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A low-complexity hybrid algorithm based on particle swarm and ant colony optimization for large-MIMO detection

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ABSTRACT

With rapid increase in demand for higher data rates, multiple-input multiple-output (MIMO) wireless communication systems are getting increased research attention because of their high capacity achieving capability. However, the practical implementation of MIMO systems rely on the computational complexity incurred in detection of the transmitted information symbols. The minimum bit error rate performance (BER) can be achieved by using maximum likelihood (ML) search based detection, but it is computationally impractical when number of transmit antennas increases. In this paper, we present a low-complexity hybrid algorithm (HA) to solve the symbol vector detection problem in large-MIMO systems. The proposed algorithm is inspired from the two well known bio-inspired optimization algorithms namely, particle swarm optimization (PSO) algorithm and ant colony optimization (ACO) algorithm. In the proposed algorithm, we devise a new probabilistic search approach which combines the distance based search of ants in ACO algorithm and the velocity based search of particles in PSO algorithm. The motivation behind using the hybrid of ACO and PSO is to avoid premature convergence to a local solution and to improve the convergence rate. Simulation results show that the proposed algorithm outperforms the popular minimum mean squared error (MMSE) algorithm and the existing ACO algorithms in terms of BER performance while achieve a near ML performance which makes the algorithm suitable for reliable detection in large-MIMO systems. Furthermore, a faster convergence to achieve a target BER is observed which results in reduction in computational efforts.

1. Introduction

Employing multiple-input multiple-output (MIMO) systems in wireless communication provides a linear increase in capacity with minimum number of the transmit and the receive antennas (Foschini & Gans, 1998; Telatar, 1999). Using multiple antennas, several data streams can be transmitted simultaneously which results in a higher spectral efficiency without the need of additional spectrum. Recently, large MIMO systems (i.e. systems with tens to hundreds of antennas) are getting increased research attention (Chockalingam & Rajan, 2014) because of their potential to achieve a higher diversity as well as multiplexing gains. Practical implementation of large-MIMO systems relies on the computational complexity incurred in the reliable detection of the transmitted symbol vector. Minimum bit error rate (BER) performance can be achieved by using maximum likelihood (ML) detector which performs an exhaustive search over all the possible transmit symbol vectors. But the computational complexity of ML detection increases exponentially with increase in the number of transmit antennas. Sphere decoder (SD) is a well known ML detector but it suffers from variable complexity which depends on the received signal to noise ratio (SNR) and is practical only up to certain number of dimensions (Viterbo & Boutros, 1999). Low-complexity sub-optimum detectors for MIMO systems include linear detectors which are zero-forcing (ZF), minimum mean squared error (MMSE) detector and the non-linear detectors like vertical Bell laboratories layered architecture (V-BLAST) detector (Wolniansky, Foschini, Golden, & Valenzuela, 1998). The ZF, MMSE and V-BLAST detectors are low-complexity algorithms but are inferior in performance when compared to ML performance. For this reason they are least selective and are used to get an initial solution in some of the other detection algorithms. Several algorithms for MIMO detection have been proposed in the literature, some of which are based on lattice reduction (LR) (Marinello & Abrão, 2013; Maurer, Matz, & Seethaler, 2007; Seethaler, Matz, & Hlawatsch, 2007) where the detection is carried out into a different space obtained by transforming the channel matrix into an equivalent matrix with near orthogonal column vectors, message passing based detection algorithm

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(Som, Datta, Chockalingam, & Rajan, 2010) which utilizes the concept of belief propagation and factor graph, local search algorithm (Vardhan, Mohammed, Chockalingam, & Rajan, 2008) based on the local neighborhood search of an initial solution, mixed Gibbs sampling based detection (Datta, Ashok Kumar, Chockalingam, & Rajan, 2012) which is derived from the Monte-Carlo Markov chain (MCMC) technique, sparse sensing based algorithm (Peng, Wu, Sun, & Liu, 2015) and likelihood ascent search based detection algorithm (Pereira & Sampaio-Neto, 2015). As an alternative in our study, we focus on the application of bio-inspired algorithms in symbol vector detection in MIMO systems. Bio-inspired algorithms are promising in terms of providing better performance with less computational complexity. Further, they involve less mathematics which is another positive aspect of such algorithms.

Recently, there has been a lot of research in developing algorithms which mimics the biological phenomena such as birds flocking, fish schooling and foraging behavior of ants for solving the real world optimization problems which are hard to solve by the conventional techniques. Several algorithms in this regard have been proposed in the literature, some of which include genetic algorithm (GA) (Tang, Man, Kwong, & He, 1996), ant colony optimization (ACO) (Dorigo & Gambardella, 1997), particle swarm optimization (PSO) (Eberhart & Kennedy, 1995), cuckoo optimization algorithm (Rajabioun, 2011) and artificial bee colony (ABC) optimization algorithm (Karaboga, 2005). All these algorithms are useful in terms of finding a sub-optimal solution with lesser computational complexity for a given optimization problem. Some of the applications of these algorithms in engineering involves designing finite impulse response (FIR) filters (Boudjelaba, Ros, & Chikouche, 2014), load balanced clustering in mobile ad-hoc networks (Cheng, Yang, & Cao, 2013), non-linear channel equalization (Das, Pattnaik, & Padhy, 2014), non-linear rational filter modeling (Lin, Chang, & Hsieh, 2008) and material flow problem in manufacturing plant (Alvarado-Iniesta, Garcia-Alcaraz, Rodriguez-Borbon, & Maldonado, 2013). However, the major challenge in using bio-inspired algorithms is to find a suitable initial point and a proper update mechanism which helps in avoiding the premature or early convergence of these algorithms to a local optimal solution. PSO and ACO algorithms (considered in our study) suffer from similar problem of pre-mature convergence which results in convergence to a local minimum solution and thus, a large population size is required for getting a highly reliable solution but it unnecessarily reduces the convergence rate of the algorithms, and also sometimes the local trap cannot be overcome even by a large population of ants or particles. To overcome these drawbacks, there are several hybrid algorithms based on ACO and PSO proposed in the literature (Kaveh & Talatahari, 2009; Kıran, Özceylan, Gündüz, & Paksoy, 2012; Shelokar, Siarry, Jayaraman, & Kulkarni, 2007).

ML detection in MIMO systems is a non-deterministic polynomial (NP) hard problem and becomes impractical for higher number of antennas (large-MIMO systems) and hence, bio-inspired algorithms, because of their low-complexity, serves as a suitable candidate for MIMO detection problem. Several bio-inspired MIMO detection algorithms based on PSO (Khan, Naeem, & Shah, 2007) and ACO (Lain & Chen, 2010; Mandloi & Bhatia, 2015; Marinello & Abrão, 2013) have been proposed in the literature, recently. However, there are some deficiencies associated with these algorithms. For example, the algorithm proposed in Khan et al. (2007) achieves sub-optimal BER performance and requires more number of particles to converge to a near optimum solution. The algorithm proposed in Lain and Chen (2010) requires a large number of ants to achieve a near ML performance which leads to high computational complexity and a slow convergence of the algorithm. Congestion control based ACO algorithm in Mandloi and Bhatia (2015) is another low complexity MIMO detection algorithm however, it is sub-optimal in terms of BER performance which is due to the convergence of the algorithm to a local optimal solution. In Marinello and Abrão (2013), a lattice reduction (LR) aided ACO algorithm is proposed for MIMO detection. But the use of LR increases the computational complexity significantly for higher number of antennas. The convergence rate and trap to a local optima are the two main issues associated with the existing algorithms and thus it motivates us to work further is this direction and improve the convergence rate and escape from the local optima trap in ACO and PSO algorithms.

In this paper, we propose a low-complexity HA which is based on the two well known bio-inspired algorithms, namely PSO and ACO, for large-MIMO detection. In the proposed HA, the symbol vector detection problem in MIMO systems is solved as a traveling salesmen problem (TSP) where a set of artificial particles (N_{part}) are used to finding a solution which minimizes a given cost function. Each transmit antenna is considered as a city and the possible transmit symbols are considered as the available paths to travel the particular city. The problem now reduces to find a path (symbol vector) with minimum distance (ML cost) to travel each city (antenna) exactly once. The motivation behind the HA is that the distance traveled (as in ACO) by each particle gives only the local information about the fitness of a solution, hence to get a global information on the fitness of a solution we use the velocity update rule of each particle which uses the local best and global best solution to update itself (as in PSO). ACO and PSO alone are not suitable because of their early convergence to a local optimum solution due to the unreliable initialization of pheromones in ACO and position of particles in PSO. The proposed HA combines the concept of distance as in ACO with the velocity update rule of PSO in order to avoid the premature convergence to a local optimum solution and improve the convergence speed. In the proposed algorithm, a new probability metric is designed which is a weighted combination of the distance traveled by the particles so far and the velocity of each particle. Simulation results demonstrate that the proposed HA outperforms MMSE and the existing ACO algorithms in terms of BER and achieves a near ML performance. Our contributions in this paper are: 1. A new probability metric is devised using the hybrid of ACO and PSO algorithms, 2. Use of HA for symbol vector detection in MIMO systems is shown and the results are simulated to validate the performance of the proposed HA.

The rest of the paper is organized as follows. In Section 2, we present the general PSO and ACO algorithm. System model and mathematical formulation are given in Section 3. HA based MIMO detection algorithm is discussed in Section 4. In Section 5, we present the simulation results for BER performance versus signal to noise ratio (SNR), convergence analysis curve for BER performance versus number of particles and the complexity curve for number of computations versus the number of particles and the number of antennas respectively. a discussion on the comparison of proposed HA with ACO and PSO is given in Section 6. Section 7 concludes the paper.

2. Proposed hybrid algorithm

In this section, we briefly discuss the proposed HA along with a review of basic PSO algorithm and ACO algorithm.

2.1. Particle swarm optimization algorithm

PSO developed by Eberhart and Kennedy (1995), is a population based probabilistic search approach which is inspired by the social behavior of bird flocking and fish schooling. Fig. 1 shows the flow chart of the basic PSO algorithm. PSO starts with a number of particles and each particle is initialized with random velocity and position. In every iteration of PSO, each particle updates its velocity based on the local best (pbest) solution and the global best (gbest)