

© Copyright 2009 IEEE  
IEEE Vehicular Technology Conference  
Barcelona, Spain, 26-29 April 2009

Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes, or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works, must be obtained from the IEEE.

# MIMO performance of the next generation DVB-T

P. Atanes, A. Arrinda, G. Prieto, P. Angueira, M. M. Vélez  
Electronics and Telecommunications Department  
University of the Basque Country  
Bilbao, Spain  
patricia@bips78.bi.ehu.es,  
{amaia.arrinda, gorka.prieto}@ehu.es

P. Prieto  
Robotiker - Tecnalia  
Parque Tecnológico Edif. 202  
Zamudio-Bizkaia, Spain

**Abstract**—This paper analyses the performance of a DTT (Digital Terrestrial Television) broadcasting system that includes MIMO-OFDM techniques. The benefits of these techniques are studied comparing the results for different MIMO 2x2 (Multiple Input Multiple Output), MISO 2x1 (Multiple Input Single Output) and SISO (Single Input Single Output) system configurations. Different propagation channel models and configurations are considered for each diversity scheme. This study has been carried out in the context of development of the next generation DVB-T, called DVB-T2.

**Keywords**-DVB-T; DVB-T2; MIMO; MISO.

## I. INTRODUCTION

Since DVB-T system was designed, modulation techniques and error coding methods have suffered an important development [1]. Moreover, it is now possible to add much more sophisticated technology in receivers maintaining costs. These facts together with a larger capacity requirement for HDTV (High Definition Television) have lead to the necessity of the next generation DVB-T called DVB-T2 [2].

The inclusion of MIMO techniques in DVB-T2 seems to be a fact. At the moment, in the first draft specification of DVB-T2 [2] MISO techniques are considered, which could be the beginning for a complete diversity support by a further inclusion of MIMO techniques.

Nowadays, MIMO transmissions are being studied for a vast range of services, as they allow an important capacity rise [3]. Its principle is benefiting from spatial diversity between different antennas to increase capacity and reliability without spreading transmission bandwidth [4].

There are several mathematical models, which define a codification for transmitting in a MIMO scheme. Decoding formulas have been developed to extract the transmitted information from the received signals, always assuming a complete knowledge of the propagation channel. In OFDM systems the most used techniques to include MIMO support are the space-time and space-frequency coding techniques [5]. The proposed codification technique for MISO in the DVB-T2 draft [2] is based on the Alamouti's code [6]. The proposed method is a space-frequency code, derived from a modified coding matrix of the original Alamouti space-time code.

The modifications to Alamouti's code proposed in this paper, are the necessary ones to allow the expansion of the

MISO scheme to a full MIMO diversity scheme. This will allow, with the help of polarization diversity, backwards compatibility with SISO receivers that have no MIMO decoding logic.

In order to use MISO techniques it is necessary to increase the number of transmit antennas and modify the transmission and reception equipment. Additionally, in the case of MIMO, it is also necessary to add antennas to the receivers. All this means an important investment in infrastructure so, it must be studied first if the improvement in the system performance justifies it.

## II. OBJECTIVES

The main objective is to compare the reception quality in the actual SISO DVB-T broadcasting scheme with the new proposed MISO and MIMO diversity schemes.

As one of the proposed modified Alamouti's code characteristic is the fact that it allows backwards compatibility when using polarization diversity, this ability has to be proven. So it will be analysed not only the benefits of using MIMO diversity, but also how will it affect to actual broadcasts while both systems coexist.

It is also important to study if the proposed modification to the Alamouti's code for the MIMO configuration affects to the system efficiency, comparing it to the one of the original Alamouti's coding matrix.

## III. SYSTEM

### A. General system

A simulator has been developed in Matlab to carry out all the studies. This simulator includes a transmission and reception DVB-T chain, to which MIMO coding and decoding blocks are added (Fig. 1).

At the transmitter side, after the coding and modulation process – including: MUX adaptation & energy dispersal, outer coder, outer interleaver, inner coder, inner interleaver and mapping data in the constellation – the MIMO coding process is performed. The outputs of this process are handled as two independent fluxes to which pilot insertion, frequency to time translation and guard interval insertion must be applied. The receiver consists on the complementary blocks, so it recovers the transmitted information.

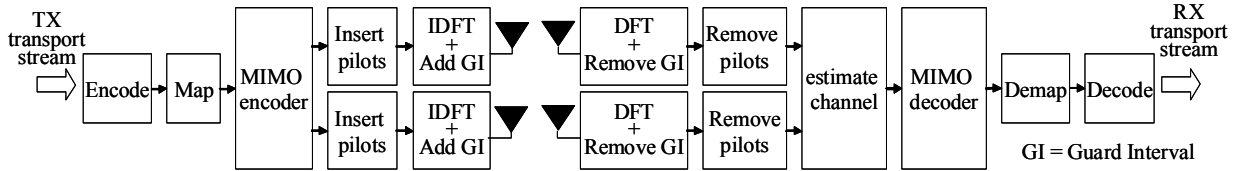


Figure 1. Simulated MIMO system

For the MISO case only the receiver has to be modified. The receiver has only one reception antenna and, from the received information, it estimates the channel response and decodes the information.

The SISO case corresponds to the usual DVB-T transmission and reception scheme [7], [8].

### B. Coding

Alamouti's space-time code [6] is represented by the following matrix (1):

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

where  $x_i^*$  represents the conjugation of  $x_i$ .

Each row represents the transmitting antenna and each column represents a time interval. Thus, in the first time interval  $x_1$  symbol will be transmitted from the first antenna and  $x_2$  from the second one, while in the second time interval  $-x_2^*$  will be transmitted from the first antenna and  $x_1^*$  from the second one.

Taking this code as the base and moving the time technique to the frequency domain, the frequency-time code results into the one in (2).

$$\bar{X} = \begin{bmatrix} X_{(2n-1)} & -X_{(2n)}^* \\ X_{(2n)} & X_{(2n-1)}^* \end{bmatrix} \quad (2)$$

Each row represents, as before, the transmitting antenna but now the column represents the data carrier. Thus from the first antenna, in the first carrier the first data carrier of the OFDM symbol is transmitted. In the second one the carrier of the symbol in the same position but conjugated and inverted is transmitted. From the second antenna, in the first carrier the second data carrier is sent. In the second carrier the first data carrier in OFDM symbol conjugated is transmitted. This code is applied to every pair of data carrier in each OFDM symbol.

The modified code proposed to allow backwards compatibility, is the transposed matrix of (2).

$$\bar{X} = \begin{bmatrix} X_{(2n-1)} & X_{(2n)} \\ -X_{(2n)}^* & X_{(2n-1)}^* \end{bmatrix} \quad (3)$$

The first row represents the data carriers transmitted by the first antenna. Data carriers transmitted from this antenna maintain the position and value of the original OFDM symbol.

This means that from the first antenna, the same signal as the one that would be broadcasted in a SISO scheme is transmitted, which eases backwards compatibility.

By using orthogonal polarization in the transmitter antennas, both transmissions can be received separately. The first antenna will be horizontally polarized, as it is the case of current DVB-T receivers, and the second antenna will have vertical polarization. Hence current receivers will receive mainly the data transmitted by the first antenna. On the other hand, new receivers including MIMO decoding will be provided of two antennas, one with horizontal polarization and the other one with vertical polarization, so they can receive information from both paths, benefiting from spatial diversity. It must not be ignored that a small amount of signal level can be received by the antenna with the opposite polarization. This will also be considered in the simulations (Fig. 2).

In order to simulate this effect, a cross-polar factor (XPD) has been defined so it attenuates  $h_{ij}$   $i \neq j$ , paths. The factor has been taken from [9] where the median value of discrimination by the use of orthogonal polarization at these frequencies is said to be 18 dB. The minimum and maximum values are 9 dB and 25 dB respectively.

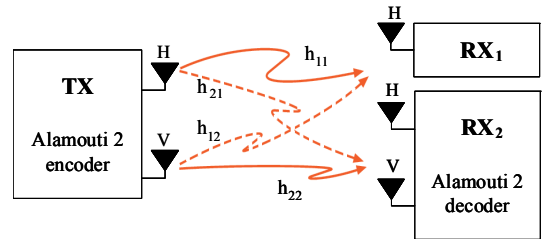


Figure 2. Broadcasting scheme when coexisting MIMO and SISO receivers

In [2] it is proposed an optional MISO inclusion in DTT broadcasts with the codification shown in (3). There is no mention to the use of polarization diversity, so that solution would create the necessity of using new frequencies.

### C. Channels

To obtain useful results, it is a crucial point to simulate suitable propagation channels. For that reason F1, P1 and TU6 have been selected as the propagation channels. These three channel types are the most commonly used for this kind of simulations. F1 and P1 are the ones considered in the DVB-T specification [7], and TU6 is a typical channel for mobile reception [10]. These channels have also been used in other studies related to DVB-T2 [11].

Channels in MIMO form a matrix (4), which shows all the possibilities of paths between each transmitter and receiver antenna. In MISO the matrix reduces to the array (5):

$$\overline{H} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \quad (4)$$

$$\overline{H} = [H_{11} \quad H_{12}] \quad (5)$$

where  $H_{ij}$  represents the path between the 'i' receiver and the 'j' transmitter.

#### D. Channel estimation

The propagation can be represented as (6), independently of used encoder:

$$\overline{R} = \overline{H} \cdot \overline{X} + \overline{V} \quad (6)$$

where  $\overline{R}$  is received carrier matrix,  $\overline{H}$  is channel matrix,  $\overline{X}$  is transmitted carrier matrix and  $\overline{V}$  is noise matrix.

The way to estimate the channel, is to particularize the expression just for the reference pilots, which amplitude and phase are known. Accordingly, the channel at those pilot positions is estimated as shown in (7). For SISO it is simplified to (8) for each reference pilot, where 'i' is the position of the reference carrier. The channel response for the rest of the carriers has been obtained by linear interpolation for this study.

$$\overline{H}_{ref} = \overline{R}_{ref} \cdot \overline{X}_{ref}^{-1} \quad (7)$$

$$\tilde{H}_{ref\_i} = \frac{R_{ref\_i}}{X_{ref\_i}} \quad (8)$$

For MIMO and MISO  $\overline{X}_{ref}^{-1}$  shall be calculated. If the modulation of the reference pilots transmitted from both antennas is maintained the same, it is not possible to obtain an inversion for this matrix. So it is necessary that some distinction is made in the modulation of the reference pilots. These reference pilots can be continual or scattered pilots. The first ones are commonly used for frequency synchronisation and using them would affect the performance of the system [12]. Thus the adopted solution consist on using the scattered pilots as considered in [2], which just implies little changes to the equalizer.

To maintain the first antenna's transmission unaffected, the modification will be made in the scattered pilots of the second transmitting antenna. Scattered pilots will be inverted alternatively, if one scattered pilot is inverted, the next one will be sent without inversion. Therefore, the inversion of the matrix used to estimate the channel (9) is possible, as (10) turns into (11).

$$\overline{X}_{ref} = \begin{bmatrix} X'_{12(n)+3\cdot rem+1}(Tx1) & X'_{12(n+1)+3\cdot rem+1}(Tx1) \\ X'_{12(n)+3\cdot rem+1}(Tx2) & X'_{12(n+1)+3\cdot rem+1}(Tx2) \end{bmatrix} \quad (9)$$

Subindex in (9) represent the position of scattered pilots, where 'rem' is the rest of the division 'l/4' ('l' is the symbol number in an OFDM frame); and 'n' is an integer.

$$\overline{X}_{ref} = \begin{bmatrix} A_{ref} & A_{ref} \\ A_{ref} & A_{ref} \end{bmatrix} \quad (10)$$

$$\overline{X}_{ref} = \begin{bmatrix} A_{ref} & A_{ref} \\ A_{ref} & -A_{ref} \end{bmatrix} \quad (11)$$

As it can be seen, two scattered pilots per antenna are necessary to obtain an estimated sample of the channel. That estimated sample has been allocated in the centre position, between both scattered pilots.

## IV. RESULTS

The selected values for modulation and coding parameters in all the simulations are the ones used for Spanish DVB-T transmissions. These values are the following ones.

- Transmission mode: 8K
- Non-hierarchical mapping.
- Constellation: 64-QAM.
- Code rate: 2/3.
- Guard interval: 1/4.

The QEF (Quasi Error Free) reception quality criteria has been used to analyse the reception quality. QEF means one uncorrected event per hour, it corresponds to a BER of  $10^{-11}$  after Reed-Solomon decoder and a BER of  $2 \cdot 10^{-4}$  after soft Viterbi decoder. BER after Viterbi decoder is the parameter that will be analysed.

For all the simulations, except for the one used to compare both codes, the code used is the one in (3). For MIMO simulations, polarization diversity has been considered with a cross-polar attenuation of 18 dB. Cross-polar attenuation values of 20 dB and 25 dB have also been used for the backwards compatibility specific simulation.

### A. Channel

In order to validate the performance of the simulator, the first simulation shows the effect of all the propagation channels considered in the case of a SISO transmission (Fig. 3).

Required C/N value to achieve a BER of  $2 \cdot 10^{-4}$  after Viterbi decoder can be compared in Gaussian, F1 and P1 channels, with the C/N thresholds in [7].

The C/N thresholds obtained are approximately 2 dB higher, which is due to the linear channel estimation used instead of using the optimal 2-D Wiener estimation in the equalizer. This is not a significant difference for the comparative study as all the techniques considered use the same equalizer.

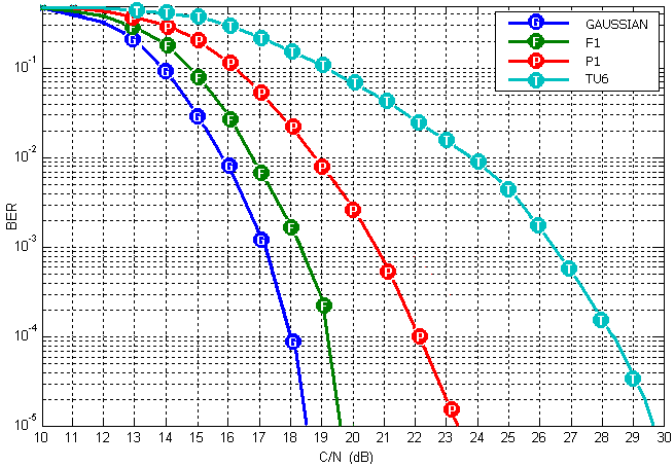


Figure 3. BER after Viterbi for different simulation channels

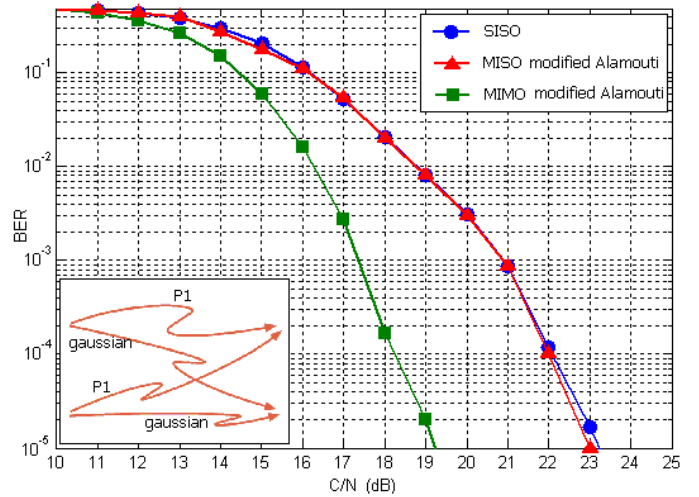


Figure 5. Diversity results when both channels to the same receiving antennas are P1 and the rest are Gaussian

### B. Diversity

The effect of diversity on reception quality has been studied by comparing the SISO, MISO and MIMO techniques proposed with different channels configurations. This is depicted in Fig. 4, Fig. 5, Fig. 6 and Fig. 7, and the results for other combinations are summarized in Table 1.

When the redundant propagation paths are better than the SISO one, MISO and MIMO benefit from those redundant channels to improve the reception quality (Fig. 4). Depending on what channels have better propagation characteristics, it can be more effective MIMO solution (Fig. 5), or the MISO one. If redundant channels are worse than the one involved in SISO propagation, the redundant channels do not improve significantly the reception quality (Fig. 6).

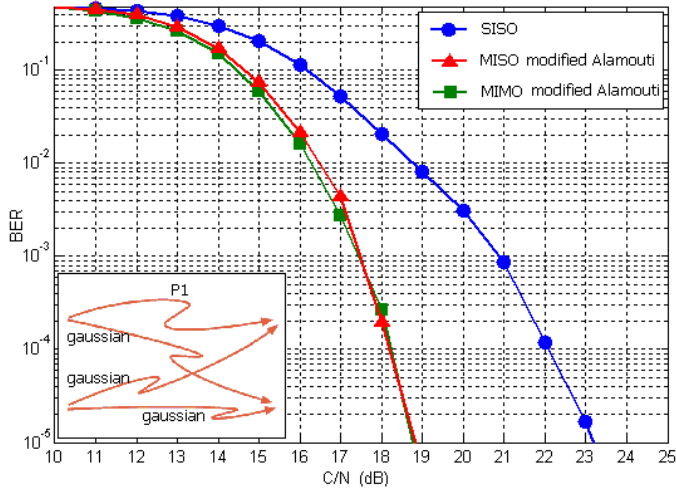


Figure 4. Diversity results when SISO channel is P1 and the rest are Gaussian

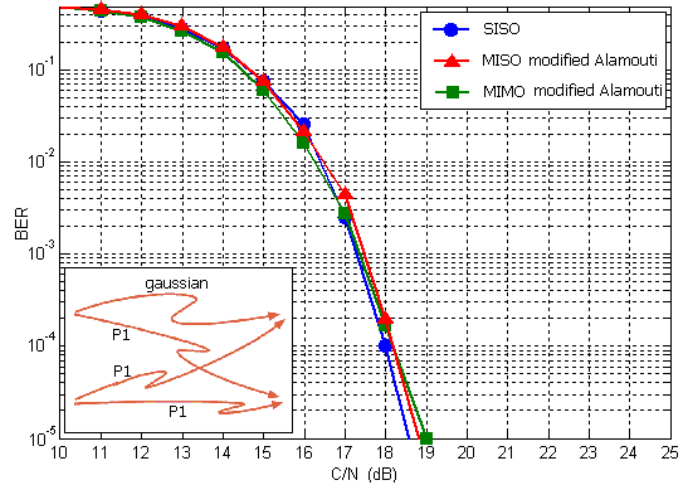


Figure 6. Diversity results when SISO channel is Gaussian and the rest are P1

There is also another fact to take into account: being  $h_{ij}$  the ones in the proposed MIMO scheme reduced by cross-polar factor, if  $h_{12}$  is the best propagation path, MISO can benefit from it to achieve a better reception while MIMO cannot, since it is received in the orthogonal polarization. This is shown in the columns where  $h_{12}$  is the only Gaussian channel (Table 1).

TABLE I. REQUIRED S/N (dB) FOR BER =  $2 \cdot 10^{-4}$  AFTER VITERBI

Combination of:	$F_1$ and Gaussian (G) channels				$P_1$ and Gaussian (G) channels				TU6 and Gaussian (G) channels				
	$G$	$F_1$	$F_1$	$F_1$	$G$	$P_1$	$P_1$	$P_1$	$G$	TU6	TU6	TU6	TU6
$h_{11}$	$G$	$F_1$	$F_1$	$F_1$	$G$	$P_1$	$P_1$	$P_1$	$G$	TU6	$G$	TU6	$G$
$h_{12}$	$F_1$	$G$	$F_1$	$G$	$P_1$	$G$	$P_1$	$G$	TU6	$G$	TU6	$G$	TU6
$h_{21}$	$F_1$	$G$	$F_1$	$F_1$	$P_1$	$G$	$P_1$	$P_1$	TU6	$G$	TU6	$G$	TU6
$h_{22}$	$F_1$	$G$	$G$	$F_1$	$P_1$	$G$	$G$	$P_1$	TU6	$G$	$G$	$G$	TU6
SISO	17.6	19	19	19	17.6	21.5	21.5	21.5	17.6	27.8	27.8	27.8	27.8
MISO	17.8	17.8	19	17.8	18	18	21.5	18	18.5	18.5	27.8	18.5	18.5
MIMO	17.8	17.8	17.8	19	18	18	18	21.5	18.5	18.5	18.5	18.5	27.8

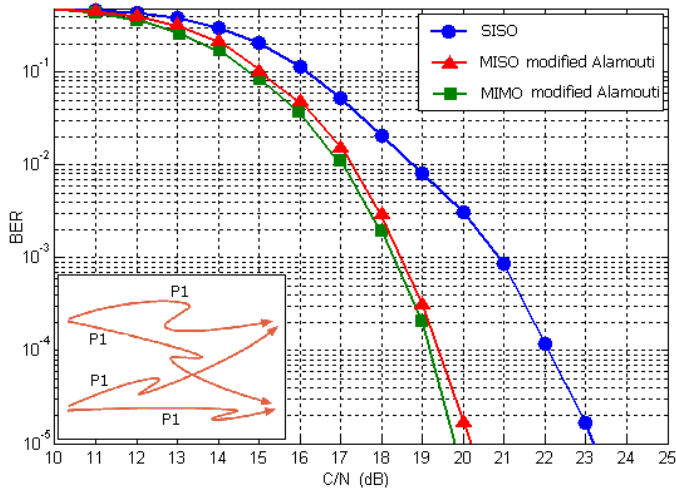


Figure 7. Diversity results when SISO channel is Gaussian and the rest are P1

### C. Backwards compatibility

As it has been said before, the proposed MIMO scheme allows backwards compatibility with SISO. To study this property, interference's influence has to be compared to C/N's influence. For this comparison, it has to be studied first which type of propagation channel makes the most harmful interference. When the principal path is Gaussian the interference propagated through a TU6 channel is the most harmful. For any other type of main path, the worst propagation channel for interference is Gaussian.

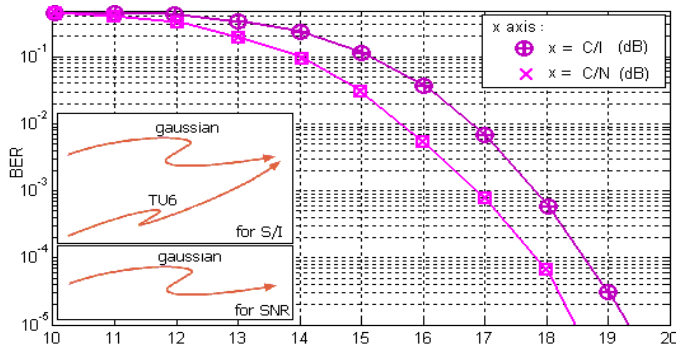


Figure 8. Influence of noise / Influence of interferences

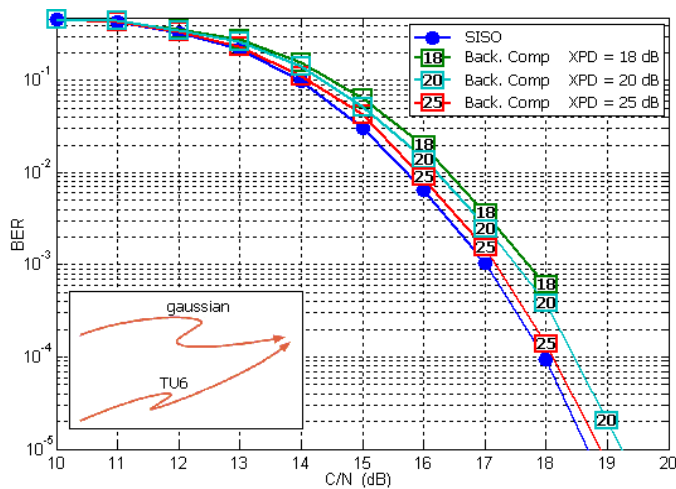


Figure 9. Backwards compatibility

The minimum value for cross-polar attenuation must be a little bigger than 18 dB (Fig. 8), which would correspond to 16 dB if a Wiener channel estimation is used instead of the linear one as explained before. In the same way the graphic with a 20 dB XPD would correspond to 18 dB (Fig. 9).

## V. CONCLUSIONS

Diversity schemes introduce gain when  $h_{11}$  has bad propagation properties and the rest of the paths are better. For the simulated channel models, a maximum gain of 9.3 dB is obtained when SISO channel is TU6 and the rest are Gaussian.

MIMO is the technique which allows more path combinations as it has more redundant propagation paths. When orthogonal polarizations are used,  $h_{ij} \neq j$  paths do not affect much to the reception and the MISO and MIMO solutions considered, have a similar efficiency.

Anyway if backwards compatibility is desired, it is necessary to use the proposed MIMO solution with Alamouti modified coding and polarization diversity. It is also necessary to control in a precise way the cross-polar attenuation to its higher possible values. From this study it can be concluded that the minimum required cross-polar attenuation is 16.5 dB.

## REFERENCES

- [1] L. Chia-Yu, K. Mong-Kai, C. Yi-Hsing Chien "Long Length LDPC Code Construction and the Corresponding Decoder Implementation with Adjustable Parallelism" Vehicular Technology Conference, 2008. VTC Spring 2008 IEEE, pp: 1423-1427, May 2008.
- [2] "Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2)," DVB Document A122, June 2008.
- [3] W. Hongmei, X. Xibin, Z. Ming, W. Weiling, Y. Yan "Efficient Transmission Schemes for Multiuser MIMO-OFDM Downlink Systems in Time-Varying Channels" Vehicular Technology Conference, 2008. VTC Spring 2008 IEEE, pp: 812-816, May 2008.
- [4] M. Jankiraman "Space-Time Codes and MIMO systems," Artech House universal personal communications library, 2004.
- [5] W. Zhang, X.G. Xia, K.B. Letaief "Space-Time/Frequency Coding For MIMO-OFDM In Next Generation Broadband Wireless Systems" IEEE Wireless Communications, June 2007.
- [6] S.M. Alamouti "A simple transmit diversity technique for wireless communications" Selected Areas in Communications, IEEE Journal on Vol.16, Issue 8, pp:1451 - 1458, Oct. 1998.
- [7] "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television." European Telecommunications Standard Institute, ETSI 300 744 v1.5.5 (2004-06).
- [8] "Call for Technologies" DVB SB 1644R1, Approved in the 54th meeting of the DVB Steering Board, 16 April 2007.
- [9] ITU-R Recommendation BT.419-3, "Directivity and polarization discrimination of antennas in the reception of television broadcasting" (1963-1986-1990-1992).
- [10] J. Poikonen, D. Gomez-Barquero, "Validation of a DVB-H dynamic system simulator using field measurements" Broadband Multimedia Systems and Broadcasting, 2008 IEEE International Symposium, on pp: 1-6, March-April 2008.
- [11] S. Ruiz-Boqué, C. López, C. Enrique, L. Alonso, J. Olmos, M. García, F. Minerva, "Performance of DVB-T2 improvements over low Doppler mobile channels" Castelldefels School of Technology, EPSC (UPC) COST 2100 TD(08) 451, Wroclaw, Poland, February 2008.
- [12] J.D Mitchell, P.N. Moss and M.J. Thorp "A dual polarisation MIMO broadcast TV system" Research White Paper, WHP 144, December 2006, BBC.