Symbol Mapping Optimization for Cooperative Systems with a Hybrid Search Algorithm

Rafael Fernandes Lopes, Marcelo Sampaio de Alencar and Omar Andrés Carmona Cortes

***Abstract*— Cooperative diversity is an important method that has been widely studied in the recent years. In this scheme, a source node wishing to transmit data to a destination node can benefit from other nodes in its neighborhood (relay nodes) to forward copies of the original signal to the destination. However, the performance of cooperative systems can be significantly improved by using the constellation rearrangement technique (CoRe), in which different signal constellations are used in different retransmissions. In this context, this paper proposes the use of a hybrid search algorithm, which uses genetic mutation and clonal selection, to perform the optimization of the constellation mapping. The performance evaluation of the algorithm shows that a good performance is achieved when compared to other approaches outlined in the literature.**

***Keywords*— Cooperative diversity, Constellation rearrangement, Symbol mapping.**

***Resumo*— Diversidade cooperativa é um importante método que vem sendo largamente estudado nos últimos anos. Nesse esquema, um nó origem que deseje transmitir dados para um nó destino pode se beneficiar de outros nós em sua vizinhança (*relays*) para realizar o reencaminhamento de cópias do sinal original ao destino. No entanto, o desempenho de sistemas cooperativos pode ser significativamente melhorado por meio do uso da técnica de rearranjo de constelações (CoRe – *Constellation Rearrangement*), em que diferentes constelações de sinais são utilizadas em diferentes retransmissões. Nesse contexto, este artigo propõe a utilização de um algoritmo híbrido de busca, que usa seleção clonal e mutação genética, para realizar a otimização do mapeamento de constelações. A avaliação de desempenho do algoritmo mostra que um bom desempenho é obtido quando se compara com outras abordagens apresentadas na literatura.**

***Palavras-Chave*— Diversidade cooperativa, Rearranjo de constelações, Mapeamento de símbolos.**

I. INTRODUCTION

Fading, caused by multipath propagation of electromagnetic signals, can significantly degrade the performance of digital wireless communications systems. Several methods have been proposed to improve the performance of these systems, including diversity techniques [1]–[4]. Basically, the diversity techniques generate a redundancy of the transmitted signals at the receiver, so that multiple versions of the original signal experience different fading and interference levels.

One important method that has been widely studied in recent years is the cooperative diversity [5], in which several network terminals combine their resources to improve the overall performance of the transmission. In this scheme, a source node that transmits data to a destination node can benefit from other nodes in its neighborhood (relay nodes) to forward copies of the original signal to the destination. The destination node performs an appropriate combination of all received signals, improving the performance of the communication system.

By the cooperation among multiple spatially distributed terminals, a virtual antenna array is formed. Therefore, multiple copies of the same signal are transmitted by independent communication channels and a diversity gain is achieved.

In the cooperative diversity scheme, two operation modes are studied in the literature: (a) amplify-and-forward (AF) and (b) decode-and-forward (DF). In the first approach, the relay nodes amplify the received signals before retransmiting them. On the other hand, in the second approach, the signals received by the relays are completely decoded and recoded before being forwarded to the destination. Thus, while in the AF scheme the relay nodes act as simple analog repeaters, in DF the relays operate as digital regenerative repeaters [6].

However, the performance of the cooperative systems can be significantly improved using the constellation rearrangement technique (CoRe) [6]–[9]. The CoRe technique can be applied to cooperative systems based on the DF scheme, in which different signal constellations are used in different retransmissions (with no changes in the modulation order). Therefore, the source node uses a different constellation from the one used by the relay node (the constellations may differ in the position of the constellation points and in the mapping of codewords). The CoRe technique is also named transmodulation [8], constellation change [7] and symbol mapping diversity [10].

The main aspect related to the use of the CoRe technique in cooperative systems is the design of the signal constellations to be used on different transmissions. An exhaustive search is impractical, since it requires a large number of operations. For instance, in a single relay case, the total number of constellations to be generated during the search is $16! = 2.0923 \times 10^{13}$ for 16-QAM constellations and $64! = 1.2689 \times 10^{89}$ for 64-QAM constellations.

To reduce the search space of the signal constellations optimization problem, different heuristics have been proposed in the literature [6], [8], [9] considering uniform constellations (*i.e.,* equally spaced points) and non-uniform constellations. In this context, this paper proposes the use of a hybrid search algorithm [11], based on clonal selection and genetic mutation, to perform the optimization of the symbol mapping on uniform constellations. The performance evaluation of the technique has shown that a good performance is achieved when compared to other approaches outlined in the literature.

This paper is organized as follows. Section II presents the system model. An analysis of the constellation mapping optimization problem in cooperative systems, as well as the formulation of the optimization model and of the hybrid

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optimization algorithm are described in Section III. The results of the performance analysis considering the use of the hybrid algorithm is presented in Section IV. Finally, Section V is devoted to the conclusions and future research.

II. SYSTEM MODEL

For simplicity, a network composed of three nodes is considered: a base station (BS), a relay station (RS) and a user terminal (UT), each of them using a single antenna. The RS cooperates with the UT transmissions, since it suffers from poor channel conditions. The DF strategy is used by the RS to collaborate with the transmissions. Due to hardware limitations, the relay can not transmit and receive simultaneously and a half-duplex transmission is assumed (the time division duplexing technique is adopted). Figure 1 illustrates the system model.

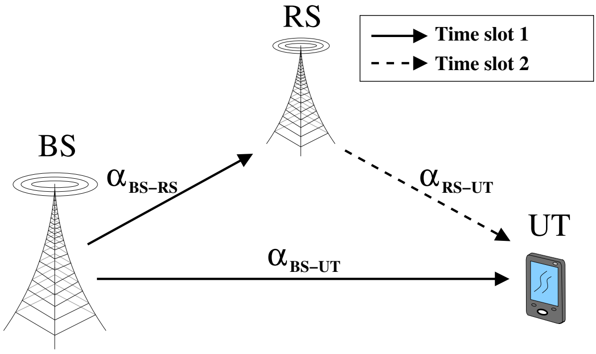


Fig. 1. System model of a single relay cooperative system.

In the proposed system, the BS transmits a packet containing L data bits to the RS in the first time slot. Due to the broadcast nature of the wireless communication channels, the UT also receives the packet transmitted by the BS. Then, the received packet is completely decoded by the RS node and its integrity is verified using a CRC (Cyclic Redundancy Check) code. If the packet has been correctly received, the RS retransmits the packet in the second time slot. Otherwise, the RS refrains from retransmitting the packet and a negative acknowledgment bit is sent to the BS, indicating that there were errors in the reception of the packet. In this case, the BS uses the second time slot to send the packet again to the UT. Finally, the UT uses both transmissions to decode the packet. In this protocol, the errors detected by the RS are not propagated to the UT. Furthermore, since the RS is fixed, it can be installed in a strategic location in which there is a line of sight between the BS and RS. Normalized M-QAM constellations are used in all transmissions, in which M is the number of constellation points.

On a conventional DF system, both BS and RS use the same constellations for all transmissions. On CoRe schemes, the BS and the RS use different signal constellations in each time slot. The symbols used in the first transmission (BS-RS and BS-UT) are defined as $\{s_1^{(1)}, s_2^{(1)}, \ldots, s_M^{(1)}\}$, and the symbols used in the second transmission (RS-UT) are defined as $\{s_1^{(2)}, s_2^{(2)}, \ldots, s_M^{(2)}\}$. Since the constellation points are represented by complex numbers, they are denoted as

$$s_k^{(1)} = x_k^{(1)} + jy_k^{(1)} \text{ and } s_k^{(2)} = x_k^{(2)} + jy_k^{(2)}, \tag{1}$$

in which k is the number of the symbol in the constellation.

The model for the channels BS-UT, BS-RS and RS-UT can be written as

$$r_{\text{BS-UT}} = \alpha_{\text{BS-UT}}\, s^{(1)} + z_{\text{BS-UT}}, \tag{2}$$

$$r_{\text{BS-RS}} = \alpha_{\text{BS-RS}}\, s^{(1)} + z_{\text{BS-RS}}, \tag{3}$$

$$r_{\text{RS-UT}} = \alpha_{\text{RS-UT}}\, s^{(2)} + z_{\text{RS-UT}}, \tag{4}$$

in which $\alpha_{\text{BS-UT}}$, $\alpha_{\text{BS-RS}}$ and $\alpha_{\text{RS-UT}}$ are the fading coefficients of each channel, and $z_{\text{BS-UT}}$, $z_{\text{BS-RS}}$ and $z_{\text{RS-UT}}$ represent the additive white Gaussian noise (AWGN) samples for each channel. For simplicity, the time indices of the samples were omitted.

It is assumed that the channel fading coefficients $\alpha_{\text{BS-UT}}$, $\alpha_{\text{BS-RS}}$ and $\alpha_{\text{RS-UT}}$ are known by the receivers. The coefficients $|\alpha_{\text{BS-UT}}|$ and $|\alpha_{\text{RS-UT}}|$ are modeled by Rayleigh random variables (*i.e.,* no line of sight exists between the UT and the other nodes), while the coefficients $|\alpha_{\text{BS-RS}}|$ are modeled by Rice random variables (*i.e.,* there is a line of sight between the BS and the RS). The noise samples $z_{\text{BS-UT}}$, $z_{\text{BS-RS}}$ and $z_{\text{RS-UT}}$ are modeled by circularly symmetric, independent and identically distributed complex Gaussian random variables with zero mean and variance $N_0/2$ by dimension. Thus, the value of the average signal-to-noise ratio (SNR) of each channel can be calculated by: $\bar{\gamma}_{\text{BS-UT}} = E[|\alpha_{\text{BS-UT}}|^2]/N_0$, $\bar{\gamma}_{\text{BS-RS}} = E[|\alpha_{\text{BS-RS}}|^2]/N_0$ and $\bar{\gamma}_{\text{RS-UT}} = E[|\alpha_{\text{RS-UT}}|^2]/N_0$.

The UT uses the signals received from the two independent branches (BS-UT and RS-UT) to achieve the spatial diversity. Furthermore, to properly combine the signals received from the RS and the BS, the UT employs the maximum-ratio combining (MRC) technique. Thus, based on the received symbols $r_{\text{BS-UT}}$ and $r_{\text{RS-UT}}$, an estimate of the transmitted symbol $\hat{s} = s_{\hat{i}}^{(1)}$ is performed, in which

$$\hat{i} = \underset{k=1,\ldots,M}{\operatorname{argmin}} \left\{ \left| r_{\text{BS-UT}} - \alpha_{\text{BS-UT}}\, s_k^{(1)} \right|^2 + \left| r_{\text{RS-UT}} - \alpha_{\text{RS-UT}}\, s_k^{(2)} \right|^2 \right\}, \tag{5}$$

and, for some symbol x, $|x|^2 = xx^*$. It is worth to mention that this detector requires a total of M comparisons to decode a symbol.

III. SYMBOL MAPPING OPTIMIZATION IN COOPERATIVE SYSTEMS

Similarly as in [9], the optimization process of the constellation mapping performed in this paper considers the minimization of the union bound (UB) [12] of the system symbol error rate (SER), given by

$$P_S \leq P_S^{\text{UB}} = \frac{1}{M} \sum_{i=1}^{M} \sum_{\substack{j=1,\\ j\neq i}}^{M} P(\mathbf{s}_i \to \mathbf{s}_j), \tag{6}$$

in which $\mathbf{s}_i = [s_i^{(1)} s_i^{(2)}]$, $s_i^{(k)}$ denotes the i-th symbol of the k-th constellation, M is the number of constellation points and $P(\mathbf{s}_i \to \mathbf{s}_j)$ represents the pairwise error probability (PEP) that $\mathbf{s}_j$ is detected when $\mathbf{s}_i$ was transmitted.

Because the MRC receiver is assumed in the UT node, then the PEP for the cooperative system can be calculated solving (7). Thus, applying the Chernoff bound ($Q(x) \leq \exp(-x^2/2)$), performing the integration and omitting the constants (which are irrelevant to the optimization process), the constellation mapping optimization problem can be described as follows (as presented in [9])

$$\min_{\substack{s_i^{(1)}, s_i^{(2)},\\ \forall i \in \{1,\ldots,M\}}} \sum_{i=1}^{M} \sum_{j=i+1}^{M} \frac{1}{\left|s_i^{(1)} - s_j^{(1)}\right|^2 \left|s_i^{(2)} - s_j^{(2)}\right|^2}, \tag{8}$$

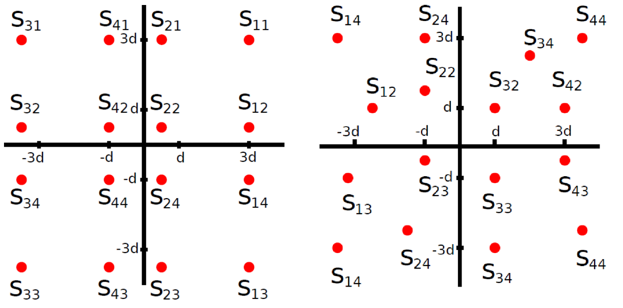
$$\text{subject to } \frac{1}{M} \sum_{i=1}^{M} \left|s_i^{(t)}\right|^2 \leq 1, \forall t, \tag{9}$$

$$s_i^{(1)}, s_i^{(2)} \in \mathbb{C}, \forall i, \tag{10}$$

in which $s_i^{(1)}$ and $s_i^{(2)}$ (for $1 \leq i \leq M$) correspond to the points of the constellation used, respectively, in the first and second transmissions and $\mathbb{C}$ is the set of complex numbers.

The objective function of the problem is shown (8). The constraint (9) limits the average energy per symbol for each transmission unit, and (10) implies that the constellation points may assume any value in the complex space.

Based on the presented optimization model, it is possible to generate a signal constellation that minimizes the system SER. In [9], the optimization is performed considering non-uniform constellations. Those constellations can be classified as: (a) decomposable and (b) non-decomposable. Decomposable constellations are those generated by the Cartesian product of two pulse amplitude modulation (PAM) constellations. On the other hand, the non-decomposable constellations are not necessarily formed by the Cartesian product of two PAM constellations. Figures 2(a) and 2(b) illustrate, respectively, examples of decomposable and non-decomposable constellations.



(a) Decomposable constellation. (b) Non-decomposable constellation.

Fig. 2. Examples of non-uniform 16-QAM constellations, obtained from [9].

In [9], an adaptation of the original model (to make it convex) was performed in the optimization of the decomposable constellations. Based on this new convex model, a local optimization technique was used to minimize the system SER. On the other hand, the optimization process of non-decomposable constellations is not a convex problem and, therefore, a local optimum does not necessarily represent a global optimum. Thus, in the optimization of the non-decomposable constellations, the authors of [9] used the previously obtained decomposable constellations as a starting point, but without the constraint of being formed by a Cartesian product of two PAM constellations.

However, the use of non-uniform constellations makes the system implementation more complex. Thus, more efficient optimization techniques should be employed to improve the system performance with the use of uniform constellations. In this context, this paper proposes the use of a hybrid search algorithm [11], which uses genetic mutation and clonal selection to perform the symbol mapping optimization on uniform constellations.

The hybrid algorithm combines three search techniques to improve its performed: hill-climbing, clonal selection and genetic algorithm. It was originally proposed in [11] and aims to improve the quality of the solutions found by combining the best features of each of the three techniques: the choice of the best solution for the next generation from the hill-climbing algorithms; the cloning of the best solution from the clonal selection algorithm; and the mutation operation from the genetic algorithms. This algorithm belongs to a class of solutions of optimization problems called evolutionary strategies, since it is based on the process of natural evolution of the species to search for satisfactory solutions

Similarly to the genetic algorithms [13], in the hybrid algorithm each solution in the search space should be encoded as a chromosome. A chromosome is composed of a group of alleles (*i.e.,* the possible values that form each solution), each one arranged in a given position of the chromosome (named locus).

In this paper, each solution C is represented by a chromosome with length M (*i.e.,* the number of points of the constellation). In addition, each locus associates a symbol of the constellation $s \in \mathbb{C}$, to an integer value i, $0 \leq i \leq M-1$. In the symbol mapping problem, the encoding scheme of the chromosome C is subject to the following constraints: (a) an allele must be mapped (*i.e.,* all values of i, $0 \leq i \leq M-1$, should appear in the chromosomes); and (b) no alleles should be repeated (*i.e.,* the integer values i, $0 \leq i \leq M-1$, should not appear twice on the same chromosome). The pseudo-code of the hybrid algorithm is as follows.

Algorithm 1 Pseudo-code of the hybrid algorithm.

```
$C \Leftarrow$ Initialize_solution($M$);
Evaluation($C$);
while NOT(Termination Criteria) do
    $P \Leftarrow$ Clone($C, n_c$);
    $P' \Leftarrow$ Mutation($P$);
    $C \Leftarrow$ Evaluation($P'$);
end while
```

The algorithm starts with only one chromosome C that is randomly generated according to the previously discussed constraints. The process continues with the evaluation of chromosome C using the objective function presented in (8). This function is used to verify the improvement of the solutions during the interaction of the algorithm.

After this step, n_c clones of C are generated to create a new population of solutions P. The mutation operator is then applied on all chromosomes contained in P, generating a variety of new solutions (a new population P'). The same mutation operator classically adopted when solving the traveling salesman problem (TSP) with genetic algorithms [14] is used in the hybrid algorithm. The mutation operator works as follows: two different loci are randomly selected on a chromosome; the alleles positioned in those loci are then exchanged, generating a new chromosome.

After the mutation process, the new solutions are evaluated to determine which chromosome represents the best solution

$$P(s_i, s_j) = 4\int_0^\infty \int_0^\infty Q\left(\sqrt{\frac{\bar{\gamma}_{\text{BS-UT}}}{2}\ \alpha^2_{\text{BS-UT}}\ \left|s_i^{(1)} - s_j^{(1)}\right|^2 + \frac{\bar{\gamma}_{\text{RS-UT}}}{2}\ \alpha^2_{\text{RS-UT}}\ \left|s_i^{(2)} - s_j^{(2)}\right|^2}\right) \cdot \alpha_{\text{BS-UT}}\ \alpha_{\text{RS-UT}}\ \exp\left[-\alpha^2_{\text{BS-UT}}\right]\ \exp\left[-\alpha^2_{\text{RS-UT}}\right]\ d\alpha_{\text{BS-UT}}\ d\alpha_{\text{RS-UT}} \tag{7}$$

(*i.e.,* the chromosome that generates the mapping with the lowest evaluated cost). This chromosome is then defined as the new current solution C and it is preserved for the next iteration (whereas the other solutions are discarded). The algorithm can be easily adapted to preserve more solutions between two interactions, improving the performance of the algorithm (at the cost of an increased execution time). This process is repeated while the stopping criterion is not reached. In this paper, a number of 200 interactions (named generations) is adopted as the stopping criterion.

IV. RESULTS

This section presents the results of the performance evaluation of the a cooperative system based on the CoRe technique. The constellation mapping was optimized using the hybrid algorithm described in Section III. Furthermore, the performance of the constellation optimized with the hybrid algorithm is compared to the uniform and non-uniform (decomposable and non-decomposable) CoRe constellations. The protocol discussed in Section II is used in the evaluation.

Table I presents the constellation mappings used in the performance evaluation. Those mappings are classified according to the technique adopted to generate them: (a) conventional, (b) uniform, (c) non-uniform decomposable, (d) non-uniform non-decomposable and (e) hybrid uniform. In the conventional scheme, the same constellation is used in the BS and RS. In the uniform scheme, different uniform constellations (optimized by the heuristic proposed in [6]) are used in the cooperative system. The non-uniform constellations were obtained according to the techniques presented in [9], resulting in different constellations with irregularly spaced points. Finally, in the hybrid uniform scheme, the signal constellation optimization was performed using the hybrid algorithm presented in Section III. The number of generations and clones in the hybrid algorithm was defined as 300 and 200, respectively.

TABLE I

OPTIMIZED M-QAM CORE CONSTELLATIONS.

M	***Slot***	**Constellations** $\{s_1^{(t)}, s_2^{(t)}, \ldots, s_M^{(t)}\}$
Uniform Constellations		
16	$t = 1$	$\{-3-3j, -3-1j, -3+1j, -3+3j, -1-3j, -1-1j, -1+1j, -1+3j, 1-3j, 1-1j, 1+1j, 1+3j, 3-3j, 3-1j, 3+1j, 3+3j\} \times 0.3162$
	$t = 2$	$\{-1-1j, -1+3j, -1-3j, -1+1j, 3-1j, 3+3j, 3-3j, 3+1j, -3-1j, -3+3j, -3-3j, -3+1j, 1-1j, 1+3j, 1-3j, 1+1j\} \times 0.3162$
Non-Uniform Decomposable Constellations		
16	$t = 1$	$\{-3.05-3.05j, -3.05-0.84j, -3.05+0.84j, -3.05+3.05j, -0.84-3.05j, -0.84-0.84j, -0.84+0.84j, -0.84+3.05j, 0.84-3.05j, 0.84-0.84j, 0.84+0.84j, 0.84+3.05j, 3.05-3.05j, 3.05-0.84j, 3.05+0.84j, 3.05+3.05j\} \times 0.3162$
	$t = 2$	$\{-0.84-0.84j, -0.84+3.05j, -0.84-3.05j, -0.84+0.84j, 3.05-0.84j, 3.05+3.05j, 3.05-3.05j, 3.05+0.84j, -3.05-0.84j, -3.05+3.05j, -3.05-3.05j, -3.05+0.84j, 0.84-0.84j, 0.84+3.05j, 0.84-3.05j, 0.84+0.84j\} \times 0.3162$
Non-Uniform Non-Decomposable Constellations		
16	$t = 1$	$\{-1.87-3.78j, -3.48+1.13j, -1.23+1.77j, -2.18+3.63j, 2.56-1.90j, 0.19-2.40j, -3.61-1.10j, -1.04+0.23j, 1.66-3.72j, 1.73+0.15j, -1.67-1.25j, 0.68+3.86j, 4.05+0.19j, 2.95+2.42j, 0.44-0.93j, 0.83+1.71j\} \times 0.3162$
	$t = 2$	$\{0.09+0.46j, -0.95+2.34j, -2.47-3.02j, 1.60-0.10j, 3.26+0.09j, 0.34+4.05j, 1.34-2.17j, 3.35+2.46j, -2.18-1.23j, -2.97+2.67j, -4.05+0.13j, -1.81+0.33j, -0.17-1.49j, 1.11+2.08j, 0.15-4.20j, 3.37-2.41j\} \times 0.3162$
Hybrid Uniform Constellations		
16	$t = 1$	$\{-3-3j, -3-1j, -3+1j, -3+3j, -1-3j, -1-1j, -1+1j, -1+3j, 1-3j, 1-1j, 1+1j, 1+3j, 3-3j, 3-1j, 3+1j, 3+3j\} \times 0.3162$
	$t = 2$	$\{1-1j, 1+3j, -1-3j, -1+1j, -3+1j, 3-3j, -3+3j, 3-1j, 3+1j, -3-3j, 3+3j, -3-1j, -1-1j, -1+3j, 1-3j, 1+1j\} \times 0.3162$

The transmission of packets with 188 bytes (video packets) is assumed in the evaluation. The mapping schemes are compared in terms of the obtained cooperative system SER. Two different scenarios were simulated: (a) the symmetric case, in which all channels are subject to the same SNR (*i.e.,* $\bar{\gamma}_{\text{BS-UT}} = \bar{\gamma}_{\text{BS-RS}} = \bar{\gamma}_{\text{RS-UT}}$), and (b) the non-symmetric, in which the channels have different SNR values, since the UT is usually closer to the RS than the BS (*i.e.,* $\bar{\gamma}_{\text{BS-RS}} = \bar{\gamma}_{\text{RS-UT}} + 15$ dB, $\bar{\gamma}_{\text{BS-UT}} = \bar{\gamma}_{\text{RS-UT}} - 15$ dB). In addition, the Rice factor used in the BS-RS link was defined as $K = 10$ dB. Figure 3 presents the performance, in terms of SER, of the different CoRe schemes applied to the 16-QAM modulation scheme.

As can be seen in Figure 3, the hybrid uniform scheme generated a lower SER than the conventional, uniform and non-uniform decomposable schemes. Only the non-uniform non-decomposable presented a lower SER than that obtained with the hybrid algorithm (in both symmetric and non-symmetric cases).

In the non-symmetric case, the hybrid uniform scheme presented gains of 2.53 dB, 0.30 dB and 0.18 dB when compared, respectively, to conventional, uniform and non-uniform decomposable schemes (considering a SER value of 10^{-3}). On the other hand, the use of constellations generated with the hybrid uniform scheme has presented a loss of 0.17 dB when compared to non-uniform non-decomposable constellations. However, it is important to emphasize that the use of non-uniform constellations increases the complexity of the system implementation.

The gains obtained in the symmetric case are similar to the non-symmetric case. Thus, gains of 2.50 dB, 0.32 dB and 0.18 dB were obtained by the hybrid uniform scheme in comparison to the conventional, uniform and non-uniform decomposable schemes (considering a reference SER value of 10^{-3}), respectively. However, that scheme presented a loss of 0.21 dB in relation to the non-uniform non-decomposable scheme, at the cost of a higher system complexity.

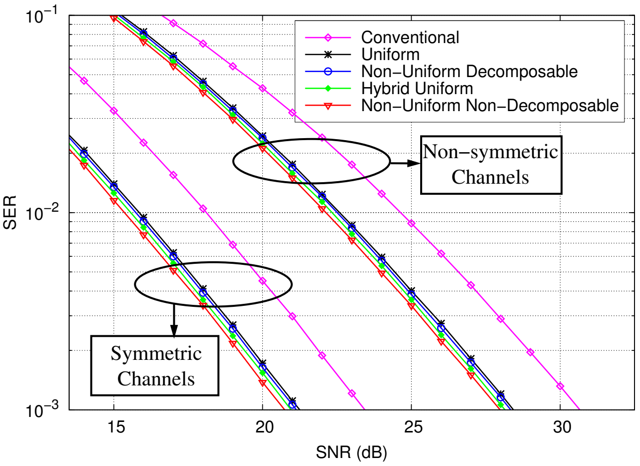


Fig. 3. Performance of the different CoRe schemes in terms of system SER (16-QAM).

By the presented analysis, one can note that the use of the hybrid uniform scheme represents a good solution to the constellation mapping optimization problem in cooperative systems. Although the hybrid algorithm requires a greater number of executions than the other approaches (which are mainly based on heuristics and local optimization techniques), this scheme has generated constellations with good performances in terms of SER. However, the execution time of the optimization algorithm is not a critical aspect to the problem, since the optimization is not performed with the system in operation. Furthermore, the performance evaluation has shown that the symbol mapping obtained with the hybrid algorithm presents a lower SER than the one obtained by the non-uniform decomposable scheme which requires a high complexity transceiver.

V. CONCLUSION AND FUTURE RESEARCH

Diversity schemes have been widely exploited to mitigate the effects of wireless communications channels, and the cooperative diversity techniques are an effective alternative to improve the performance of communications networks without increasing the system bandwidth.

Cooperative diversity implies that several network terminals combine their resources to improve the transmission performance. In this scheme, a source node that transmits data to a destination node can benefit from other nodes in its neighborhood (relay nodes) to forward copies of the original signal to the destination. By the cooperation between multiple spatially distributed terminals, a virtual antenna array is formed. Multiple copies of the same signal are transmitted by independent communication channels to achieve a diversity gain.

The performance of the cooperative systems can be significantly improved using the constellation rearrangement (CoRe) technique. The CoRe technique can be applied to cooperative systems based on the DF scheme, in which different signal constellations are used in different retransmissions (without changes in the modulation order).

In this paper, a hybrid search algorithm, based on clonal selection and genetic mutation, is used to optimize the symbol mapping of uniform constellations in cooperative systems. The evaluation of the technique has shown that a good performance is achieved when compared to other approaches outlined in the literature (such as [9]), without increasing the system complexity.

It is important to note that the solution proposed in this paper is not intended to improve the convex optimization process proposed in [9] for non-uniform decomposable constellations. Instead, the heuristic search has been used to improve the original uniform CoRe scheme, achieving better results for 16-QAM than the non-uniform decomposable constellation presented in [9].

In the future, the authors intend to extend the presented analysis to higher order constellations (such as the 64-QAM) to determine whether gains of the same order are obtained. Furthermore, the obtained mapping schemes can be combined with other diversity (such as modulation diversity) and encoding techniques to further improve the performance of the cooperative systems.

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