Joint C-V-BLAST and DS-NOMA for Massive MIMO

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Abstract. We investigate the performance of modified non orthogonal multiple access (NOMA) which uses the modified low complexity Vertical Bell Laboratories Layered Space Time (C-V-BLAST) in an uplink massive multiple-input-multiple-output (MIMO) deployment with distributed single-antenna users and a large base-station array. Unlike previous work which assumes no spreading, we focus on the scenario where signal spreading is included by using the Gold Code family. It is shown that the proposed scheme provides a significant performance improvement over the conventional V-BLAST system for a large MIMO deployment when the number of transmit and receive antennas are comparable by exploiting the extra dimension added by the spreading to mitigate the interference. However, for a massive MIMO system, both schemes provide similar performance. We also show that the proposed scheme has a much better performance when the average received power for the users is the same, a scenario that the C-V-BLAST scheme struggles with due to its dependence on the ordering of users according to their power levels.

Keywords: Gold code · Massive MIMO · MRC
Non Orthogonal Multiple Access (NOMA) · V-BLAST

1 Introduction

It has been shown that massive multi-input multi-output (MIMO) systems increase throughput, the degrees of freedom, energy efficiency and reliability of wireless systems [1,2]. Hence, massive MIMO is one of the key proposed technologies for fifth generation (5G) systems. Due to the large number of base station (BS) antennas, finding the right tradeoff between system performance and receiver complexity is a critical concern.

One of the most successful receiver strategies for traditional MIMO is the Vertical Bell Laboratories Layered Space Time (V-BLAST) method. It is a multilayer symbol detection scheme. It combines linear (interference suppression) and

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nonlinear algorithms (serial cancellation). The majority of works on traditional V-BLAST consider the use of minimum-mean-square-error (MMSE) or zero forcing (ZF) detection. Therefore, conventional V-BLAST is too computationally intensive for massive MIMO. In [3], a modified V-BLAST scheme was proposed by replacing ZF or MMSE receivers with maximal ratio combining (MRC) and using a one-shot ordering method based on channel norms. This scheme, which is denoted as C-V-BLAST, has similar performance to linear ZF detection, but lower complexity. Both MRC and the single ordering technique were needed in [3] to obtain the reduction in complexity.

Non-Orthogonal Multiple Access (NOMA) techniques introduce redundancy by coding/spreading to facilitate the users signals separation at the receiver. In NOMA, multiple users are encouraged to transmit at the same time, code and frequency, but with different power levels. In fact, NOMA allocates less power to the users with better channel conditions, and these users can decode their own information by applying successive interference cancellation. Conventional V-BLAST with code division multiple access (CDMA) has been studied in [4–6]. NOMA for 5G has been studied such as in [7–10].

To the best of our knowledge, the performance of NOMA with C-V-BLAST in the context of massive MIMO has not been investigated. Thus, in this paper, our contribution is that we proposed a modified NOMA algorithm to investigate massive MIMO system performance. Instead of applying successive interference cancellation at each stage, we use the idea of C-V-BLAST by sorting the users once and this will reduce the receiver complexity. Each user data is spread using a Gold Code to provide further separation among the users resulting in an improved performance of the C-V-BLAST scheme with minor increase in complexity. We study the effect of power distribution of users and system size.

The rest of the paper is organized as follows. Section 2 introduces the system model. Section 3 gives an overview of receiver structures used in this work. Simulation results are provided in Sect. 4, and finally our conclusions are in Sect. 5.

2 System Model

We consider an uplink system with N_t single antenna user equipments (UEs) and a base station (BS) with N_r receive antennas. The vector, $\mathbf{s}$, of size $N_t \times 1$ is $\mathbf{s} = [s_1, s_2, \ldots s_{N_t}]^T$, where s_j is the data symbol of UE j drawn form a finite alphabet. The spreading code matrix $\mathbf{C}_c = [\mathbf{c}_1, \mathbf{c}_2, \ldots \mathbf{c}_{N_t}]$ and has a size of $N_t \times L_c$, where L_c is the code length. Note that $\mathbf{c}_j$ is vector of size $L_c \times 1$ representing the code of user j. In this paper we consider Gold Code for with $L_c = 127$. Suppose the transmitted data symbol matrix $\mathbf{X} = [\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_{N_t}]$ where, $\mathbf{x}_j = s_j \mathbf{c}_j$, $s_j = \{-1, 1\}$ and $j = 1, \ldots, N_t$. The channel matrix of size $N_r \times N_t$ is $\mathbf{H} = [\mathbf{h}_1 \cdots \mathbf{h}_{N_t}]$, where $\mathbf{h}_i = [h_{i1} h_{i2} \ldots h_{iN_r}]^T$. The noise matrix, $\mathbf{N}$, of size $N_r \times L_c$ has independent and identically distributed (i.i.d.) complex Gaussian elements, i.e., $n_i \sim \mathcal{CN}(0, \sigma^2)$. The received signal, $\mathbf{Y}$ of size $N_r \times L_c$, is given by

$$\mathbf{Y} = \mathbf{HX} + \mathbf{N} = \mathbf{Hs}\mathbf{C}_c^T + \mathbf{N}. \tag{1}$$

The transmitted signal power is $\mathrm{e}[|x_j|^2] = E_s = 1$ and the noise power is $\mathrm{e}[|n_i|^2] = \sigma^2$. When there is no spreading, $C = 1$ and $L_c = 1$.

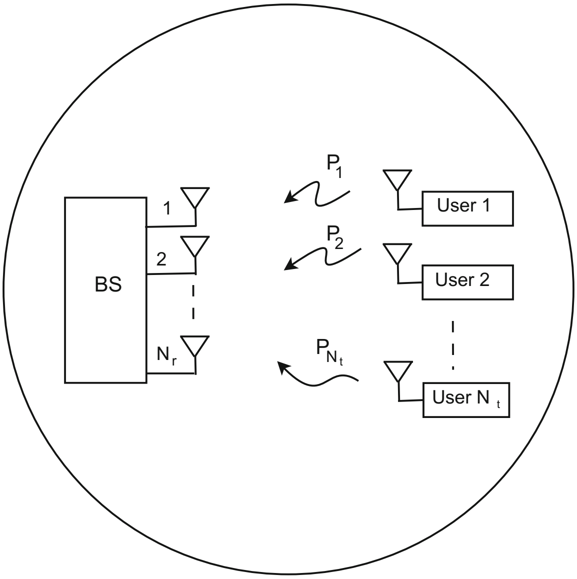

Fig. 1. System diagram where UEs are located randomly in a circular coverage area.

The channel matrix is given by

$$\boldsymbol{H} = \boldsymbol{U}\boldsymbol{P}^{\frac{1}{2}}. \tag{2}$$

The channel coefficient, h_{ij}, from UE j to receive antenna i has a link gain $\mathrm{e}[|h_{ij}|^2] = P_j$. The elements of $\boldsymbol{U}$ are i.i.d. $\mathcal{CN}(0, 1)$, and the link gain matrix is $\boldsymbol{P} = \mathrm{diag}(P_1, P_2, \ldots, P_{N_t})$ where P_j is the link gain of user j, which accounts for path loss, shadowing, etc. We utilize a simple model [11] so that the link gain of the j^{th} user can be calculated as $P_j = \mathcal{A}\beta^{j-1}$, where β controls the rate of decay of the link gains ($0 < \beta \leq 1$), and $\mathcal{A}$ is the link gain of the strongest UE. This model gives ordered link gains of the users such that $P_1 > P_2 > \cdots > P_{N_t}$. This has no effect on the generality of the results because the user order is arbitrary. As $\beta \to 0$ the link gains are dominated by one strong UE, while as $\beta \to 1$ the link gains become equal. This simple model is used in order to control the P_j's with a single parameter, β, which has a physical interpretation. Additionally, this model is useful because of the importance of the decay rate in V-BLAST, which is heavily dependent on the differences between the link gains.

3 Receivers

In this paper, we focus on MRC within a low complexity V-BLAST structure (C-V-BLAST) [3]. The simplest linear combiner, MRC, of the form, $\boldsymbol{H}^H\boldsymbol{Y}$, where $\boldsymbol{H}^H$ represents the complex conjugate transpose of $\boldsymbol{H}$. The linear zero forcing combiner in general performs better than MRC. The combining matrix of ZF is calculated by $\boldsymbol{W} = \boldsymbol{H}(\boldsymbol{H}^H\boldsymbol{H})^{-1}$. Note that ZF combiner involves matrix inversion which may be undesirable in massive MIMO because of stability and complexity issues.

The C-V-BLAST method [3] utilizes V-BLAST combined with MRC detection and a single ordering based upon instantaneous channel norms. This technique provides results similar to V-BLAST combined with linear ZF [3] while avoiding the computational bottlenecks of conventional V-BLAST. Assume ordered set $S^{(C)} = \{k_1^{(C)}, k_2^{(C)}, \ldots, k_{N_t}^{(C)}\}$ be a permutation of $\{1, 2, \ldots, N_t\}$, which decides the detecting order of $\boldsymbol{x}$. The ordering for C-V-BLAST is calculated by [3]

$$k_i^{(\mathrm{C})} = \underset{j \notin \{k_1, k_2, \ldots, k_{i-1}\}}{\arg\max} ||\boldsymbol{h}_j||^2. \tag{3}$$

We used the same receiver structure as the C-V-BLAST scheme but with an additional operation that processes the baseband received spread message for each user and de-spread it with its corresponding Gold Code. The output of the de-spreading block is applied to the C-V-BLAST detector for normal processing. Algorithm 1 shows the pseudo-code algorithm of the proposed (Gold C-V-BLAST) scheme. The de-spreading operation is relatively simple to implement with a total number of additional $N_t L_c$ complex multiplications.

In terms of the number of complex multiplications, the complexity of C-V-BLAST is $O(N_r N_t)$, but that of ZF is $O(N_r N_t^2)$ [3]. Table 1 shows a comparison of the implementation complexity of the proposed scheme to the ZF and C-V-BLAST.

Table 1. Complexity comparison

Technique	Complexity
ZF	$O(N_r N_t^2)$
C-V-BLAST	$O(N_r N_t)$
Gold C-V-BLAST	$O(N_r N_t + N_t L_c)$

4 Simulation Results

In this section, we use numerical simulations to investigate the performance of massive MIMO receivers.

Performance is measured by the symbol error rate (SER) assuming quadrature phase shift keying (QPSK) modulation. The results were averaged over the users and 10,000 independent channel realizations. In the figures, the SNR is the SNR of the strongest UE, given by $\frac{\mathcal{A}}{\sigma^2}$, where $\mathcal{A} = 1$ without loss of generality.

The C-V-BLAST receiver is used with and without spreading. Gold Code is used for spreading but other types of codes might be used as well. In this paper,

Algorithm 1. Gold C-V-BLAST Algorithm

1) Initialization:	
$i = 1$	i is the iteration number.
$\mathbf{c}$	$\mathbf{c}$ is the code matrix.
$\mathbf{y}$	$\mathbf{y}$ is the received signal.
$\mathbf{H}$	$\mathbf{H}$ is the channel matrix.
$\mathbf{k}$	Sort decently based on k_i.
	$k_i = \underset{j \notin \{k_1, k_2, \ldots, k_{i-1}\}}{\arg\max} \lVert \boldsymbol{h}_j \rVert^2$.
2) Iterative Process:	
$\mathbf{W} = \mathbf{H}$	Calculate the MRC linear combiner.
$\mathbf{G} = \mathbf{W}^H$	Find the Hermitian of the linear combiner, $\mathbf{W}$.
$\mathbf{m}_{k_i} = (\mathbf{G}_i)_{k_i}$.	$\mathbf{m}_{\mathbf{k_i}}$ is the i^{th} row of $\mathbf{G}$.
$\tilde{x_i} = \mathbf{m}_{ki}\mathbf{y}$	Calculate the estimated input signal $\tilde{x_i}$.
$\hat{x_i} = \hat{Q}[\sum_{i=1}^{L_c} \tilde{x_i}\mathbf{c}_{k_i}]$	$\hat{Q}(.)$ is the quantization (slicing) operation appropriate to the constellation in use.
$\mathbf{y}_{i+1} = \mathbf{y}_i - \mathbf{h}_{k_i}(\hat{x_{k_i}}\mathbf{c}_{k_i})$	The interference due to $\hat{x_{k_i}}\mathbf{c}_{k_i}$ is canceled.
$\mathbf{H}_{i+1} = \mathbf{H}_i^{\bar{k_i}}$	Update $\mathbf{H}$ at iteration i by zeroing the k_i column. This is denoted by $\mathbf{H}_i^{\bar{k_i}}$.
$i = i + 1$	Update i,.
$k_i = \mathbf{k}(i)$.	Update k_i index.

we consider the length of Gold Code with $L_c = 127$. We use [1 0 0 0 1 0 0] and [1 0 0 0 1 1 1] as the preferred polynomials for length 127 code generation [12]. We assume that the code is fixed for each user.

The baseline parameters are: $\beta = 0.7, N_t = 10, N_r = 100$ and the modified NOMA which C-V-BLAST uses Gold Code with length 127 (Gold C-V-BLAST 127). Where other parameters are used, they are given in the figure captions.

Figure 2 shows the SER performance of C-V-BLAST and Gold C-V-BLAST 127 vs SNR with $N_t = 10$, $\beta = 0.7$, $N_r \in \{10, 50, 100\}$. We notice that as N_r decreases and approaches N_t, spreading becomes beneficial since the C-V-BLAST system cannot cope with the high interference with the small number of antennas and the extra dimension added by the spreading is exploited to mitigate the interference. Note that when $N_r > N_t$, spatial diversity will improve the C-V-BLAST system performance and there is no gain from using the spreading scheme.

Figure 3 shows the SER performance of C-V-BLAST and Gold C-V-BLAST 127 vs SNR with $N_r = 10$, $\beta = 0.7$, $N_t \in \{10, 50, 100\}$. As N_t exceeds N_r with larger size, C-V-BLAST performance is already poor and hence spreading will not help much. When the ratio $N_r/N_t = 1$, coding becomes beneficial when the system size is small, i.e. small number of base station antennas.

Figure 4 shows the SER performance of C-V-BLAST and Gold C-V-BLAST 127 vs SNR with $N_r = 100$, $\beta = 0.7$, $N_t \in \{10, 50, 100\}$. It is observed that as Nt increases, the performance of both schemes improve but there is no performance difference with or without spreading. We have noticed that for systems with a large size (i.e. N_r/N_t exceeds 10), spreading is not beneficial.

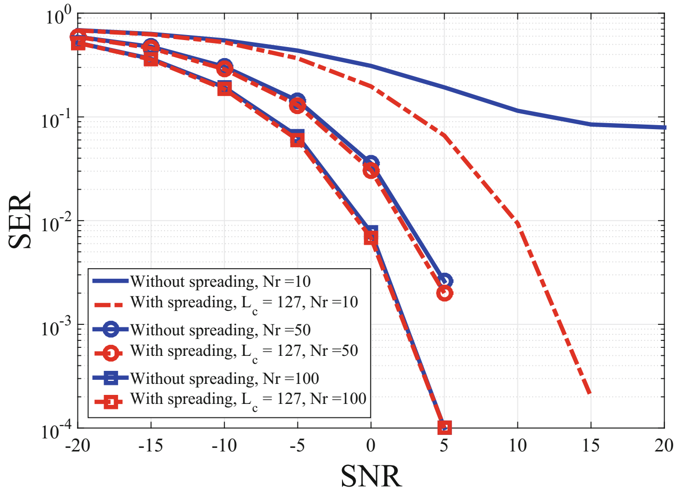

Fig. 2. SER versus SNR for C-V-BLAST (without spreading) and Gold C-V-BLAST 127 (with spreading). $N_t = 10$, $\beta = 0.7$, $N_r \in \{10, 50, 100\}$.

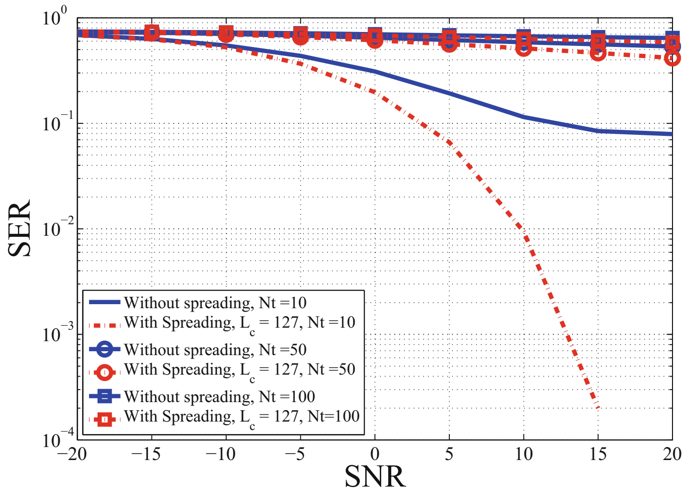

Fig. 3. SER versus SNR for C-V-BLAST (without spreading) and Gold C-V-BLAST 127 (with spreading). $N_r = 10$, $\beta = 0.7$, $N_t \in \{10, 50, 100\}$.

Figure 5 shows the SER performance of C-V-BLAST and Gold C-V-BLAST 127 with $N_t = 10, N_r = 10$, $\beta \in \{0.5, 0.9, 0.7\}$. The system performance is strongly affected by β. As β increases, the proposed scheme provides more improvement over the C-V-BLAST scheme, which suffers from poor performance when the channel link gain are not widely distinctive.

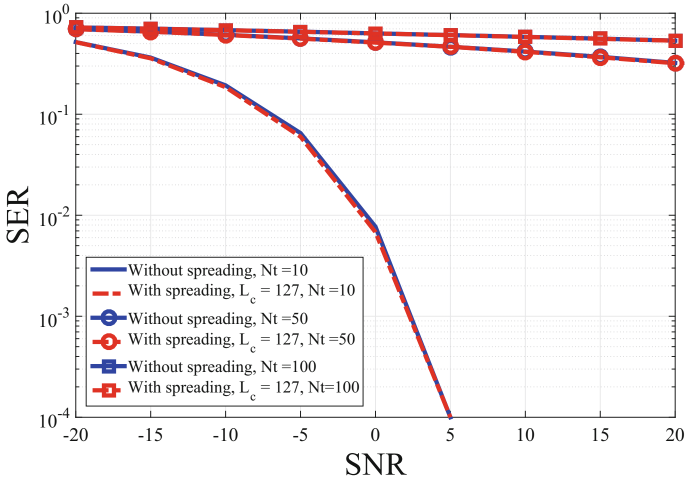

Fig. 4. SER versus SNR for C-V-BLAST (without spreading) and Gold C-V-BLAST 127 (with spreading). $N_r = 100$, $\beta = 0.7$, $N_t \in \{10, 50, 100\}$.

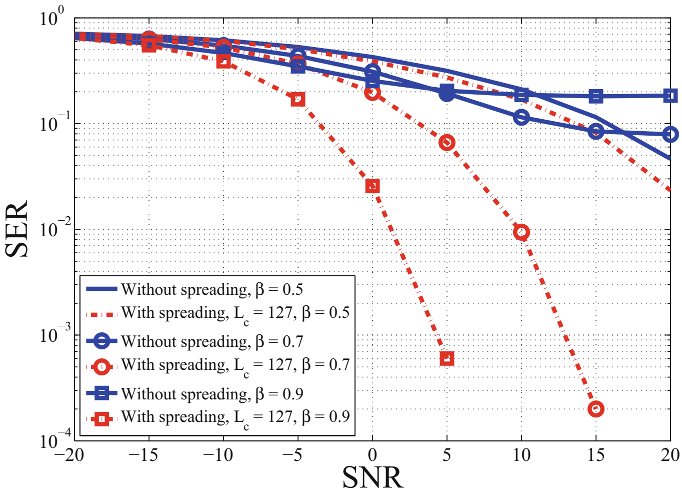

Fig. 5. SER versus SNR for C-V-BLAST (without spreading) and Gold C-V-BLAST 127 (with spreading). $N_t = 10, N_r = 10$, $\beta \in \{0.5, 0.9, 0.7\}$.

For more clarification of Fig. 5, the SER performance of C-V-BLAST and Gold C-V-BLAST 127 vs β with $N_t = \{10, 100\}, N_r = \{10, 100\}$ at SNR = 0 dB is presented in Fig. 6. It is noted that as β increases, the SER performance degrades. This is because C-V-BLAST works best when there is a wide difference among the users' powers but fails to perform adequately when the channel links have similar power levels. However, spreading the users' data using the Gold Codes results in good performance when the users have almost equal powers.

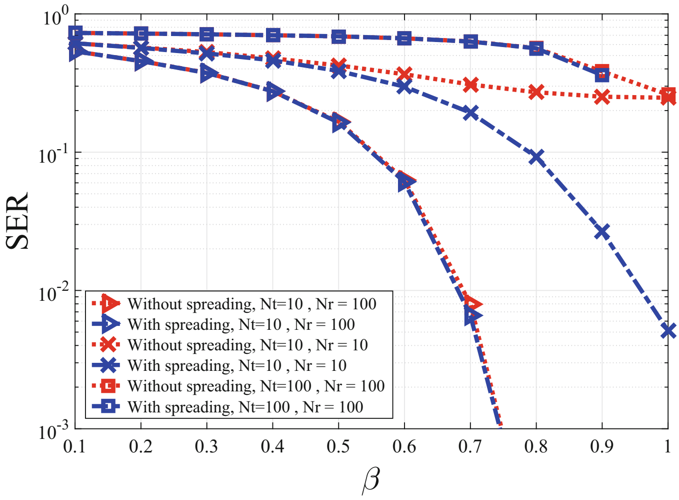

Fig. 6. SER versus β for C-V-BLAST (without spreading) and Gold C-V-BLAST 127 (with spreading). $N_t = \{10, 100\}, N_r = \{10, 100\}$ and SNR $= 0$ dB.

5 Conclusions

In this paper, we propose a modified NOMA scheme for uplink massive MIMO applications. The user data is spread using a Gold Code prior to transmission and a reduced complexity receiver based on C-V-BLAST structure is used. It is shown that spreading results in improved symbol error rate performance for large size MIMO system. However, for a massive MIMO system with a large number of receive antennas, there is no gain from spreading. Finally, the impact of the link gain difference among the users is investigated.

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