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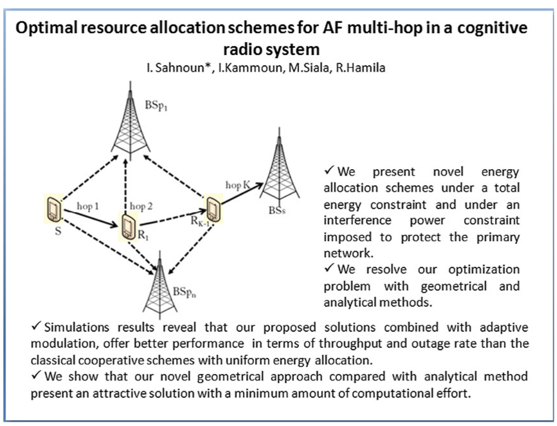
Energy allocation optimization for AF multi-hop in a cognitive radio system

Imen Sahnoun [a,b,*], Ines Kammoun [c], Mohamed Siala [a], Ridha Hamila [b]

[a] Higher School of Communication of Tunis, University of Carthage, Tunisia
[b] Electrical Engineering Department, Qatar University, Qatar
[c] National School of Engineers of Sfax, University of Sfax, Tunisia

GRAPHICAL ABSTRACT



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ABSTRACT

In this paper, novel optimal energy allocation schemes for the secondary users in an amplify-and-forward multi-hop underlay cognitive network are proposed. The optimization problem is formulated as a maximization of the instantaneous received signal to noise ratio, under interference power constraints that are imposed to protect the primary network. First, a novel geometrical approach is proposed for the two and three hop cases. Simulations show that the proposed approach combined with adaptive modulation outperforms the cooperative cognitive system with uniform energy distribution. Then, a Lagrange-based analytical approach solution is proposed to the problem for the 2-hop case. Numerical results show that the Lagrangian resolution leads to the same results as the geometrical one. The advantage of the geometrical approach is to get more insight for the 2-hop case and makes the resolution tractable for more hops in the network.

1. Introduction

The radio spectrum is becoming a critical resource for wireless communication networks due to the success of 3G and 4G systems and the explosion of high date rates hungry multimedia

* Corresponding author at: Higher School of Communication of Tunis, University of Carthage, Tunisia.

E-mail address: imen.sahnoun@supcom.tn (I. Sahnoun).

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services [1]. Multiple solutions have been proposed such as MIMO systems, massive Multi-User MIMO systems, cooperative communications and cognitive radio. Cognitive radio (CR) [2] is a promising technology to deal with this frequency scarcity caused by the current inflexible spectrum allocation policy. Different paradigms for CR have been discussed in [3] and are classified into three main approaches, according to the ways the secondary users (SUs) access to the primary spectrum: overlay, interweave, and underlay CR systems [4]. In overlay networks, the SUs are allowed to transmit only when transmissions of the primary users (PUs) are considered absent. This approach requires that the SUs deal with spectrum sensing to identify the unused bands and exploit them for their own transmissions [5]. However, for underlay and interweave CR systems, the SUs are allowed to exploit the same band being used by the primary users based on interference limitation or avoidance, respectively. These two approaches are especially appealing for practical deployments since they do not involve complex spectrum sensing mechanisms that requires time consuming and power intensive processes [6–8].

Here, the underlay approach, that allows the SUs to operate in parallel with the PUs is considered. While transmitting, the SUs have to maintain the interference level they cause to the PUs below a predefined threshold. This constraint limits their transmission energy as well as their coverage areas. Because of this restricted coverage area, cooperative relaying techniques are used [9,10] in order to make communication possible between two distant nodes. Furthermore, for each communication is allocated a total available power that must be well distributed among all involved nodes. In this context, and given that power is a critical resource, optimizing the usage of this resource is crucial.

In the literature, several power allocation approaches for non-cognitive cooperative networks have been studied under different cooperatives schemes and optimization criteria. In [11] and [12], the authors propose a power allocation scheme for multi-hop transmission systems that minimizes the outage probability under a total power constraint. In [11], both individual and total power constraints have been treated in the dual-hop case. The individual power constraint is however overlooked when resolving the multihop case. In [13] and [14], the total power consumption in a multi-hop network is minimized while keeping the SNR above a certain threshold [14], and the end-to-end Bit Error Probability (BEP) below a predefined target [13]. In [15], the authors aimed to maximize the instantaneous received SNR in an Amplify-and-Forward (AF) multi-hop network under short-term and long-term power constraints. A power allocation scheme was also proposed in [16] to maximize the achievable data rate in a multi-channel multi-hop relay network where both (AF) and decode-and-forward (DF) relaying approaches are studied. In [17], a selection relay scheme combined with a power optimization was studied, under both individual and total power constraints, to maximize the source–destination channel capacity. Different from these non-CR, in CR, the design of power allocation approaches of the SU should consider the interference caused to the PU in order to protect the quality of service of the PU. In [18], the optimal power allocation approaches to achieve the ergodic and outage capacity for a fading CR under both transmit and interference power constraints are investigated. The authors in [19] proposed a transmit power control approach using directional transmission technique for relay-assisted CR networks in order to optimize the secondary performance system while limiting interference to the primary receivers. In [20], Lagrange multiplier based convex optimization has been adopted to address the optimal power allocation issue of CR system formulated under outage and interference constraints in both dual-hop and multi-hop scenarios.

Note that, all these aforementioned research works only proposed analytical resolutions for power allocation problems, that demands high computational complexity. In authors' previous works [21,22], energy optimization schemes in cognitive cooperative networks are investigated with only secondary relay where both non-regenerative (AF) and cooperative Alamouti space–time (ST) coding protocols are studied and compared to each other [21]. Moreover, the authors in [22] combined a selective-relay scheme where only one "best" relay is chosen with an optimal energy allocation scheme for source and relay nodes to maximize the instantaneous received SNR under the system constraints.

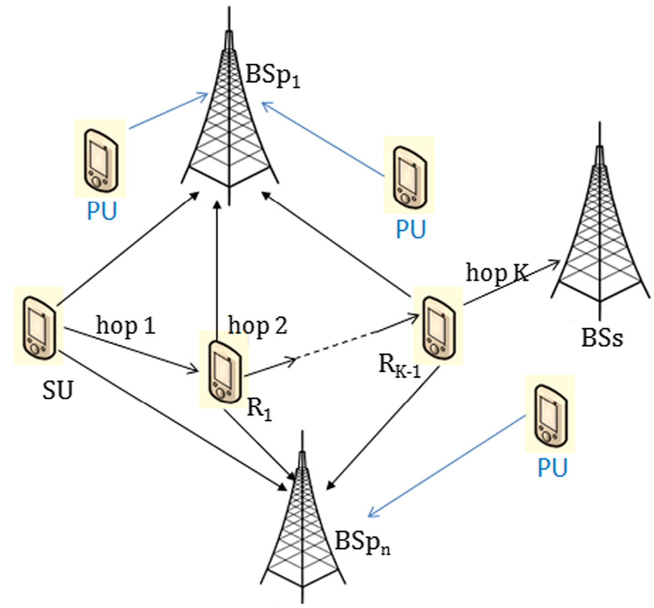

Fig. 1. Generic system model: A multi-hop secondary network in the presence of primary base stations.

The novelty in the present paper is to generalize the above-mentioned works to an AF multi-hop cognitive system and to find novel optimal power allocation schemes for the source and relays nodes that maximize the instantaneous SNR at the secondary destination in the underlay network. Therefore, both total and individual power constraints are considered to skirt the interference cost received at the primary network. It is noted here that, in authors' previous work, the source and the relay adapted their energy while keeping a total fixed available energy, while in the current work this constraint is more practical and requires only that the sum of users energy still kept below a total fixed available energy. To solve the optimization problem, both geometrical and Lagrangian approaches are proposed. For the geometrical approach , the two and three hops cases are studied, while for the Lagrangian approach only the two-hop case is considered, given the resolution complexity of the problem. Furthermore, an adaptive modulation is proposed at the secondary user in order to compensate the throughput loss due to the relaying [23,24] and to improve the data rate at the secondary base station.

Note here that, up to the authors' knowledge, the proposed geometrical optimization approach, as well as the Lagrangian approach in the cognitive multi-hop context, have not been considered in the literature.

The organization of this paper is as follows. In Section 2, the multi-hop cognitive system model is introduced then the total received SNR at the secondary base station is expressed. The principle of the adaptive modulation used for the throughput loss compensation is also presented. In Section 3, a Lagrange-based analytical approach is developed for the constraints imposed on the secondary users. In Section 4, the proposed energy optimization