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Abstract—This letter presents a joint scheme of receive antenna selection and symbol detection for multiple-input, multiple-output (MIMO) systems based on the maximum likelihood (ML) criterion. To mitigate the computational complexity, a novel variant of the genetic algorithm (GA) is addressed to solve the nonlinear optimization involved, where a new heterogeneous crossover and a new heterogenous mutation are conducted in the chromosome evolution process. Furnished simulations show that the new approach provides superior performance with substantially lower computational load compared with previous works in both correlated and uncorrelated channels.

Index Terms—Symbol detection, genetic algorithm, antenna selection, heterogenous crossover/mutation, MIMO.

I. INTRODUCTION

In multiple-input, multiple-output (MIMO) systems, multiple antennas, deployed at both the transmitter and the receiver, can effectively enhance the transmission rate with spatial multiplexing and the quality of service with appropriate space-time coding. The hardware cost such as the RF chains, however, increases with the number of antenna elements. One effective approach is based on the concept of the antenna selection scheme [1], [2], [3], where only a subset of transmit or receive antennas is employed.

Various approaches have been addressed for the receive antenna selection without significantly degrading the performance. For example, Gore et al. [2] designed the optimal receiver based on the maximum likelihood (ML) criterion and then devised an antenna selection scheme to approach the theoretic bound achievable by this receiver. Dai et al. [3] considered a zero-forcing (ZF) detector and a subset of receive antennas is then selected accordingly to minimize the symbol error rate (SER). Despite their effectiveness, such approaches, however, can not guarantee to attain the optimum antenna selection subset due to the use of the approximated theoretic bound or achieve the best SER performance as the optimum antenna subset does not necessarily yield ideal performance.

To mitigate the performance loss incurred in the antenna selection, this letter jointly considers the receive antenna selection scheme and the receiver for symbol detection based on the ML criterion. Moreover, to alleviate the computational complexity, a genetic approach is also proposed to succinctly solve the nonlinear optimization involved. The genetic algorithms (GAs) have been successfully applied to the antenna selection or symbol detection in MIMO systems. For instance, Guo et al. [4] employed the GA for transmit antenna selection to maximize the MIMO channel capacity. Also, Hong et al. [5] considered an ML-based symbol detection based on the GA. However, the conventional GA (the GA uses the standard crossover and standard mutation operations developed in [6]) employed in [4] may encounter the difficulty that the number of the selected antennas, corresponding to the number of genes with 1’s, may not be equal to the prescribed one. To account for different generic natures of the antenna selection and symbol detection, a novel variant of the GAs, referred to as the heterogeneous GA (HGA), is also proposed, where each chromosome consists of two parts, an integer string for the antenna selection and a bit string for the symbol detection. Furthermore, the HGA employs a new heterogeneous crossover and a new heterogeneous mutation in the chromosome evolution process. Furnished simulations show that the HGA provides superior performance with substantially lower computational complexity compared with previous works for both correlated and uncorrelated channels.

II. SYSTEM MODEL

Consider a spatial multiplexing MIMO system with $M_T$ transmit and $M_R$ receive antenna elements, the received data in the $k^{th}$ sample time, can then be expressed as [1], [2], [3]

$$r(k) = \sqrt{\frac{E_s}{M_T}} H s(k) + n(k)$$

where $r(k) = [r_1(k), r_2(k), \cdots, r_{M_R}(k)]^T$ is the $M_R \times 1$ received vector, in which $r_i(k), 1 \leq i \leq M_R$, is the output of the $i^{th}$ receive antenna, and $(j)^T$ denotes transposition. $s(k) = [s_1(k), s_2(k), \cdots, s_{M_T}(k)]^T$ is the $M_T \times 1$ transmitted symbol vector with $s_i(k), 1 \leq i \leq M_T$, being statistically independent, BPSK modulated, and transmitted with the same power of $E_s/M_T$ from the $i^{th}$ transmit antenna. $n(k)$ denotes the $M_R \times 1$ complex Gaussian noise vector with zero mean and covariance matrix $N_0I_{M_R}$, where $I_{M_R}$ is an $M_R \times M_R$ identity matrix. For flat fading channels, the channel matrix $H$ can be represented as $H = R_R^{1/2} H_w R^T_R$, where $R_R$ and $R_T$ denote an $M_R \times M_R$ receive covariance matrix and an $M_T \times M_T$ transmit covariance matrix, respectively, and $H_w$ is an $M_R \times M_T$ spatially white matrix with i.i.d., zero mean, and unit variance complex Gaussian elements.

III. THE PROPOSED GA SCHEME

Assume that the perfect channel state information is available at the receiver. Then, based on the ML criterion, the

Manuscript received July 3, 2008. The associate editor coordinating the review of this letter and approving it for publication was C. Comaniciu.

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This work is supported in part by the National Science Council of R.O.C. under contract number NSC 96-2221-E-011-012.

Digital Object Identifier 10.1109/LCOMM.2009.081036

1089-7798/09$25.00 c 2009$ IEEE
over possible candidates in requires an enormous amount of computations to search all part containing.

Step 0: Initialization:

The overall procedures of the HGA are delineated as follows:

- **Exchange - empty:**
  - **Antenna selection part:**
    - Parent A: 1111 1111
    - Crossover mask: 0111 1101
    - Offspring A: 1111 1111
  - **Symbol detection part:**
    - Parent A: 1111
    - Crossover mask: 0111 1101
    - Offspring A: 1111

Fig. 1. Illustration of the heterogeneous crossover operation

joint scheme of the receive antenna selection and the symbol detection can be readily shown to be

\[
\hat{s}(k), \hat{\mathbf{H}} = \arg \min_{s(k) \in S, \mathbf{H} \in \mathcal{U}} \| \mathbf{r}(k) - \sqrt{\frac{E_s}{M_T}} \hat{\mathbf{H}} s(k) \|\quad (2)
\]

where \( \mathcal{U} \) is the set of all possible sub-blocks of channel matrix, selecting \( N_R \) out of the \( M_R \) receive antennas, \( S \) is the set of all possible symbol vectors, and \( \mathbf{r}(k) \) is obtained by deleting the corresponding elements in (1). This ML approach, however, requires an enormous amount of computations to search all over possible candidates in \( \mathcal{U} \) and \( S \).

To mitigate the computations, in the following we consider a GA-based approach. For the joint optimization problem in (2), we consider a variant of the GA, the HGA, where every (heterogeneous) chromosome consists of two parts: the antenna selection part and the symbol detection part. However, if we employ the conventional GA [5], [6] for the antenna selection part by associating it with a bit string with genes being 1’s to denote the selection of the corresponding antenna elements, the total number of the antennas selected could be different in the evolution process and may not meet the prescribed one. To overcome this dilemma, the genes in the antenna selection part are now an integer string denoting the priority in choosing the desired receive antennas, whereas the ones in the symbol detection part are a bit string denoting the detected output. Furthermore, a heterogeneous mechanism is addressed, modifying the two main steps of the conventional GA, namely, the crossover and the mutation operations. The overall procedures of the HGA are delineated as follows:

**Step 0: Initialization:**

- First, we construct the parent population containing \( P \) heterogeneous chromosomes, where \( P \) is the population size. Each chromosome consists of two parts: the antenna selection part containing \( M_R \) genes and the symbol detection part containing \( M_T \) genes. For the former, the genes are a random permutation of \( \{1 \cdots M_R\} \). We associate every receive gene at the \( i \)th position with the \( i \)th receive antenna element and genes with a larger value indicate a higher antenna selection priority. Such an initialization scheme with the following manipulations ensures the genes in the antenna selection part of the chromosomes remain a permutation of \( \{1 \cdots M_R\} \) throughout the iterations so antenna selection can be achieved by the resulting gene values. The gene values in the symbol detection part are randomly chosen as 1 or -1. For example, if \( M_R = 4, N_R = 2, M_T = 2 \), two parent heterogeneous chromosomes, \( \mathbf{A} \) and \( \mathbf{B} \), are as shown in Fig. 1, where parent chromosome \( \mathbf{A} \) indicates that the receive antennas \( \{1, 4\} \) will be selected and the estimated symbol vector is \([-1 1]^T\). Hence the selected channel \( \hat{\mathbf{H}} \) for (2) is formed by the \( \{1, 4\} \) rows of the channel matrix \( \mathbf{H} \). Likewise, for parent chromosome \( \mathbf{B} \), the selected channel \( \hat{\mathbf{H}} \) is formed by the \( \{1, 3\} \) rows of the channel matrix \( \mathbf{H} \) and the estimated symbol vector is \([1 -1]^T\).

**Step 1: Evaluation and Selection**

In each generation, the fitness values are computed for each of the \( P \) chromosomes of the parent population by substituting the corresponding selected channel matrix \( \hat{\mathbf{H}} \) and the estimated symbol \( s(k) \) into the joint ML decision statistic in (2). Thereafter, the \( T \) chromosomes with the smallest fitness values are chosen for a mating pool, from which two chromosomes are randomly selected for the next step.

**Step 2: Heterogeneous Crossover:**

The crossover between two heterogeneous chromosomes consists of two types of crossover operations: the priority crossover for the antenna selection part and the conventional crossover [6] for the symbol detection part. First, an \((M_R + M_T) \times 1\) sequence, referred to as the crossover mask, is constructed, consisting of 1’s and 0’s generated with equal probability [6]. When the elements of the crossover mask are 1’s, the genes of the two parent chromosomes in the corresponding positions will exchange. However, if they are 0’s, the genes in the antenna selection part will be emptied while those in the symbol detection part remain unchanged.

Next, we refill the missing gene values sequentially in a descending order in the antenna selection part of the chromosomes, beginning with genes of larger integer values before the aforementioned exchange-empty step. Also, the genes filled in are those integers not appearing after the exchange-empty step to ensure that genes with larger values still possess higher priority after crossover, simply reflecting the fitness-survival principle of the GA [6]. For example, the values of the first and the third genes are missing in the antenna selection part of offspring \( \mathbf{A} \), as shown in Fig. 1. Since the first and the third genes of parent \( \mathbf{A} \) are with values 4 and 2, we thus fill in 4 and 3 in offspring \( \mathbf{A} \), respectively, in these two positions as these two integers do not appear after the exchange-empty step. Likewise, we will fill in the third and the first genes at the antenna selection part of offspring \( \mathbf{B} \) with 4 and 2, respectively, not appearing after the exchange-empty step. It is noteworthy that based on this new crossover, the genes at the antenna selection part of the chromosomes will always contain a permutation of \( \{1 \cdots M_R\} \), so the antenna selection can be easily made. This heterogeneous crossover operation will repeat until the number of the new population size is \( P \).

**Step 3: Heterogeneous mutation:**

As the above, there are two types of mutation operations: the priority mutation for the antenna selection part and the conventional mutation for the symbol detection part. First, for each chromosome, an \((M_T + 1) \times 1\) mutation mask, consisting of 1’s and 0’s generated according to the mutation probability \( p_m \), is created [6], where the first element and the remaining \( M_T \) elements account for the antenna selection part and the symbol detection part, respectively. If the first element of the
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