Optimized Power Allocation and Channel Sensing in Multi-User Cognitive OFDM System

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Abstract: The increasing demand for wireless communication has led to a shortage of frequency spectrum, with primary users (PUs) underutilizing their licensed bands and secondary users (SUs) restricted from accessing them, causing inefficiency. This project focuses on optimizing power allocation and channel sensing in multi-user cognitive OFDM systems. We propose a dynamic power allocation scheme that ensures secondary users meet required SINR while minimizing interference with primary users, using techniques like water-filling and game-theory-based algorithms. Additionally, we employ spectrum sensing methods such as energy detection and cycle stationary feature detection to identify available spectrum and reduce interference. By integrating optimized power allocation and spectrum sensing, this approach improves spectrum efficiency, data throughput, and reduces interference, enhancing overall performance in cognitive radio networks.

Key words : OFDM, *Cognitive radio, SVD, MIMO*

1. INTRODUCTION:

The increasing demand for wireless communication services has led to significant pressure on the available radio frequency spectrum. However, spectrum scarcity has been exacerbated by the static allocation of frequency bands, where large portions remain underutilized at any given time. Cognitive Radio (CR), a software-defined radio technology, addresses this issue by enabling opportunistic spectrum access for secondary users (SUs) without interfering with primary users (PUs). Through dynamic spectrum sensing, CR facilitates the identification of spectrum holes—unused frequency bands—thus improving spectrum utilization. Spectrum sensing is the cornerstone of CR networks and can be classified into three primary techniques: Energy Detection (ED), Matched Filter Detection (MFD), and Feature Detection (FD). Energy detection is a widely used approach due to its simplicity and minimal computational complexity. However, it fails to distinguish between noise and signal, leading to performance degradation in noisy environments. MFD is optimal under stationary Gaussian noise but requires prior knowledge of the primary signal, which is often not available in practical settings. Feature detection, while more robust in identifying modulated signals amidst noise and interference, incurs higher computational overhead. Effective spectrum sensing, therefore, remains a critical challenge in the development of CR systems, particularly for multi-user environments. In Orthogonal Frequency Division Multiplexing (OFDM)-based systems, spectrum utilization is suboptimal when only a single user occupies all subcarriers. Although Orthogonal Frequency Division Multiple Access (OFDMA) enables multiple users to share the available subcarriers simultaneously, interference management and power allocation remain significant challenges. OFDMA reduces Inter-Carrier Interference (ICI) and enhances system performance by providing flexible resource allocation; however, the lack of dynamic power control and optimal channel allocation limits the potential gains in a multi-user scenario. In addition to spectrum access, Fixed Relays (FRs) are increasingly deployed to enhance coverage and mitigate signal degradation in cellular networks. These low-power transmitters improve link quality, especially at the cell edge, by forwarding data between the base station and users. However, the challenge of Point-to-Multi-Point (PMP) relaying, where a relay must serve multiple users, arises due to limited relay resources. To optimize the capacity of PMP relays, Multiple-Input Multiple-Output (MIMO) communication offers significant advantages by using multiple antennas at both the base station and the relay to improve system throughput and combat fading effects. While Point-to-Point MIMO relay systems have been extensively studied, the use of MIMO in PMP relay systems remains under explored. This paper proposes an optimized power allocation and adaptive channel sensing strategy for multi-user Cognitive OFDMA systems with MIMO-enabled fixed relays. The goal is to maximize spectrum efficiency and fairness while ensuring interference management and quality of service (QoS) requirements. The contributions of this paper are as follows: Optimized Power Allocation: A dynamic power allocation strategy is proposed, where power is allocated based on instantaneous channel conditions and interference levels, ensuring efficient spectrum utilization. Adaptive Spectrum Sensing: A novel adaptive sensing algorithm is introduced to minimize spectrum sensing overhead while enhancing detection accuracy and spectrum availability. Multi-User MIMO Relay System: The paper develops a system model that incorporates multi-user MIMO relays for point-to-multi-point communication, enhancing throughput and reducing coverage gaps, particularly at the cell edges. The rest of the paper is organized as follows: Section II reviews the related work on power allocation, spectrum sensing, and relay-assisted systems. Section III introduces the system model and problem formulation. Section IV presents the proposed optimization framework. Section V discusses the simulation setup and performance evaluation. Section VI concludes the paper with potential future research directions.

2. SYSTEM MODEL

In this section, we discuss about the system model of multiuser fixed relay system. We elaborate the system block diagram and assumption of system and then deal with downlink signal model. Single Input Single Output System (SISO):SISO is a standard radio channel, in which both transmitter and receiver operates with a single antenna. There is neither diversity required nor additional processing Single Input Multi Output System (SIMO):

In this system, the transmitter has a single antenna and the

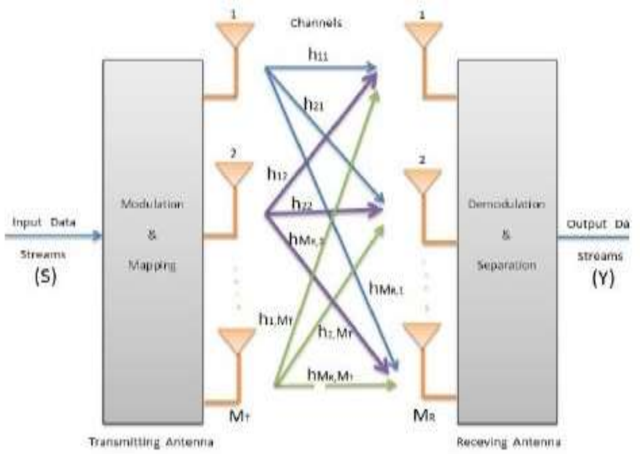


Figure 3.6 MIMO (Multiple Input Multiple Output

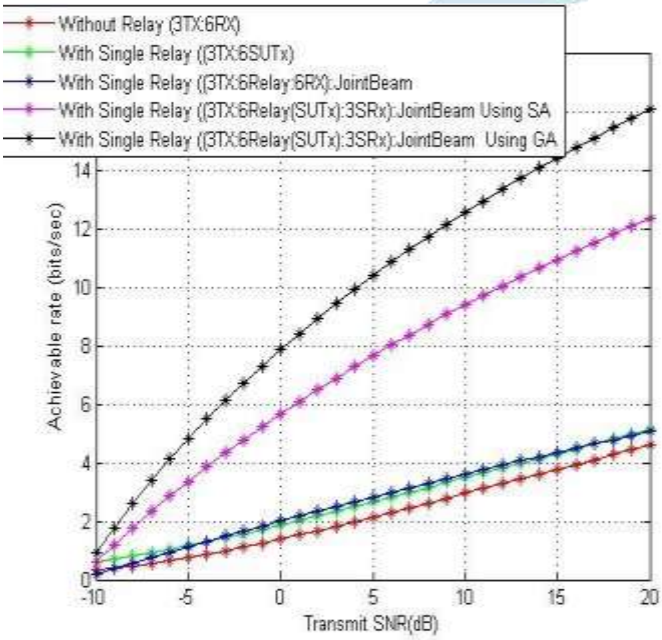
receiver has multiple antennas. This is called as receiver diversity. It is often used in a system where the receiver receives signals from independent sources to tackle the effects of fading. SIMO is relatively easy to implement but requires processing in the receiver. Applications of SIMO may be limited due to the size, cost and battery drain in mobile receiver. Multi Input Single Output System (MISO): In MISO systems, transmitter has multiple antennas where receiver has a single antenna. This is also called transmit diversity. The receiver has the ability to receive optimal signal from the multiple transmitted signals and can extract the required data. Multi Input Multi Output System (MIMO): MIMO system has multiple antennas at both the transmitter and the receiver. MIMO system has improved channel robustness and channel throughput. In order to fully attain benefit from a MIMO system it is necessary to code channels to separate data from different paths. This requires complex processing but provides high throughput and channel robustness. MIMO Relay Path Process: Fading may affect a channel and will impact signal to noise ratio and in turn increase the bit error rate (assuming digital data is transmitted). The principle of diversity is to provide the receiver with multiple versions the transmitted signal. Diversity helps in stabilizing a link, improving performance and reducing bit error rate. Signal transmitted has the lower chances of getting affected by noise through all the signal paths. MIMO is a radio antenna technology as it enables multiple signal paths to transmit data. The core idea behind the MIMO wireless systems space- time signal processing, in which time is complemented with space dimensions uses the multiple spatially distributed antennas i.e. use of multiple antennas located at multiple points. MIMO wireless systems are an extension to smart antennas that have been used to improve wireless technology. The small moment of antennas can cause new signal paths for transmission and receiving of data. The number of paths occurring between the transmitter and receiver depends on the number of objects between them. These multi paths caused interference in the previous methods but in MIMO systems it acts as an advantage. These paths can provide additional robustness to the data link by increasing the signal to noise ratio or the link capacity

Beam Forming Analysis:

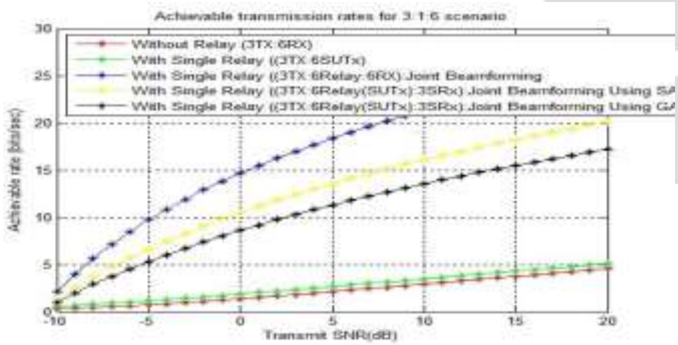
In this paper, we consider joint source-relay beam forming three-node MIMO relay network with a source destination direct link. We assume that both source and relay are equipped with multiple antennas where-as, destination is equipped with a single antenna. This scenario is similar to the relay enhanced cellular network where base station and relay nodes can have multiple antennas but mobile has a single antenna due to size constraints. In downlink transmission to mobile nodes the overall performance of cellular system is reduced. So, our systems aims to fully utilize the advantage of MIMO relay channel to increase the channel through-put. We identify several unique properties of optimal beam forming vectors for source and relay nodes for various systems. This process of deriving expressions for beam forming antenna is not so simple because of the MIMO cannel between the source and the relay and the MISO channel between the relay and the destination has to be equally balanced allocation which helps in determining the neighbour channel. If the neighbour channel gives any performance development then it is selected. SA also helps in improving the SNR value at the SU transmitter. In addition to Beam forming technique used for achieving maximum transmission rate, we also implement two searching algorithms namely Genetic Algorithm and Simulated Annealing Algorithm in order to increase the SNR value at the secondary user transmitter.

4. SIMULATION RESULTS

The simulation results have been given in this chapter. 100 channel realizations has been used for simulations in mat lab. Then SNR values from -10 to 20 dB has been used.

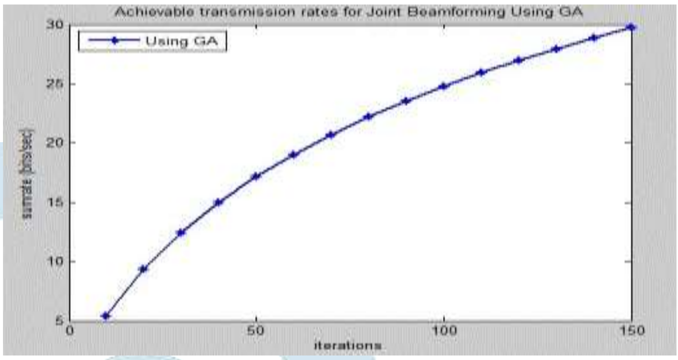


The above are the results regarding the outputs of the transmission rates under the conditions as without relay, with relay, along with beam forming, using the algorithms for channel allocation.



This plot is another example for the above plot on related to different output results in a same plot. But the only difference is the plotting range and the plot is been plotted between the transmission rate that is SNR ratio to the available rate for the each case individually

This is the individual plot estimating the results on comparison between the number of iterations and sum rate for genetic algorithm.



This is the plot that has been plotted between the number of iterations and sum rate for simulated annealing based algorithm.

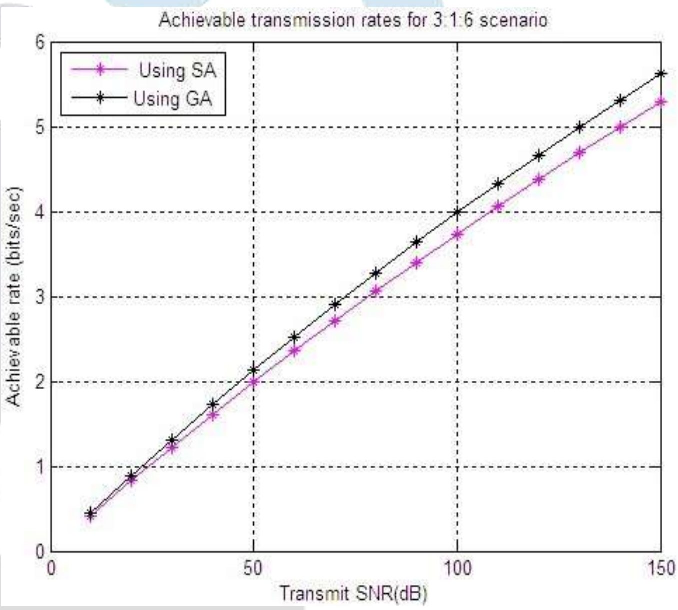


Figure 4.6 Comparison between GA and SA

The comparison between the channel allocation algorithm is been plotted hear that conveys that the we would get the better results on using both the algorithms together to avoid the complications .By using genetic algorithm we get the output related to optimum joint beamforming, and by using the simulated annealing base algorithm get the output related to optimal channel allocation of the consent channel.

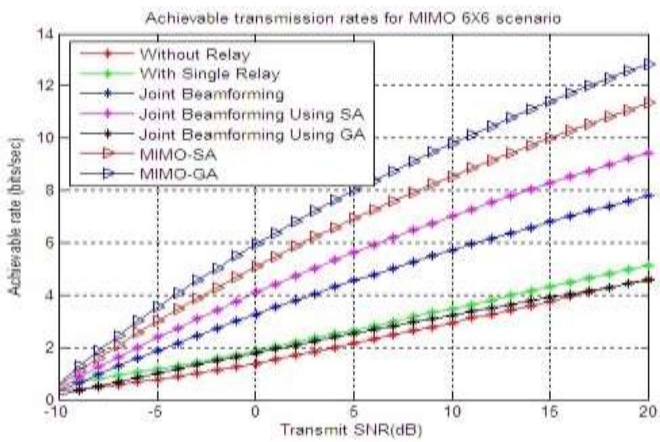


Fig : Comparison of all possible ways

The final output is relating to all the combination of the above mention outputs individually in a combined form. The components like without relay, with signal relay, only joint beam forming, joint beam forming using SA and GA algorithms and finally all together on MIMO systems

5. CONCLUSION

In this paper, we investigate the joint optimization of beamforming, power allocation, and channel allocation in multi-user, multi-channel underlay cognitive radio networks. The optimization problem is framed as a non-convex Mixed-Integer Nonlinear Programming (MINLP) challenge, which is known to be NP-hard. To simplify the problem, we divide it into two sub problems. The first sub problem focuses on finding feasible beamforming vectors and power allocations for a given channel allocation using an iterative approach that employs Semi-Definite Relaxation (SDR) and an auxiliary variable. The second sub problem addresses channel allocation, where we use the MIMO Genetic Algorithm (MIMO-GA) and MIMO Simulated Annealing (MIMO-SA) to derive suboptimal solutions. Simulation results show that the BPCA-MIMO-GA method closely Figure 4.6 Comparison between GA and SA.MIMO-SA provides nearly identical performance with much lower computation time. Furthermore, our beamforming technique, which includes interference tolerance, demonstrates superior performance compared

6. FUTURE SCOPE

The proposed techniques lay a strong foundation, but several areas of future research could enhance their practical applicability and performance. One important direction is to implement the algorithms in real-world cognitive radio networks, where factors such as dynamic channels, user mobility, and interference from other devices must be considered. Another promising avenue is to combine different optimization techniques, like integrating deep learning with genetic algorithms or simulated annealing, to develop more efficient solutions with lower computational complexity while still achieving strong performance. Extending the model to multi-tier cognitive radio networks, which integrate small cells with macro networks, could improve spectrum efficiency and overall system performance. Additionally, exploring beamforming and power allocation within complex network architectures that involve multiple base stations, relays, and MIMO systems could result in more efficient spectrum management and better network throughput. Addressing these future research challenges will enhance the performance and practicality of multi-user cognitive radio networks, particularly for large-scale, real-time deployments.

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