

A Simple Massive MIMO Scheme based on the Overlap of STBC

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ABSTRACT:The construction for Massive MIMO based on the overlap of Alamouti codes over the spatial dimension is proposed. In order to separate the overlapped streams at the receiver, the V-BLAST algorithm is employed such that the scheme achieves a combination of diversity and multiplexing gain. It is found that the scheme outperforms the superimposed but non-overlapped approach proposed by Tan and Calderbank already for a relatively small setup with 6 transmit and 20 receive antennas. Though not discussed in this first work, it is evident from the presentation that a similar overlapping strategy can also be employed in time and based on more general space time code constructions. If confirmed, the method can lead to very simple and scalable schemes to be used in Massive MIMO systems.

KEYWORDS: Massive MIMO, Space-time block codes (STBC), Alamouti STBC, V-BLAST, Alamouti-BLAST scheme, Overlapped Alamouti codes.

I. INTRODUCTION

The benefits of the multi-user MIMO over the conventional point-to-point MIMO helps in the simplification of active terminals by working with the low cost antennas. However, multi-user MIMO is not a scalable technology. The earlier work in [1] focus on the pros and cons with the scaling of large antenna arrays. Massive MIMO [2] overcomes the drawbacks of the multi-user MIMO systems as they use relatively large number of antennas. Thus, they scale the MIMO systems to the possible orders compared to the available system. The need for the massive MIMO systems explained in [3] [4] explores the potentials in terms of energy efficiency, robustness and reliability. Massive MIMO reduces the complexity and scales the users by achieving the minimum power consumption [5]. In order to maintain the scalability, the techniques involved need to be simpler and this can be achieved through the Space-time block codes (STBC) where additional diversity gain can be obtained along with the spatial multiplexing transmission [6]. The orthogonal design of STBC [7] using the multiple transmitting antennas helps to improve the channel gain and thus exploits the maximum diversity gain [8]. The STBC proposed by Alamouti on transmit diversity [9] is a full rate scheme. But, it does not benefit from the diversity gain at the transmitter. The amount of diversity and degrees of freedom can be increased by the multiple antennas in the wireless communication systems with the use of STBCs [9] [10]. The combination of these in [11] explains that the diversity and multiplexing gain can be simultaneously obtained with trade-off between the gains of multiple-access fading channels. In [12], the Alamouti codes are used with the combination of V-BLAST scheme where the first two antennas transmit symbols same as that in [9] and the remaining antennas follow the V-BLAST scheme using successive interference cancellation (SIC) to reduce the receiver complexity. For the large number of transmit antennas, the overlapped Alamouti codes using the Toeplitz codes showed better performance to the orthogonal STBC(OSTBC). Unfortunately, they have a large number of zeros in the equivalent channel matrix, thus transmitting zeros at all transmit antennas and increase the computational complexity of the system. In order to overcome this drawback, the system avoiding the transmission of zeros by half the number of transmitting antennas and with easier implementation than the overlapped Alamouti codes was explained in [13]. The current work implements the advantages of [11] [12]. Here, the transmission of zeros are nullified on the transmit antennas. We try to establish the diversity and multiplexing gains by overlapping the Alamouti codes combined with

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the V-BLAST decoder showing the better performance in terms of SNR [14] in space and time domains to outperform the existing systems.

II. PRILIMINARIES

In this section, we shall briefly revise a few state-of-the-art works, which will prove useful when explaining the original material to be introduced in Section III. In passing, some of the notations used throughout the paper will also be defined.

A. The Alamouti Scheme

Let us briefly revise the Alamouti scheme [9]. Consider the symbol vector

$$\mathbf{s} \triangleq [\mathbf{s}_1 \mathbf{s}_2]^T, \tag{1}$$

with corresponding Alamouti encoding matrix

$$\mathbf{C} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix}. \tag{2}$$

Define the channel and noise vectors respectively by

$$\mathbf{h} \triangleq [\mathbf{h}_1 \quad \mathbf{h}_2]^T \text{ and } \mathbf{w} \triangleq [\mathbf{w}_1 \quad \mathbf{w}_2]^T. \tag{3}$$

Then the received signal vector corresponding to a single receive antenna can be written as

$$\mathbf{r} = \mathbf{C} \cdot \mathbf{h} + \mathbf{w} = \begin{bmatrix} s_1 h_1 + s_2 h_2 + w_1 \\ -s_2^* h_1 + s_1^* h_2 + w_2 \end{bmatrix}. \tag{4}$$

Correspondingly, the symbol estimates obtained from \mathbf{r} and in knowledge of \mathbf{h} are given by

$$\tilde{s}_1 = h_1 r_1 + h_2 r_2^*, \tag{5a}$$

$$\tilde{s}_2 = h_2 r_1 - h_1 r_2^*. \tag{5b}$$

Let us define an equivalent channel matrix \mathbf{H} , a modified noise vector $\tilde{\mathbf{w}}$ and a modified received vector $\tilde{\mathbf{r}}$ respectively as

$$\mathbf{H} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}, \tag{6}$$

$$\tilde{\mathbf{w}} \triangleq [\mathbf{w}_1 \quad \mathbf{w}_2^*]^T, \tag{7}$$

$$\tilde{\mathbf{r}} \triangleq [r_1 \quad r_2^*]^T = \mathbf{H} \cdot \mathbf{s} + \tilde{\mathbf{w}}. \tag{8}$$

Then, equation (5) can be combined into,

$$\tilde{\mathbf{s}} = \frac{\mathbf{H}^\dagger \cdot \tilde{\mathbf{r}}}{\mathbf{h}^\dagger \cdot \mathbf{h}} = \frac{\mathbf{H}^\dagger \cdot \mathbf{H}}{\mathbf{h}^\dagger \cdot \mathbf{h}} \cdot \mathbf{s} + \tilde{\mathbf{w}} = \mathbf{A} \cdot \mathbf{s} + \tilde{\mathbf{w}}, \tag{9}$$

where we have implicitly defined the equivalent system matrix of the Alamouti scheme $\mathbf{A} \triangleq \frac{\mathbf{H}^\dagger \cdot \mathbf{H}}{\mathbf{h}^\dagger \cdot \mathbf{h}}$ where \mathbf{H}^\dagger is the conjugation of the channel matrix \mathbf{H} . With respect to equation (9) it is easily observed that, $\frac{\mathbf{H}^\dagger}{\mathbf{h}^\dagger \cdot \mathbf{h}} = \mathbf{H}^{-1} \rightarrow \mathbf{A} = \mathbf{I}$, where \mathbf{I} is the identity matrix. In other words, after processing by the adequate combining operations at the receiver the Alamouti scheme results in a trivial linear system.

The generalization of the Alamouti scheme to a system with an arbitrary number N of receiver antennas is equally trivial. Specifically, let the generalised channel vector and corresponding equivalent channel matrix be respectively defined as

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$$\mathbf{h} \triangleq \begin{bmatrix} h_{11} \\ h_{12} \\ \vdots \\ h_{N1} \\ h_{N2} \end{bmatrix} \quad \text{and} \quad \mathbf{H} \triangleq \begin{bmatrix} h_{11} & h_{12} \\ h_{12}^* & -h_{11}^* \\ \vdots & \vdots \\ h_{N1} & h_{N2} \\ h_{N2}^* & -h_{N1}^* \end{bmatrix} \quad (10)$$

Then, we may succinctly write

$$\bar{\mathbf{r}} = \mathbf{A} \cdot \mathbf{s} + \bar{\mathbf{w}}, \quad (11)$$

With*

$$\bar{\mathbf{r}} = \frac{\mathbf{H}^\dagger}{\mathbf{h}^\dagger \cdot \mathbf{h}} \cdot \mathbf{r} \quad \text{and} \quad \bar{\mathbf{w}} = \frac{\mathbf{H}^\dagger}{\mathbf{h}^\dagger \cdot \mathbf{h}} \cdot \mathbf{w}, \quad (12)$$

where again it is easy to observe that $\mathbf{A} = \mathbf{I}$, such that in this (Alamouti) case $\bar{\mathbf{r}} = \mathbf{r}$.

In possession of the estimated symbol vector $\bar{\mathbf{s}}$, the symbols can then be detected independently, i.e.

$$\tilde{\mathbf{s}}_k = \min_n \{ |\mathbf{S}_n - \tilde{\mathbf{s}}_k| \}, \quad \forall \mathbf{k} \in \{1, \dots, K\}, \quad (13)$$

where \mathbf{S}_n is the n -th element of the symbol constellation \mathbf{S} from which the symbols s_k 's are drawn.

B. The V-BLAST Scheme

Next, let us briefly revise the V-BLAST scheme [10] with K transmit and N receive antennas. Consider the symbol and the noise vectors respectively to be,

$$\mathbf{s} \triangleq [s_1 s_2 \dots s_K]^T \quad \text{and} \quad \mathbf{w} \triangleq [w_1 w_2 \dots w_N]^T, \quad (14)$$

and the channel matrix defined by

$$\mathbf{H} \triangleq \begin{bmatrix} h_{11} & \dots & h_{1K} \\ \vdots & \ddots & \vdots \\ h_{N1} & \dots & h_{NK} \end{bmatrix}, \quad (15)$$

such that the received signal vector under the V-BLAST scheme can be written as

$$\mathbf{r} = \mathbf{H} \cdot \mathbf{s} + \mathbf{w}. \quad (16)$$

The latter linear system is fully determined for $K = N$, over-determined for $K < N$ and under-determined for $K > N$. Since in the latter case only a portion N of the total number K of symbols can be recovered, we shall ignore this degenerate case and hereafter focus on the cases where $K \leq N$. Under this assumption equation (16) can be transformed into a fully determined equivalent linear system by

$$\bar{\mathbf{r}} = \mathbf{H}^\dagger \cdot \mathbf{r} = \mathbf{H}^\dagger \cdot \mathbf{H} \cdot \mathbf{s} + \bar{\mathbf{w}} = \mathbf{A} \cdot \mathbf{s} + \bar{\mathbf{w}}, \quad (17)$$

where $\mathbf{A} \triangleq \mathbf{H}^\dagger \cdot \mathbf{H}$ and $\bar{\mathbf{w}} \triangleq \mathbf{H}^\dagger \cdot \mathbf{w}$.

The similarity between equations (9) and (17) can be immediately recognised. However, unlike the Alamouti case $\mathbf{A} \neq \mathbf{I}$, which implies that $\bar{\mathbf{r}} \neq \mathbf{r}$, such that the linear system in equation (17) needs to be inverted. Furthermore, the system matrix \mathbf{A} has unequal norms. The iterative approach is summarized where we first convene that $\langle \mathbf{A} \rangle_n$ denotes the column of the matrix \mathbf{A} such that the n -th row of its inverse \mathbf{A}^{-1} has the smallest norm. Next, let the operation of replacing the n -th column of \mathbf{A} with zeros be denoted by $\mathbf{A}|_{\langle \mathbf{A} \rangle_n \leftarrow 0}$, and define the sequence of iteratively constructed matrices

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$$G_1 \triangleq [A + \rho I]^{-1}, \tag{18a}$$

$$G_2 \triangleq [A|_{\langle A \rangle_{i_1 \leftarrow 0}} + \rho I]^{-1}, \tag{18b}$$

$$\vdots$$

$$G_K \triangleq [A|_{\langle A \rangle_{\{i_1, i_2, \dots, i_{K-1}\} \leftarrow 0}} + \rho I]^{-1}, \tag{18c}$$

where $\rho \triangleq \text{SNR}^{-1}$.

Notice that from the sequence of operations shown above, we obtain an ordered set of indices $I_{\text{BLAST}} \triangleq \{i_1, i_2, \dots, i_K\}$ where i_K is the remaining element not in $\{i_1, i_2, \dots, i_{K-1}\}$ such that the i_k -th symbol in s is the one that undergoes the i_k -th most favourable equivalent channel.

The estimates for all the transmitted symbols are retrieved optimally via the iteration,

$$\xi_{i_k} = \langle G_k, r_k \rangle_{i_k}, \tag{19}$$

$$\hat{s}_{i_k} = \min_n \{|S_n - \xi_{i_k}|\}, \tag{20}$$

$$r_{k+1} = r_k - \langle A \rangle_{i_k}^T \cdot \hat{s}_{i_k}. \tag{21}$$

where $r_1 \triangleq r$ and we have in equation (20) utilised a implicitly defined extension of the notation introduced above so by writing $\langle G_k, r_k \rangle_{i_k}$ to denote the i_k -th row of the k -th iteration of the estimate symbol vector $\tilde{r} = G_k \cdot r_k$.

C. The Alamouti-BLAST Scheme

From the above revision of the Alamouti and the V-BLAST schemes, it can be observed that both techniques are not fundamentally distinct, in so far as both lead to linear systems with system matrices obtained from channel gains. However, in the Alamouti case, the parity (in terms of column norms) encountered in the system matrices, offers an advantage of diversity gain at the expense of a reduction in total rate; while the V-BLAST scheme sacrifices diversity gain in favour of maintaining a full rate.

Let us consider a system for combining both the design objectives in which the signals are first encoded according to the Alamouti scheme, and then spatially multiplexed and detected according to the V-BLAST algorithm, so as to retain the space-time diversity gain offered by the former while achieving the higher rates afforded by the latter. To this end, consider a technique proposed in [16] where an ensemble of K synchronous co-channel users with two transmit antennas each, transmit to a common receiver with N receive antennas. Then, define the equivalent channel of matrix corresponding to the k -th user and the N receive antennas given by,

$$H \triangleq \begin{bmatrix} h_{1,2k-1} & h_{1,2k} \\ h_{1,2k}^* & -h_{1,2k-1}^* \\ \vdots & \vdots \\ h_{N,2k-1} & h_{N,2k} \\ h_{N,2k}^* & -h_{N,2k-1}^* \end{bmatrix}, \tag{22}$$

such that the equivalent multi-access channel matrix corresponding to the entire system can be written as,

$$\bar{H} = [H_1 \dots H_K]. \tag{23}$$

The corresponding system can be concisely defined by,

$$\tilde{r} = \bar{H}^\dagger \cdot \tilde{r} = \bar{H}^\dagger \cdot \bar{H} \cdot s + \bar{H}^\dagger \cdot \tilde{w} = A \cdot s + \tilde{w}, \tag{24}$$

with

$$\tilde{r} = \bar{H} \cdot s + \tilde{w}, \tag{25}$$

where similar to the above we have

$$s \triangleq [s_1 s_2 \dots s_{2K-1} \ s_{2K}]^T, \tag{26}$$

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$$\bar{w} \triangleq [w_1 w_2 \dots w_{2N-1} w_{2N}^*]^T, \text{ and} \quad (27)$$

$$\bar{r} \triangleq [r_1 \ r_2^* \dots r_{2N-1} \ r_{2N}^*]^T. \quad (28)$$

Notice that the system matrix A in equation (24) has pairwise equal-norm columns, but distinct norms amongst different pairs. Specifically, start by constructing the sequence of matrices

$$G_1 \triangleq [A + \rho I]^{-1}, \quad (29a)$$

$$G_2 \triangleq [A|_{\langle A \rangle_{p_1} \leftarrow 0} + \rho I]^{-1}, \quad (29b)$$

$$\vdots$$

$$G_K \triangleq [A|_{\langle A \rangle_{(p_1, p_2, \dots, p_{K-1})} \leftarrow 0} + \rho I]^{-1}, \quad (29c)$$

where we have implicitly extended the notation introduced earlier such that $\langle A \rangle_{p_k}$ denotes the p_k -th pair of columns of A , and correspondingly $\langle A \rangle_{\{p_1, p_2, \dots, p_{K-1}\}} \leftarrow 0$ denotes the nulling of the pairs of columns in the list $\{p_1, p_2, \dots, p_{K-1}\}$.

Given that the ordered set of index pairs $\mathbf{P} \triangleq \{p_1, p_2, \dots, p_K\}$, the corresponding symbol pairs are detected via the iteration

$$\tilde{s}_{p_k} = \langle \mathbf{G}_k, \mathbf{r}_k \rangle_{p_k}, \quad (30)$$

$$\hat{s}_{p_k(1)} = \min_n \{ |s_n - \tilde{s}_{p_k(1)}| \}, \quad (31a)$$

$$\hat{s}_{p_k(2)} = \min_n \{ |s_n - \tilde{s}_{p_k(2)}| \}, \quad (31b)$$

$$\mathbf{r}_{k+1} = \mathbf{r}_k - \langle A \rangle_{p_k}^T \hat{s}_{p_k}, \quad (32)$$

where \hat{s}_{p_k} and \tilde{s}_{p_k} denote 2-by-1 estimate/detected vectors corresponding to the p_k -th pair, and $\tilde{s}_{p_k(i)}$ and $\hat{s}_{p_k(i)}$ denote the i -th estimate/detected symbol of the p_k -th pair, respectively.

III. OVERLAPPED ALAMOUTI-BLAST

We now describe a system in which the Alamouti-BLAST system is overlapped in space. Here a single user is equipped with multiple transmit antennas and just with fewer receive antennas we can achieve better performance compared to conventional BLAST system.

A. Alamouti-BLAST Overlapped in Space

We now define a system that has the symbol vector with $2(K-1)$ symbols that can be given by,

$$\mathbf{s} \triangleq [s_1 s_2 \dots s_{2(K-1)}]^T, \quad (33)$$

and the symbols are in pairs given by s_{2k-1}, s_{2k} where $k = \{1, \dots, K-1\}$. The encoding matrix is given by,

$$\mathbf{C} = \begin{bmatrix} s_1 & s_2 + s_3 & \dots & s_{2k-2} + s_{2k-1} & s_{2k} \\ -s_2 & s_1^* - s_4^* & \dots & s_{2k-3}^* - s_{2k}^* & s_{2k-1}^* \end{bmatrix}. \quad (34)$$

The received vector is given similarly to the above schemes, namely

$$\bar{\mathbf{r}} = \bar{\mathbf{H}} \cdot \mathbf{s} + \bar{\mathbf{w}}, \quad (35)$$

where $\bar{\mathbf{H}}$ is the equivalent channel matrix given by,

$$\bar{\mathbf{H}} = [H_1 \dots H_{p-1}], \quad (36)$$

where the equivalent channel matrix are in pairs P given for odd and even columns respectively given by,

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$$H_{2p-1} \triangleq \begin{bmatrix} h_{1,2p-1} & h_{1,2p} \\ h_{1,2p}^* & -h_{1,2p-1}^* \\ \vdots & \vdots \\ h_{N,2p-1} & h_{N,2p} \\ h_{N,2p}^* & -h_{N,2p-1}^* \end{bmatrix}, H_{2p} \triangleq \begin{bmatrix} h_{1,2p} & h_{1,2p+1} \\ h_{1,2p+1}^* & -h_{1,2p}^* \\ \vdots & \vdots \\ h_{N,2p} & h_{N,2p+1} \\ h_{N,2p+1}^* & -h_{N,2p}^* \end{bmatrix}. \quad (37)$$

We can now have a similar system corresponding to the above that is given by,

$$\bar{r} = \bar{H}^\dagger \cdot \bar{r} = \bar{H}^\dagger \cdot \bar{H} \cdot s + \bar{H}^\dagger \cdot \bar{w} = A \cdot s + \bar{w}, \quad (38)$$

so that the detection process is similar to that of the previous schemes, that is, feeding the MMSE-BLAST decoder with the system matrix $A \triangleq \bar{H}^\dagger \cdot \bar{H}$ and the vector $\bar{r} = \bar{H}^\dagger \cdot \bar{r}$.

B. Alamouti-BLAST Overlapped in Space and Time

Let us define a system that has the symbol vector with $K(K - 1)$ symbols that can be given by,

$$s \triangleq [s_1 s_2 \dots s_{4(K-1)}]^T. \quad (39)$$

The encoding matrix for this scheme can be defined as,

$$C = \begin{bmatrix} s_1 & s_2 + s_3 & & s_{2k} \\ -s_2^* + s_{2k+1}^* & s_1^* - s_4^* + s_{2k+2}^* + s_{2k+3}^* & \dots & s_{2k+1}^* + s_{4k}^* \\ -s_{2k+2} & s_{2k+1} - s_{2k+4} & & s_{4k-1} \end{bmatrix}, \quad (40)$$

such that the corresponding modified receive vector can once again be given by equation (35) only with the change in the construction of the equivalent channel matrix given by,

$$\bar{H} = [H_1 \dots H_{p-1} H_1^* \dots H_{p-1}^*], \quad (41)$$

with H_{2p-1} and H_{2p} as given in equation (37). The corresponding system is defined in equation (38).

IV. SIMULATIONS AND RESULT

The fundamental diversity rate trade-off between the Alamouti and V-BLAST schemes is illustrated in Figure 1.

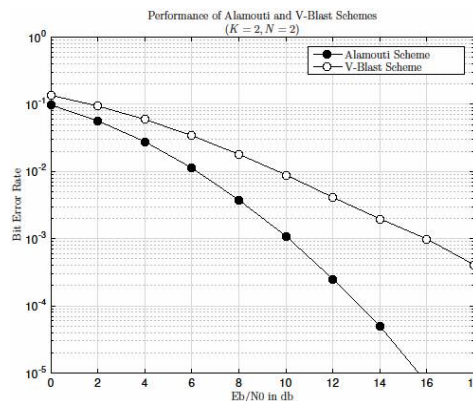


Figure 1: Comparison of conventional Alamouti and V-BLAST schemes

It is found that the two approaches are extreme opposites of the trade-off curves.

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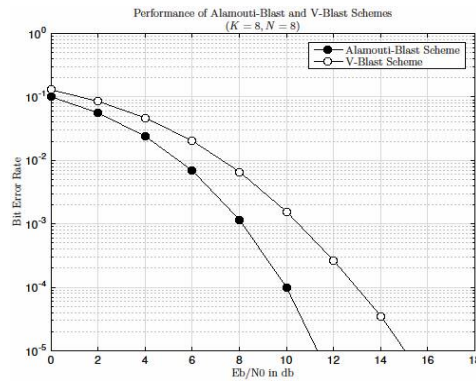


Figure 2: Comparison of Alamouti-BLAST and V-BLAST schemes

As illustrated in Figure 2, it can be observed that the performance of the V-BLAST scheme achieves significant diversity gain as the antennas grow in size and the curve comes closer to the Alamouti-BLAST scheme for large antenna system.

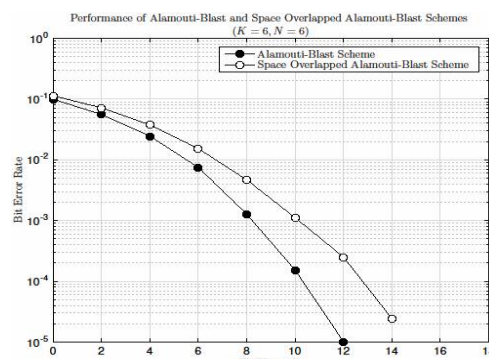


Figure 3: Comparison of Alamouti-BLAST and Space-Overlapped Alamouti-BLAST schemes

Figure 3 shows that the curve tends to come closer to the Alamouti-BLAST scheme with the overlapping of Alamouti codes in space.

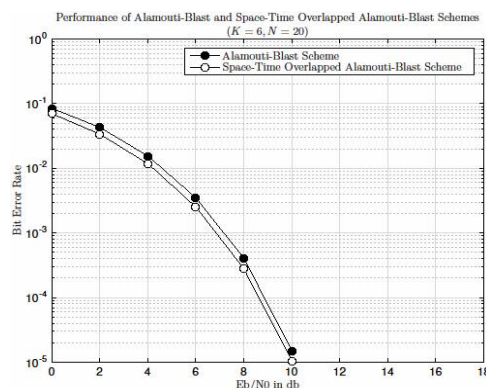


Figure 4: Comparison of Alamouti-BLAST and Space and Time Overlapped Alamouti-BLAST schemes

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The performance of the Space and Time Overlapped Alamouti-BLAST scheme illustrated in Figure 4 shows the significant improvement as the curve tends to cross the gain of the Alamouti-BLAST scheme.

V. CONCLUSION

The approach for a simple Massive MIMO scheme based on the overlap of space time codes is proposed. By overlapping the Alamouti codes in spatial dimension and decoding them with the MMSE-BLAST decoder, it is possible to achieve better gain in terms of diversity and multiplexing. The overlapping strategy proposed in space and time with better results, when implemented with more generic space time code constructions can be considered as a very simple and efficient method in order to scale the Massive MIMO systems.

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