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Simulation of per Antenna Coding Schemes of Receiver for Wireless Communication

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Abstract

A very promising approach for various wireless applications to use multiple antennas at both the transmitter and the receiver. The error rate performance and complexity of the algorithms are evaluated for different antenna configurations, for various constellation sizes, for different channel properties with and without coding. It is shown that Maximum Likelihood Detection (MLD) [1] outperforms the other schemes. Its complexity, however, is the highest and growing exponentially with the number of transmit antennas. Less complex alternatives are found that have only a slightly worse performance. Since V-BLAST techniques are simulated. It is shown that the maximum diversity gain equals the product of the number of transmit and receive antennas and the effective length of the channel impulse response.

Introduction
Recent research on wireless communication systems has shown that using multiple antennas at both transmitter and receiver offers the possibility of wireless communication at higher data rates compared to single antenna systems. The information-theoretic capacity of these multiple-input multiple-output (MIMO) channels was shown to grow linearly with the smaller of the numbers of transmit and receiver antennas in rich scattering environments, and at sufficiently high signal-to-noise (SNR) ratios. Some special detection algorithms have been proposed in order to exploit the high spectral capacity offered by MIMO channels. One of them is the V-BLAST (Vertical Bell-Labs Layered Space-Time) algorithm which uses a layered structure. This algorithm offers highly better error performance than conventional linear receivers and still has low complexity.

The MIMO Channel Model

Throughout this project, we use the MIMO channel model depicted in Fig. 1 with M transmitter and N receiver antennas.

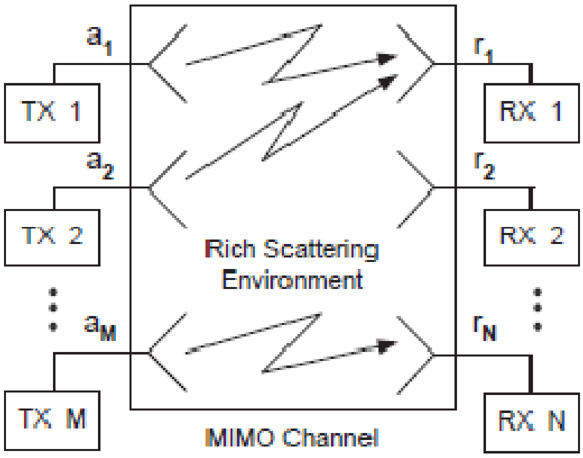

Figure 1: MIMO channel model. TX and RX stand for transmitter and receiver antennas

In each use of the MIMO channel, a vector a = ($a_1; a_2; : : : ; a_M)^T$ of complex numbers is sent and a vector r = ($r_1; r_2; : : : ; r_N)^T$ of complex numbers is received. We assume an input-output relationship of the form

$$r = Ha + v$$

where H is a $N \times M$ matrix representing the scattering effects of the channel and v = ($v_1; v_2; : : : ; v_N)^T$ is the noise vector. Throughout, we assume that H is a random matrix with independent complex Gaussian elements { h_{ij} } with mean 0 and unit variance. We also assume throughout that v is a complex Gaussian random vector with i.i.d. elements vi » $CN(0;N0)$. It is assumed that H and v are independent of each other and of the data vector a. We will assume that the receiver has perfect knowledge of the channel realization H, while the transmitter has no such channel state information (CSI). Receiver's possession of CSI is justified in cases where the channel is a relatively slowly time-varying random process.

Flat Fading MIMO Techniques

Besides the channel conditions, also the structure of the transmit signal of a MIMO system has a strong impact on the achievable capacity and performance. In addition, the signal design directly influences the complexity of the transmitter and, particularly, the receiver. These observations have led to numerous research activities to proper MIMO techniques. Basically, the proposed schemes can be split in two groups: Space Time Coding (STC) and Space Division Multiplexing (SDM). STC increases the robustness/performance of the communication system by coding over the different transmitter branches, while SDM achieves a higher data rate by transmitting independent data streams on the different transmitter branches simultaneously and at the same carrier frequency. These basic concepts have been the basis for various flavors of transmission approaches, which resulted in a multiplicity of candidate transmission schemes. Combined with corresponding receiver techniques, these schemes offer a variety of trade-offs between capacity-attainment capability, frame error-rate performance, computational complexity/simplicity and sensitivity to channel/interference estimation mismatch.

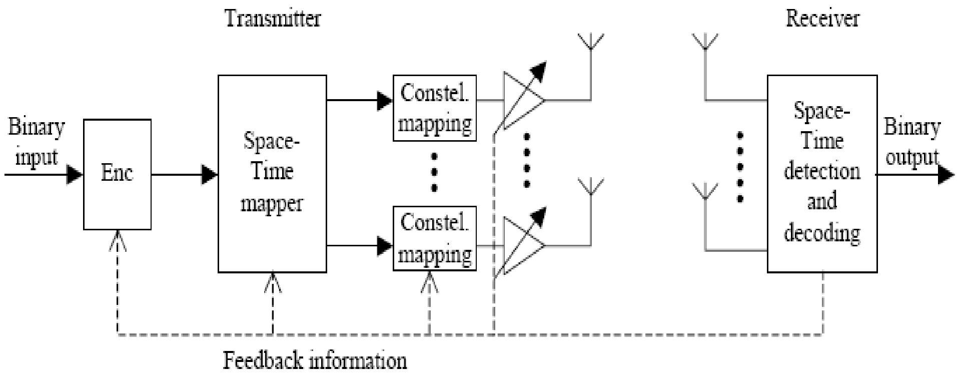

Figure 2: General structure of a MIMO system.

This framework could form the basis of a unified theory on MIMO techniques. Regarding the TX structure, in general, a TX signal for a MIMO system with *Nt* transmit antennas is generated by performing the following tasks on the incoming bit stream:

- channel encoding,
- mapping of the encoded bits on the spatial and/or temporal dimensions,
- mapping the (coded) bits onto a constellation diagram

On the receive side, generally speaking, detection is performed jointly over the spatial and temporal dimension. The complexity strongly depends on the TX signal design. When nothing is undertaken to reduce the complexity, the number of codewords can grow exponentially with the size of the spatial and temporal dimension. Proper design of the TX signal, however, allows for less complex receivers achieving (near) optimal performance. The general structure of a MIMO system is given in Figure 2.

Although, in our opinion, the introduced general MIMO scheme can cover (most of) the MIMO algorithms reported in literature, generally, a number of distinctions are made to classify the different algorithms. The commonly used classifications are:

- *Open-loop* versus *closed-loop* techniques. The distinction is made between systems that do not rely on knowledge of the channel responses at the transmitter, i.e., open-loop schemes, and systems that do assume partial or full availability of the channel information at the TX through some form of feedback mechanism, i.e., closed-loop schemes. In general, the feedback loop is designed to provide information for selection of the coding rate, constellation size, type of space-time mapping, and/or TX power per antenna (see Figure 2)

- *Transmit diversity* versus *spatial multiplexing* algorithms. If the wireless communication channel is richly scattered, a distinction can be made depending on to what extent the algorithms exploit the transmit diversity provided by the channel. On the one hand, transmit diversity schemes fully use the spatial dimension for adding more redundancy, thus, keeping the data rate equivalent to a single antenna system, with the goal to increase robustness. When the redundancy is generated through coding over the spatial and temporal dimension, the principle is called Space-Time Coding [2]. On the other hand, spatial multiplexing algorithms exploit the spatial dimension by transmitting multiple data streams in parallel on different antennas, with the goal to achieve high data rates. These algorithms are referred to as Space Division Multiplexing (SDM) algorithms. - *Joint Coding (JC)* versus *Per-Antenna Coding (PAC)*. When the original bit stream is first encoded and then demultiplexed into coded substreams of which each is modulated and mapped onto the corresponding transmit antenna, it is called Joint Coding (or vertical encoding). With Per-Antenna Coding (or horizontal encoding), the original bit stream is first demultiplexed into a number of uncoded bit substreams which are then individually encoded, modulated and mapped onto the transmit antennas. The advantage of the former is that the coding is performed over the space and time dimension, which could result in a better performance than the latter. The advantage of the latter, however, is that its receiver architecture might be less complex, since the encoding over the time and spatial dimension are separated.

Coded Space Division Multiplexing OFDM

When the potential diversity gain is high enough and the SNR of interest is low enough, the traditional code design criterion of maximizing the minimum Euclidean distance between any pair of code words ($||C - E||$) is more appropriate than specific Space-Frequency code design rules, i.e., the diversity and coding gain criteria. This can be explained by the fact that, when a reasonably large diversity gain is achievable through transmit, receive, and/or frequency diversity, a frequency-selective MIMO fading channel converges to a Gaussian channel (based on the Central Limit Theorem [3]) under the condition that proper encoding is applied across the diversity dimensions. As a result, under above conditions, standard SISO codes together with some form of space and frequency multiplexing may outperform handcrafted Space-(Time-) Frequency codes. Based on this argument, the concatenation of coding with the straightforward multiplexing over space and frequency of Space Division Multiplexing (SDM) [6] OFDM is a promising starting point. Moreover, such a coded SDM OFDM scheme offers the flexibility of easily adapting the constellation order and/or coding rate. Basically, there are two options to add coding to SDM OFDM, namely Joint Coding (JC) and Per-Antenna-Coding (PAC), which are explained in the next subsections.

Joint Coding

In Joint Coding (JC), also referred to as vertical coding, the information bit stream is first encoded and then converted into *Nt* parallel substreams of which each is modulated and mapped onto the corresponding transmit antenna. A transmitter scheme in which JC is applied to SDM OFDM is shown in Figure 3, where S/P denotes the serial-to-parallel conversion. After the S/P block, each branch in parallel performs interleaving (Π), QAM mapping, pilot insertion, *Nc*-point IFFT, and adds a Cyclic Prefix before the final TX signal is shaped, converted up to the Radio Frequency (RF), and transmitted.

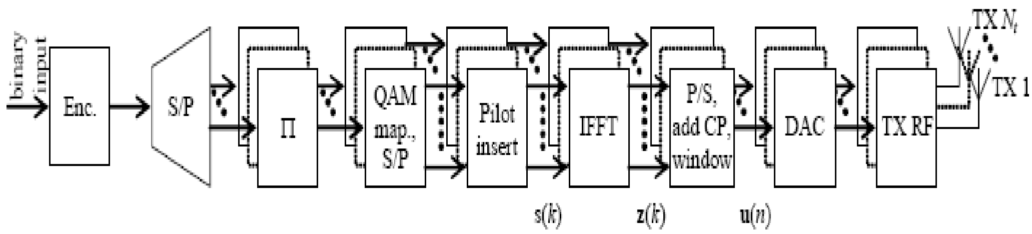

Figure 3: Schematic representation of a Joint-Coded SDM OFDM transmitter.

Per-Antenna-Coding

In Per-Antenna-Coding (PAC) [4] schemes, the incoming bit stream is first transformed to *Nt* parallel substreams and then encoding is performed per substream. So, basically, the transmitter consists of *Nt* OFDM transmitters among which the information bits are multiplexed, as shown in Figure 4.

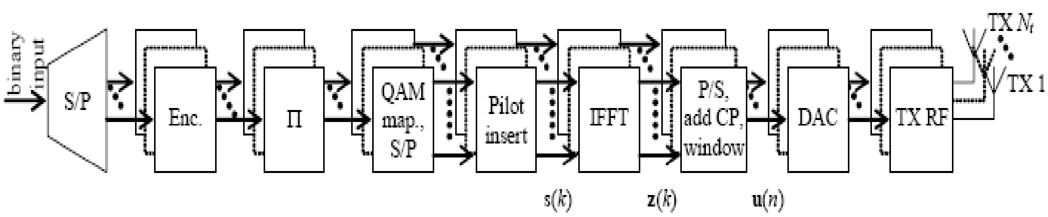

Figure 4: Schematic representation of a PAC SDM OFDM Transmitter.

The receiver for a PAC transmitter is exactly the same as that for a JC transmitter up to and including the interleavers. The difference is that after interleaving the *Nt* detected substreams are first decoded per stream before they are converted into a serial stream. A schematic representation of such a receiver is given in Figure 4

V. Performance Evaluation for Various Schemes of Receiver

Zero Forcing (ZF)

Zero Forcing is a linear MIMO technique. In previous section, it is shown already that the processing takes place at the receiver where, under the assumption that the channel transfer matrix H is invertible, H is inverted and the transmitted MIMO vector s is estimated by

$$\mathbf{s}_{\text{est}} = \mathbf{H}^{-1}\mathbf{x}\,. \tag{1}$$

This principle is based on a conventional adaptive antenna array (AAA) technique, namely, linear combinatorial nulling [5]. In this technique, each substream in turn is considered to be the desired signal, and the remaining data streams are considered as "interferers". Nulling of the interferers is performed by linearly weighting the received signals such that all interfering terms are cancelled. For Zero Forcing, nulling of the "interferers" can be performed by choosing $1 \times Nr$ dimensional weight vectors wi (with $i = 1, 2, \ldots, Nt$), referred to as nulling vectors, such that

$$\mathbf{w}^{i}\mathbf{h}_{p} = \begin{cases} 0, & p \neq i \\ 1, & p = i \end{cases} \tag{2}$$

where hp denotes the p-th column of the channel matrix H. Let wi be the i-th row of a matrix W, then it follows that

$$\mathbf{WH} = \mathbf{I}_{N_t} \tag{3}$$

where W is a matrix that represents the linear processing in the receiver. So, by forcing the "interferers" to zero, each desired element of s can be estimated. If H is not square, W equals the *pseudo-inverse* of H (denoted by H†):

$$\mathbf{W} = \mathbf{H}^{\dagger} = \left(\mathbf{H}^{H}\mathbf{H}\right)^{-1}\mathbf{H}^{H} \tag{4}$$

If the elements of H are assumed to be i.i.d., the pseudo-inverse exists when Nt is less than or equal to Nr. For Nt larger than Nr, HHH is singular and its inverse does not exist. When the pseudo-inverse exists, the estimates of s (given by sest) can be found by

$$\begin{aligned}\mathbf{s}_{\text{est}} &= \mathbf{Wx} = \mathbf{H}^{\dagger}\mathbf{x} = \left(\mathbf{H}^{H}\mathbf{H}\right)^{-1}\mathbf{H}^{H}\mathbf{x} \\ &= \mathbf{s} + \left(\mathbf{H}^{H}\mathbf{H}\right)^{-1}\mathbf{H}^{H}\mathbf{n}\end{aligned} \tag{5}$$

Denote the i-th component of sest by (sest)i, then, as a final step, (sest)i must be sliced to the nearest constellation point. In this way, all Nt elements of s can be decoded at the receiver. A big disadvantage of Zero Forcing is that it suffers from noise enhancement, especially for channels with a high condition number $\kappa(H^H H)$. This can be readily observed.

Maximum Likelihood Detection (MLD)

Maximum Likelihood Detection (MLD) [1] is a method that performs a maximum likelihood search over all possible transmitted vectors s. The most likely transmitted vector is found as follows:

$$\mathbf{s}_{\mathrm{ml}} = \arg \min_{\mathbf{s}_i \in \{\mathbf{s}_1,\ldots,\mathbf{s}_I\}} \left\| \mathbf{x} - \mathbf{H}\mathbf{s}_i \right\|^2 \tag{6}$$

where a search is performed over all vectors si that are part of the ensemble {s1, …, sI} formed by all possible transmitted vectors. Their number equals

$$I = M^{N_t} \tag{7}$$

where M denotes the number of constellation points. Note that for MLD it is not required that $Nt \leq Nr$. A way to arrive at the most likely transmitted vector is by stating that we want to find the vector si from the ensemble {s1, …, sI} for which the probability Pr(s = si|x), or Pr(si|x) in short, is maximal. This is called the *Maximum A posteriori Probability* (MAP).Finding such a vector leads to the minimisation of the probability of error. When applying Bayes' rule, Pr(A|B) = Pr(B|A)·Pr(A)/Pr(B), the probability Pr(si|x) may be expressed as

$$\Pr\left(\mathbf{s}_i \middle| \mathbf{x}\right) = \frac{p\left(\mathbf{x} \middle| \mathbf{s}_i\right)\Pr\left(\mathbf{s}_i\right)}{p(\mathbf{x})} \tag{8}$$

where p(x|si) is the conditional probability density function of the observed vector given that si has been sent and Pr(si) is the probability of the i-th vector being transmitted. When no *a priori* knowledge is available on the probability that a certain vector is sent, it is best to assume that the I vectors are equally probable to be transmitted, hence Pr(si) = 1/I. When this assumption is made, the resulting detection method is not longer the MAP method but is generally called Maximum Likelihood Detection.

V-BLAST scheme for Receiver

The V-BLAST detection algorithm is a recursive procedure that exctracts the components of the transmitted vector a according to a certain ordering (k1; k2; :::; kM) of the indices of the elements of a. Thus, (k1; k2; :::; kM) is a permutation of (1; 2; :::;M). In V-BLAST, this permutation depends on H (which is known at the receiver by assumption) but not on the received vector r.

The V-BLAST/ZF algorithm is a variant of V-BLAST derived from ZF rule.

V-BLAST/ZF Detection Algorithm

$$\mathbf{W}_1 = \mathbf{H}^{+} \tag{9}$$

$$i = 1 \tag{10}$$

$$k_i = \arg\min_{j \notin \{k_1 \ldots k_{i-1}\}} \|(\mathbf{W}_i)_j\|^2 \tag{11}$$

$$y_{k_i} = (\mathbf{W}_i)_{k_i} \mathbf{r}_i \tag{12}$$

$$\hat{a}_{k_i} = Q(y_{k_i}) \tag{13}$$

$$\mathbf{r}_{i+1} = \mathbf{r}_i - \hat{a}_{k_i}(\mathbf{H})_{k_i} \tag{14}$$

$$\mathbf{W}_{i+1} = \mathbf{H}^{+}_{\bar{k}_i} \tag{15}$$

$$i = i + 1 \tag{16}$$

where H+ denotes the Moore-Penrose pseudoinverse of H, (W*i*)*j* is the *j* 'th row of *Wi*, *Q*(*¢*) is a quantizer to the nearest constellation point, (H)*ki* denotes the *ki*'th column of H, H*ki* denotes the matrix obtained by zeroing the columns *k*1*; k*2*; :::; ki* of H, and H+*ki* denotes the pseudo-inverse of H*ki*.

Results

Zero Forcing equalization

In Figure 5, the BERs for different MIMO detection techniques are depicted against the average SNR per receive antenna for a 2 × 2 system that operates in a flat Rayleigh fading environment followed by AWGN. A BPSK modulation scheme is used for Maximum ratio combining.

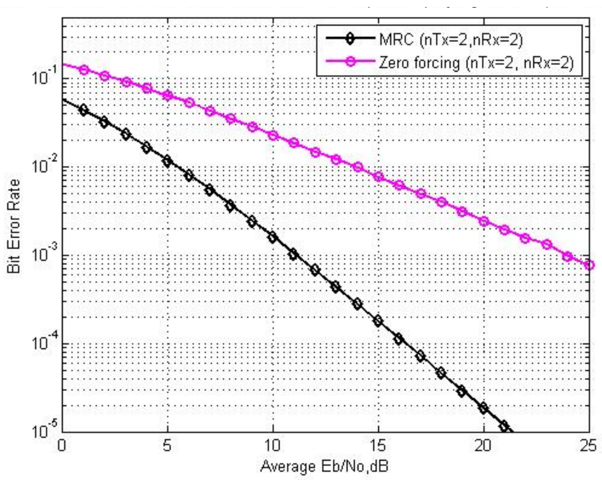

Figure 5. 2 x 2 MIMO-PAC using ZF and MRC with Rayleigh channel.

ZF equalization & MRC Schemes with AWGN

Bit Error Rate versus average SNR in dB can be evaluated by adding the Additive Gaussians Noise in the Rayleigh channel for 2 transmit and 2 receiver antennas. In figure 6 the BER versus SNR evaluation shown for MRC and ZF equalization schemes in Rayleigh channel with AWGN.

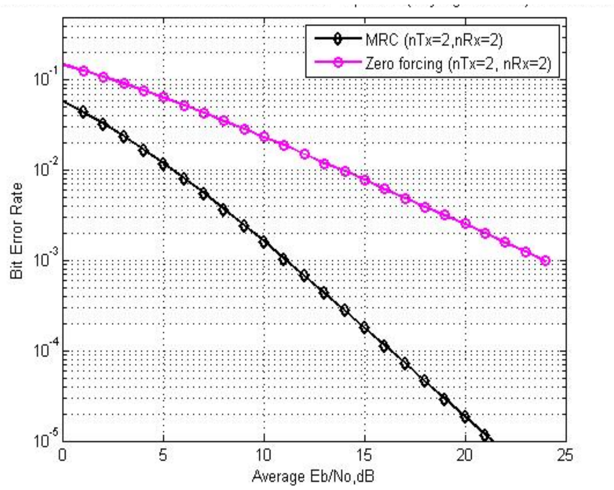

Figure 6. 2 x 2 MIMO-PAC using ZF with AWG

Maximum Likely- hood detection

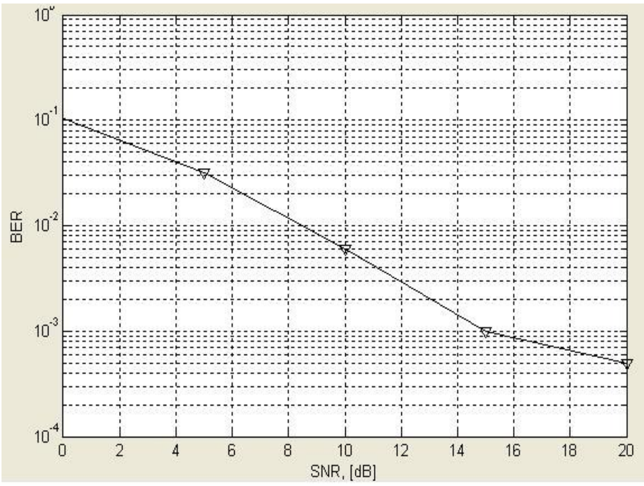

Figure 7. 1 x 1 MIMO system using MLD

V-BLAST scheme for Receiver

V-BLAST schemes are used with the various schemes like ZF, MAP, LLSE, MMSE. As well as also in combination of two or more.

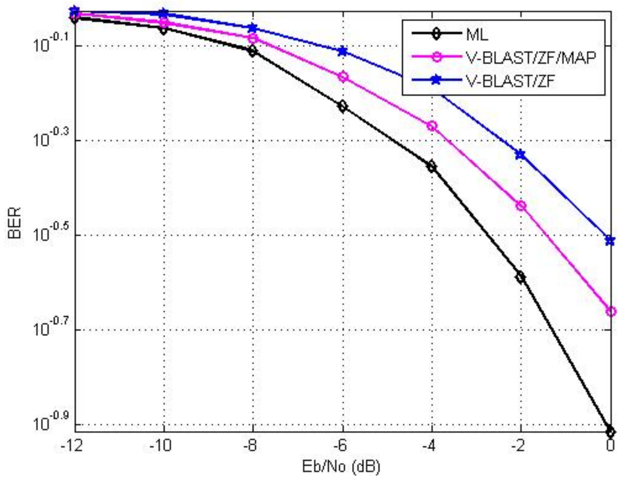

Figure 8. 2 x 2 MIMO system using V-BLAST Schemes and MLD.

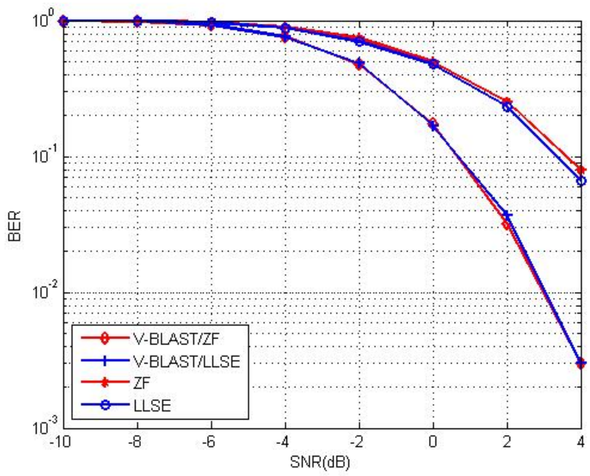

Figure 9. 2 x 2 MIMO system using V-BLAST/ZF and V-BLAST/LLSE Schemes.

Conclusions

The SNR increases BER drastically reduces after 16 dB SNR for MRC detection Scheme and proposed scheme with MRC perform better than ZF for SNR values for Rayleigh channel environment. The similar results for the additive white Gaussian noise only the BER of ZF is reduced. As the SNR increases BER drastically reduces after 16 dB SNR for MRC detection Scheme and proposed scheme with MRC perform better than ZF for SNR values for Rayleigh channel environment with AWGN. For MLD detection scheme our system is robust for 31.62 dB SNR which will theoretically better for outdoor communication. Further this system is symmetrically work for 1 x 1, 2 x 1 and 2 x 2, 1 x 2.

After the comparison of all three methods of MIMO detection schemes shows that V-BLAST is recursive adaptive detection scheme perform better along with ZF and

MAP. Negative sign of SNR indicates complex conjugate of original signals and noise is approaches towards minimal due to adaptiveness of V-BLAST. Weight vector tuned for V-BLAST and LLSE is superior to remaining ones which will adapt the system with noisy environment and performs robustly.

References

[1] Junqiang Li, Khaled Ben Letaief "*A Reduced-Complexity Maximum-Likelihood Method for Multiuser Detection*" IEEE Transactions on Communications, Vol. 52, No. 2, February 2004.

[2] 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

[3] J. G. Proakis, *Digital Communications*, Third Edition, New York, McGraw-Hill, 1995, McGraw-Hill Series in Electrical and Computer Engineering

[4] A. Van Zelst "*Per-Antenna- Coded Schemes for MIMO OFDM*" 0-7803-7802-4/03 @ 2003 IEEE

[5] 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*", in *Proc. of the URSI International Symposium on Signals, Systems, and Electronics (ISSSE) 1998*, Pisa, 29 Sept. - 2 Oct. 1998, pp. 295-300

[6] A. van Zelst, R. van Nee, and G. A. Awater, "*Space division multiplexing (SDM) for OFDM systems*", in *Proc. of the IEEE 51st Vehicular Technology Conference (VTC) 2000 Spring*, vol. 2, May 2000, pp. 1070-1074

[7] M. Sima, M. Senthilvelan, D. Iancu, J. Glossner, M. Moudgill, and M. Schulte "*Software Solutions for Converting a MIMO-OFDM Channel into Multiple SISO-OFDM Channels*" Third IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob 2007)

[8] Y. Lomnitz and D. Andelman "*Efficient maximum likelihood detector for MIMO systems with small number of streams*" IEEE Electronics Letters 25th October 2007 Vol. 43 No. 22

[9] K. Sam Shanmugam, *Digital and Analog Communication Systems*, J. Wiley &Sons, Inc., New York, 1985

[10] T. S. Rappaport, *Wireless Communications, Principles and Practice*, New Jersey, Prentice-Hall, 1996