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PERFORMANCE ANALYSIS OF MIMO TECHNOLOGY IN MOBILE WIRELESS SYSTEMS

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Abstract: **The main goals in developing new wireless communication systems are increasing the transmission capacity and improving the spectrum efficiency. Space-time codes and spatial multiplexing codes exploit the richly scattered wireless channel by using multiple transmit and receive antennas in order to improve the reliability of data transfer and greatly increase the data transmission rates without additional radio resource requirements. Significant performance gain is achieved by varying some transmit and receive parameters.**

Key words: *MIMO, space-time coding, space division multiplexing*

I. INTRODUCTION: MIMO-OFDM

MIMO (Multiple Input Multiple Output) technology uses multiple antennas at the transmitter and at the receiver, thus improving the capacity of the wireless link when operating in a dense multipath scattering environment. MIMO system can also be applied to provide a more reliable communication and a higher transmission rate than that of a SISO (single-input single-output) system, without additional radio resource requirements [1]. The spectral efficiency of a MIMO system grows linearly with the minimum number of transmit and receive antennas.

MIMO technology uses the OFDM based modulation, in order to avoid the inter-symbol interference by modulating narrow orthogonal carriers. The achievable capacity and performance depend on the channel conditions and on the structure of the transmit signal. The signal design directly influences the complexity of the transmitter and, particularly the receiver. The MIMO coding techniques can be split into three groups according to [3]: space-time coding (STC) - aims to improve the power efficiency by maximizing spatial diversity, space division multiplexing (SDM) - uses a layered approach to increase capacity and the third one is beamforming which exploits the knowledge of channel at the transmitter.

The purpose of this paper is to evaluate the performances of a MIMO system and to see the parameters that influence the quality of the transmission. The rest of the paper is organized as follows. In Section II the space-time block codes are presented and how the transmit parameters influence the capabilities of the wireless link. In Section III the V-BLAST architecture is introduced and the performances that are achieved by varying the characteristics of this system. Finally, Section IV presents a comparison between the performances achieved with the two systems. The simulations were done using Matlab 7.0.1.

II. SPACE-TIME CODES

Space-time codes are used to redundantly transmit multiple copies of a data stream across a number of transmit antennas and to exploit the received copies of the data to improve the reliability of the wireless link [5]. Space-time coding can achieve transmit diversity and power gain over spatially uncoded systems without sacrificing the bandwidth and without the need to increase the transmit power. In the figure bellow it is represented the scheme of a space-time block code (Alamouti code).

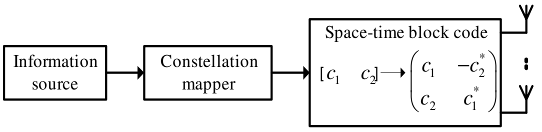

Figure 1. Transmission model using STBC

The incoming bit stream is mapped into a number of modulated symbols from a real or complex constellation [6]. Then a block of Y data symbols are encoded into a codeword matrix C of size $[N_t x N_s]$, which will then be sent simultaneously through N_t antennas in N_s OFDM blocks The rate of STBCs is defined as $R = Y / N_s$. If the channel state information (CSI) is available at the receiver, the optimal maximum likelihood detection can be performed [6]. The received signal at each receive antenna is a linear superposition of the n transmitted signals perturbed by noise.

The diversity order of these codes is equal with the product between the number of receive antennas and the

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number of transmit antennas, thus improving the link quality by combating deep fades.

Regarding the efficiency, the orthogonal STBCs do not always fully exploit the available MIMO channel capacity. A STBC is optimal with respect of capacity when it is rate one and it is used over a channel of rank one [5]. The rate of complex orthogonal STBCs with more than two transmit antennas drops bellow one, the result is a capacity penalty. Non-orthogonal STBCs are able to achieve rate one, but at the expense of performance.

II.1. PERFORMANCE ANALISYS OF STBC BASED SYSTEMS

There are a number of parameters that affect the performances of the transmission based on space-time block codes. These parameters are: the number of transmit/receive antennas, the modulation type and constellation size, the type of encoder, the coding rate. The influence of these parameters will be analyzed in this paper.

In the first simulation the input date are modulated with 4-PSK modulation and encoded with a rate one code [2]. The number of received antennas is varied between 1 and 5 in order to analyze the effect on the performance of the system. As it can be seen in Figure 2, receive diversity is an efficient and simple possibility to increase the link reliability. With the increase in the number of received antennas the bit error rate is reduced.

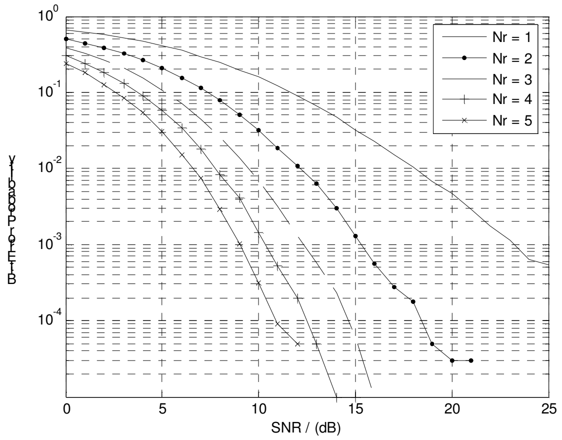

Figure 2. Number of receive antennas influence in a STBCs system

Since each element receives an independently copy of the same signal, the output SNR not only increases, but also the fluctuations in the output SNR are reduced, so the bit error rate is smaller. The increase of the diversity order determines the exponential decay of the error rate with the SNR; as it can be noticed the slope of the BER curves also increases with the number of received antennas.

Figure 3 shows the performance of a system with the space-time encoder based on the rate one complexorthogonal design G_2, while the type of modulation and the constellation size are varied.

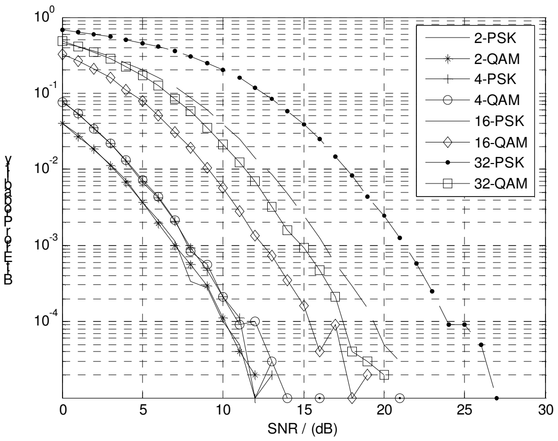

Figure 3. M-PSK vs. M-QAM in STBCs systems

For the small size constellation (2-4 PSK/QAM) the performances are almost the same. For the higher size constellations the QAM modulation exploits the signal space more efficiently than the PSK modulation. For a $BER = 10^{-3}$, the 32-QAM modulation is 7dB better than the 32-PSK modulation, and it performs even better than the 16-PSK by about 2 dB.

In the next simulations are examined the performances of STC schemes for identical spectral efficiencies. This can be achieved by using an appropriate modulation scheme for each STC. For a spectral efficiency of 2 bits/s/Hz the date are modulated using QPSK and encoded with the complex orthogonal design G_2 with the code rate $R_c = 1$, then the modulation used is 16-QAM with the encoded schemes based on G_3 and G_4 orthogonal designs, codes with a lower rate $R_c = 1/2$. At low SNRs the code with two transmit antennas is has the best results. QPSK is more robust than 16-QAM against the influence of noise. At high SNRs, the code with four transmit antennas gains about 1dB and 2dB relative to the codes with two and three antennas. So, the higher diversity degree becomes obvious only for high SNRs.

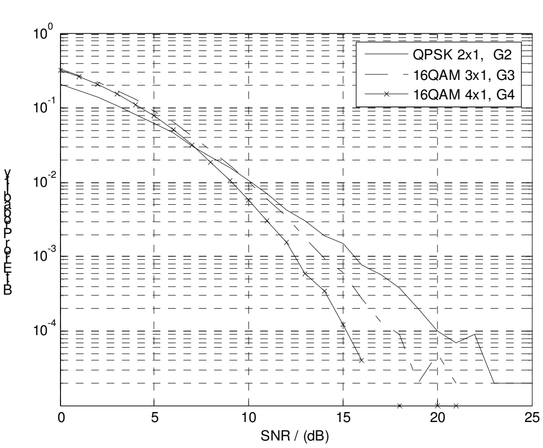

Figure 4. Transmission performance for the same spectral efficiency and different orthogonal STCs

III. LAYERED SPACE-TIME CODES

The codes based on spatial multiplexing are used to improve the multiplexing gain by transmitting at each period of time a number of independent data streams, number that is equal with the number of transmit antennas. The data rates increases linearly with $\min(M_T, M_R)$.

The configuration for vertical encoding is shown in the figure bellow [1]. The input bit stream is encoded, interleaved and mapped, before being fed to a demultiplexer. The input data is spread over all the transmit antennas and each stream is received by all the receive antennas.

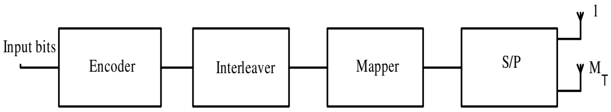

Figure 5. V-BLAST architecture

III.1.PERFORMANCE ANALYSIS OF V-BLAST BASED SYSTEMS

There are a number of parameters that affect the performances of the transmission based on V-BLAST architecture. The most important one for this type of transmission is the detection algorithm that is used at the receiver [8]. Other parameters are: the number of transmit/receive antennas, the modulation type and constellation. The influence of these parameters will be also analyzed in this paper.

The influence of the number of receive antennas is being analyzes for this system too. The decoding algorithm used for this simulation is ZF-OSUC, because it has a lower complexity order, but the performances are affected too. The modulation scheme is 4-PSK. As it is observed in Figure 6, the receive diversity is used to decrease the bit error rate.

The table bellow contains the values needed for the SNR, in order to obtain a $BER = 10^{-4}$, when a STBC based system, respectively a V-BLAST based system are used.

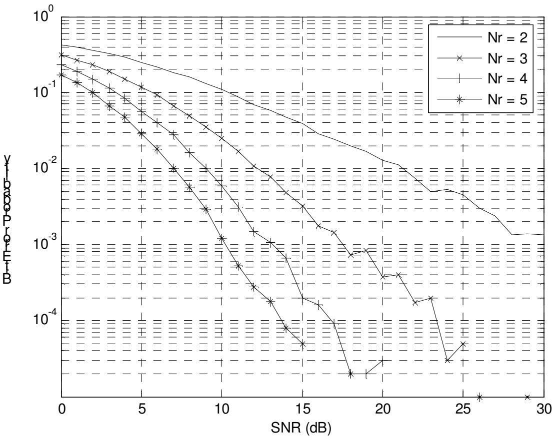

Figure 6. The influence of the number of receive antennas in a V-BLAST system

N_r /SNR(dB)	1	2	3	4	5
STBC	>25	18.5	14.5	12.5	11
V-BLAST ZF-OSUC	-	>30	23	17	14

Table 1. Simulation results: different number of receive antennas

From the results , it can concluded that for the same number of receive antennas the STBC system performs better than the V-BLAST system with a ZF-OSUC decoder, because of the more precise ML decoding used by the space-time codes. The gain is smaller when increasing the numer of receive antennas. When $N_r = 3$ the SNR needed by the V-BLAST system is with 8dB higher that the one needed by the STBCs to obtain the same performance, but when $N_r = 5$ the difference is only about 3dB.

The influence of the constellation type and size are also analyzed. For this simulation the maximum likelihood detection algorithm (ML) was implemented, so the diversity order is equal to the number of received antennas. The best performances are obtained for the small size constellation. For a $BER = 10^{-3}$, the 16-QAM modulation is 3dB better than the 16-PSK modulation. If using 32-QAM modulation the performances are almost the same as for the 16-PSK modulation.

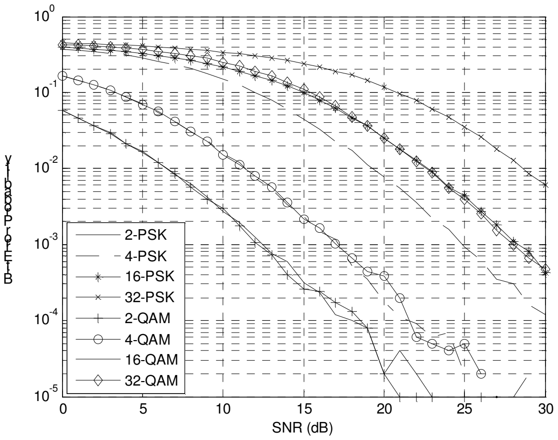

Figure 7. M-PSK vs. M-QAM in V-BLAST systems

In the table bellow are the values of the SNR needed when using the two systems with different modulation and costellations size, in order to obtain the same performance, $BER = 10^{-4}$.

For all the SNR range, no matter the modulation or the constellation, the STBCs based systems perform much better than the ones based on V-BLAST, because of the higher diversity order. With the increse of the constellation size the difference between the two systems is even higher. Because of the transmit diversity the STBCs exploit the signal spec more efficiently.

SNR(dB)	Mary	STBC	V-BLAST
PSK	2	10	17
	4	12	20
	16	19	32
	32	24	>>30
QAM	2	10	18
	4	12	21
	16	15.5	31
	32	17	>>30

Table 2. Simulation results: M-PSK and M-QAM

An important analyze is obtained when varying the detection algorithm. When using the ML detection the performances are better, but the complexity of the system is higher. The slope of the curve is different because with ML the diversity order is M_R, and when using other detection the slope is $M_R - M_T + 1$.

For a $BER = 10^{-4}$ the ML detection algorithm is better by at least 8dB.

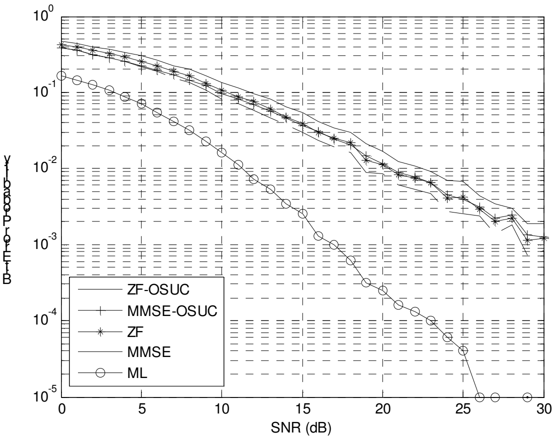

Figure 8. Influence of the detection algorithms

IV. CONCLUSIONS

The simulation results confirm that with STBC or V-BLAST and multiple transmit antennas a significant performance gain can be achieved at almost no processing expense.

At low SNR the V-BLAST algorithm with ML performs better that the space-time code, but at a SNR above 10dB it is noticed that with the Alamouti scheme the BER is the smallest. Another advantaje of the Alamouti scheme compared to the V-BLAST implementation with a ML detection is the reduce receiver complexity.

From the simulations performed, it can be concluded that a simple way to improve the quality of the transmission is to increase the number of receive antennas. For small devices, where the number of antennas is limited, a solution is to increase the number of transmit chains with very little decoding complexity. When the SNR is high diversity is important and overcompensates the larger sensitivity of high-order modulation schemes. At low SNR robust modulation schemes should be used because the diversity gain is smaller. For both systems at low SNRs it is recommended to use PSK based modulation schemes, while at high SNRs, QAM modulation can be used to obtain better results.

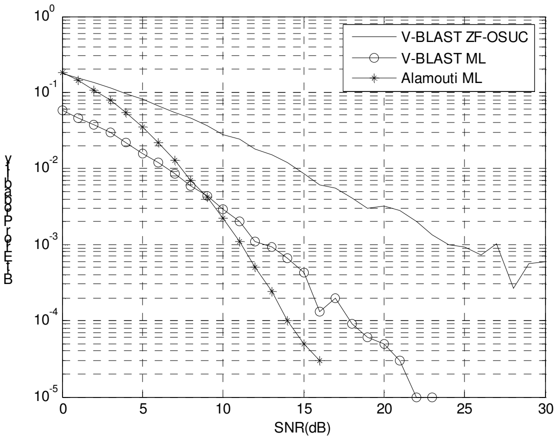

Figure 9. Comparison between V-BLAST and Alamouti systems

REFERENCES

[1] M. Jankiraman, Space-time codes and MIMO systems, Artech House, 2004

[2] V. Tarokh, Space-time block codes from orthogonal designs, IEEE Transactions on information theory, Vol. 45, No. 5, July 1999

[3]H. Jafarkhani, Space-time coding: Theory and Practice, Cambridge, 2005

[4] B. Vucetic, J. Yuan, Space-Time Coding, John Wiley&Sons, Ltd, 2006

[5] A. Zselt, MIMO-OFDM for Wireless LANs, Ph.D. Thesis

[6] D. Gesbert, From Theory to Practice: An Overview of MIMO Space-Time Coded Wireless Systems, IEEE Journal, Vol. 21, No. 3, April 2003

[7] G. J. Foschini, Layered Space-Time Architecture for Wireless Communication in a Fading Environment When Using Multiple Antennas, Bell Laboratories Technical Journal, Vol. 1, No. 2, Autumn, 1996, pp. 41-59.

[8] G. D. Golden, G. J. Foschini, R. A. Valenzulea and P. W. Wolniansky, Detection Algorithm and Initial Results using VBLAST Space-Time Communication Architecture, IEE Electronics Letters, vol. 35, no. 1, Jan. 1999.

[9] P.W.Wolniansky, G. J. Foschini, G. D. Golden and R. A. Valenzuela, VBLAST: An Architecture for Realizing Very High Data Rates Over the Rich-Scattering Wireless Channel, Bell Labs, Lucent Tech

[10] Fenghua Li, Performance Analysis of V-BLAST Detectors for the MIMO channel, KTH Electrical Engineering, 2007