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Optimum discrete phase-only multicast beamforming with joint antenna and user selection in cognitive radio networks

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ABSTRACT

Spectrum underlay technique for secondary multicast network is an effective approach in cognitive radio. In such communication schemes, quality of service constraints are satisfied for the secondary users while interference to the primary users is kept under a threshold. Previous literature consists of suboptimum methods for the solution of the individual problems such as antenna and user selection. In this paper, the joint antenna and user selection problem is considered and solved in an optimum manner. Complete problem is formulated for a discrete beamformer which permits linear constraints and cost function resulting a form suitable for mixed integer 0–1 linear programming. It is shown that antenna selection is very effective to improve the user signal-to-noise ratio while user selection can be employed to increase feasibility. The proposed method performs significantly better compared to suboptimum only-antenna and only-user selection methods in the literature. The problem is further modified to design robust beamformers for any l_p ball uncertainty region by using a linear approximation. Several simulations are done and it is shown that the proposed approach generates significant improvements in the transmit power and the number of serviced secondary users in a quality of service aware scenario.

1. Introduction

As the demand for radio spectrum increases due to emerging wireless services, better spectrum access strategies are required for efficient spectrum usage. Cognitive radio (CR) is proposed to improve the utilization of the radio spectrum [1,2]. CR allows the reuse of available spectrum by exploiting the spectrum holes unoccupied by the primary users. In CR, the idea of spectrum sharing is supported by multiple transmit antennas and transmit beamforming techniques [3,4]. In spectrum sharing, secondary spectrum licensing is possible as long as the secondary network users cause acceptable performance degradation on the primary network communications. Therefore the problem is to construct spectrum sharing strategies and methods that satisfy quality of service (QoS) requirements for the secondary users while the primary users are ensured with low or acceptable interference.

Multicast transmit beamforming exploits channel state information (CSI) at the base station to steer a beampattern towards the users while nulls are placed towards the primary users [5]. Multicast beamforming is a part of enhanced multimedia broadcast multicast service (EMBMS) of the long term evolution (LTE) standard [6,7]. In this paper, a special case of multicast beamforming, namely single group multicast or broadcast beamforming is considered. Cognitive base station is equipped with an antenna array in secondary broadcast network. The objective is to transmit a common information to secondary users while guaranteeing that the interference on the primary users are below interference temperature in accordance with spectrum underlay perspective of spectrum sharing problem [3]. When the interference limits dictated by the primary network are demanding and the number of primary users is large, admission control or secondary user selection at the cognitive base station becomes a critical task [8,9]. In fact, it is usually not possible to support all the secondary users and hence some secondary users should be selected to satisfy the QoS requirements in the secondary network. In practice, the number of transmit antennas is less than the secondary users which also leads to the user selection in order to satisfy the QoS requirements and increase the degrees of freedom for the beamformer [10]. The main goal in user selection is to maximize the number of secondary users while minimizing the total transmit power and interference to the primary users.

Multicast beamforming problem is usually investigated in continuous case where the beamformer weight vector has continuous amplitude and phase [5,11]. The continuous problem is nonconvex and NP-hard even for single group multicasting [7,11]. The typical approach to solve this difficult nonconvex problem is the

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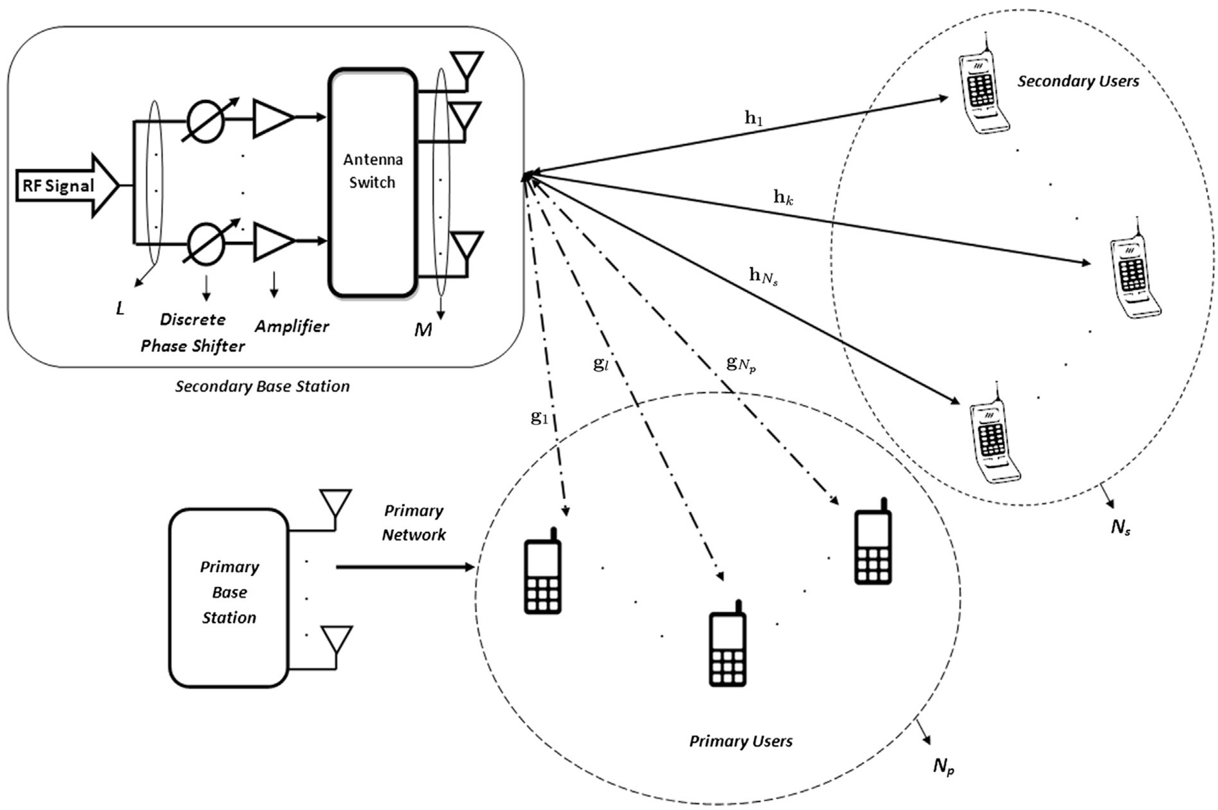

Fig. 1. Single group multicast transmit beamforming with antenna and user selection in a spectrum underlay scenario where primary and secondary users are considered in a QoS-aware CR system.

semidefinite relaxation (SDR) [5,11,12]. The solution found by SDR is not guaranteed to be optimum in general. Optimum solution can only be obtained when there is a single broadcast network with less than four users [13]. However, for practical wireless scenarios, where the number of users is larger than the antennas, the performance of SDR becomes unacceptable. Randomization is employed to overcome this problem whose performance degrades as the number of users increases [11,13]. Another disadvantage of continuous beamformers is the requirement to use digital beamforming with an RF chain for each antenna. While the performance of digital beamforming improves with the number of antennas; the cost, size, power and demand on real time signal processing become a major drawback [14,15].

Motivated by the shortcomings of aforementioned approaches, we propose discrete structure by employing analog beamforming. The number of digital transceivers is much less than the number of antennas in case of analog beamforming [15]. In Fig. 1, a single RF chain is used with a network of analog discrete phase shifters to reduce insertion loss and improve accuracy and noise robustness [16]. An example of such an analog beamformer in mm Wave is tested successfully in [17]. Discrete structure is more suitable for fabrication, decreasing the system complexity and cost as well as increasing the controllability [18,19]. Due to quantization loss, discrete formulation of the optimization problem is more suitable than its continuous counterpart when the phase shifters are used to control the beampattern [18]. Simple quantization of the continuous beamformer coefficients results significant performance loss compared to optimum discrete beamformers. This point is elaborated in the simulations part. Furthermore, in order to decrease complexity, codebook based beamforming has gained more attention in many standardized systems, such as IEEE802.16e and 3GPP LTE [20]. Using phase-only codebook for beamforming weight vector has certain advantages [18,21,22]. Phase-only control modules using equal amplitude are less expensive to produce. Phase-only approach has lower computational complexity compared to both amplitude and phase solution in discrete case. Recently, beamforming antennas with discrete phase shifters become the key technology of millimeter wave communication systems where it is possible to obtain higher data rate and performance with minimum power consumption [16,20]. One of the most important advantages of discrete beamformers is the fact that their formulation admits linear forms which can be effectively solved in optimization problems. This feature of discrete transmit beamformers has been overlooked in the literature except some of our previous works in [23–25].

The cost and complexity of analog beamforming can be further reduced by using antenna selection. Antenna selection results less transmit power, increases the number of serviced users and improves the feasibility of the spectrum sharing in multicast beamforming in comparison to the same number of antennas in a fixed structure. Furthermore, the best performance is not always guaranteed when all the antennas are employed in systems where phase-only codebook is used in beamforming. In this case, selecting the transmit antennas with good channel conditions is more effective than using fixed antenna structure under the same transmit power [21].

There exist several works on user and antenna selection separately in broadcast cognitive scenario [8,9,26,27]. However, the first work which considers the joint problem is [28]. In [28], the joint problem is solved in an optimum manner. This paper extends the work in [28] by including a detailed treatment of the joint antenna and user selection in addition to the robust formulation of the problem. Furthermore, comparisons with suboptimum only-antenna and only-user selection algorithms in the literature are presented as well as several detailed simulation results. The proposed method finds the optimum solution for the secondary user subset, the best L out of M antennas and the transmit beamformer coefficients jointly. In order to achieve this result, the nonconvex