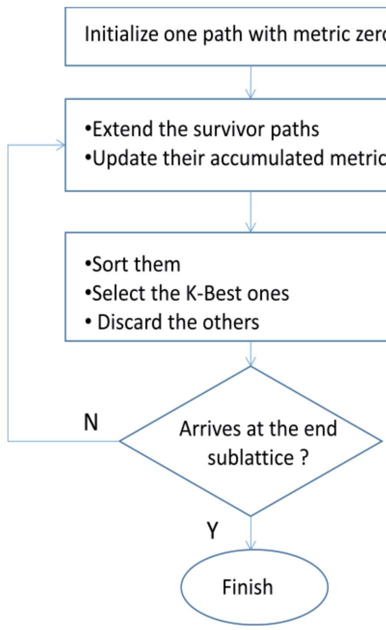

Fig. 1. K-Best decoding steps.

ISBN 978-3-8007-3529-7

Proposed Adaptive K-Best Sphere Decoders

The tradeoff between complexity and performance of the K-Best decoding method depends on the number K of the paths that will be searched by decoder. When choosing a small K, the algorithm provides a lower complexity in the cost of degradation in the performance and vice versa for large K. The main idea behind proposing to adapt the K-paths, the AKBSD, is to compromise the complexity and the performance governed by the choice of K. This can be achieved by defining a sub-optimum K suitable for different channel states.

A. Method1: CQE-based

Assuming a known Channel State Information (CSI) at the receiver, and performing a Channel Quality Estimation (CQE) by making use of the Channel Impulse Response (CIR) [14], we can measure 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 parameter as the ratio between the two coefficients $\frac{|h_1|^2}{|h_2|^2}$.
- If $C >$ threshold value Γ, the channel is most likely a high frequency selective channel and if $C < \Gamma$, the channel is somehow a frequency selective while if $|h_1|^2 = |h_2|^2$ the channel is non-frequency selective.
- If $C > \Gamma$, we can enter Mode1 of adaptation by defining a small K and vice versa at $C < \Gamma$ where Mode 2 defines a higher K.

Since for the 2x1 varying channel Matrix in SFBC MISO environment is as defined above $\mathbf{H}=\begin{bmatrix} h_{11} & -h_{21} \\ h_{22}^{\ *} & h_{12}^{\ *} \end{bmatrix}$. We here 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. This work is a modification of the work presented in [15] and inspired by [9], where only three modes for modifying the K are defined. Here, the system distinguishes the different channel conditions by introducing Mode 2 and Mode 3.

TABLE I. DIFFERENT ADAPTATION MODES OF OPERATION

Mode #	***Conditions***		***Actual K***
Mode 1	$C_1 > \Gamma$ & $C_2 > \Gamma$		K_1
Mode 2	$C_1 < \Gamma$ & $C_2 > \Gamma$	m_l around m_{ideal}	K_2
		m_l far from m_{ideal}	K_3
Mode 3	$C_1 > \Gamma$ & $C_2 < \Gamma$	m_l around m_{ideal}	K_2
		m_l far from m_{ideal}	K_3
Mode 4	$C_1 < \Gamma$ & $C_2 < \Gamma$		K_4

We employed another method that gives an indicator for the individual signals (x_1 and x_2) strength during these modes and hence we can assign different K values to each tree level during these modes. In Mode 2 and 3 we employ the columns norm

$$m_l = \|\boldsymbol{h_l}\|_2 \,, l = 1,2,..N_t \tag{9}$$

where h_l is the l^{th} column vector of the channel $\boldsymbol{H}$ and N_t is the number of transmitted antennae. Using the column norm enables us to adapt the K value over the two transmitted symbols (in case of 2x1 MISO) within the pair of the payload cells rather than a fixed K over each pair of cells; based on the fact that h_l column vector affects only the corresponding x_l transmitted symbol as in equation (3) and therefore gives us a more degree of freedom in adaptation during the two similar modes 2 and 3. The two column norms m_1 and m_2 are used as an indicator of the strength of their equivalent received signals x_1 and x_2 and hence the channel state affecting them and therefore can be used to define a suitable K for the current tree level by comparing them against ideal column norm m_{ideal} and if m_l lies within a threshold value around m_{ideal} a small K value (value of mode 1) is assigned because of small deviation from the ideal norm value and if m_l lies far from the m_{ideal} a higher K value is assigned as shown in table I.

B. Method 2: Estimated SNR

In this method (inspired by [9]), the K value is assigned according to the Signal-to-Noise Ratio (SNR) value calculated by:

$$\text{SNR}= \frac{E_s}{\sigma^2 \left\|\boldsymbol{W_{zf}}\right\|^2} \tag{10}$$

where σ^2 is the statistical information of noise and $\mathbf{W}_{zf}$=$(\mathbf{H}^{\mathbf{H}}\mathbf{H})^{-1}\mathbf{H}^{\mathbf{H}}$ and E_s is the transmitted signal energy. We divide the SNR asymptote into regions and each region specify a suitable K that passed to the KBSD to work on as shown in fig.3. In low SNR, different K values SD have a near Bit-Error-Rate (BER) values (as shown in fig. 2) and so we need only small value of K to reduce the complexity while in high SNR we need higher K values to approach a ML BER.

In this method we need the knowledge of the statistical information of the noise to include its effect in the adaptation process. Also calculating the weight $\mathbf{W}_{zf}$ is required, however if these data are available, a low complexity decoding is obtained. On the other hand, method 1 makes use of the knowledge of the CSI which is already available at the receiver via previous blocks (channel estimator) and so additional signal processing is not required but higher complexity decoding than method 2 is needed, which is proved by the simulation results.

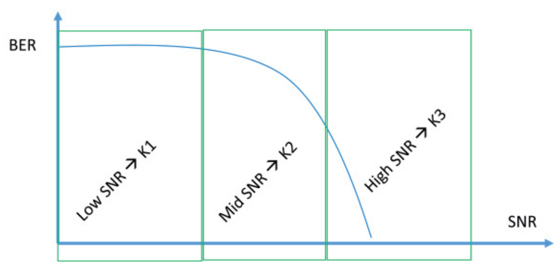

Fig. 2. Assigning different K values for SNR Regions

ISBN 978-3-8007-3529-7

IV. Simulation Results

Simulations were run for the 2x1 SFBC MISO system using 256-QAM modulation scheme that the DVB-T2 included recently over a frequency selective Rayleigh channel. BER curves, normalized execution time and number of visited nodes, for different K values (k=2 and 16) were plotted against the ZF, ML and the AKBSD decoding methods to measure the performance and the complexity of each system. Applying the two AKBSD methods (with threshold Γ=0.8 for Method 1) shows performance enhancement rather than the ZF linear method and approaching the ML BER as shown in fig.3 with small increase in complexity as shown in fig.4. Figure 4 shows zoomed curves for the execution times of ZF, fixed KSD and the two AKBSD normalized to the ML execution time (which takes the value of one and not shown in the figure). Method2 (SD-Ka2) shows a variable increase in complexity with the SNR due to the need of higher K to approach the ML performance.

Exhaustive search (ML) visits 17092 nodes during decoding while the number of visited nodes for the two methods is much smaller as can be seen from fig. 5. SD-Ka1 method visits average of 146 nodes while visited nodes for SD-Ka2 method are from 35 to 100 according to the SNR. The AKBSD ideas described here are applicable for MIMO systems as long as MISO, and therefore can be considered a sub-optimum decoding method that suits the DVB-T2 and DVB-NGH broadcasting systems.

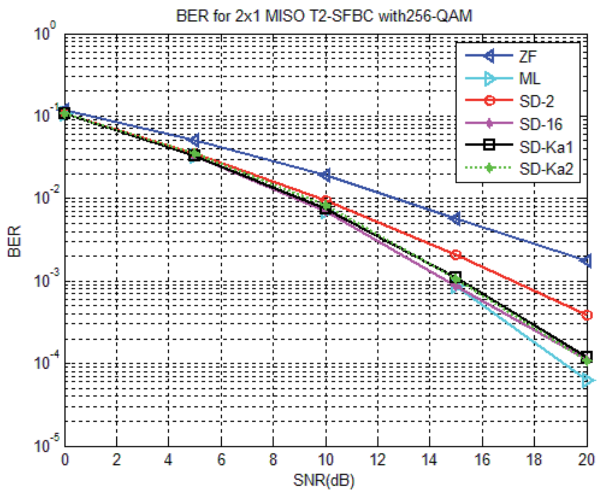

Fig. 3. BER Performance for AKBSD (SD-Ka1,Ka2 legends) versus ZF, ML and different K-SD.

V. Conclusion

This paper proposes two possible adaptation techniques to change the K-paths of the KBSD and is applied on the SFBC MISO codes developed by the DVB-T2 standard. The first AKBSD method employ the CIR as one of the CQE methods, and is intended to measure the selectivity of the channel and according to the channel selectivity/state, it specifies a suitable K-paths that the KBSD will concern in decoding. The other method uses the estimated SNR value in the adaptation process and therefore both methods give a better performance with acceptable complexity that enable the decoder to be implemented via flexible engines such as Application Specific Instruction Set Processor (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.

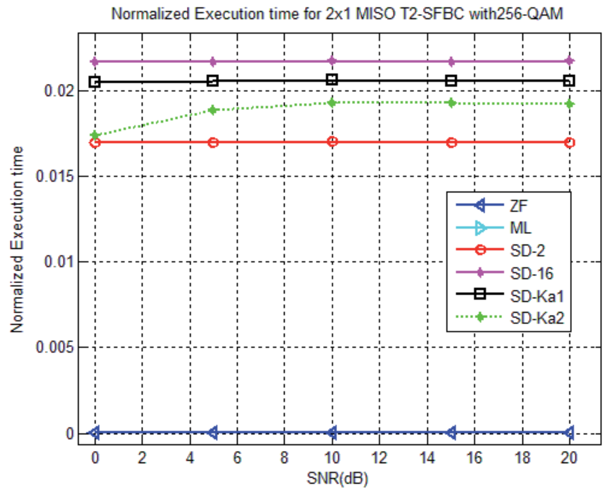

Fig. 4. Complexity in terms of normalized execution time (to ML time) for AKBSD (SD-Ka1,Ka2 legends) versus ZF and different K-SD decoding methods.

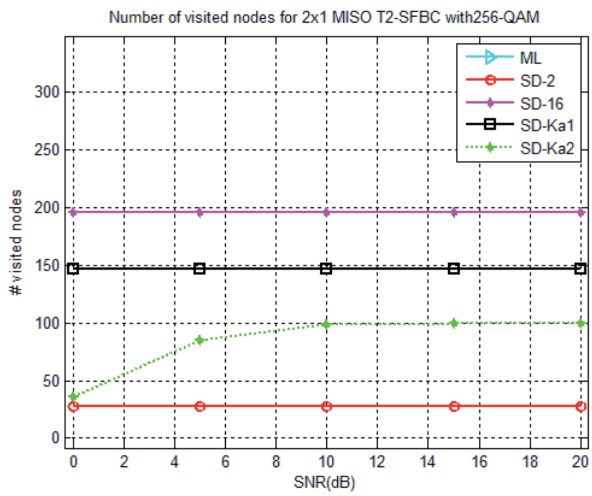

Fig. 5. Complexity in terms of number of visited nodes for AKBSD (SDKa1,Ka2 legends) versusExhaustive search.

Acknowledgment

This work has been supported by the Egyptian National Telecommunications Regularization Authority (NTRA) as part of the project "Design and implementation of DVB-T/T2 solution".

References

[1] Han-Kui Chang, Meng-Lin Ku, Li-Wen Huang and Jia-Chin Lin,"Multiple Antenna Techniques, Recent Advances in Wireless Communications and Networks," Prof. Jia-Chin Lin (Ed.), ISBN: 978-953-307-274-6, InTech, 2011.

[2] A. Goldsmith "Wireless Communications," ISBN-10: 0521837162, Cambridge University Press,2005.

ISBN 978-3-8007-3529-7

[3] L. Vangelista et. al, “Key Technologies for Next-Generation Terrestrial Digital Television Standard DVB-T2,” IEEE Communications Magazine, pp146-153, October 2009.

[4] ETSI, “Digital Video Broadcasting (DVB); Implementation guidelines for a second generation digital terrestrial television broadcasting system (DVB-T2). DVB Document A133,” February 2012.

[5] ETSI, “Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2)DVB Document A122,” June 2008.

[6] S. Alamouti, “A simple transmit diversity technique for wireless communications,” IEEE Journal on Selected Areas inCommunications, vol. 16, no. 8, pp. 1451 – 1458, October1998.

[7] ETSI, “Digital Video Broadcasting (DVB); Next Generation broadcasting system to Hanheld, physical layer specification (DVB-NGH). DVB Document A160,” November 2012.

[8] Sajid Bashir, Muhammad Naeem, Adnan Ahmed Khan, Syed Ismail Shah, “An application of univariate marginal distribution algorithm in MIMO communication systems,” International Journal of Communication systems, Volume 23, Issue 1, pages 109-124, January 2010.

[9] Yong Soo Cho, Jaekwon Kim, Won Young Yang and Chung G. Kang, "MIMO-OFDM Wireless Communications with MATLAB," chapter 10, John Wiley & Sons (Asia) Pte Ltd, 2010.

[10] U. Fincke and M. Pohst, “Improved methods for calculating vectors of short length in a lattice, including a complexity analysis,” Math. Comput., vol. 44, no. 5, pp. 463–471, May 1985.

[11] C. P. Schnorr and M. Euchner, “Lattice basis reduction: Improved practical algorithms and solving subset sum problems,” Math. Programming, vol. 66, no. 2, pp. 181–191, Sept. 1994.

[12] Zhan Guo and Peter Nilsson, “Algorithm and Implementation of the K-Best Sphere Decoding for MIMO Detection,” IEEE Journal on Selected Areas on Communications, vol. 24, no. 3, March 2006

[13] Kwan-wai Wong, Chi-ying Tsui, Roger Shu-kwan Cheng and Wai-Ho Ho Mow, “A VLSI architecture of a K-best lattice decoding algorithm for MIMO channels,” IEEE Int. Symp. on Circuits and Syst., volume 3, pages 273--276, May 2002.

[14] Joseph Boccuzzi, “ Signal Processing for Wireless Communications,” by The McGraw-Hill Companies, Inc.,Copyright © 2008.

[15] A.A.A El-Banna and Maha El-Sabrouty, “CIR-based adaptive K-Best sphere decoder for DVB-T2,” First international workshop on modeling, measurements and optimization of video performance over wireless networks -- In conjunction with Wiopt 2013. May 17, 2013.

ISBN 978-3-8007-3529-7