

Cost Effective Scheduling In MIMO Empowered Cognitive Radio Ad Hoc Networks

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Abstract: *Multiple-input multiple-out (MIMO) and cognitive radio (CR), can both effectively participate in the transmission interference among links and thus increase the network throughput in wireless communications. The goal of this work is to develop a distributed algorithm that can concurrently exploit the agility of CR and MIMO to benefit from both the opportunities of spare spectrum channels and spatial degree of freedom (DoF) for an overall higher throughput and lower delay in a multi-hop wireless network. In this paper, here propose a jointly optimized relay selection scheme for by primary users (PUs), and the frequency bands unused by primary users (PUs) are sensed and assigned to secondary users (SUs), aiming to reduce the computational burden of the selection procedure. Hence, it is possible to select an optimum relay with only one selection algorithm for two scheduling of PUs and SUs tasks.*

Key Words: MIMO, Cognitive Radio, DoF, Primary Users, Secondary Users.

1. Introduction

The cognitive radio technology allows the design of dynamic spectrum sharing techniques where unlicensed secondary users can use frequency bands owned by license primary holders. Thus, this emerging technology is regarded as the ideal candidate that can enhance the efficiency of spectrum usage for the next generation of wireless communication system. This paper considers the problem of spectrum sharing and user scheduling in a cognitive radio MIMO system. A secondary network made up of a multi-antenna base station and several secondary receivers share the same frequency bands owned by primary users.

In fact, the MIMO technology offers several advantages to enhance system performances. It can be used either to increase throughput and/or reliability of the secondary transmissions or to eliminate or reduce the interference caused to the primary receivers. However, the additional spatial resource inherent in MIMO systems makes the design of efficient spectrum sharing techniques a challenging task. In this context, the authors considers the problem of joint transmit beam-forming and power control in the downlink of a multiuser MIMO secondary network. In the studied model, the cognitive Multi-antenna base station (BS) has to satisfy the QoS constraints of the served secondary users (SUs) while protecting one primary receiver from interference. Their work also assumes that the number of single antenna users is less than the number of antenna deployed at the BS. The same authors investigate the uplink transmission

in while assuming multiple primary receivers. They extend algorithms initially proposed for traditional wireless networks to the case of cognitive radio MIMO networks. In a user selection algorithm is proposed with the objective of maximizing the secondary sum rate. Assuming the use of transmit beam forming, the secondary BS has to protect the primary user (PU) while selecting the best SUs.

Chapter 1 discussed about introduction, in section 2, here describe about related work, chapter 3 discussed about Preliminary and Motivation, in section 4 describing about Problem Statement, In chapter 5 discussing about Proposed Greedy Algorithm, in section 6 describing about Simulation Results and in Chapter 7 contains conclusion.

2. Related Work

Currently, the advances of CR (see [2], [7]–[9]) and MIMO (see [4]–[7]) are largely independent and in parallel. Due to the challenge of each research direction, there is very limited work studying the two together to exploit both spectrum opportunities and spatial opportunities. Some recent studies [3]–[9] investigate the information gain by exploiting MIMO beam forming to constrain the interference towards the primary users instead of the joint exploration of spectrum and spatial resources. Without knowledge of primary user signatures, it is also hard to measure the channels and constrain the interference in reality. A recent work in [10] intends to

understand the potential capacity gain with joint use of MIMO and CR. The implicit assumption that an antenna can simultaneously access multiple frequency bands makes it similar to conventional work on MIMO and fundamentally different from our framework. The paper focuses on forming an optimization framework, rather than provides an actual transmission algorithm. The ordering of transmissions may be difficult to realize distributively, and the OFDM kind of transmissions may apply to sub-carriers but not to wide spectrum channels.

Different from work on multi-channel allocations [5]–[8] which normally assume all nodes access the same group of channels and mainly consider channel coordination, our design takes into account the difference in channel availability at different nodes as an inherent nature of cognitive radio transmissions, the different channel conditions and multi-user diversity, and particularly the opportunities and constraints of antennas in supporting concurrent MIMO and CR transmissions. Here focus on addressing the challenge of exploiting concurrent MIMO and CR opportunities, while assuming the spectrum availability can be detected via various spectrum sensing techniques [1]–[6] proposed in the literature.

The goal of this work is to develop a distributed algorithm that can concurrently exploit the agility of CR and MIMO to benefit from both the opportunities of spare spectrum channels and spatial degree of freedom (DoF) for an overall higher throughput and lower delay in a multi-hop wireless network. Different antennas can transmit over different idle frequency channels to harvest the spectrum gain, while all or a subset of antennas of a node can also form a MIMO array to exploit the spatial gain. There is a trade-off between the two options and how to assign transmission channels and antennas depend on many factors, including the network topology, the physical channel conditions, the node density, and the traffic patterns.

The studied system is composed by a multi-antenna cognitive BS which serves secondary receivers equipped with single antenna. The secondary network shares several frequency bands with multiple primary transmitters and receivers. The BS has to assign efficiently the available frequency bands to a portion of the SUs with the objective of approaching the maximum achievable sum rate. The primary receivers are assumed to not allow any interference from the cognitive BS. Therefore, by sacrificing some of its degrees of freedom, the BS protects the primary receivers by using zero forcing beam forming and thus the presence of the secondary network is totally transparent to the licensed network. The choice of this transmit beam forming technique is motivated by its very low complexity and near-optimal performances. Compared to the optimal dirty paper coding, this technique offers a good tradeoff between implementation complexity and performance.

2. Preliminary and Motivation

Here consider a secondary network which shares frequency bands with a primary network. The secondary network consists of a M -antenna cognitive BS and K single antenna SUs whereas the primary network consists of several transmitter and receiver nodes. It is assumed that each frequency bands is used by exactly one primary transmitter serving one or multiple primary receivers. The number of primary receivers on band is denoted by $N_p^{(n)}$.

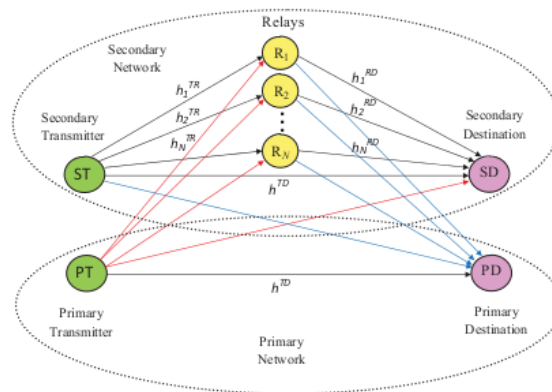


Figure 1. Cognitive Radio Network Model

These receivers tolerate no interference from the cognitive BS transmission. Also, frequency bands are assumed to be orthogonal and so there is no interference between simultaneous transmissions using different bands. Furthermore, it is assumed that the secondary BS has the ability to transmit over all the frequency bands used by the primary links by employing orthogonal frequency division multiple accesses.

This section describes how to implement cooperative MIMO relay using the MIMO scheme in cognitive radio networks. First, give a simple example to illustrate why we select some MIMO nodes as relays in cognitive radio networks. Then, we explain why the proposed MIMO scheme is suitable to be implemented in MIMO relays, and finally we present the details on how to implement this MIMO scheme.

A. Cooperative MIMO Relay

In the network here consider, there are several PUs that have the licensed spectrum, one access point (AP) and several SUs. This AP has multiple antennas to get the spatial multiplexing/diversity gain. Some SUs are equipped with multiple antennas while others with single antenna. The SUs are allowed to use the spectrum of the PUs to communicate with AP when PUs do not occupy the spectrum. The AP and SUs periodically sense the spectrum to update the information of availability of channels.

B. Transmitter Selection

As a result of the half-duplex nature of wireless communications, there is a need of selecting a set of nodes to be the transmitters in a TD. Instead of randomly selecting several nodes as transmitters, our algorithm adaptively chooses transmitters such that a queue with the higher priority would be transmitted with a higher probability to reduce the transmission delay, while also introducing some randomness for transmission fairness. In a meshed network enabled with MIMO and CR, a transmitter can transmit simultaneously to multiple receivers with one-to-many transmission, while multiple transmitters can also transmit simultaneously to a receiver with many-to-one transmission. Both types of transmission can be carried over multiple frequency channels or multiple spatial channels.

C. Channel Assignment

The secondary BS implements a spectrum sharing algorithm available frequency bands among that is responsible of sharing the SUs. In fact, at the beginning of each new TS, the BS has to perform a new user selection, to arrange the selected users in at most sets corresponding to the available frequency bands and finally to allocate optimally the available power among these users. This sharing should be based on the instantaneous channel qualities of the secondary and primary users and has the objective of maximizing the sum rate of the secondary network while eliminating any interference to the primary receivers.

D. Distributed Stream Allocation

In the distributed scheduling, the stream allocation decision can be made either at the transmitter nodes or at the receiver nodes, and there is a trade-off for taking either of the options. We propose a distributed stream allocation algorithm which makes decision first at the receiver nodes based on the measured channel conditions and finalizes the decision at the transmitter nodes to concurrently consider the priority and quality of the streams and constrain the number of data and interference streams to be within the decoding capability of the receivers.

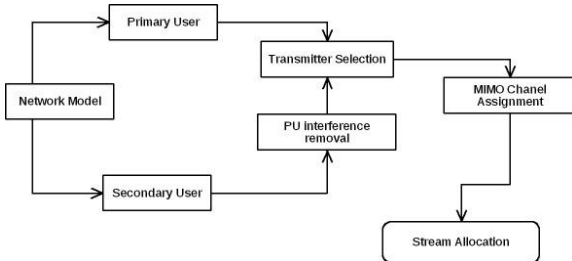


Figure 2. Architecture Diagram

3. Graph Based Problem Formulation

A. System Model Building

The cognitive radio MIMO network is formulated as a weighted graph $G = (V, E, C)$ where V denotes the set

of vertices, E denotes the set of edges and E is the $K \times N$ matrix where each row represents the N different weights corresponding to each vertex in V . The different components of network G can be obtained as follows:

- 1) The set of vertices V : Each secondary user K in the system is represented by a vertex $v_k \in V$. The primary transmitters and receivers are not represented as vertices.
- 2) The set of edges E : The edges represent the degree of orthogonality between the channel vectors of the secondary users on each frequency band. Hence, each two vertices will have at most N edges. Each edge corresponds to exactly one frequency band. Graphs that have multi-edges are also referred in the graph theory literature as multi-graphs or pseudo-graphs.

To model the degree of orthogonality between the channels of secondary users k and k' on each frequency band, the degree can be defined as

$$e_n(K, K') = \frac{|h_{k,n} h_{k',n}^*|}{\|h_{k,n}\| \|h_{k',n}\|}$$

Hence, it is possible to draw an edge corresponding to the band between two secondary vertices v_k and $v_{k'}$ where $(k, k') \in \{1, \dots, K\}^2$ if and only if

$$e_n(k, k') > \epsilon_s$$

i.e. the channels of users k and k' are not ϵ_s -orthogonal where ϵ_s is a constant orthogonality threshold between the channels of secondary users which have to be chosen carefully in order to achieve high system performances. Finding the optimal threshold values is analytically intractable, and hence the choice of orthogonality thresholds is performed by means of simulations. The impact of this choice will be discussed in Section VI.

In order to differentiate edges having the same endpoints but corresponding to different frequency bands, the frequency band index is added to each edge. For example, if the channels of users k_1 and k_2 on band n are not ϵ_s -orthogonal, then an edge $\{v_{k_1}, v_{k_2}, n\}$ is added to the set. In this case, the two vertices v_{k_1} and v_{k_2} are called n -adjacent.

3) The weight matrix : In order to model the degree of orthogonality between a secondary user $K, K = 1, \dots, K$ and a primary receiver $P_n, P_n = 1, \dots, N_p^{(n)}$ on each band n , degree can be defined as

$$e(K, P_n) = \frac{|h_{k,n} g_n(P_n)|}{\|h_{k,n}\| \|g_n(P_n)\|}$$

For each vertex, we define N positive weights. For vertex v_k , the weight corresponding to frequency band n is defined as follows

$$C_{k,n} = \begin{cases} \|h_{k,n}\|^2, & \text{if } \forall p_n : e(k, p_n) \leq \epsilon_p \\ 0, & \text{otherwise} \end{cases}$$

i.e. the weight of a vertex v_k is equal to the channel gain of the corresponding secondary user if and only if the channel of this user is ϵ_p -orthogonal to the channels

of the primary receivers operating in the same frequency band n . Otherwise, this weight is equal to zero.

4) The availability vector B : In our model, the number of possible users sharing the same frequency band is limited due to the number of primary receivers on this frequency band and to the use of frequency bands. Hence, here defines a $N \times 1$ availability vector B where the n th element corresponds to the number of degrees of freedom available for scheduling secondary users in band n which is equal to $b_n = M - N_{p_n}$.

4. Problem Statement

As previously reported by many works dealing with user scheduling for MIMO systems using frequency bands, the achievable sum rate approaches its optimal value if the BS schedules simultaneously near orthogonal users. In this paper, instead of evaluating all the possible combinations of users we limit our search to near-orthogonal users. In our network representation, near-orthogonal users are clearly characterized by the absence of edges between their corresponding vertices in a given frequency band. Such users can be scheduled in the same set and hence can share the same frequency band without penalizing the achievable sum rate. Furthermore, the weight vector associated with each vertex (user) represents the sum rate gain achieved when scheduling the corresponding user. At the same time, it forbids scheduling the users that are not quasi-orthogonal to primary receivers in a given frequency band.

Therefore, based on this network formulation, it can be concluded that the objective of finding a spectrum sharing that approaches the optimal achievable sum rate is similar to the one of finding a special proper coloring of the system graph. In fact, the formulated spectrum sharing problem is similar to coloring a subset of the vertices of $G(V' \subseteq V)$ with N colors while maximizing the total weight of the colored vertices, i.e. $\sum_{vk \in V'} C_{k,n(k)}$ where $n(k)$ is the color given to vertex vk . Note that we mean by proper vertex coloring the operation of assigning colors to vertices such that two n -adjacent vertices cannot both have the color n . Since vertices corresponds to users, colors to frequency bands and weight vectors to channel gains, coloring a vertex vk using a color n is equivalent to scheduling the corresponding user k in the band n .

5. Proposed Greedy Algorithm

The coloring problem formulated in this paper can be shown to be NP -hard based on the proof of Lemma. In fact, it suffices to take $N = 1$ and our coloring problem becomes similar to the maximum stable set problem which is known to be NP hard. Therefore, this motivates the design of heuristic algorithms which sacrifice optimality in return of a considerable reduction of computational complexity. This section presents a

heuristic greedy algorithm that obtains near optimal solutions to the announced problem.

The algorithm takes as input matrices H and G denoting the channel coefficients between the BS and the secondary users, and between the BS and the primary receivers, respectively.

It uses also ε_δ and ε_p . The first step of the algorithm is the system network construction. Then, the algorithm starts assigning colors to vertices one at a time in a greedy fashion. The picked vertex on each iteration must be the best vertex to color (which is considered as locally optimal) based on a given selection criterion. Each time a vertex is assigned its best choice color, the algorithm proceeds to an update of the weight vectors of its adjacent uncolored vertices. This update is performed by reducing to zero the weights corresponding to color n . Also, has to be updated by decrementing the availability vector B has to be updated by decrementing its element that corresponds to the assigned color.

The algorithm terminates when the availability vector B is equal to the null vector or when there are still no vertices that can be colored. The main steps of the proposed greedy algorithm are outlined in where O_N and $O_{K,N}$ are the $K \times 1$ zero vector and $K \times N$ zero matrix respectively.

The most important phase in the proposed greedy scheduler is the way the next vertex to be colored is picked. In the case of unweighted graphs, most vertex coloring heuristic algorithms colors at each iteration the vertex having the larger degree, i.e. the vertex having the larger number of adjacent vertices. They are based on the intuition that a vertex having a larger degree will be more difficult to color if it is delayed. Here some new parameters are introduces which are vertices' weights:

1. $C_d(V_k)$ is the weight degree of v_k . It is represented by the sum of the weights of vertex v_k . Note that when the algorithm chooses the vertex having the larger $C_d(V_k)$, the total weight of the solution increases considerably. However, the total weight of the final solution may be penalized if the chosen vertex has a large number of adjacent vertices.
2. $E_d(V_k)$ is the edge degree of v_k . It is the number of edges whose endpoints are vertex v_k and a non colored vertex. As it will be shown through simulations, this criterion results in poor performance since it does not take into account the vertices' weights.
3. $D_d(V_k)$ is the magnitude of the difference between the two largest weights in the weight vector of vertex v_k . If the algorithm uses the largest magnitude $D_d(V_k)$, it will color a vertex v_k with its first choice color before its adjacent vertices. Hence, this selection criterion will avoid penalizing vertices by a long delay.

4. $M_d(V_k)$ Let define $M_d^{(n)}(V_k)$ as the difference between the n th weight of vertex v_k (i.e. $C_{k,n}$) and the largest n th weight among its adjacent non-colored vertices, i.e.

$$M_d^{(n)}(v_k) = \max_{k'} c_{k'n} \forall \{v_k, v_{k'}\} \in E,$$

where $v_{k'}$ is a not yet colored vertex. Hence, it is possible to define $M_d(V_k)$ as the largest $M_d^{(n)}(V_k)$ for each vertex v_k . The rationale behind this criterion is that each vertex is only compared to its adjacent vertices. Thus, a vertex having a larger $M_d(V_k) = \max M_d^{(n)}(V_k)$ will receive the n corresponding color before its adjacent vertices.

6. Simulation Results

This section analyzes the performance of the proposed algorithm in terms of the maximum achievable sum rate. Nodes are distributed uniformly over a $400m \times 500m$ area. Each node has a transmission range of 150m. The MIMO channel between node pair is modelled based on the node distance with path attenuation loss factor set as 3.5, and the small-scale fading coefficients following the Rayleigh model. White Gaussian noise with SNR = 10dB is added to include environment noise and interference that cannot be cancelled. If not otherwise specified, the number of nodes in the network is 80, the number of antenna elements at each node is 4 for all the algorithm simulations, and the number of available frequency channels in the network is 5. The set of available frequency channels at each node is randomly selected from this 5-channel pool.

Figure 4. No of node v/s delay

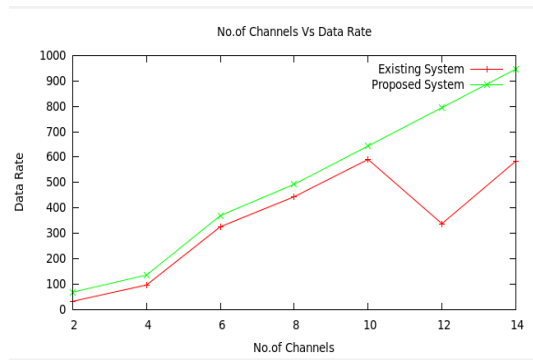


Figure 5. No of channel v/s data rate

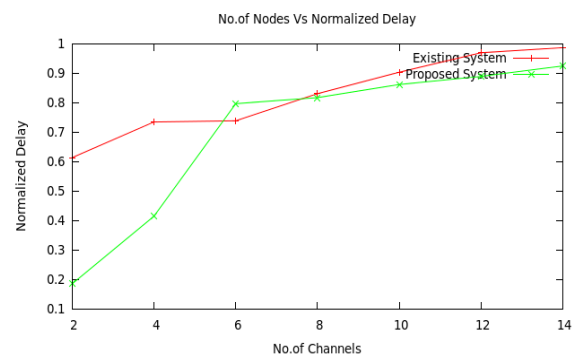


Figure 6. No of channel v/s delay

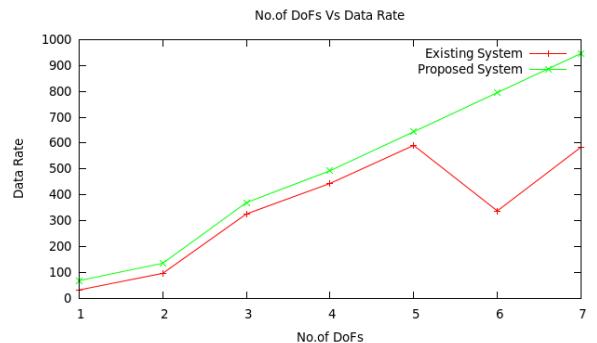


Figure 7. No of DoF v/s data rate

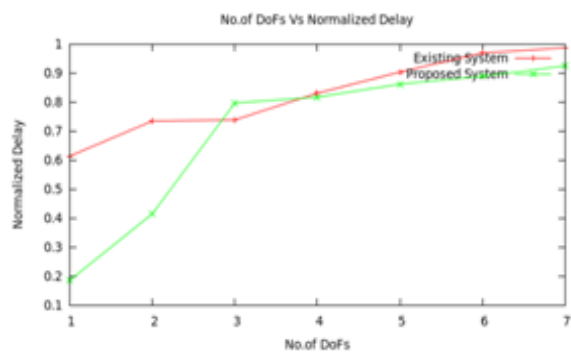


Figure 8. No of DoF v/s delay

There is no distributed scheme existing for concurrent exploration of CR and MIMO, to demonstrate the effectiveness of our scheduling algorithms and the

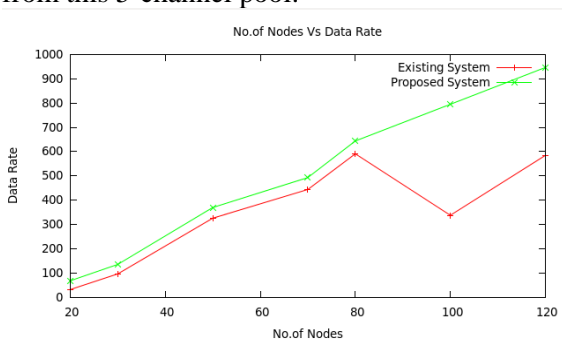
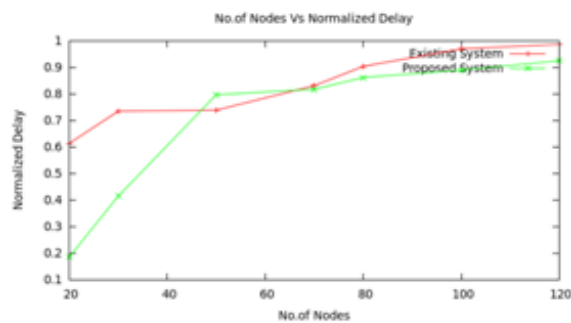


Figure 3. No of node v/s data rate



benefit of using many-to-many cooperative transmission by taking advantage of MIMO over CR, the performance of our algorithms is compared with: (1) existing MIMO CR; (2) MIMO CR with primary and secondary Users.

7. Conclusion

In this paper, Here considered the problem of spectrum sharing in cognitive MIMO systems. The studied system assumes the coexistence of a point to multipoint MIMO secondary network with multiple primary transmitters and receivers. Here proposed a spectrum sharing algorithm in order to approach the maximum achievable sum rate. Based on graph theory, the algorithm starts by constructing a weighted multi graph taking as input all the system parameters. Afterwards, the algorithm solves a special case of vertex hard in a coloring problem that to be proved in a greedy fashion. The algorithm uses one of the designed vertex selection criteria. Here also presented a binary integer formulation of the coloring problem in order to find its optimal solution using branch-and-bound techniques. Finally, comparison can be done with simulations and the performances of the proposed algorithm to the optimal solution and it is shown that it resolves efficiently the complexity/ performances trade-off. Future work in this area involves considering more practical issues such as insuring fairness. A thorough computational complexity study shall also be provided in future work.

8. References

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