Hybrid-Relay-Selection Improves the Security-Reliability Trade-Off in Cognitive Radio Systems

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ABSTRACT

We analyze both the intercept probability and outage probability of the proposed single relay and multiple relay hybrid selection schemes for the secondary transmission. We also evaluate the performance of classic direct transmission and artificial noise based methods for the purpose of comparison with the proposed relay selection schemes. The intercept probability requirement is relaxed, the outage performance of the direct transmission and the relay selection schemes improves, and vice versa. This implies a trade-off between the security and reliability of the secondary transmission in the presence of eavesdropping attacks, which is referred to as the security reliability trade-off (SRT). Our results show that as expected, the multi-relay hybrid selection achieves better SRT performances than the single-relay hybrid selection. The IP and OP, BER and channel capacity is derived for single relay and multiple relay hybrid approach for improving SRT in cognitive radio network. The scenario derived for the proposed system in Rician fading channels. This analysis is helpful in determining the IP, OP, capacity and Bit error rate for optimum usage of power and bandwidth is better. This analysis is also helpful to compare the result of single relay and multiple relay hybrid graphs.

Keywords: Security reliability trade-off, intercept probability, outage probability, single relay selection, multiple relay selection.

Introduction

In daily life the wireless technologies is a compulsory communication tool rather than being a complementary communication tool. The increasing demand for high speed and high quality wireless communications, the radio spectrum did become a limited and precious resource for wireless communications. So that cognitive radio is a best technique for this problem. Cognitive radio is a radio frequency transceiver designed to intelligently detect whether a particular segment of radio spectrum is in use. Cognitive radio is used to jump into and out of temporarily unused spectrum very immediately without interfering with the transmission of other authorized users. Cognitive radio enables secondary user to sense which portion of spectrum are available, select best available channel, coordinate spectrum access with other users and vacate the channel when a primary user reclaims the spectrum usage rights. The allocated frequency band to licensed users is mostly underutilized so find out a way to make use of this bandwidth whenever it is not utilized as shown in Figure 1. This is one of the aspirations of cognitive radio systems.

Fig 1: Primary user network and cognitive radio user network
The primary challenge in building a CRN is equipping each device to continuously maintain the information which is necessary to properly route the traffic. As CRNs are illustrated by limited bandwidth and node mobility, there is demand to take into account the energy efficiency of the nodes. Cognitive radio (CR) promise to increase spectrum usage by supporting secondary users to share licensed bands.

**Methodology**

In this only the best secondary relays is chosen. By using secondary transmission we analyze both the intercept probability and outage probability. We also evaluate the performance of direct transmission based method for the purpose of comparison with the proposed relay selection schemes. The intercept probability requirement is relaxed; the outage performance of the direct transmission, selection schemes improves.

Let H₀ and H₁ represent the event that the licensed spectrum is unoccupied and occupied by the primary base station [1]. Moreover, let H denote the status of the licensed spectrum detected by spectrum sensing. Specifically,

H = H₀ represents the case that the licensed spectrum is deemed to be unoccupied, While H = H₁ indicates that the licensed spectrum is deemed to be occupied [3].

The probability (P₀) of correct detection of the presence of primary base station and the associated false alarm probability (Pᵩ) are denoted as

\[
P₀ = \Pr (H = H₁/H₁),
\]

\[
Pᵩ = \Pr (H = H₁/H₀),
\]

The missed detection of the presence of primary base station will result in interference between the secondary transmitter and secondary destination [5]. In order to guarantee that the interference imposed on the primary users is below a tolerable level, both the successful detection probability P₀ and false alarm probability Pf should be within a meaningful target range.

Detection probability versus false rate: Fake rate refers to the probability that a particular slot is decided to be occupied. Detection probability is the probability that free slot or occupied slot is detected correctly. To calculate False rate and detection rate Monte Carlo simulations are run:

**OOBS and SBS Algorithm:** The OOBS (On/Off Base Scheduling) technique is used in this method allows only those signals which are above the predefined SNR values. The SNR of the each user compared with the predefined value and acceptable signals only pass through the channel [3]. The SBS scheduling will allow the unacceptable signals if some part of the channels is ideal. These selection techniques will continue until the channel bandwidth utilization is full.

The power is efficiently allocated based on the SNR value of each user and given by the formula shown below.

\[
\text{Power} = \frac{1}{\text{SNR}} \times \frac{\text{initial power}}{\text{no of user}}
\]

The user with lowest SNR is allocated maximum power and the user with highest SNR allocated minimum power [10].

**Relay schemes**

**Amplify-and-Forward (AF) relay scheme**

In this relaying scheme, the relay sends an amplified received signal to the fusion center in last time slot [3]. It requires much less delay because the relay node operates time-slot by time-slot. It also consumes less computing power because decoding or quantizing operation is performed at the relay side.

**Decode-and-Forward (DF) relay scheme**

In this scheme, the relay decodes the message in one block and transmits the re-encoded message in the next block.

**Decode-Amplify-and-Forward(DAF) relay scheme**

In this relay scheme cognitive radio detects received signal in the observation interval. Decode amplify and forward approach shown in Fig.2. If the decision is that primary user is absent, the cognitive radio keeps quiet and transmits only an indicator signal to the fusion center during its relaying time slot [9]. Otherwise,
if the primary user is present, the cognitive radio amplifiers the signal and forwards it to the fusion center [4]. According to the decode amplify and forward scheme, every cognitive radio user performs detection and takes its own decision about the primary user. The source and destination nodes are fixed along with some intermediate nodes. The intermediate nodes act as the relay. Here the signals are chosen based on the SNR value.

Fig.2: Hybrid approach

If the signal’s SNR value is greater than 10dB then those signals are acceptable, otherwise those signals are considered non-acceptable signals [12]. High SNR signals are selected and passed to the channel. The signal selections are based on the SNR value and channel bandwidth.

Proposed model

The proposed work deals with hybrid relay selection scheme in cognitive radio network based on single and multiple relay approach for improving the security and reliability trade-off. In this research work we have used signal to noise ratio for the relay selection. Practical systems operate from SNR regions. This research derives the outage probability and intercepts probability that is valid for any arbitrary SNR region. We design a network with multiple nodes. Hybrid (DF+AF) approach is used for signal transmission. First node behaves as a source and last node behave as a destination. From source to relay, decode and forward technique is chosen. This will help to reduce the error present in the transmitted signals, and retransmit to the next relay or destination. If the next node is a relay, then decode and forward is chosen else if the next node is destination, then amplify and forward is chosen. Amplify and forward is mainly used to amplify the received signals. So hybrid protocol is used to obtain secured data. The destination node may receive more than two independent signals of the same packet e.g. via the selected relay node and directly via the source.

Expression for relay selection

Arrival rate for primary and secondary user due to found using Poisson equation, since number of users are large.

Let $\lambda_p$ = Primary user arrival

Let $\lambda_s$ = Secondary user arrival

Let $\beta$ = Average primary packets in queue

Let $\gamma$ = Average secondary packets in queue

Let $\beta_{average}$ = Average queuing time for primary user
Waiting time for primary user:

\[ W_p = (\text{Time})_{\text{Beginning of slot}} + \frac{1}{\mu} \beta \]

\[ \beta = \lambda_p \beta_{\text{average}} \]

\[ W_p = (\text{Time})_{\text{Beginning of slot}} + \frac{1}{\mu} \lambda_p \beta_{\text{average}} \]

Waiting time for secondary user:

Secondary user has to wait extra time to see subsequent arrival of primary user.

\[ W_s = (\text{Time})_{\text{Beginning of slot}} + \frac{1}{\mu} \gamma + \text{constant term} \quad (2) \]

Using above equation we can calculate the number of packets sent by primary and second as:

\[ P_p = \lambda_p + \frac{\lambda_p}{2(1-\frac{\lambda_p}{\mu} - \frac{\lambda_s}{\mu})} \quad (3) \]

\[ P_s = \lambda_s + \frac{\lambda_s}{2(1-\frac{\lambda_p}{\mu} - \frac{\lambda_s}{\mu})} \quad (4) \]

From the above equation (3) and (4) it is clear that secondary user has to wait for primary user.

Detection probability rate:

Fake rate refers to the probability that a particular slot is decided to be occupied. Detection probability is the probability that free slot or occupied slot is detected correctly.

To calculate false rate and detection rate Monte Carlo simulations are run:

[Using probability to detect false rate]

Let \( x_j \) be the different value of \( x \) and \( P_j \) are list of their probability.

\[ E[X] = \sum_{j=1}^{l} x_j P_j \quad (5) \]

\[ P_j = \lim_{\#\text{Realization} \to \infty} \frac{\#\text{occurrence of } X_j}{\text{Realization}} \quad (6) \]

\[ \sum_{j=1}^{l}(\#\text{occurrence of } X_j) \quad (7) \]

Calculation of on detection probability

Let \( P_f \) is the false alarm

\( P_m \) is miss alarm

\( P_d \) detection probability

\[ P_{\text{detection -probability}} = P_d \ast P_{\text{on}} + P_{\text{off}} \ast P_f \]

\[ P_{\text{on}} = \frac{0.2}{0.8 + 0.2} = \frac{0.2}{1.0} = 0.2 \]

\[ P_{\text{off}} = \frac{0.8}{1.0} = 0.8 \]
\[ P_{on} + P_{off} = 0.2 + 0.8 = 1(1) \]

Since sum of probability is =1

\[ P_{off
detect} = P_m * \left(1 - P_f\right) * P_{off} \]

Flow chart of proposed method

**Simulation Results**

The whole scenario is taken place in MATLAB 2016a. We have used MATLAB because it is one of the efficient computing tools to achieve high end analysis in an effectual manner. The result refers to develop a hybrid approach for single relay and multiple relay for improving SRT in cognitive radio network. This method compares the result parameters of single relay hybrid approach and multiple relay hybrid approach depending performance parameters viz intercept probability, outage probability, bit error rate, channel capacity.

**Intercept and outage probability of single relay and multiple relay hybrid approach**

The X-axis represents the outage probability and Y-axis represents the intercept probability. From our proposed methodology the signal transmitted by single relay and multiple relya approach through source to destination with and without hybrid approach.
Fig 4: Simulation result of the single relay hybrid selection scheme

Figure 4 shows OP vs IP of the single relay hybrid selection scheme. This graph shows that an unoccupied licensed band would be detected more accurately and hence less mutual interference occurs between the PUs and SUs, which results in a better SRT for the secondary transmissions.

Fig 5: Simulation result of the multiple relay hybrid selection scheme

Figure 5 shows OP vs IP of the multiple relay hybrid selection schemes. This graph shows an unoccupied licensed band would be detected more accurately and hence less mutual interference occurs between the PUs and SUs, which results in a better SRT in multiple relay hybrid approach for the secondary transmissions.

Fig 6: Simulation result comparison between single relay and single relay hybrid selection scheme
Figure 6 shows IP vs OP comparison between multiple relay and multiple relay hybrid approach. Result shows better SRT for the secondary transmissions, the single relay hybrid approach is better than the single relay approach scheme in terms of the SRT.

Fig 7: Simulation result comparison between multiple relay and multiple relay hybrid approach

Figure 7 shows IP vs OP comparison between multiple relay and multiple relay hybrid approach. Result shows better SRT for the secondary transmissions, the multiple relay hybrid approach is better than the multiple relay approach scheme in terms of the SRT.

Fig 8: IP vs OP comparison between single relay, multiple relay and single relay hybrid approach, multiple relay hybrid approach, direct transmission and artificial noise
Figure 8 shows that both the proposed single relay hybrid and multiple relay hybrid schemes outperform the direct transmission and the artificial noise based approaches in terms of their SRT that showing the advantage of exploiting relay selection against the eavesdropping attack. Moreover, the SRT performance of the multiple relay hybrid approach is better than that of the single relay hybrid approach.

![Graph showing SRT comparison](image)

**Figure 9: IP vs OP comparison between single relay and multiple relay hybrid approach over fading channel**

Figure 9 shows IP vs OP comparison between single relay and multiple relay hybrid approach over fading channel. The SRTs of the SRS and MRS schemes improve accordingly. This is due to the fact that for an improved sensing reliability, an unoccupied licensed band would be detected more accurately and hence less mutual interference occurs between the Pus and SUs, which results in a better SRT for the secondary transmissions it shows that multiple relay hybrid selection approach is better than the single relay hybrid selection scheme over fading channel in terms of the SRT.

**Table 1: Performance Evaluations Of single relay and multiple relay hybrid approach in terms of channel capacity, bit error rate and outage probability**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Single Relay hybrid approach</th>
<th>Multiple Relays hybrid approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (bits/s/Hz)</td>
<td>11.62</td>
<td>1402</td>
</tr>
<tr>
<td>Bit Error Rates (db)</td>
<td>0.04032</td>
<td>0.0194</td>
</tr>
<tr>
<td>Outage Probability (db)</td>
<td>2.282</td>
<td>0.6474</td>
</tr>
</tbody>
</table>

Result shows that in multiple relay hybrid approach BER is minimum and channel capacity is high as compared to single relay hybrid approach. It means multiple relay hybrid approach improve SRT performance.
Discussion
Cognitive network consisting of a secondary source, a secondary destination and multiple secondary relays in the presence of a snoop. We examined the security and reliability performance of the single relay hybrid approach and multiple relay hybrid approach assisted secondary transmissions in the presence of relay sensing and spectrum sensing. The security and reliability of secondary transmissions are denoted in terms of IP and OP, respectively. Furthermore, we demonstrate that the SRTs of the single-relay and multi-relay hybrid selection schemes are generally better than that of classic direct transmission, explicitly demonstrating the advantage of the proposed relay selection in terms of protecting the secondary transmissions against eavesdropping attacks. Our results show that as expected, the multi-relay hybrid selection achieves better SRT performances than the single-relay hybrid selection. Result shows that in multiple relay hybrid approach BER is minimum and channel capacity is high as compared to single relay hybrid approach. It means multiple relay hybrid approach improve SRT performance.

References