Relay Based Cooperative Spectrum Sensing in Cognitive Radio Networks over Nakagami Fading Channels

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Abstract— **In this paper, we address the issue of cooperative spectrum sensing in cognitive radio networks. Here relay stations are introduced in cognitive radio network. In the proposed research, the detection performance of energy detector used for cognitive radio network is evaluated for single relay and multiple relays regimes. The analysis focuses on Nakagami-m fading channels, independent and identically distributed. Probability of detection and probability of false alarm is evaluated/ simulated with and without incorporating the direct path between primary use and cognitive centre.**

Keywords— Cognitive Radio Network, Amplify-and-Forward, Relays and Fading Channels

I. INTRODUCTION

With the rapid growth of wireless technologies over the last few decades, the demand for spectrum resources is on rise. As a result the radio spectrum has become a limited resource. According to the current spectrum management policy, all of the frequency bands are assigned to specific wireless systems [1]. However, most of the licensed spectrum is underutilized in vast regions of the world. This spectral inefficiency can be improved by using the novel concept of cognitive radio, which has emerged as a revolutionary technology. The cognitive radio allows the secondary users (unlicensed users) to access idle licensed spectrum (spectrum hole) without causing interference to primary users (licensed users) [2]. Spectrum sensing, a key feature in cognitive radio network, is performed in order to avoid harmful interference to primary users.

Spectrum sensing techniques can be carried out in three ways: energy detection, matched filter detection and cyclostationary feature detection. Among these spectrum sensing techniques, the energy detector (non coherent detection through received energy) is the simplest one because it gives high detection probability in very short time while signal-to-noise ratio is very high[3]. In order to improve spectrum sensing accuracy, large benefits can be gained from cooperation among different terminals [4]. The novel concept of relay optimal location is proposed using network coding [5]. Akyildiz *et. al*. in [6], introduced an optimal spectrum sensing framework for cognitive radio networks, where both spectrum efficiency and interference avoidance were considered. The benefits of spectrum sensing for cognitive radios with multiple secondary users are explained in [7] and [8]. Adaptive Neuro Fuzzy based relay selection [9] and Fuzzy logic based detection has been proposed for reliable spectrum sensing [10]. The Fuzzy logic cooperative spectrum sensing in cognitive radio has been explained in [11]. Relay based cooperative spectrum sensing over Rayleigh faded channel is presented in [12]. Various routing protocols are proposed which are mainly categorized as proactive and reactive in [13] and [14]. The relaying schemes normally used at the relays are Amplify-and-forward (AF) and Decode-and-forward (DF) [15]. Analysis of the Equal Gain Combining (EGC) in energy detection for cognitive radio network is shown in [16]. Here the channels are modeled as Nakagami-m. The series form exact solution has been derived for detection probability and false alarm probability.

In this paper, we employ energy detection as our proposed spectrum sensing scheme. Here the concept of relay based spectrum sensing is proposed. This concept is based on the utilization of relay nodes to carry the signal transmitted from primary users to a cognitive receiver, which will then make a decision about the presence or absence of primary activities. Relay nodes use amplify-and- forward protocol. The channels from primary user to relay nodes and from relay nodes to cognitive receiver are (i.i.d) Nakagami faded.

The rest of the paper is organized as follow: Section II describes the system model for our cooperative spectrum sensing scheme .In section III energy detector is analyzed. Simulation results are presented in section IV. Finally, section V presents our conclusion.

II. SYSTEM MODEL

A. Channel Model

It is assumed that the wireless network is using independent and identically distributed Nakagami-m fading channels. The probability density function is given by Nakagami.

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$$f|h_{xy}| = \left(\frac{m}{\Omega_{xy}}\right)^m \frac{2|h_{xy}|^{2m-1}}{\Gamma(m)} \times \exp\left(\frac{-m|h_{xy}|^2}{\Omega_{xy}}\right) \qquad |h_{xy}| \geq 0$$

Where $\Gamma(.)$ is a gamma function, h_{xy} is the fading magnitude of link X ⟶ Y and $\Omega_{xy} = E(|h_{xy}|^2)$ is the mean channel power.

For m = 1 the Nakagami-m distribution becomes the Rayleigh distribution. w_n at node n is Additive white Gaussian Noise (AWGN) with power spectral density N_o.

B. Cooperative Spectrum sensing Schemes

In cooperative based spectrum sensing, the relay stations are introduced in the cognitive radio network. Here the relay stations listen to the transmission of primary user. As primary user gets active, the relay stations receive its data. The relay stations then, resend this data to Cognitive centre using amplify & forward scheme, where the relay stations amplify the original signal along with noise.

The cognitive centre uses energy detector to make a decision about the presence or absence of primary user. The energy detector compares the received signal strength with a decision threshold value.

C. Single Relay Communication/Station

It is a two hop cooperative cognitive network, where at time slot 1, the signal x from primary user to cognitive centre reaches via a relay station. If x is the transmitted signal, the received signal at relay station y_r is given by:

$$y_r = \sigma h_{sr} x + w_1$$

Where h_{sr} is the fading coefficient, and w_1 is the additive noise signal at relay station. Where the primary activity indicator, σ =1 shows the presence of primary user and σ=0 shows the absence of primary user. At time slot 2, the relay station uses variable gain amplify and forward scheme to forward the scaled version of the message signal to the cognitive radio. The amplification factor is given by:

$$A_r = \sqrt{\frac{E_p}{E_p|h_{sr}|^2 + N_o}}$$

Where E_p is the average energy of the transmitted signal from primary user to relay station.

At time slot 2, the relay station forwards its received signal to the cognitive centre. The received signal at cognitive centre is given by:

$$y_d = A_r\, y_r h_{rd} + w_0$$

Where w_0 is AWGN added at cognitive centre and A_r is the amplification factor.

In an energy detector, the received signal is passed through bandpass filter, which filters out the undesired noise. This filter is followed by a squaring device & an integrator which measures the received energy signal over an observation time interval T and is normalized by noise variance. The output "Y" of the integrator is then compared to a decision threshold □. The time bandwidth product TB=u, is assumed to be an integer number. The detector at cognitive centre uses binary hypothesis:

$$\begin{cases} H_o:\ y_d = w & \sigma = 0 \\ H_1:\ y_d = hx + w & \sigma = 1 \end{cases}$$

The total SNR for single relay station is given by

$$\gamma = \frac{1}{N_0}\left(\frac{E_p E_r |h_{pr}|^2 |h_{rd}|^2}{\Omega_{pr}E_p + N_0 \quad \frac{E_r}{\Omega_{pr}E_p + N_0} \quad |h_{rd}|^2 + 1}\right)$$

Where h_{pr} and h_{rd} are channel coefficients of links from primary user to the cognitive relay and from the cognitive relay to the cognitive coordinator, respectively.

D. Multiple Relay Communication/Station

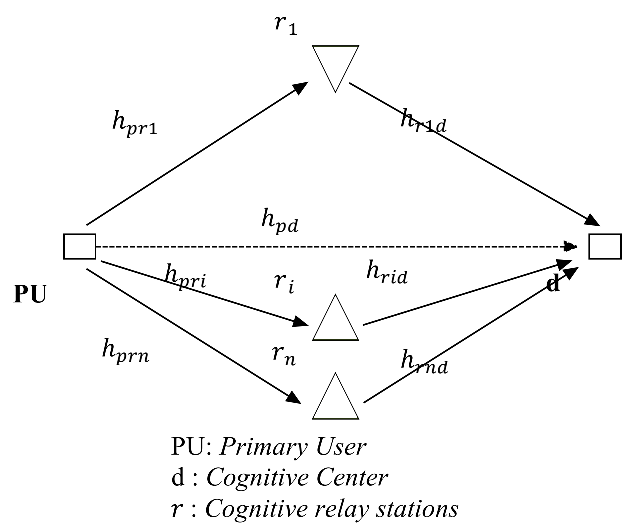

Fig. 1: Multiple Relay Communication

In multiple relays cooperative network, N number of cognitive relays cooperates for spectrum sensing as shown in Figure 1. Let all these relays encounter independent and identically distributed (iid) Nakagami-m fading.

At time slot 1, the signal from primary user reaches to relay stations over independent fading channels. The received signal at i^{th} relay is given by:

$$y_r = \sigma h_{sri} x + w_{ri1}$$

Where $i = 1,2,3,\dots,N$ and w_{ri1} is the additive white Gaussian noise at i^{th} relay.

At time slot 2, the relay stations, use amplify- and-forward (AF) scheme to forward the scaled version of the message signal to the cognitive radio. The amplification factor is given by

$$A_r = \sqrt{\frac{E_p}{E_p|h_{sri}|^2 + N_o}}$$

The links of transmission from primary user to cognitive relay stations and from relay stations to cognitive centre are orthogonal. All the relay stations use time division multiple access (TDMA) based protocols for forwarding the received signal to cognitive centre. The maximal combining ratio (MRC) is used at cognitive centre. The output is then given to an integrator and compared with decision threshold.

The total end-to-end SNR for multiple relay stations is given by

$$\gamma = \frac{1}{N_0}\left(\sum_{i=1}^{N} \frac{E_{pri}E_{rid}|h_{pri}|^2|h_{rid}|^2}{\Omega_{pri}E_{pri} + N_0 \quad \frac{E_{rid}}{\Omega_{pri}E_{pri} + N_0} \quad |h_{rid}|^2 + 1}\right)$$

Where $|h_{pri}|$ and $|h_{rid}|$ are channel gain coefficients from primary user to relay stations and from relay stations to cognitive centre.

E. Incorporating the direct link

In the above subsections, transmission from primary user to cognitive centre takes place through cognitive relay stations. However, the transmission from primary user to cognitive centre takes place through a direct and relay link.

The total SNR at cognitive centre for single relay and direct link is given by:

$$\gamma = \gamma_d + \gamma_r$$

$$\gamma = \frac{1}{N_0}|E_{pd}|h_{pd}|^2 + \frac{1}{N_0}\left(\frac{E_pE_r|h_{pr}|^2|h_{rd}|^2}{\Omega_{pr}E_p + N_0 \quad \frac{E_r}{\Omega_{pr}E_p + N_0} \quad |h_{rd}|^2 + 1}\right)$$

The total SNR at cognitive centre for multiple relay stations and direct link is given by

$$\gamma = \gamma_d + \sum_{i=1}^{N}\gamma_{ri}$$

$$\gamma = \frac{1}{N_0}E_{pd}|h_{pd}|^2 + \frac{1}{N_0}\left(\sum_{i=1}^{N}\frac{E_{pri}E_{rid}|h_{pri}|^2|h_{rid}|^2}{\Omega_{pri}E_{pri} + N_0 \quad \frac{E_{rid}}{\Omega_{pri}E_{pri} + N_0} \quad |h_{rid}|^2 + 1}\right)$$

The links of transmission from primary user to cognitive centre (direct link) and from relay stations to cognitive centre are orthogonal.

III. ENERGY DETECTION

Shown in Fig. 2 [17], in an energy detector, the received signal is passed through bandpass filter, which filters out the undesired noise. This filter is followed by a squaring device & an integrator which measures the received energy signal over an observation time interval T and is normalized by noise variance. The output "Y" of the integrator is then compared to a decision threshold □. The time bandwidth product TB=u, is assumed to be an integer number.

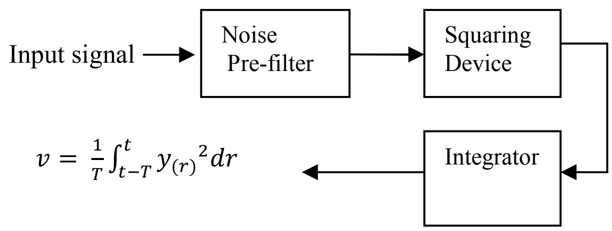

Fig. 2: Energy Detector

The detector at cognitive centre uses binary hypothesis to determine the presence or absence of primary activity.

$$\begin{cases} H_o : y_d = w & \sigma = 0 \\ H_1 : y_d = hx + w & \sigma = 1 \end{cases}$$

The energy detection based spectrum sensing method has the performance parameters, the probability of detection p_d and the probability of false alarm p_f .

In cognitive radio network, p_d determines accurate detection, providing interference protection to primary user. While p_f , determines wrong detection, indicating higher spectrum utilization.

These probabilities of detection and false alarm can be evaluated by:

$$p_d = p\left(y > \frac{\lambda}{H_1}\right)$$

$$= Q_u(\sqrt{2\gamma}, \sqrt{\lambda})$$

and

$$p_f = p\left(y < \frac{\lambda}{H_o}\right)$$

$$= \frac{\Gamma(u, \lambda/2)}{\Gamma(u)}$$

Where λ is the decision threshold, $Q_u(.)$ the generalized Marcum-Q function, and $\Gamma(.)$ is the incomplete gamma function.

IV. SIMULATION RESULTS

The simulations results are presented in this section. The receiver/ detector performance is determined by means of p_d. Vs. □ (decision threshold). The decision threshold is in the range of 0 to 70. The channels from primary user to relay and from relays to cognitive centre are independent and identically Nakagami faded with average SNR equal to 5dB. The decision is made by comparing the received signal energy with decision threshold values and hence the probability of detection p_d. is determined. The time bandwidth factor (u) is equal to 2.

Fig. 3 shows the effect of decision threshold on probability of detection p_d. p_d decreases as decision threshold (□) increases. It is also shown that the probability of detection is increased by increasing the number of relays. Better performance is achieved by increasing the fading index m. plots for m=1 and m=3 are shown. The incorporation of direct link from primary user to cognitive centre increases the probability of detection shown in Fig. 4.

Fig. 5 shows the performance variations of probability of detection p_d with probability of false alarm p_f. It is shown that probability of detection increases for larger values of Nakagami Parameter. From Fig. 6, it can also be seen that the number of cognitive relays as well as the direct path has a great impact on the probability of detection.

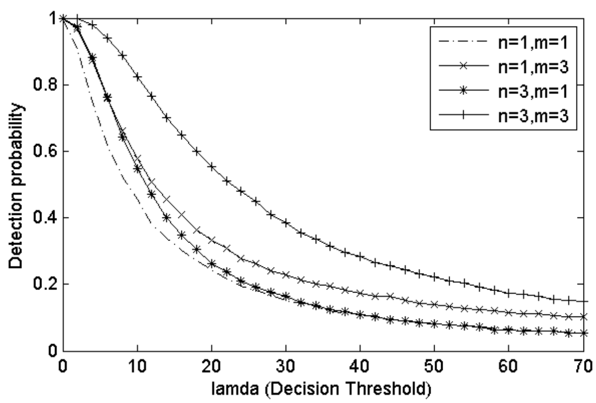

Fig. 3: Detection probability in Nakagami fading channels (m=1 and m=3)

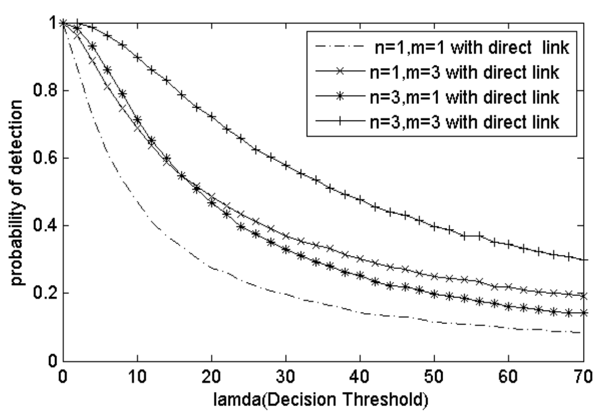

Fig. 4: Impact of direct link on detection probability

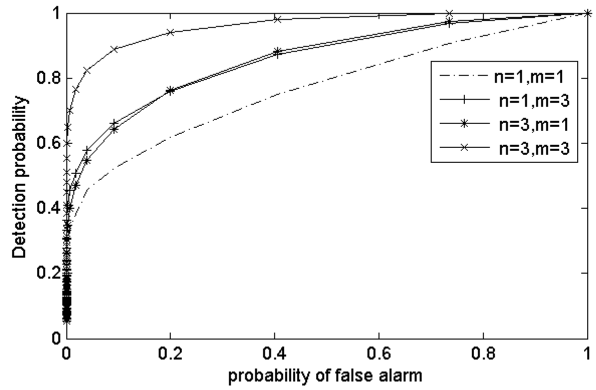

Fig. 5: Detection probability variations with probability of false alarm for n number of relays

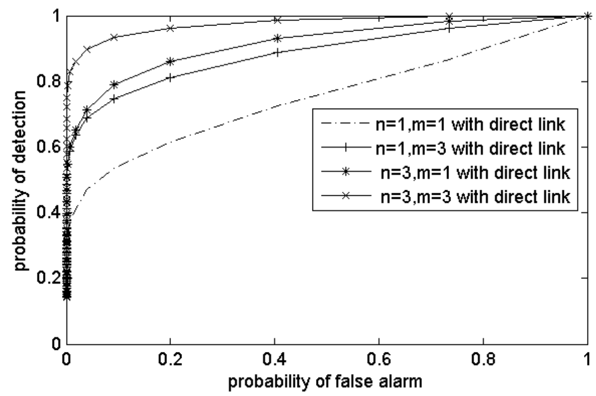

Fig. 6: Detection probability variations with probability of false alarm for n number of relays and with Direct link

V. CONCLUSION

The cooperative spectrum sensing of relay based cognitive radio network is studied over Nakagami-m fading channels. Here Analog-and-Forward multiple-relay stations are introduced in cognitive radio network. The network is analyzed in terms of probability of detection and probability of false alarm with and without incorporating the direct path between primary user and cognitive center. It is shown that probability of detection increases for larger values of Nakagami-m parameter. Moreover the number of cognitive relays as well as the direct path has a great impact on the probability of detection.

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