SNR Maximization through CSI based Relay-Subset Selection in Amplify-and-Forward Cognitive Radio Networks

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Abstract:
This paper addresses the issues in Underlay Cognitive Radio Networks employing amplify-and-forward relaying. The secondary users operating in an underlay mode in the frequency band of primary users must satisfy interference constraints to keep primary communication undisturbed. We propose a solution to this problem using cognitive relays and perform channel state information (CSI) based relay selection to choose an optimal subset of relays from the whole relay set, which maximizes secondary system performance while satisfying interference threshold of the primary network. We aim to give priority to those relays which exhibit better channel conditions towards destination as compared to the primary user. Simulation results prove the effectiveness of the proposed scheme.

Keywords-component; Amplify-and-Forward, Channel State Information, Cognitive Radio Networks

I. INTRODUCTION

Cognitive Radio (CR) [1] allows secondary users (SUs) to utilize the spectrum allocated to primary users (PUs) using either overlay, underlay or interweave mode of the spectrum access [2]. Underlay spectrum sharing environment severely limits the transmit power of the SUs in order to keep the interference offered by the SUs to the PUs below a predefined threshold [3] which in turn degrades the secondary network’s performance. Relay assisted cognitive radio networks (RCRNs) based on the concept of cooperative diversity technique [4] offer a potential solution to these problems and utilize multiple relays between source-destination pair to enhance secondary system performance. Amplify- and-Forward (AF) [5] is the most commonly employed relaying protocol due to its inherent
simplicity and low power consumption, because a relay just scales the received message and retransmits it in AF mode. A lot of research work has already been done in the area of single and multiple relay selection schemes in RCRNs [6] – [8].

In this work, we present an idea of CSI based multiple relay scheme from a potential relay set that allows only those relays to participate in the communication which exhibit good channel conditions towards the secondary destination as compared to the PU, thus attempting to maximize secondary performance keeping primary communication undisturbed. Our proposed scheme employees AF relaying and maximizes signal-to-noise ratio (SNR) at the destination.

The remaining paper is arranged as follows. System model of the scenario under consideration is explained in section II along with the problem formulation. Section III elaborates the proposed algorithm followed by section IV where simulation results are illustrated. The conclusion of the whole paper is made in section V.

II. SYSTEM MODEL AND PROBLEM FORMULATION

Consider a CRN as shown in figure (1) consisting of source-destination pair assisted by cognitive relays in their communication. Deep fading is assumed for the direct communication path between source-destination pair, thus the end-to-end communication is only possible via the relay network that consists of L potential relays. The whole relay network is operating in an underlay spectrum sharing mode in the vicinity of a PU, thus, experiencing strict interference constraints imposed by the primary network.

![Figure 1: Relay Assisted Cognitive Radio Network](image-url)

Let $h_{si}$, $h_{id}$, and $h_{ip}$ denote the $l^{th}$ channel coefficient between source-relay, relay-destination and relay-PU. The end-to-end communication is completed in two time slots. The signal transmitted from the source is received by the relay network in the first time slot. The received signal is then amplified by each relay and forwarded to the destination in the second time-slot. The amplification factor of each relay is adjusted in such a way to satisfy the transmit power constraint $P_{max}$ for each $l^{th}$ relay i.e. $0 \leq P_l \leq P_{max}$. The received SNR $\gamma_D$ at the destination with L relays using AF relaying is given as [9],

$$\gamma_D = \frac{\left| h_{ip} \right|^2}{\left| h_{id} \right|^2}$$
\[ \gamma_D = \sum_{l=1}^{L} \gamma_i = \sum_{l=1}^{L} \frac{P_S |h_{SI}|^2 P_i |h_{ID}|^2}{1 + P_S |h_{SI}|^2 + P_i |h_{ID}|^2} \]  

where, \( P_S \) is the transmit power with which the source transmits.

The multiple relay selection scheme works as follows. First, all possible non-trivial subsets of transmit power vector \( \bar{P} = [P_1, P_2, \cdots, P_L] \) of the whole relay set is obtained, where the number of non-trivial subset in \( \Phi \) is given by,

\[ J = \sum_{m=1}^{L} \binom{L}{m} \]

Thus, given \( J \) subsets, the relay subset selection algorithm selects \( M \leq J \) subsets denoted by \( \Omega_m \) such that, each element in the \( m^{th} \) subset \( \Omega_m \) satisfies the condition \( h_{IP} < h_{ID} \). Next is to compute the total interference \( I \) offered by each \( m^{th} \) subset where interference offered by each \( l^{th} \) relay is defined as \( I_i = P_i |h_{IP}|^2 \). Thus, the combined interference of the \( m^{th} \) subset \( \Omega_m \) is given by,

\[ I = \sum_{l \in \Omega_m} I_i = \sum_{l \in \Omega_m} P_i |h_{IP}|^2 \]  

As obvious from the above equation, the better is the channel coefficient towards the PU, the higher is the interference offered by that relay. Thus, satisfying the condition \( h_{IP} < h_{ID} \) effectively selects those relays which are less harmful to the PU. Finally that subset is declared as the selected subset out of \( M \) subsets which maximizes the SNR received at the destination, conditioned on that it satisfies the interference constraint. Thus, the relay subset selection problem takes the final form as,

\[ \max \left( \gamma_D = \sum_{l \in \Omega_m} \gamma_i = \sum_{l \in \Omega_m} \frac{P_S |h_{SI}|^2 P_i |h_{ID}|^2}{1 + P_S |h_{SI}|^2 + P_i |h_{ID}|^2} \right) \]  

while satisfying:

\[ C1: \quad P_i \leq P_{max} \]

\[ C2: \quad I = \sum_{l \in \Omega_m} I_i = \sum_{l \in \Omega_m} P_i |h_{IP}|^2 \leq \lambda \]

III. THE PROPOSED ALGORITHM

Let \( \Psi_{\text{initial}} = \{1, 2, \cdots, L\} \) denotes the initial set of potential relays. The proposed algorithm initializes the transmit power of each relay while satisfying eq. (4) and then picks up all possible subsets of the relays which satisfy the condition \( h_{IP} < h_{ID} \) for each element in any particular subset. Finally, that subset is declared as the selected subset which maximizes SNR give in eq. (3) at the destination while satisfying eq. (5). The pseudo code of the proposed algorithm is given in Table I below.
TABLE I: THE PSEUDO CODE

<table>
<thead>
<tr>
<th>Inputs : $P_s, \lambda, \Psi_{\text{initial}} = \Psi_{\text{set}} = L, N_0,{h_{Sl}, h_{LD}, h_{LP}} \quad \forall l \in \Psi_{\text{initial}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_l = (A_s)^2(P_s</td>
</tr>
<tr>
<td>$[\Phi]<em>j \subseteq \Phi \quad \forall l \in \Psi</em>{\text{initial}}$</td>
</tr>
<tr>
<td>$\Omega = [\Omega_m]<em>{m=1}^M \in \Phi \quad \forall l \in \Psi</em>{\text{initial}}$</td>
</tr>
<tr>
<td>for $m = 1 : M$</td>
</tr>
<tr>
<td>$\text{check interference constraint given in eq. 5}$</td>
</tr>
<tr>
<td>end for</td>
</tr>
<tr>
<td>for $n = 1 : N$</td>
</tr>
<tr>
<td>$\gamma^n_D = \sum_{l \in \Omega^n} \frac{\gamma^n_{SR} \gamma^n_{RD}}{1 + \gamma^n_{SR} + \gamma^n_{RD}}$</td>
</tr>
<tr>
<td>end for</td>
</tr>
<tr>
<td>$\Omega_s \in \Omega \quad \text{s.t.} \quad \gamma^n_D \quad \text{in} \quad \Omega_s \quad \text{is max imum}$</td>
</tr>
<tr>
<td>$\Psi_{\text{set}} = L' \leq \Psi_{\text{initial}} \quad \text{for each} \quad m^{th} \quad \text{subset} \quad \Omega_m$</td>
</tr>
<tr>
<td>Outputs : $\Psi_{\text{set}}, \gamma_D$</td>
</tr>
</tbody>
</table>

IV. SIMULATION RESULTS

The effectiveness of the proposed CSI based relay subset selection scheme is proved in this section. Source transmit power $P_s$ is set to 10W. Additive white Gaussian noise with zero mean unit variance is assumed for each hop. Furthermore, $L$ and $L'$ denote the number of potential relays and selected relays respectively.

In figure 2, we compare two cases of cooperative diversity, one which employs all relays and the other which works according to the proposed algorithm and we examine SNR by varying the total number of potential relays $L$ for two different interference threshold levels $\lambda$. The performance is evaluated for five different values of total number of relays $L$ taken as, $L = \{6,8,10,12,14\}$. The results achieved are, $L' = \{2,3,3,4,4\}$ with $\lambda = 1$ and $L' = \{3,4,4,5,6\}$ with $\lambda = 10$. We observe that the multiple relay selection algorithm outperforms full cooperative diversity technique for both cases of interference threshold $\lambda$. The improved performance is due to the freedom of selecting that subset of relays from the whole relay network which exhibit good channel conditions towards the destination. Whereas for the case of full cooperative diversity utilizing whole relay set, the transmit power of the source needs to be suppressed keeping in view the interference constraint of the PU, which in turn causes negative
Figure 2: SNR for different number of relays L

effect on the SNR received at the secondary destination. We have another strong observation that as compared to full cooperative diversity technique, the SNR significantly increases in the case of relay subset selection as the relay network grows. This shows the effectiveness of the proposed algorithm as larger relay set increases the probability of selecting those relays which exhibit good channel conditions towards destination as compared to PU thus showing higher improvement. On the other hand, less improvement is observed for both cases of cooperative diversity for \( L > 12 \) because a larger relay network makes it difficult to satisfy interference threshold. Finally, relaxing \( \lambda \) allows the relays to transmit at high power thus enhancing secondary SNR for both cases.

V. CONCLUSION

We propose a relay subset selection scheme for Amplify-and-Forward based Underlay Cognitive Radio Networks. Our proposed scheme performs CSI based multiple relay selection that effectively enhances secondary system performance while satisfying primary interference constraint and outperforms full cooperative diversity technique.

REFERENCES


