# The Particle Swarm Optimization (PSO) for Symbol Detection in MIMO-OFDM System

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***ABSTRACT:*** *This paper propose some solutions to improve the performance of terminals mobile transmissions at high speeds, low cost and low power consumption. Indeed, the increase in rates implies that the transmission channels are more difficult, making the task of receivers more difficult. , we are interested in solving the classical problem of detection of a linear mixture of Gaussian noise for MIMO OFDM telecommunication systems from a noisy observation of an input signal mixed with a known matrix representing the behavior of the channel, we seek the vector minimizing the Euclidean distance between the noisy output and the noiseless one. MIMO OFDM systems have large frequency diversity. In this context, we investigate in a first part in the study of performance of conventional equalizers (ML, ZF, MMSE...).*

*In a second part, we propose a detection algorithm with near-optimal performance in terms of bit error rate BER very close to ML called PSO (Particular Swarm Optimization) for its complexity relatively small compared to other detectors.*

**Keywords:** MIMO, OFDM ,ZF , MMSE, ML ,PSO, BER , SNR

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## 1. Introduction

The world of communications is currently at a very important crossroads of his evolution. Thanks to the miniaturization of technologies, their performance has increased.

The areas of wireless communication and mobile communication are significant challenges. Over time, several generations have passed to improve the speed and capacity while maintaining an appreciable quality of service. The wireless world passed through the analog modulation prior to final adoption of digital modulation.

By using multiple antennas at both transmitter and receiver (MIMO system) the throughput can be increased by simultaneously transmitting different streams of data on the different transmit antennas but at the same carrier frequency. In addition the orthogonal frequency-division multiplexing (OFDM) has a potential to increase spectral efficiency. The combination of the throughput enhancement of MIMO system with the robustness of orthogonal frequency division multiplexing (OFDM) against frequency-selective fading caused by severe multipath scattering and narrowband interference is regarded as a very promising basis for future high speed data communication. That's why the challenge is to provide a MIMO-OFDM system with high efficiency and low complexity [1].

However, for these systems symbol detection is required at the receiver for coherent demodulation, but MIMO detection is computation extensive and not a trivial work.

For this reason, various algorithms such as maximum likelihood (ML), zero forcing (ZF) and minimum mean square error (MMSE) algorithms have been proposed to detect symbols. Although the implementation of ZF and MMSE are quite easy and also less complex algorithm, it underperforms in fast fading and time varying environments. In comparison with other algorithm, ML algorithm reveals excellent performance in these environments [2]. But the main drawback of ML is its extremely high computational complexity. It searches the candidate symbol vector on each subcarrier and euclidean distance between received and actual symbols is computed in all the possible combinations of transmitted symbols. In addition to this, search space grows exponentially with the number of transmitter and receiver antennas, so computational complexity becomes intensive [3].

In this paper, we study the different detection algorithms and analyze their performances and in order to reduce the search space of ML detector and to reduce the computational complexity, we propose a heuristic approach PSO.

**2. Problem Formulation**

Before introducing the signal detection we briefly describe a MIMO-OFDM system.

Figure 1 shows the simplified block diagram of MIMO-OFDM system. For this system, we consider $N_{tx}$ transmit, $N_{rx}$ receive antennas, $n$ OFDM symbols and $K$ subcarriers.

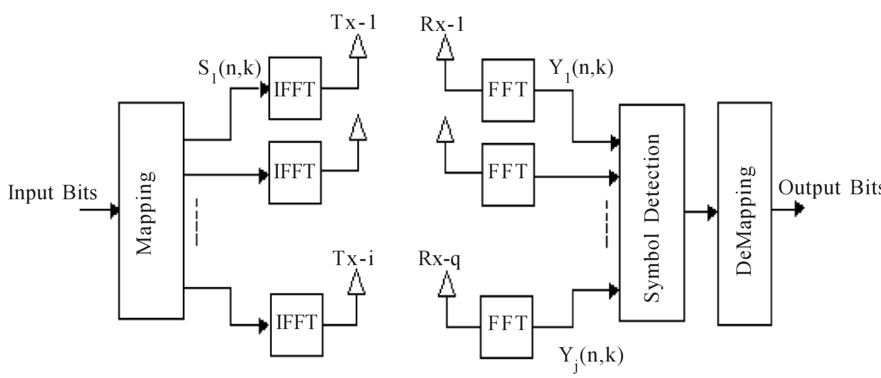


Figure 1.Block diagram of MIMO-OFDM system

Data stream is mapped on to complex symbols considering modulation type. The transmitted symbol vector is expressed as

$$S[n, k] = [S_1(n, k),..., S_{Ntx}(n, k)]^T, k = 0....1 \tag{1}$$

Where $S_i[n, k]$ is symbol which is transmitted at the $n_{th}$ symbol, $k_{th}$ subcarrier and $i_{th}$ antenna. $[.]^T$ is transpose operation. By applying inverse fast Fourier transform (IFFT), symbol vectors are turned into OFDM symbol:

$$S_n[m] = \frac{1}{\sqrt{kN_{tx}}} \sum_{k=0}^{k=1} S[n, k]\, e^{j2\pi m/k}, m = 0....k \tag{2}$$

To eliminate inter symbol interference (ISI) we add cyclic prefix (CP), and then signal vectors are fed though the $i_{\mathrm{th}}$ transmitter antenna. In reception CP is removed from signal vector at $q_{\mathrm{th}}$ receiver antenna and fast Fourier transform (FFT) is applied.

Then the received signal vector can be expressed as

$$Y_q[n,k] = \sum_{i=1}^{Ntx} H_i[n,k]\, S_i[n,k] + W_q[n,k] \quad (3)$$

$H_i[n, k]$ is channel impulse response vector and $W_q[n, k]$ is additive white Gaussian noise.

The task is detecting $N_{tx}$ transmitted symbols S from a set of $N_{rx}$ observed symbols $Y$ that have passed through a non-ideal communication channel $H$, typically modelled as a linear system followed by an AWGN $W$ [4].

**3. ZF , MMSE and Ml Equalizers Performances in MIMO-OFDM system**

We study the assessment of the BER according to the SNR while modifying: the type of Equalizer, the mapping technique adopted and the number of antenna.

**3.1 Influence of the type of Equalizer on the BER variation according to the SNR**

We suppose that the channel is multi – fading to compare the characteristic BER according to the SNR for MMSE, ZF and ML Equalizer, we use for simulation QAM-4 modulation for 2 × 2 MIMO-OFDM system with 64 subcarriers and 16 the length of the Cyclic prefix. The result of this comparison is on the Figure 2.

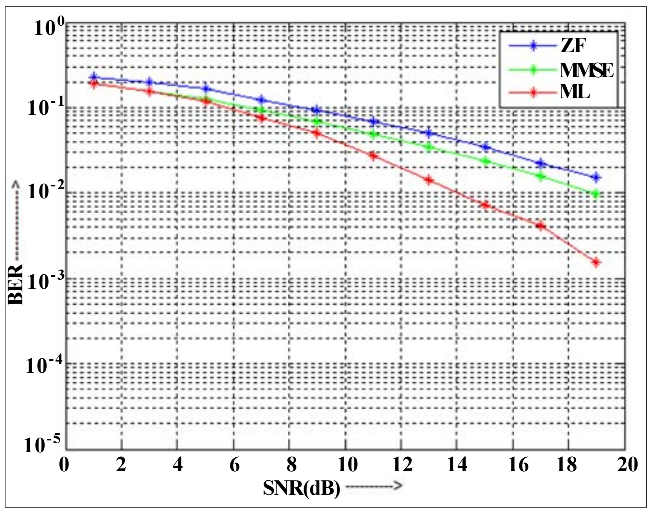


Figure 2. BER according to SNR for ZF, MMSE and ML detector using Rayleigh canal for 2 × 2 MIMO-OFDM systems for modulation QAM-4

In Figure 2, the bit error rate (BER) versus the signal-to-noise ratio (SNR) performance of symbol detectors in the 2 × 2 MIMO-OFDM systems is shown. As it can be seen, the ML has better performance than ZF and MMSE algorithms. For optimal solution of ML detection, all $M N_{tx}$ possible combination of transmitted symbols must be searched. For this reason, the computational complexity increases with transmitter antenna.

**3.2 Influence of the technique modulation on the BER variation according to the SNR for a ZF,MMSE and ML Equalizer**

We suppose that the channel is multi – journeys, number of subcarriers is 64, 16 the length of the cyclic prefix for 2x2 MIMO-OFDM systems.

The figure 3 and 4 show respectively the performance in term BER of ZF and MMSE Equalizer while using the QAM-4 modulation, QAM-16, QAM-64 and the performances using ML detector with the same condition of simulation.

Passing from QAM-4 to QAM-64 the number of possible states, in the diagram of constellation, increases, therefore the principle of worth precinct observed becomes more and more complicated while sweeping the whole diagram ,then more that the number of state is big more the binary mistake probability increases.

**3.3 Influence of the number of antenna on the BER variation according to the SNR**

We suppose that the channel is multi – fading to compare the characteristic BER according to the SNR for different number of

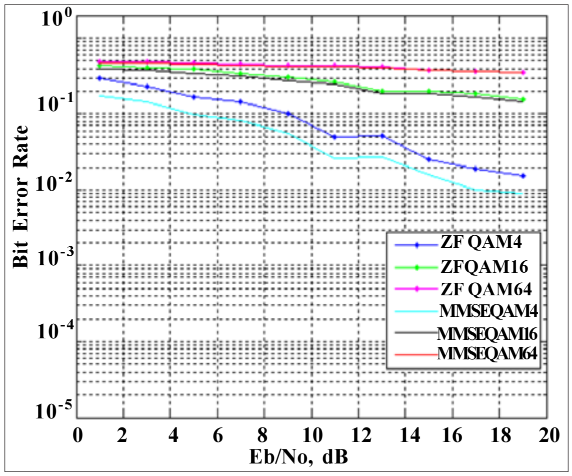


Figure 3. BER according to the SNR for the QAM-4, QAM16, QAM-64 modulations of ZF and MMSE Equalizer for $2 \times 2$ MIMO-OFDM systems

antenna, we use for simulation QAM-4 modulation with 64 subcarriers and 16 the length of the Cyclic prefix for 4x4 MIMO-OFDM system.

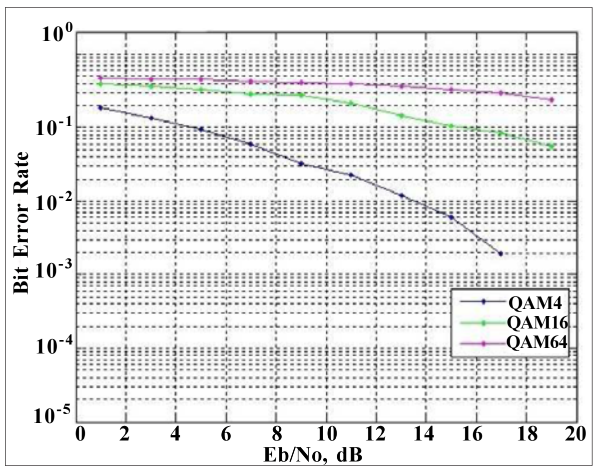


Figure 4. BER according to the SNR for the QAM-4, QAM16, QAM-64 modulations of ML detector for $2 \times 2$ MIMO-OFDM system

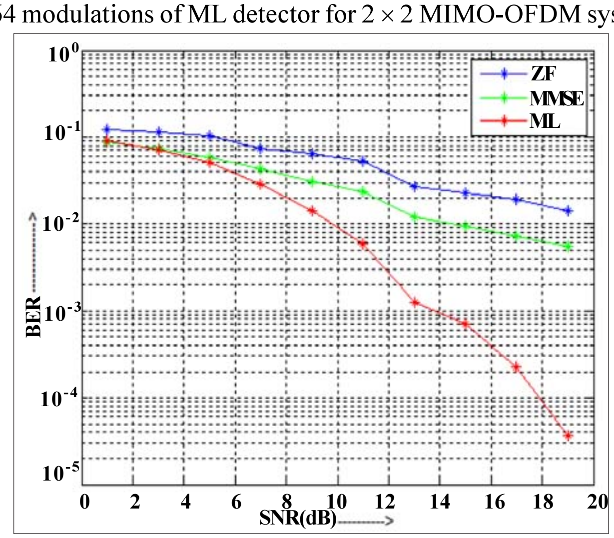


Figure 5. BER according to SNR for ZF, MMSE and ML detector using QAM-4 modulation and $4 \times 4$ MIMO-OFDM systems

Compared with the figure 2 we remark that the performance of the system is proportional to the number of antenna due to the capacity of channel which increases with the increasing number of antenna.

## 4. Symbol detection in MIMO-OFDM System Using Particle Swarm Optimization Meta-Heuristics

Transmitted symbols from a known finite alphabet $v = \{x_1,..., x_M\}$ of size $M$ are passed to the channel. The detector chooses one of the $M^{Ntx}$ possible transmitted symbol vectors from the available data. Assuming that the symbol vectors $x \in V_{Ntx}$ are equiprobable, the maximum likelihood (ML) detector always returns an optimal solution according to the following:

$$X = \arg_{x \in V_{Ntx}} \max P\,(\,y \text{ is observed} \mid x \text{ was sent}) \tag{4}$$

Assuming the additive noise $w$ to be white and Gaussian, the ML detection problem can be expressed as the minimization of the squared Euclidean distance to a target vector y over $N_{tx}$-dimensional finite discrete search set

$$X = \arg_{x \in V_{Ntx}} \min \| y - Hx \|^2 \tag{5}$$

The optimal ML detection scheme needs to examine all $M_{Nt\,x}$ or $2^{bNtx}$ symbol combinations ($b$ is the number of bits per symbol). The problem can be solved by enumerating over all possible x and finding the one that causes the minimum value as in (5). Therefore, the computational complexity increases exponentially with constellation size $M$ and the number of transmitters $N_{tx}$.

We present PSO algorithms-assisted MIMO-OFDM symbol detectors thus viewing the MIMO symbol detection issue as a combinatorial optimization and approximate the near optimal solution iteratively with lesser than ML computational complexity.

### 4.1 Particle swarm optimization (PSO)

A swarm consists of a number of particles (possible solutions) that move (fly) through the feasible solution space to explore the optimal solution that can be coded as binary strings or real valued vectors. The particles are capable of interacting with each other in a given neighbourhood and traverse a search space where a quality measure, fitness, can be evaluated. The particles are evolved through cooperation and competition among themselves over iterations. The coordinates of each particle represent a possible solution associated with two vectors, position ($X_i$) and velocity ($V_i$).

Each particle experiences an iterative procedure of adaptation to two types of major information, i.e. individual learning and cultural transmission, which means that the procedure accelerates particles at each time step towards personal best (best value recorded by each particle) and the position of the most recent global best point (best position returned form the swarm).

A key attractive feature of the PSO approach is its simple mathematical model involving two model equations and fewer parameters to adjust [5].

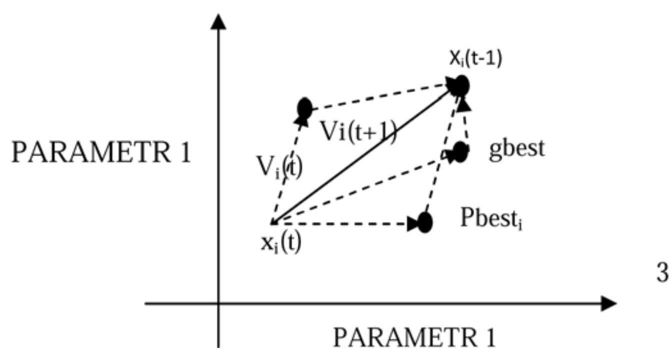


Figure 6. Vector representation of PSO model

### 4.2 PSO-MIMO detection algorithm

An important step to implement PSO is to define a fitness function; this is the link between the optimization algorithm and the real-world problem. The fitness function is unique for each optimization problem. The fitness function using the coordinates of the particle returns a fitness value to be assigned to the current location. If the value is greater than the value at respective personal best (pbest) for each particle, or global best (gbest) for the swarm, then previous locations are updated with the present locations. The velocity of the particle is changed according to the relative locations of pbest and gbest. Once the velocity of the particle is determined, it simply moves to the next position. After this process is applied on each particle, it is repeated till the maximum number of iterations is reached.

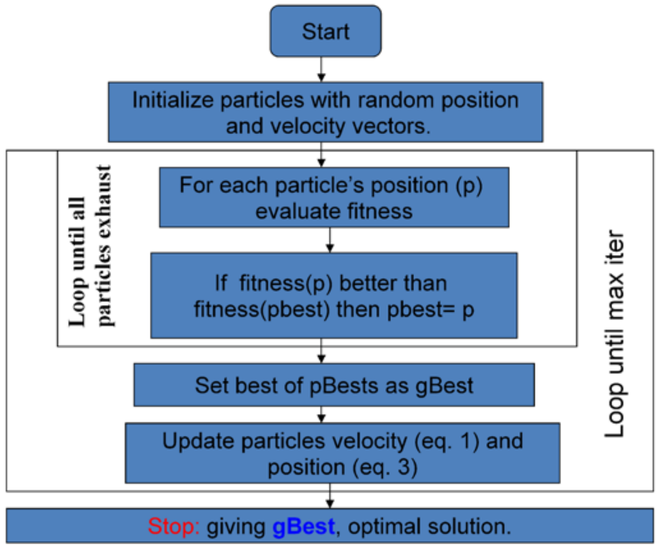


Figure 7. Flow chart depicting the PSO Algorithm

The proposed MIMO detection algorithm based on standard continuous PSO [6] is described below:

1- Initialize the particle size (swarm) by taking the initial solution guess. Initialize the algorithm parameters.

2- Fitness of each particle is calculated using (5):

$$f = \| y - Hx \|^2 \tag{6}$$

Minimum Euclidean distance for each symbol represents the fitness of solution. Find the global best performance '*gbest*d' in the population that represents the least Euclidean distance found so far. Record the personal best '*pbestid*' for each bit along its previous values.

3-Velocity for each particle is computed using the following PSO velocity update equation:

$$V_{id}(k) = V_{id}(k-1) + \varphi_1 rand\,[pbest_{id} - x_{id}(k-1)] + \varphi_2 rand_2\,[gbest_{id} - x_{id}(k-1)] \tag{7}$$

4- The particle position is updated depending on the following PSO velocity update equation:

$$x_{id}(k) = x_{id}(k-1) + v_{id}(k) \tag{8}$$

5- Repeat from step 2 until maximum number of iterations is reached. Here '*k*' is the number of iterations. An optimum number of iterations are tuned for efficient performance. The solution gets refined iteratively [7].

### 4.3 Simulation results

We compare the performance of ZF, MMSE, ML and PSO detector with 64 subcarriers, CP length is 16, BPSK for modulation and $2 \times 2$ MIMO-OFDM systems.

Figure 8 shows the BER versus *E*b/*N*o performance of ZF, MMSE, ML and PSO detectors compared with ML for $2 \times 2$ 2-QAM MIMO-OFDM system. As it can be seen, PSO has better performance than ZF and MMSE algorithms and the BER performance of PSO is close to the ML detectors. For instance, the BER difference between PSO and ZF is more than $10^{-1}$ at a 17-dB SNR value. However, a substantial ML complexity reduction is achieved, which is discussed in the next subsection.

### 4.4 Computational complexity theoretical evaluation

Here we examine the computational complexity of the reported PSO-MIMO detector and formulate a theoretical expression for

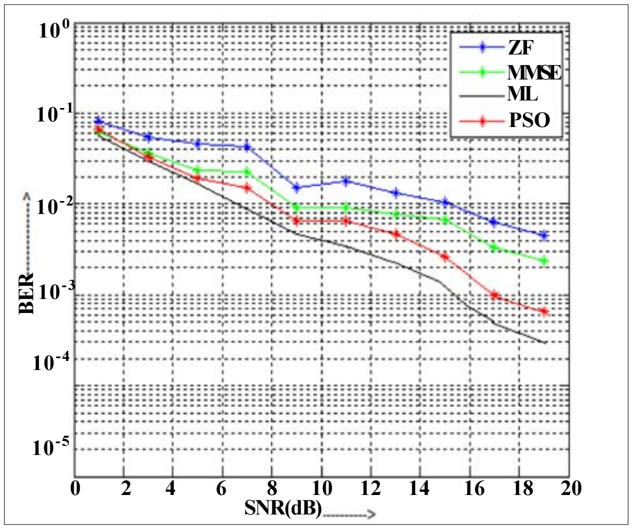


Figure 8. BER according to SNR for ZF, MMSE, ML and PSO detector using BPSK modulation and 2 × 2 MIMO-OFDM

computational complexity. A comparison with the conventional *ML* optimal detection method is also drawn. As the hardware cost of each algorithm is specific implementation, we try to provide a rough estimate of complexity in terms of the number of complex multiplications.

The computational complexity is computed in terms of the *Ntx*, *Nrx* and the constellation size *M*.

For the *ML* detector as seen from (5) $MN_{tx}\,(N_{rx}N_{tx})$ multiplications are required for matrix multiplication operation and additional $M\,N_{tx}N_{rx}$ multiplications are needed for square operation [8]. Therefore, *ML* complexity becomes

$$\xi_{ML} = N_{rx}(N_{tx} + 1)\,M_{Ntx} \tag{9}$$

For the proposed detector, first fitness of each particle in population $N_p$ using (5) is calculated. Multiplication complexity ($\xi_{PSO}$) becomes

$$\xi_{PSO} = N_p\,(N_{tx}N_{rx}) \tag{10}$$

Velocity update in *PSO* and pheromone updates require $\mu_{vel}$ additional multiplications per iteration from (7). To reduce some complexity $w = 1$ and $\varphi_1 = \varphi_2 = 1$ is assumed. Therefore, the complexity becomes

$$\xi_{PSO} = N_p\,(N_{tx}N_{rx} + \mu_{vel}) \tag{11}$$

This procedure is repeated $N_{itr}$ times to converge to the near-optimal BER performance. Therefore,

$$\xi_{PSO} = N_p\,(N_{tx}N_{rx} + \mu_{vel})\,N_{itr} \tag{12}$$

The complexity of *ML* is exponential with $N_{tx}$ and *M*. This increase is even significant with higher-order modulation schemes in MIMO systems with more transmitters.

However, this complexity estimate is only meaningful in the order-of-magnitude sense since it is based on the number of complex multiplications only. The above complexity is estimated on subcarrier-by-subcarrier for the MIMO-OFDM system [7].

## 5. Conclusion

In recent years, global research in the field of digital communications without son is more developed. The synthesis of new systems aims to transmission of digital information at higher bandwidths and service for a quantity more demanding. After the presentation of the basic principles of digital transmission and exposure characteristics of the linear model of the wireless channel, examples of systems studied in the literature and depicted as linear radio channels are given and an analysis of detection techniques under optimal suboptimal most popular is described. These sensors have no compromise between performance and complexity; note for example that the simple linear detectors have poor performance as maximum likelihood detectors which have a computational complexity much more complex. In this article, we focused on the different detection algorithms classical MIMO-OFDM system such as ZF, MMSE and ML results show that ML is the optimal detector, but with a search space and the high computational complexity. So, we proposed PSO approach to reduce it. Approach particle detection swarm PSO shows promising results. Their simple mathematical model, reducing the complexity of implementation, resistance to being trapped in local minima, convergence guaranteed with a reasonable solution to make fewer iterations these techniques inspired by nature a suitable candidate for the detection symbol in real time in the MIMO-OFDM system. The PSO algorithm has its own means of ingenious natural to explore the search space to find an optimal solution from a surface complexity of ML detector expensive. The effectiveness of these algorithms is also a simple calculation code in the central algorithm with few parameters to adjust. Reducing the computation time with higher order modulations and antenna transmission make these detection algorithms proposed system particularly useful for high rate data transmission. There are still other approaches to study meta heuristics and other parameters of MIMO OFDM modified to improve performance. The use of other types of QAM modulation and the other function instead of the IFFT is possible. To experimentally validate the performance study, a real implementation on a FPGA algorithms developed is a possible perspective of this work.

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