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Power Minimization Through Relay Subset Selection Inunderlay Cognitive Radio Networks

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Abstract: In this paper, we consider a dual-hop Cognitive Radio Networkthat consists of a secondary source-destination pair assisted by cognitive relays in their communication. The whole network is operating in an underlay mode near a primary user. Underlay networks allow simultaneous primary and secondary transmissions but at the cost of strict interference constraints towards the secondary users, whichenforces them to limit their transmit power and hence their coverage area.Cognitive Relay networks offer a potential solution to such problems in the form of relay selection. In this work,we select an optimal subset of relays from a potential relay set aiming to ensure minimum QoS requirements at primary and secondary networks. Our proposed scheme considers Amplify-and-Forward relaying and declares that subset as the optimal choice after exhaustive search which minimizes the total transmit power at the relay network while satisfying interference and SNR (Signal-to-Noise Ratio) thresholds of the primary and secondary networks. The simulation results prove the effectiveness of relay selection for underlay cognitive radio networks.

Key words: Underlay Network · Relay Selection · Amplify-and-Forward · Cognitive Radio Network

INTRODUCTION

Enabling secondary transmissions with minimum QoS requirementsusing constrained transmit power ability isone of the major challenges faced by underlay Cognitive Radio Networks (CRNs). The aim of limiting the transmit power of secondary users (SUs) is to keep the interference received at the primary user (PU) below a predefined threshold level [1]. Thissituation becomes worse when secondary source-destination pair is unable to connect directly due to several reasons like deep fading or shadowing etc. Relay assisted CRNs offer a potential solution to such problems. Cooperative relaying aims to improve the diversity order of the signal at the receiver side with higher diversity orders achieved by utilizing multiple relays instead of usingbest one relay [2]. Literature review of relaying techniques reveals that Amplify-and-forward is the simplest and most widely employed non-regenerative relaying protocol in which the relay just scales the received message and forwards it to the destination [3].

A lot of research work is already done on relay selection in underlay CRNs with relatively less contribution in the area of multiple relay selection than selecting the single best relay due to the complexity involved in selecting a subset of potential relay set. Few research contributions are as follows [4] proposes an idea of selecting the best relay in an underlay CRN on the basis of quotient of SNR towards secondary destination and interference towards the PU of the relay link. Multiple relay selection scheme to improve secondary network's performance in an underlay CRNs is proposed in [5]. Naeem *et al.* propose a multiple relay selection scheme with interference awareness for underlay CR systems in [6]. The highlighted contributions present both best and multiple relay selection schemes employing Amplify-and-Forward (AF) relaying protocol with interference and transmit power constraints in underlay CRNs.

In this work, we consider an AF based underlay CRN and propose a simple and efficient multiple relay selection scheme that selects the optimal subset of the relays from a potential relay set which is able to satisfy the target SNR threshold of the secondary network and the interference threshold of the primary network while consuming minimum total transmit power at the relay network.

The rest of the paper is arranged as follows. Section II explains the system model to be considered and provide mathematical formulation of the problem. The algorithm proposed to solve the problem of multiple relay selection is explained in III. Simulation results are presented in section IV while the whole paper is concluded in section V.

System Model and Problem Formulation: We consider a cognitive radio network with L+2 terminals that consist of a secondary source S, secondary destination D and a potential relay set of L relays. The whole network coexists with a PUin the underlay spectrum sharing mode and is shown in Figure 1. We consider the worst case scenario in which the communication between secondary source-destination pair is only possible via intermediate relay network as the direct path suffers from deep fading.

We define the i^{th} channel coefficient between source-relay, relay-destination and relay-PU as hs h_{si},h_{iD} and h_{ip} respectively. The channels are independent and identically distributed (i.i.d.) and undergo Rayleigh flat fading.The source-destination pair and the PU are assumed to be in the range of the whole relay network, while the source is not causing interference to the PU. Amplify-and-Forward (non-regenerative) relaying with adjustable gains is being employed at the relay network. End-to-end communication takes place in two phases. First phase is the broadcast phase, in which the message transmitted by source is received by the whole relay network. Second phase is the relaying phase in which relay subset selection scheme selects the best combination of relays to forward the scaled version of the received message to the destination using AF protocol. The objective behind performing relay selection is to choose the optimal subset of relays which is able to achieve secondary target SNRζ utilizing minimum sum transmit power at the relay network while satisfying primary interference thresholdδ.

Let P_i be the transmit power of i^{th} relay defined according to Amplify-and-Forward (AF) relaying as,

$$P_i = A_i^2 (P_S \mid h_{Si} \mid^2 + N_0) \quad (1)$$

where A_t represents the amplification factor of i^{th} relay. In an Underlay mode, P_i has restriction not only due to battery capacity but also due to the interference level which the PU can tolerate. Let $\overline{P}$ denotes the transmit

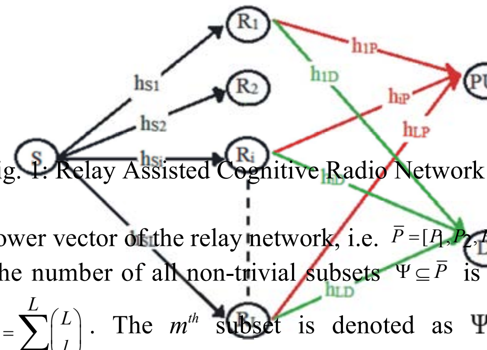

Fig. 1: Relay Assisted Cognitive Radio Network

power vector of the relay network, i.e. $\overline{P} = [P_1, P_2, P_3, \ldots\ldots, P_L]$. The number of all non-trivial subsets $\Psi \subseteq \overline{P}$ is given by $R = \sum_{l=1}^{L} \binom{L}{l}$. The m^{th} subset is denoted as Ψ_m where $(m \in \{1, 2, \ldots\ldots\ldots, R-1\})$. The cardinality of subset $|\Psi_m|$ is denoted as L' where $L' \leq L$.

Relay subset selection works as follows. First interference power I due to each m^{th} subset of relays towards the PU is computed where interference power I_i due to i^{th} relay in any subset is given by, $I_i = P_i \mid h_{iP} \mid^2$. Let K be the number of subsets out of R, such that for every subset $[\Phi_k]_{k=1}^{K}$, sum interference power thres hold δ towards the PU is satisfied. The interference constraint for k^{th} such subset can be given as,

$$I^k = \sum_{i \in \Phi_k} I_i = \sum_{i \in \Phi_k} P_i \mid h_{iP} \mid^2 \leq \delta \quad k = 1, 2, \ldots\ldots\ldots, K \quad (2)$$

In a similar way, P number of subsets, given by $\left[\Omega_p\right]_{p=1}^{P}$ are selected out of R which are able to satisfysignal-to-noise ratio (SNR) threshold ζ at the secondary destination. The SNR constraint for p^{th} such subset can be given as,

$$\gamma_D^p = \sum_{i \in \Omega_p} \frac{\gamma_{SR_i}^p \gamma_{R_i D}^p}{1 + \gamma_{SR_i}^p + \gamma_{R_i D}^p} \geq \zeta \qquad p = 1, 2, \ldots\ldots\ldots, P \quad (3)$$

where γ_{SR_i} and $\gamma_{R_i D}$ are the instantaneous values of S-R_i and R_i -D SNR,respectively and are given by, $\gamma_{SR_i} = \frac{P_S \mid h_{Si} \mid^2}{N_0}$ and $\gamma_{R_i D} = \frac{P_i \mid h_{iD} \mid^2}{N_0}$.

Table 1: Pseudo code

$$INPUTS: P_S, \delta, \zeta, \Gamma_{initial} = L, \Gamma_{sel} = L, N_0, \{h_{Si}, h_{iD}, h_{iP}\} \quad \forall i \in \Gamma_{initial}$$

$$P_i = (A_i)^2 (P_S |h_{li}|^2 + N_0) \quad 0 < P_i \le P_{\max} \quad \forall i \in \Gamma_{initial}$$

$$\Psi \subseteq \overline{P} \qquad // \ All \ non-trivial \ subsets \ of \ \overline{P}$$

$$I^k = \sum_{i \in \Phi_k} I_i = \sum_{i \in \Phi_k} P_i \ |h_{iP}|^2 \le \delta \quad where, [\Phi_k]_{k=1}^K \in \Psi$$

$$\gamma_D^p = \sum_{i \in \Omega_p} \frac{\gamma_{SR_i}^p \gamma_{R_i D}^p}{1 + \gamma_{SR_i}^p + \gamma_{R_i D}^p} \ge \zeta \qquad where, \left[\Omega_p\right]_{p=1}^P \in \Psi$$

$$\Psi_m = [\Phi]_{k=1}^K \cap [\Omega]_{p=1}^P \ // \Psi_m \ contain \ all \ matching \ subsets$$

$$having \ P_i \ at \ same \ indices$$

$$\Psi_{sel} \in \Psi_m \ s.t. \sum_{\hat{i} \in \Psi_{sel}} P_{\hat{i}} \ in \ \Psi_{sel} \ is \ \min imum$$

$$\Gamma_{sel} = L' \le \Gamma_{initial}$$

$$OUTPUTS: \Gamma_{sel}, \sum_{\hat{i} \in \Psi_{sel}} P_{\hat{i}}$$

After having two types of subsets, i.e. $[\Omega]_{p=1}^P$ which achieves SNR threshold ζ and $[\Phi]_{k=1}^K$ which satisfies interference threshold δ, the intersection of $[\Phi]_{k=1}^K \cap [\Omega]_{p=1}^P$ is performed to extract all matching subsets in $\Psi_m \in \Psi$ and having same number of relays and position of each relay in the matching subsets. Finally, that subset is declared as the selected subset from the matching subsets which consumes minimum sum transmit power at the relay network according to the proposed criterion.

Thus we mathematically formulate our relay subset selection algorithm as,

$$\text{minimize} \sum_{\hat{i}} P_{\hat{i}}$$

s.t.

$$\gamma_D = \sum_{\hat{i} \in \Psi_m} \frac{\gamma_{SR_{\hat{i}}} \gamma_{R_{\hat{i}} D}}{1 + \gamma_{SR_{\hat{i}}} + \gamma_{R_{\hat{i}} D}} \ge \zeta \quad \hat{i} \in L'$$

$$I = \sum_{\hat{i} \in \Psi_m} I_{\hat{i}} \le \delta \qquad \hat{i} \in L'$$

where $\hat{i}$ corresponds to the i[th] relay in the final selected subset $\Psi_s \in \Psi_m$

The Proposedalgorithm: Let $\Gamma_{initial} = \{1, 2, \ldots\ldots, L\}$ be the initial set of potential relays. The proposed algorithm initializes the transmit power of each relay in the potential relay set followed by performing exhaustive search on

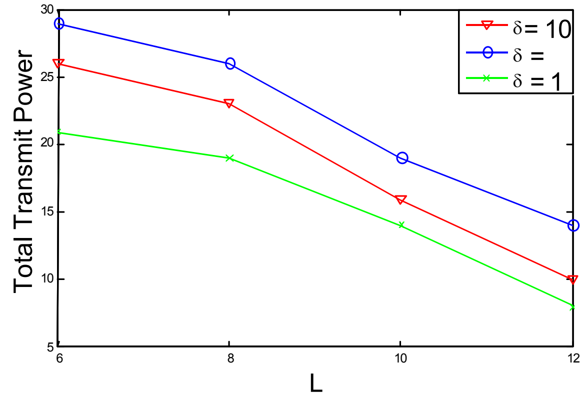

Fig. 2: Transmit Power Allocation to Relay Network for $\zeta = 1$ and different number of relays L

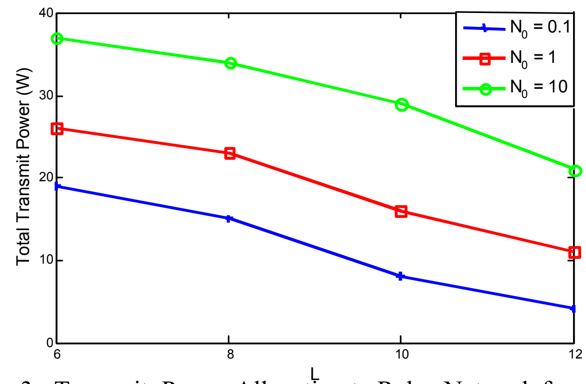

Fig. 3: Transmit Power Allocation to Relay Network for $\delta = 10$, $\zeta = 1$ and different number of relays L

$\sum_{l=1}^{L} \binom{L}{l}$ combination of relays. The aim is to sorting out all possible subsets of relays which satisfy interference threshold δ and target SNR threshold ζ at the same time. Finally that subset is declared as the selected subset which consumes the minimum transmit power out of all subsets.

The pseudocode of the proposed algorithm is shown in Table 1.

Ivsimulation Results: In this section, we will prove the effectiveness of our proposed scheme for multiple relay selection to achieve cooperative diversity while satisfying minimum QoS requirements of both the primary and secondary networks.For all simulations, source transmit power P_s is set to 10W. Furthermore, L and L' represent the number of potential relays and selected relays respectively.In figure (2), the behavior of the relay network is evaluated in terms of total transmit power required for four different values of L taken as,

L = 6,8,10,10,12. For each value of L, we consider three different cases of interference threshold δ keeping target SNR threshold ζ = 1. Noise variance is assumed to be one for each hop.The achieved results are L' = 2,3,4,4 for δ = 10, L' = 3,4,4,5 for δ = 10 and L' = 5,6,7,7 for δ = 20. The figure shows that total transmit power required at the relay network reduces significantly by increasing the number of potential relays. This is due to the fact that the total number of non-trivial subsets increases by increasing the number of potential relays, which in turn increases the probability of selecting those relays which exhibit good channel conditions towards the destination than the PU, thus reducing the total transmit power required at the relay network to meet while satisfyingδ. Furthermore, the relaxation in the value of not only generates more matching subsets $\Psi_{msusets}$ obtained from $\Phi\cap\ \Omega$ but also gives more freedom to the relays to participate in the communication at high transmit power thus achieving high SNR at the destination. For δ = 20,total transmit power of the selected subset of relays is $\sum_{i\in\Psi_s} P_i > 2P_S$ when N = 6 which further reduces to $\sum_{i\in\Psi_s} P_i < P_S$ when N = 12 which suggest that the subset with larger number of relays transmitting at low sum transmit power willbe an optimal choice.

Figure (3) demonstrates the behavior of the proposed algorithm under different levels of noise power. As the noise power increases, relay selection problem becomes critical as in order to satisfy the SNR threshold, transmit power of the relays needs to be increased, due to which the interference power experienced by the PU increases significantly. Thus increasing the noise power requires more transmit power at the relay network to satisfy the SNR threshold of the secondary destination which in turn increases the total interference power experienced by the PU. The overall effect is the reduced number of matching subsets obtained.We take δ = 10, ζ = 1 and four different values of L taken as, L' = 6,8,10,12 . The obtained results are L' = 2,2,3,3 for N_0 = 10, L' = 3,4,4,5 for N_0 = 1 and L' = 5,7,7,8 for N_0 = 0.1. Clearly the simulation results show that increasing the noise level significantly decreases the number of relays participating in communication and thus it becomes difficult to obtain the matching subsets which satisfy both the interference and SNR thresholds of primary and secondary networks respectively.

CONCLUSION

We proposed a multiple relay selection algorithm for Cognitive Radio Network operating in underlay environment in the vicinity of a primary user. In this scenario, we select the optimal combination of relays from the potential relay set which consumes minimum transmit power while satisfying interference threshold and SNR threshold of the primary and secondary network respectively.

REFERENCES

1. Chen, D., H. Ji and X. Li, 2011. “Optimal Distributed Relay Selection in Underlay Cognitive Radio Networks: An Energy-Efficient design approach”, IEEE WCNC 2011, pp: 1203-1207.
2. Kartlak, H., N. Odabasioglu and A. Akan, 2011. “Joint Multiple Relay Selection and Power Optimization in Two-Way Relay Networks”, IEEE I CUMT 2011, pp 1-4.
3. Behbahani, A.S. and A.M. Altawil, “Amplify-and-Forward Relay Networks under Received Power Constraint”, IEEE transactions on Wireless Communications, 8(11): 5422-5426.
4. Hussain, S.I., M.M. Abdallah, M.S. Alouini, M. Hasna and K. Qaraqe, 2012. “Best Relay Selection using SNR and Interfernce Quotient for Underlay Cognitive Networks”, IEEE ICC, pp: 4176-4180.
5. Seyfi, M., S. Muhaidat and J. Liang, 2012. “Relay Selection in Underlay Cognitive Radio Networks”, IEEE WCNC, pp: 283-288.
6. Naeem, M., D.C. Lee and U. Pareek, 2010. “An Efficient Multiple Relay Selection Scheme for Cognitive Radio Systems”, IEEE ICC, pp: 1-5.