Journal of Network and Computer Applications 37 (2014) 253–258

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

# Potential bargaining for resource allocation in cognitive relay transmission

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A R T I C L E   I N F O

*Article history:*
Received 6 March 2012
Received in revised form
17 November 2012
Accepted 26 February 2013
Available online 14 March 2013

*Keywords:*
Cooperative transmission
Game theory
Time division
Coexistence
Cognitive networks

A B S T R A C T

Cooperative transmission between cognitive users can effectively decrease interference with primary users in underlay mode. Relay transmission between cognitive user and primary user can not only benefit the primary communications and facilitate the cognitive transmission too. Having obtain considerable profits from the cooperation, the primary user may lease its spectrum dynamically or upgrade the interference temperature timely for the cognitive user as a repayment. In this paper, we first consider a system model under the circumstances of Rayleigh fading channels which are coming close to real conditions. Then, we analyze the incomes of the primary transmitter in underlay mode and raise a rational scheme to compensate the cognitive relay by increasing certain interference temperature. In overlay mode, we propose an appropriate time-division pattern for the cooperative transmission under the deployment of dynamic spectrum leasing. Game theory is used when we resolve the bargaining problem of time division. Simulation tests are further run in MATLAB platform to prove the feasibilities of our proposals. The results demonstrate that both the primary and cognitive users can benefit from the cooperation.



## 1. Introduction

With the rapid development of wireless services and applications, currently deployed radio spectrum is becoming more and more crowded. However, some researches show that spectrum resources of partial licensed frequency have not been fully utilized, so there is "spectrum hole" in time and space (Federal Communications Commission, 2002; Yang, 2004). Cognitive radio (CR) is widely considered as a promising technology that deals with the spectrum shortage problem caused by the current inflexible spectrum-allocation policy (Zhou and Harada, 2012).

To make full use of the spectrum resources, the applications of transmit-power control and dynamic spectrum management are necessary for CR (Haykin, 2005). In the underlay mode, secondary user (cognitive user) is allowed to use primary spectrum only when the interference is below a certain level called interference temperature (Notice of Inquiry and Notice of Proposed Rule Making, 2002). In the overlay mode, the secondary user utilizes the channel in the condition of the absence of primary user and it has to leave when the owner shows up. Many solutions and assumptions have been considered to resolve the problem of the coexistence between primary users and cognitive users in CR networks. In addition, if the secondary user can act as a relay to improve the communication performance of the primary user, then it may obtain the spectrum authorization as a repayment. This scheme will bring considerable gains to both where the cooperative relay communication under cognitive networks should be deployed.

Cooperative relay communication has been introduced to enhance the performance of wireless networks for a long time, since it can mitigate the effects of path loss in wireless links and achieve cooperative diversity to counter the detrimental effect of signal fading inherent to wireless channels, thereby significantly improving the network coverage and capacity (Laneman et al., 2004). Inspired by the concepts of cognitive radio and relay networks, cognitive relay networks have recently been investigated as a potential way to improve the performance of secondary users. Recent literatures (Cheng and Yao, 2010; Zhao et al., 2011; Lee et al., 2011) have discussed cooperative relay in CR from various perspectives. In Cheng and Yao (2010), a cognitive relay technique has been discussed to mitigate intercell interference in cellular systems while several relay stations equipped with cognitive radio are deployed near the cell boundary. In Zhao et al. (2011), the problems of power and channel allocation for cooperative relay in a three-node cognitive radio network have been investigated. The outage probability of cognitive relay networks with interference constraints has been evaluated in Lee et al. (2011). And the best relay selection has been always a key point in both cognitive relay transmission and traditional relay communication (Zou et al., 2010; Chen et al., 2011; Cho et al., 2011; Bletsas et al., 2006). In general, cooperative relay communication in CR networks can be performed through using one of two approaches: cooperation between primary and secondary user, and cooperation between secondary users themselves. A number of literatures have been

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http://dx.doi.org/10.1016/j.jnca.2013.02.020

presented to discuss the latter situation whose main intention is to alleviate the interference level in the underlay mode (Lee and Yene, 2006; Suraweera et al., 2008; Mietzner et al., 2009; Kim et al., 2008). However, the cooperation between primary and secondary users in CR networks, which is the main concern in this paper, receives relatively little attention.

In this paper, based on the analysis of cognitive radio networks, an interference model is first given over Rayleigh fading channels. Furthermore, a discussion about how to improve the coexistence between cognitive users with primary networks is made. For primary users, relay transmission on several hops can lead to an extended battery life, lower outage probability, as well as lower level of system interference. In the underlay mode, we investigate the incomes of primary user in terms of decreasing outage probability, and a corresponding payment for the cognitive relay is identified. On the other hand, when the cognitive users stay in the mode of overlay, the scheme of dynamic spectrum leasing is more suitable in this situation, where the critical problem of rational time allocation for both participators needs to be fixed carefully. In this case, a novel time-division pattern is proposed by using game theory which has been proved to be an effective method to solve different bargaining problems in many areas (Li et al., 2011; Moretti and Vasilakos, 2010; Saad et al., 2011; Canales and Gallego, 2010).

The rest of this paper is structured as follows: Section 2 describes the system model of the CR relay networks. The algorithms for power allocation and time division are investigated in Section 3. Section 4 illustrates the simulation results. Finally, Section 5 concludes this paper.

## 2. System model

In this paper, we consider a model of relay system where a pair of primary users and several cognitive users locate as shown in Fig. 1. The relay works in regenerative mode, so a relay decodes the received data and then forwards it to a secondary destination. How to select the best relay position in networks is always a critical issue and has been widely investigated in many literatures, but is not the main point we want to discuss in this paper.

After identifying a suitable cognitive terminal as the relay station, if the cooperation executes in the mode of overlay, the primary user should broadcast a lease time $T$ for the cooperation which can be ascribed as $T=t_p+t_s$. Having consumed time $t_m$ to receive the signal of primary transmitter, the secondary user *SUrl* relays the signal for a time $t_p$ to the primary receiver. Then, the secondary user will reserve time $t_s$ to communicate for its own purpose. In this situation, how to rationally divide $t_p$ and $t_s$, involves the allocation of the benefits of primary user and secondary user, is a key problem for cognitive relay transmission which will be discussed in the following sections.

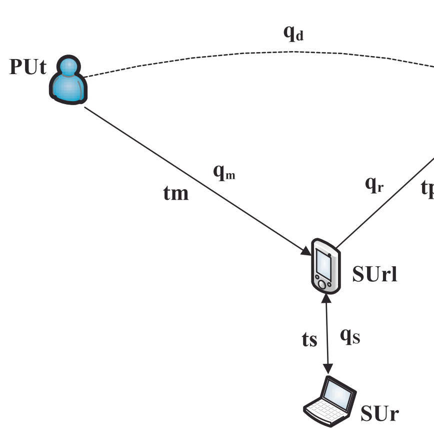


**Fig. 1.** System model of cognitive relay transmission. *PUt*, *PUr*, *SUrl*, and *SUr* represent primary transmitter, primary receiver, cognitive relay, and secondary receiver, respectively. Furthermore, $q_d$, $q_m$, $q_r$ and $q_s$ are the outage probabilities in the corresponding channels, respectively.

In the underlay mode, a chief task for cognitive users is to rationally control its interference with primary user. In this paper, we consider the model of signal-to-interference-plus-noise ratio (SINR) over Rayleigh fading environments. The power received from transmitter $j$ can be given by

$$P=G_jF_jP_j \tag{1}$$

The number $G_j$, which is positive, represents the path gain (not including fading) from the $j$th transmitter. It can be described as $G_j=h_jc_j$, where $h_j=A/r^{\alpha}$ and $c_j$ are the correlation coefficient (Koskie and Gajic, 2005). In the analysis below, we assume that $G_j$ is constant, and does not change much with time.

The number $F_j$ models Rayleigh fading. They are assumed to be independent, exponentially distributed random variables, with unit mean (Stuber, 1997). In other words, the power received from transmitter $j$ is an exponentially distributed random variable, with mean value

$$E(G_jF_jP_j)=G_jP_j \tag{2}$$

Then, the SINR $\gamma$ of the $i$th mobile can be defined as

$$\gamma_i=\frac{G_iF_iP_i}{\sum_{j\neq i}G_jF_jP_j+\sigma^2} \tag{3}$$

where $P_i$ is the power of the $i$th mobile and $\sigma^2$ is the background noise which will be given in the later simulation. One of the designing goals of communication in wireless networks is to ensure that no mobile's SINR $\gamma_i$ falls below its threshold $\gamma_i^{tar}$ to ensure adequate quality of service (QoS). Thus, there is

$$\gamma_i\geq\gamma_i^{tar}\quad\forall i \tag{4}$$

For individual mobiles, this threshold can be calculated to maintain a satisfactory frame error rate. Furthermore, we define the interference vector as $I$ which can be represented as

$$I_i(P_{-i})=\sum_{j\neq i}G_jF_jP_j+\sigma^2 \tag{5}$$

Sign $I_i(P_{-i})$ means that the interference vector of the $i$th mobile depends on all but the power vector itself. From (3), we regard $p_i$ as the power of primary user and $p_j$ as the power of cognitive user. We assume that primary users can not interfere with each other when they use different spectrums, and we ignore the interference from other cells. The primary user needs to meet the requirement of QoS, as described in (4). When the power of the primary user is constant, if we want to satisfy (4), we can achieve the following equation from (3):

$$\sum_{j\neq i}G_jF_jP_j\leq T=\frac{G_iF_iP_i}{\gamma_i^{tar}}-\sigma^2 \tag{6}$$

Eq. (6) can be rewritten as follows:

$$G_lF_lP_l+\sum_{\substack{j\neq i\\ j\neq l}}G_jF_jP_j\leq T \tag{7}$$

where $P_l$ is the power of a cognitive user. Eq. (7) can also be deduced to

$$P_l\leq\left(T-\sum_{\substack{j\neq i\\ j\neq l}}G_jF_jP_j\right)\Bigg/G_lF_l \tag{8}$$

The interference with the primary user cannot exceed a certain threshold involved in the concept of interference temperature; otherwise, it cannot ensure the QoS of the primary user. If the