Minimization of Outage Probability using Joint Channel and Power Assignment in Dual and Multi Hop Cognitive Radio Ad Hoc Networks

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ABSTRACT:
In this paper, dual-hops and multi-hops cognitive radio Ad Hoc networks has been considered. It is vital mentioning that the primary user interference effect on the secondary user has also been considered. The design of the problem is to achieve an optimal solution for channel allocation and power in dual and multi hop in Cognitive Radio Ad Hoc Networks (CRNs). The main goal is to minimize the outage probability and increasing the length of your network life time, while simultaneously observing the transmission power constraints and the threshold of interference with the primary user. This problem was solved using the standard technique of solving convex optimization problem and weighted bipartite matching. All of the analysis is for both DF, and amplifying and transmission AF protocols. Comparison and measurement of the systems performance is outage probability. Simulation results have shown that the proposed scheme not only minimizes the outage probability compared to existing ones, but also reduces PU interference and saves overall transmission efficiency by Secondary Users.

KEYWORDS: Cognitive Radio, Primary User, Secondary User, Outage Probability, Riley Channel.

1. INTRODUCTION

Primary and secondary users can simultaneously use frequency spectrum until the existing interference on PU does not pass a threshold and its QOS has been supplied; Therefore, SU power ensuring the primary user QOS will be limited. Since power of the secondary users in sharing spectrum system is limited, both of AF and DF protocols can be used in relays. DF relay decodes the received signal and transmits it. In other words, consecutive hops in DF are separated due to the decode location and system performance is limited to the worst hop. On the other hand, AF relay amplifies the received signal and transmits it, which means all of the hops participate in transmitting operation.

In this section we will focus on the previous related works on sharing cognitive radio. Performance of the cognitive radio has been studied considering the effect of PU on SUs [1], [2].

In [1], [2], the effect of primary user on secondary user has been considered while both secondary networks are two hops. In [1], DF protocol was used, several relays between transmitter and receiver were used, where best relays between all relays was chosen to transmit its signal to the receiver. This method of choosing is called best relay. Utilizing more than one relay between transmitter and receiver increases the level of diversity; furthermore, more relays leads to better system performance.

In this paper, a secondary network without relays has also been studied, results have revealed that using relays can improve the system performance. In this paper to assure primary user QOS, it is assumed that the probability of primary user to go offline should always be less than a threshold, P_{ri}, and P_{out}. Fig. 1 shows the utilized model primary and secondary networks in Cognitive radio system; (b) transmission process for adaptive cooperation with best-relay selection.

An upper bound for the secondary user's power can be obtained, which does not depend on momentary information. Only second order statistical information of this interference channel and main channel of primary network, which is between primary transmitter and receiver, suffices.

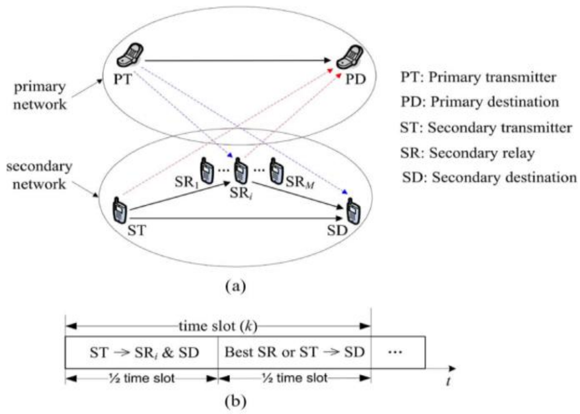

Fig. 1. (a) primary and secondary networks in Cognitive radio system; (b) transmission process for adaptive cooperation with best-relay selection.

Probability of primary user to go offline with Riley channel distribution is utilized.

Since Riley channel distribution has been considered, random variables $|h_{pt-PD}|^2, |h_{st-PD}|^2$ have exponential distribution. Therefore, utilizing joint distribution functions of these variables, outage probability of primary user is obtained.

In [1], it has been assumed that secondary user transmits with its maximum rated power. Thus, primary user's power equals to the right hand side of aforesaid unequal. It can be seen that secondary user transmitting power depends on factors such second order information of primary network channels, preliminary threshold of going offline, and primary network transmitting power. For instance, if t_{hr}, P_{ri}, P_{out} decrease, secondary user's power will also decrease. If QOS for primary network is needed to be obtained in higher levels, second user's power needs to be more limited, and interference on primary network decreases. Probability of secondary network to go offline is a measurement of system performance, and this probability is calculated considering noise effect and primary user interference on secondary user.

In [2], there is a relay with AF protocol between transmitter and receiver. Here, probability of secondary network going offline is a measurement of system performance. To assure QOS for primary user's power, secondary user's power would set up based on equations. Finally, unchanged diversity level of coding gain in presence and absence of primary user interference are different.

Assume a cognitive radio with a PU-TX primary transmitter, a PU-RX primary receiver, and CR secondary users, DF protocol has been used in secondary relays. Signal to noise ratio in secondary user k equals to [3], [4]

As can be seen in this equation, interference effect of primary transmitter on secondary users has been considered. To assure that interference power in PU-RX is always less than a threshold like IP, secondary user's power is limited. To improve the secondary system performance, it has been assumed that secondary users transmit with maximum power rate. It can be seen that the power of secondary user depends on availability of channel momentary information between secondary users and primary receiver. In [5], [6] the probability of secondary network outage is calculated. Difference between these two works is that in [6] in addition to the probability of bit error rate outage, diversity level and Ergodic capacity is also calculated. To obtain aforesaid items, the probability density function of random variable γ_k is calculated. Riley channel distribution is considered.

In [1], the outage probability of dual hop secondary network for different number of relays in secondary network is illustrated against transmitted SNR in primary transmitter, in which the ratio of transmitter power to power spectral density of noise is N0. In [1], writers offered cooperative diversity and choosing best relays for cognitive radio. In this method, best relay will be chosen among all existing relays between secondary transmitter and receiver.

In [1] with increment in transmitted SNR in primary transmitter, the probability of secondary outage decreases. This happens because increment in SNR and respectively in transmitted power in primary transmitter, allows secondary user to increase its transmitting power. Therefore, the probability of secondary outage decreases. It can also be seen that as the number of relays increases, which shows the advantages of the proposed method by the writers, the probability that best relay come up with stronger link would be increased compared to a smaller number of relays situation. As a result, the probability of secondary outage decreases. On the other hand, for a great number of transmitted SNR in primary transmitter, the probability of secondary outage is saturated, and probability of outage would not decrease by SNR increment. This happens as in great numbers of SNRs, which means great power of primary user, interference due to primary user is a limiting factor for certain occurrence of channel. In this case, secondary users should look for other methods to improve their performance. [7], [8]

In [9], [10], performance of cognitive radio has been studied without considering the effect of PUs on SUs.

The outage probability was obtained in [9] based on the average tolerable interference power on primary users. As higher the internal power that primary user can tolerate, the performance of the secondary network would be better and outage probability decreases.

Probability of secondary outage in [9] is based on SNR for two different methods of relay selection, one for relay opportunistic selection and other for partial selection in opportunistic selection. The relay with best final SNR (SNR in two hops) would be selected, while in partial selection, the relay with maximum SNR in one hop would be selected.

Secondary system performance is better when opportunistic selection is being used, because relay selection is based on one hop and does not ensure the channel quality on the other hop.

In [9], I_P is interference temperature or maximum tolerable interference power in primary receiver. N_0 is noise power spectrum. Writers assumed that the secondary users are on one line. They also normalized the distance between secondary transmitter and receiver and assumed it as one. Relays were also located between transmitter and receiver in equal distance. It can be seen that with increment in numbers of hops, the probability of secondary outage is being reduced and the performance of the secondary network is being improved, because in a constant distance, as the number of relays increases, the distance between them decreases and channel variance between them will increase. This means that the power of transmitting channel between relays has been augmented. Thus, receiving SNR in secondary receivers is increased and the probability of secondary outage is being reduced. We know that channel variance is inversely proportioned to the distance and equals to 62=d-n, in which n varies between 2 and 6 and differs for different environments.

In cases where the primary transmitter interference effect is not considered for the secondary users, the secondary system performance is better than the interference effect. This is equivalent to placing the primary transmitter in a remote location relative to the secondary users, which we can see in [9] that the transmitter distance of the primary transmitter improves the performance of the secondary system.

The use of relay selection methods also helps to improve the performance of the system and by increasing the number of relays in set of which, the relay is to be selected, the secondary outage probability is reduced, in other words, the performance is improved.

In all performed works on the cooperative cognitive network, the outage probability for the secondary network is calculated. However, in some of them, in addition to the secondary outage probability, the probability of symbol error and capacity in the secondary network has also been calculated and it has always been noted that the interference power on the primary user is limited.

The design of the system in this paper is one way in which we have a path between the source and destination in a multi hop CRN, and here we need to determine how to allocate power optimally and connect the channels to the relay node so that the possibility of outage probability data is minimized. Finding increases the network life time and at the same time observes the constraints of power transfer and threshold of PU interference. The proposed algorithm will use the Convex Optimization Framework and weighted bipartite graph. The results show that our approach to joint channel and power assignment, not only minimizes outage probability better than other methods presented in the articles, but also reduces PU interference and increases the networks life time.

2. SYSTEM MODEL

The system model consists of multi hop CRN with a linear topology of Fig. 2.

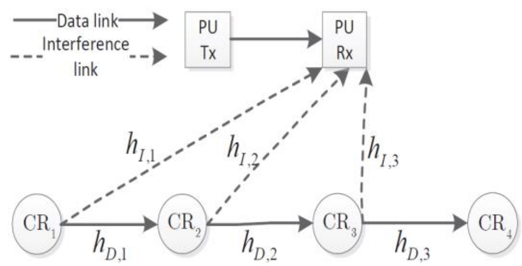

Fig. 2. Multi-hop cognitive radio ad hoc network.

Nodes are as CR1, CR2, …, CRN, with CR1 and CRN as the source and the destination node, respectively. Other nodes are AF relays. The source and the relay nodes work in complete duplex mode, meaning nodes can send and receive signals simultaneously. Primary User Source (PUS) and the Primary User Destination (PUD) are the parts that make up primary network. The wireless links to the CRN are described in the AWGN channel. The channel gain rate is random, although it remains constant during the sending of source to destination. It is assumed that channel gain in the source before the transmission is known. G_k^s is power gain of i-th channel. P_k as the transmit power allocated to CU_k when assigned i-th channel. N_0 is the average noise power at each CU. receiver has rayleigh distribution.

The signal received by the receiver SNR follows exponential distribution. The average SNR of the signal in the k + 1 node receiver will be as follows

$$\gamma_k = \frac{P_k G_k^S}{N_0} \tag{1}$$

In case outage occurs in a channel link, the SNR in the receiver cannot reach a value greater than or equal to the specified threshold (γ_{th}). There are N! ways to allocate the channel to the N-hop CRN. We denotes $C=(C_1, C_2,\dots, C_N)$ as a sample permutation where channel C_m is assigned to CU_k. G_k^p is the channel gain from k_{th} SU to PU and $P_{c,k}$ is the power allocated to k_{th} SU over C_k channel. As a result, $G_k^p P_{c,k}$ is interference from k_{th} SU to PU. So, the accumulated interference from all SUs to PU as follows:

$$\sum_{m=1}^{N} G_k^p P_{c,k} \le T_P \quad (2)$$

T_P is the accumulated interference power threshold at PUD. The channel with power limitation should meet the total power requirement of sending SUs in the CRN, which could be illustrate as follows

$$\sum_{m=1}^{N} P_{c,k} \le P_T \quad (3)$$

Where, P_T is the total power constraint for all CUs.

Joint power and channel allocation problem that minimize the end-to-end outage probability of the CRN is written as follows

$$\begin{cases} \min P_{out} \\ P_{c,k} \\ S.t(2),(3) \end{cases} \quad (4)$$

Table 1. List of Notations.

List of Notations	
G_k^s	Channel gain from k[th] CU to CU
p_k	Transmit power allocated to CU_k
N_0	Average noise power
G_k^p	channel gain from k[th] CU to PU
$P_{c,k}$	Power allocated to k[th] CU over C channel
γ	SNR
P_T	Total power transmit for all CUs
T_p	Accumulated interference power threshold

3. JOINT POWER AND CHANNEL ALLOATION

End-to-end outage probability of multi-hop AF Relay network with Rayleigh fading channels is shown as follows:

$$P_{out} = 1 - \prod_{k=1}^{N} \exp\left(-\frac{\gamma_{th} N_0}{P_{c,k} G_{c,k}^s} \right) \quad (5)$$

For Minimizing P_{out} should be minimized $\sum_{k=1}^{N} \frac{\gamma_{th} N_0}{P_{c,k} G_{c,k}^s}$

So, optimization problem as follows:

$$\begin{cases} \min_{P_{c,k}} \left(\sum_{k=1}^{N} \frac{\gamma_{th} N_0}{P_{c,k} G_{c,k}^s} \right) \\ S.t(2) and (3) \end{cases} \quad (6)$$

3.1. Optimal Power Allocation

At first, we assume a fixed channel allocation Ω and consider optimization problem as a power allocation problem. This is the optimization problem of Equation (6), which takes Lagrange to get the following form

$$L(P_{c,k}, \lambda_1, \lambda_2) = \left(\sum_{k=1}^{N} \frac{\gamma_{th} N_0}{P_{c,k} G_{c,k}^s} \right) + \lambda_1 \left[\sum_{k=1}^{N} P_{c,k} - P_T \right] + \lambda_2 \left[\sum_{k=1}^{N} P_{c,k} G_{c,k}^s - T_P \right] \quad (7)$$

We solve the minimization problem by convex optimization using KKT conditions. With differentiating equation (7) with respect to $P_{c,k}$ as follows:

$$\lambda_1 \left[\sum_{k=1}^{N} P_{c,k} - P_T \right] = 0 \quad (8)$$

$$\lambda_2 \left[\sum_{k=1}^{N} P_{c,k} G_{c,k}^s - T_P \right] = 0 \quad (9)$$

$$-\frac{\gamma_{th} N_0}{P_{C_k,k}^2 G_{C_k,k}^s} + \lambda_2 + \lambda_1 G_{C_k,k}^s = 0 \quad (10)$$
$$fork = 1,2,\ldots, N$$

Where, KKT conditions are the optimization problem.

First, we assume $\lambda_1 \ne 0$ and $\lambda_2 = 0$ and Equations (8) reduces to following formula:

$$\lambda_1 = \frac{\gamma_{th} N_0}{P_{C_k,k}^2 G_{C_k,k}^s} \quad (11)$$

Simultaneously solving equations (8) and (9) is obtained:

$$P_{C_k,k} = \frac{P_T}{\sqrt{G^s_{C_k,k}}\left(\sum_{i=1}^{N}\frac{1}{\sqrt{G^s_{C_i,i}}}\right)} \quad (12)$$

The above phrase is used to determine the power allocation, which applies to equation (2).

Then assume $\lambda_1 = 0$ and $\lambda_2 \neq 0$ and Equations (8) reduces to following formula:

$$-\frac{\gamma_{th} N_0}{P^2_{C_k,k} G^s_{C_k,k}} + \lambda_2 G^s_{C_k,k} = 0 \quad (13)$$

Simultaneously solving equations (13) and (10) is obtained:

$$P_{C_k,k} = \frac{T_P}{\sqrt{G^s_{C_k,k}}\left(\sum_{i=1}^{N}\left(\frac{1}{\sqrt{G^s_{C_i,i}}}\right)G^P_{C_i,i}\right)} \quad (14)$$

The above phrase is used to determine the power allocation, which applies to equation (3).

3.2. Optimal Channel Allocation

Using the optimal power solution from Equations (12) and (14) and applying it to the objective function (5), the value of $\sum_{k=1}^{N}\frac{\gamma_{th} N_0}{P_{C_k,k} G^s_{C_k,k}}$ is calculated for a specific channel allocation scheme. In total, there are N! methods for assigning channels among NSUs. Therefore, the objective function is to identify the optimal channel assignment scheme from N! available options, so that the target function is minimized. This problem is then modeled in weighted bipartite matching and then the optimal channel allocation is obtained based on the minimum weighted matching. We obtain weighted bipartite graph in such a way. The CUs set is represented by the N vertices. Another set of N vertices represents a set of I channels. There is a link between vertices m and k if and only if the channel I is assigned to CU_k. Now the optimal channel allocation problem matches the minimum weighted matching for the above bipartite graph, minimizing $\sum_{k=1}^{N}\frac{\gamma_{th} N_0}{P_{C_k,k} G^s_{C_k,k}}$ from N! solutions is possible. The Hungarian algorithm is used to solve the problem.

Table 2. Simulation parameters.

Parameter	Value			
Average noise power N_0	-30dBm			
SNR γ	3			
G^s_k for two- hop network	0.1	0.35		
	0.65	0.8		
G^s_k for four- hop network	0.8	0.74	0.3	.068
	0.52	0.68	0.24	0.3
	0.42	0.84	o.37	0.81
	0.88	0.63	0.51	0.59

4. SIMULATION AND PERFORMANCE EVALUATION

Appendixes, if needed, appear before the acknowledgment. Subsections for this part also should be numbered by alphabets.

We compare the performance of the proposed scheme with a channel random allocation scheme, in which the channels are initially allocated randomly to the CU. Then the power allocation will be made according to (12), (14). The desired metrics in this study are the probability and interference respectively by using (5) and (2). The parameters necessary for simulation are presented in Table I. In Fig. 3, results of the comparison of the outage probability in a two-hop network are shown using the proposed scheme and the optimal power allocation scheme. The authors of the previous work have proposed a design power allocation rely based in the CRNs for the purpose of minimizing the outage probability with total power and interference constraints. Based on the simulation, we conclude that the proposed scheme works better than previous designs in terms of overall PT power.

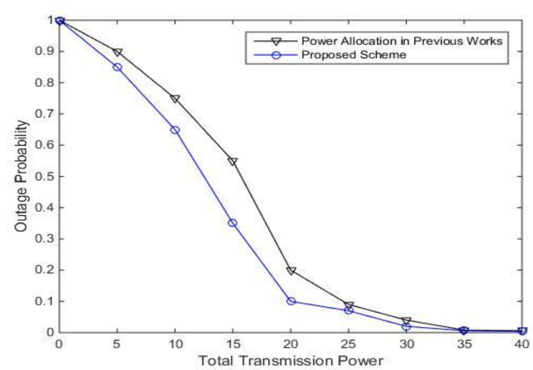

Fig. 3. Outage probability comparison between proposed scheme and Optimal Power Allocation scheme mentioned in previous designs for a two hop CRN.

Fig. 4 demonstrates the outage probability diagram of the optimal total power of the proposed scheme and the random allocation scheme. We considered Mesh and X-ray networks. It was also found that the proposal reduced the probability of a definite probability for all PT values better than the random allocation scheme.

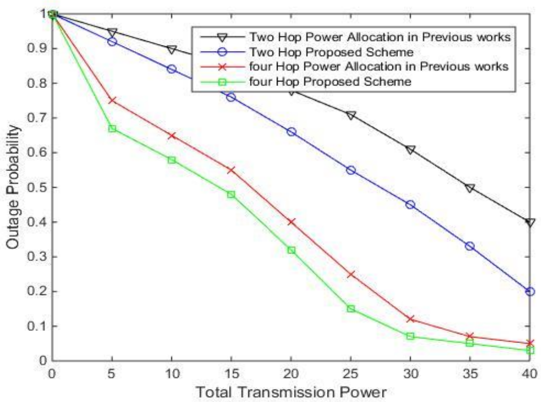

Fig. 4. Outage probability comparison for different total transmission power in the proposed scheme and previous works.

5. CONCLUSION

In this paper, we examine the issue of power and channel allocation in a cognitive radio ad hoc network in which cognitive users act as a multi hop wireless network. The purpose of this paper is to optimize the allocation of channels and the ability to send among nodes in order to minimize the outage probability network under transmission power and accumulated cognitive users' interference constraints. This problem has been solved using the standard technique of solving the problem of convex optimization and the problem of weighted bipartite graph matching with Hungarian algorithm method. The results showed that the proposed scheme could achieve much lower outage probability than the random channel allocation in previous works.

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