International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 5, July - 2012

Detection of Multi Users in OFDM

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Abstract

Design of efficient Multi-User Detection (MUD) techniques in Space Division Multiple Access (SDMA) aided Orthogonal Frequency Division Multiplexing (OFDM) systems have recently attracted intensive research interests. Out of the many MUD techniques, the Maximum-Likelihood Detection (MLD) method is known to provide the best performance, but at the cost of a computational complexity, that increases exponentially both with the number of users and with the number of bits per symbol transmitted by higher-order modulation schemes. By contrast, the Minimum Mean-Square Error (MMSE)-SDMA-MUD exhibits a lower complexity at the cost of performance degradation. But the multi-user detection has some limitations in the rank-deficient scenarios, where the number of supported users exceeds the number of receiver antennas.

In this paper work has been carried on Genetic Simulated Annealing Algorithm (GSAA) based SDMA-OFDM MUD has been presented which overcome the limitations of classical detectors in rank-deficient scenarios. They are simple to implement and their complexity in terms of decision-metric evaluations is very less as compared to MLD. The proposed work has prime importance these days because the combination of multi-input multi-output (MIMO) and OFDM has emerged as a promising solution for future high-data rate wireless communication systems.

BER performance of detectors like MMSE has been evaluated in Rayleigh multipath fading channel. The simulation has been conducted for different number of transmitters and receivers. For four user full-load case, Rayleigh channel has been incorporated with GA and SA. Next the performance of GSAA, has been done and results were compared with the performance of MMSE-MUD. Complexity of GSAA and ML has been numerically plotted and compared.

1.INTRODUCTION

Next generation wireless systems are demanding very high data rates for multimedia transmission. OFDM, which is the fundamental unit of all multi-carrier communication systems divide the radio channel into many narrowband, low-rate, frequency-nonselective sub channels or subcarriers, so that multiple symbol ls can be transmitted in parallel, while maintaining a high spectral efficiency. The employment of multiple antennas at both the transmitter and the receiver, which is widely referred to as MIMO technique, constitutes a cost-effective approach to high-throughput wireless communications. The implementation of MIMO-aided OFDM is more efficient, compared to other techniques, due to the straightforward matrix algebra used for the representation and processing of the MIMO-OFDM signals.

Recently the SDMA based techniques, as a subclass of MIMO systems, have emerged as one of the most promising techniques for solving the frequency reuse limitation of wireless communication systems. SDMA enables multiple users to simultaneously share the same bandwidth in different geographical locations. The exploitation of the spatial dimension makes it possible to identify the individual users, even when they are in the same time/frequency/code domains, thus increasing the system's capacity.

Even though MIMO-OFDM has demonstrated its potential for deployment in high data rate wireless communication systems, the associated channel estimation and detection techniques found in the multiuser MIMO-OFDM literature have various limitations. Evolutionary optimization technique like GSAA based multiuser detection has been shown to provide good performance in SDMA-OFDM systems.

Detection techniques, especially in over-loaded scenarios pose many challenging issues. The higher the number of users to be supported, the more challenging the optimization task, due to the exponentially increased number of dimensions to be estimated. While most classical techniques suffer from specific limitations in rank-deficient scenarios, the family of GAs can be efficiently incorporated into MIMO-OFDM systems and constitutes a promising solution of many challenging issues. So the possibility of developing GA based technique with better convergence properties and lower computational complexities is explored in this paper. The proposed paper is based on the IEEE 802.11n wireless local area network (WLAN) standard which uses MIMO-OFDM as the transmission technology. The IEEE 802.11n Task Group (TGn) and Stanford University Interim (SUI) channel models, which are widely used channel models for WLAN and wireless metropolitan area network (WMAN) systems respectively, are incorporated to carry out the performance analysis under realistic fading environments.

2.Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is modulation method known for its capability to mitigate multipath. In OFDM the high speed data stream is divided into Nc narrowband data streams, Nc corresponding to the subcarriers or sub channels i.e. one OFDM symbol consists of N symbols modulated for example by QAM or PSK. As a result the symbol duration is N times longer than in a single carrier system with the same symbol rate. The symbol duration is made even longer by adding a cyclic prefix to each symbol. As long as the cyclic prefix [5] is longer than the channel delay spread, OFDM offers inter-symbol interference (ISI) free transmission.

Another key advantage of OFDM is that it dramatically reduces equalization complexity by enabling equalization in the frequency domain. OFDM, implemented with IFFT at the transmitter and FFT at the receiver, converts the wideband signal, affected by frequency selective fading into N narrowband flat fading signals thus the equalization can be performed in the frequency domain by a scalar division carrier-wise with the subcarrier related channel coefficients. The channel should be known at the receiver. The combination MIMO-OFDM is very natural and beneficial since OFDM enables support of more antennas and larger bandwidths since it simplifies equalization dramatically in MIMO systems.

At the receiver side, the received signal is the convolution of the transmitted sequence and the channel impulse response. In the first step, the removal of the cyclic prefix is performed by circular convolution and the remaining samples are serial-to-parallel converted. The FFT block performs demodulation in order to obtain the transmitted symbols with the amplitude and phase corrupted by the channel response and the additive noise. The output bit stream is obtained by converting the output of the FFT block into a serial bit stream.

OFDM transmission scheme has some key advantages: [6]
It is an efficient way to deal with multipath. For a given delay spread the implementation complexity is significantly lower than that of a single carrier system with an equalizer.

In relatively slow time-varying channels, it is possible to significantly enhance the capacity by adapting the data rate per subcarrier according to the signal-to-noise ratio of that particular subcarrier.
It is robust against narrow band interference because such interference affects only a small percentage of the subcarriers.

But OFDM transmission scheme is more sensitive to frequency offset and phase noise. It has relatively large peak-to-average power ratio, which tends to reduce the power efficiency of the RF amplifier.

2.1 Multi-Input Multi-Output (MIMO) Systems

In a wireless channel, transmitted signals suffer from amplitude and phase distortions due to multipath fading, thus making it difficult for the receiver to demodulate these signals. Diversity techniques take advantage of the multipath propagation characteristics to improve receiver sensitivity. MIMO systems utilize antenna diversity to obtain the mentioned improvement and hence combat fading.

A MIMO system characterizes itself by using multiple antennas at both transmitter and receiver. However, if only multiple antennas are deployed at one end of the communication system or both ends use a single antenna, the MIMO system changes into a single-input multiple-output (SIMO), a multiple-input single output (MISO) or single-input single-output (SISO) system. In this way, when only multiple antennas are deployed at the receiver, the MIMO system reduces to a SIMO system. Similarly, when the system has only one receiver antenna but multiple antennas at the transmitter side, the MIMO system reduces to MISO. When both, transmitter and receiver use a single antenna, the MIMO system simplifies to a SISO system.

2.3 Space Division Multiple Access OFDM

SDMA can be considered as a specific branch of the family of MIMO systems, where the transmissions of the multiple transmitter antennas cannot be coordinated, simply because they belong to different users. SDMA enables multiple users to simultaneously share the same bandwidth in different geographical locations.

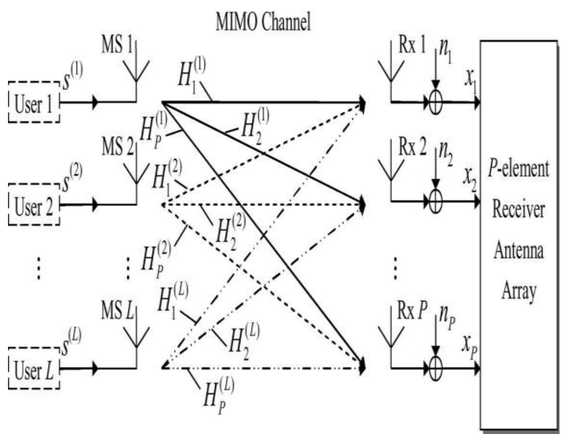

Figure 2.4 System model for MIMO SDMA-OFDM

Figure-1 shows an uplink MIMO SDMA-OFDM system model, in which the transmitted signals of L simultaneous uplink mobile users are received by the P different receiver antennas of the BS, and each mobile user is equipped by a single transmit antenna. The whole system is assumed in synchronous status, and at the sampling time k, the signal received by the P-element BS antenna array is constituted by the superposition of the independently faded signals associated with the L mobile users and contaminated by the AWGN noise, expressed as

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n},$$

Where the $(P\times1)$-dimensional vector $\mathbf{y}$, the $(L\times1)$-dimensional vector $\mathbf{x}$ and the $(P\times1)$-dimensional vector $\mathbf{n}$ are the received, transmitted and noise signals, respectively, and $\mathbf{H}$ is a $(P\times L)$-dimensional channel matrix. Here the sampling time k for each vector is omitted for the sake of notational convenience. Specifically, the vectors $\mathbf{x}$, $\mathbf{n}$, $\mathbf{y}$ and matrix $\mathbf{H}$ are given by

$$\mathbf{x} = (x^1, x^2, \ldots \ldots, x^L)^T,$$
$$\mathbf{n} = (n^1, n^2, \ldots \ldots, n^P)^T,$$
$$\mathbf{y} = (y^1, y^2, \ldots \ldots, y^P)^T,$$
$$\mathbf{H} = \begin{pmatrix} h_{11} & h_{12} & \cdots & h_{1L} \\ h_{21} & h_{22} & \cdots & h_{2L} \\ \vdots & \vdots & \ddots & \vdots \\ h_{P1} & h_{P1} & \cdots & h_{PL} \end{pmatrix}$$

Fig. 2.4 gives the uplink of an MIMO SDMA-OFDM system. It consists of U single antenna user terminals simultaneously transmitting OFDM symbols with cyclic prefix to a base station (BS) with A receiving antennas.

By choosing the cyclic prefix sufficiently long, the linear channel convolution becomes cyclic. N is the FFT size (i.e. number of sub carriers).

$x^U[N]$ represents N^{th} subcarrier symbol of the U^{th} user and $y_A[N]$ represents N^{th} subcarrier symbol of the A^{th} receiver.

3.1 Genetic Algorithm (GA)

The GA is an optimization and search technique based on the principles of genetics and natural selection. They are part of evolutionary computing which is a rapidly growing area of artificial intelligence. Optimization is based on idea that evolution represents search for optimum solution set. A GA allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the "fitness" (i.e., minimizes the cost function).

The basic algorithm of GA can be given as:

0. START: Create random population of n chromosomes
1. FITNESS: Evaluate fitness f(x) of each chromosome in the population
2. NEW POPULATION:
   2.0. SELECTION: Based on f(x)
   2.1. RECOMBINATION: Cross-over chromosomes
   2.2 MUTATION: Mutate chromosomes
   2.3 ACCEPTATION: Reject or accept new one
3. REPLACE: Replace old with new population: the new generation
4. TEST: Test problem criterium
5. LOOP: Continue step 1 – 4 until criterium is satisfied

Like any other optimization technique, it requires an optimization metric, also called fitness function.

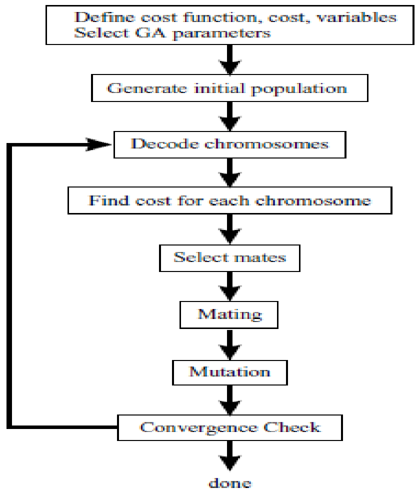

Figure 3.1 Flowchart of a binary GA [8].

3.2 Simulated Annealing (SA)

SA has been shown to be another efficient method for exploring complex nonlinear search spaces. As it is well known, MUD was rendered as a challenging multidimensional and combinatorial optimization problem. Against this background, an SA based MUD scheme is proposed in this contribution. SA MUD modifies experiential CS of traditional SA algorithm according to its use in MUD.

0. START: Create random population of 1 chromosome
1. FITNESS: Evaluate fitness f(x) of single chromosome in the population
2. NEW POPULATION:
   2.1 MUTATION: Mutate chromosomes
   2.2 ACCEPTANCE: Accept with a certain probability or reject
3. REPLACE: Replace old with new population: the new generation
4. TEST: Test problem criteria - twofold stopping criteria
5. LOOP: Continue step 1 – 4 until criteria is satisfied.

ISSN: 2278-0181
Vol. 1 Issue 5, July - 2012

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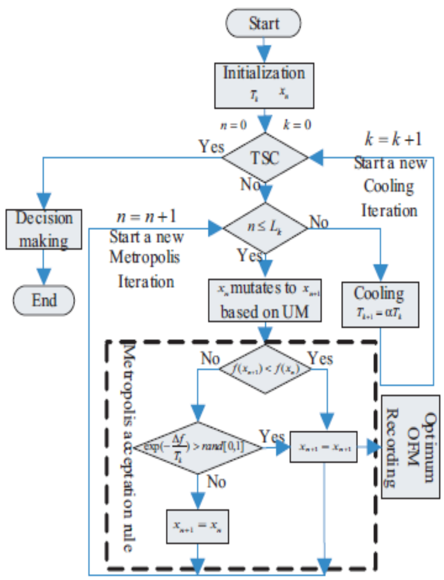

Figure 3.2 Flowchart of a binary SA [8].

3.3 Genetic Simulated Annealing Algorithm (GSAA):

The genetic algorithm (GA) has strong global search ability. The simulated annealing algorithm (SAA) has strong local search ability and also has the ability to avoid falling into the local optimal solution. GA and SAA are combined together to form a new global search algorithm GSAA.

Basic steps of GSAA algorithm:

(1) Setting the relevant parameters of the GSAA, generating the initial population and evaluating the fitness functions of the individuals.

(2) Operating with the genetic operations of the crossover and mutation, then generating a new population with the simulated annealing, and evaluating the fitness functions of the population.

(3) Generating a new population through the selection and reproduction operations.

(4) If the result does not meet the termination conditions, then turn to the second step. If the result meets the termination conditions, then output the best individual.

4.RESULTS AND DISCUSSIONS

4.1 Introduction

Simulations were carried out on a PC with 1.73 GHz dual core, Intel Pentium processor and 1.0 GB RAM using Matlab 7.8.0 (R2009a). Theoretical and simulation studies were conducted on various types of smart antenna techniques (especially Alamouti and SDMA) and OFDM systems in AWGN and flat fading channel, for single and multi-user cases.

4.2 Simulation Parameters

SDMA-OFDM system with 64 subcarriers and CP of 16 samples is considered for studying the BER Vs SNR performance in various conditions.

4.3 Comparison of performance evaluation between MMSE and GA BER versus SNR Performance

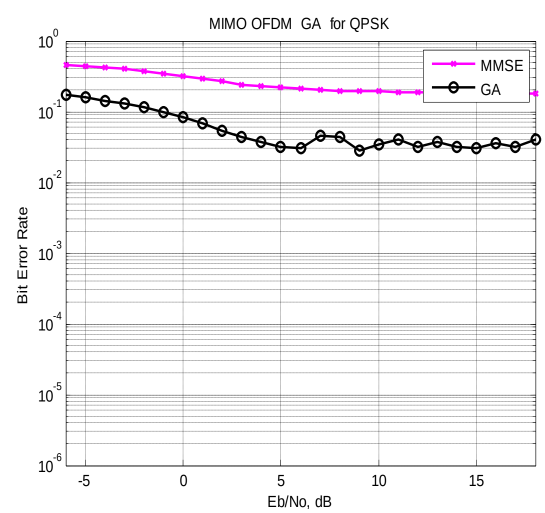

Fig 4.1: Performance comparison of, MMSE and GA in SDMA-OFDM-MUD

Each user is identified using highly uncorrelated channel coefficients (spatial signature). From the plot it is clear that GA MUD has very good performance over conventional strategy MMSE.

4.4 Comparison of performance evaluation between MMSE and SA BER versus SNR Performance

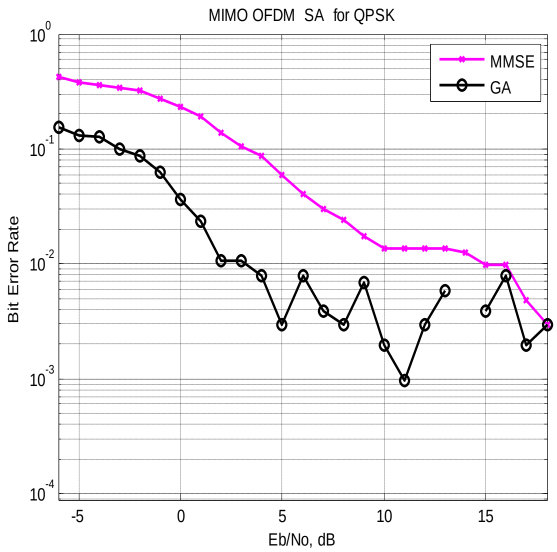

Fig 4.2: Performance comparison of, MMSE, SA, in SDMA-OFDM-MUD .

Each user is identified using highly uncorrelated channel coefficients (spatial signature). From the plot it is clear that SA MUD has very good performance over conventional strategy MMSE and especially in over – loaded scenarios.

4.5 Comparison of performance evaluation between MMSE and GSAA BER versus SNR Performance

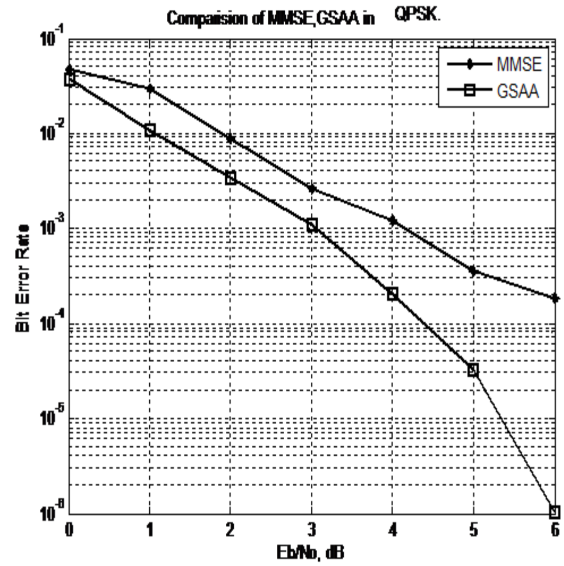

Fig 4.3: Performance comparison of, MMSE,GSAA

Each user is identified using highly uncorrelated channel coefficients (spatial signature). From the plot it is clear that GSAA MUD has very good performance over conventional strategy MMSE and SA. SA has an improvement of 1.8 dB at BER $2x10^{-4}$ over MMSE. GSAA has an improvement of 2 dB at BER $2x10^{-4}$ over MMSE.

The various parameters used in the , GA, SA and GSAA MUDs are summarized in table 1. Combination of parameters of GA, SA can be used as parameters for GSAA.

GA Parameters	Population size Mutation probability Cross over probability Iterations	20 0.1 0.85 10
SA Parameters	Mutation Probability Acceptance rate Attenuation rate Termination criteria	0.2 0.9 0.85 TSC

Table 1 Simulation parameter

5. CONCLUSIONS AND FUTURE SCOPE

5.1 Conclusions

The combination of SDMA and OFDM has emerged as a promising solution for future high-rate wireless communication systems, especially wireless uplinks like laptop WLAN cards transmitting to a WLAN access point (AP), transmission from ground station to a satellite and transmission from mobile terminal to a BS in a cellular system. In these systems, multipath propagation leads to inter-symbol interference (ISI). OFDM modulation mitigates this ISI by extending the symbol period and inserting a cyclic extension. SDMA enables bandwidth reuse by exploiting the different spatial signatures of the various users to separate them. As such, the bandwidth efficiency is improved, which increases the overall capacity.

The work has been commenced by implementing QPSK in OFDM with Rayleigh fading channel for single user. Theoretical and simulation studies on various conventional detection methods like ML and MMSE for SDMA-OFDM, where each transmitting antenna corresponds to a particular user have been performed. As expected ML detection has the optimum performance over MMSE but the computational complexity associated with it increases exponentially as number of users increases. For better performance the simulation in all scenarios was repeated for GA, SA and GSAA assisted MUDs. For much better performance MUD is employed and GA, SA and GSAA is applied to the linear detector's coefficients so as to directly minimize the error-probability or BER, rather than the mean-squared error (MSE).

5.2 Future Scope

The proposed GSAA may be further improved in various ways. For example, the value of the mutation probability can be adapted according to the number of users and the GA's generation index. Another strategy is to choose increase the number of iterations for genetic algorithm. Newly developed optimization techniques ABC, harmony search can be used in place of GSAA and the performance can be compared. With the aid of the recent advances in artificial intelligence (AI), a range of other problem-solving methods have also emerged. One of these techniques is constituted by the family of neural networks (NNs) which is based on the models that mimic the operation of how biological neurons are connected in the human brain . Specifically, NNs are also applicable to the field of multiuser detection. The optimization algorithm based multi user detection can be extended for other smart antenna techniques like beam forming as well.

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