Performance of Double Threshold Energy Detection in Cooperative-Cognitive Networks over Rayleigh and Rician Fading Channels with Path Loss Effect

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Abstract— **This paper considers cooperative spectrum sensing in cooperative-cognitive networks with path loss effect. Relays are used for cooperation between Primary User and Cognitive Centre. By using Energy Detection techniques, we figure out the crumbling effect of path loss in cooperative-cognitive network. Different scenarios are considered with the introduction of single and multiple relays and detection parameters are found at the Cognitive Centre, *i.e.*, Probability of Detection (P_d), Collision probability (P_c) and unavailable probability (P_{ua}). Monte-Carlo simulations and Maximal Ratio Combining is suggested for the energy detection algorithms over Rayleigh and Rician Fading Channels.**

Index Terms —**Amplify and Forward, Maximal Rratio Combining, SLC, CC, Cooperative-Cognitive Network**

I. Introduction

Wireless technology is increasing day by day with the cost of spectrum allocation. The frequency bands are assigned to different wireless services and permission for unlicensed (secondary) users is prohibited. However, significant portion of this allocated spectrum remains underutilized most of the time. Cognitive radio solves this problem to make spectrum available for Secondary Users (SU) without interference with the licensed Primary User (PU) [1, 2].

In general, there are four basic elements in a Cognitive Radio(CR) that include spectrum sensing, its management, its sharing and mobility where the most concerned one is the spectrum sensing in which the SU senses for a vacant hole or channel bands to start its transmission [3] [4]. The PU is detected by SU with three methods, *i.e.*, energy detection techniques, matched filter method and cyclostationary property detection whereas in energy detection, single and double energy detection techniques are mostly used [5].

In single threshold energy detection technique, the PU is mostly protected due to more probability of detection but it has also high probability of false alarm, while in double threshold detection technique, the false alarm probability is reduced [6]. Cooperative spectrum sensing is considerably better in coping with the issues like multipath fading, problem of hidden node and shadowing to protect the PU from unwanted interference with the SU [7]. For Rayleigh faded channel, the cooperative sensing technique is described in [8]. The improvement in detection performance of PU, Square Law Combining (SLC) double threshold energy detection technique has been proposed in [9]. In one of their work in [10], the authors have proposed Maximal Ratio Combining (MRC) for energy fusion while OR rule is taken for decision fusion. Our previous work in [13] analysed considering two energy detection algorithms cooperative-cognitive networks with path loss effects over AWGN channel. This work considers both Rayleigh and Rician Fading Channels for both Non-line of Sight (NLS) and Line of Sight (LoS) communication, respectively. Furthermore, the paper analyses double threshold energy detection technique in cooperative cognitive network over Rayleigh and Rician fading channels with path loss effect. Amplify and Forward (AF) relaying scheme is used for the improvement of sensing capabilities which increases detection probability.

The rest of the paper is organized as follow: Section II presents the system model with double energy detection, Section III presents the relay optimization, Simulation model and results are presented in Section IV and finally Section V concludes the paper.

II. System Plan

A. *System model:*

A cooperative-cognitive network is shown in Figure1 which consists of PU, Relay and Cognitive Centre (CC).

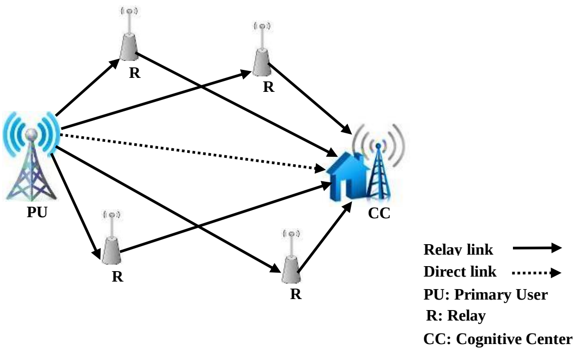

Fig. 1. Cooperative-Cognitive Network

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The relay works on AF relaying scheme in which it receives the signal from PU and then forwards it to the CC. Maximal Ratio Combining (MRC) technique is used at the CC to get the combined received signal and the required diversity.

Suppose "$s_i(t)$" is the received signal at *i*-th relay which was transmitted by the PU, *i.e.* $x(t)$ considering Path loss effect [1].

$$si(t) = d_r^{-n}\, x(t)\, h_{p-r} + n_{p-r} \qquad (1)$$

$$y_i(t) = A_{fi}\, d_d^{-n}\, si(t)\, h_{r-d} + n_{r-d} \qquad (2)$$

Where 'h_{p-r}' and 'h_{r-d}' are the channel responses from PU to relay and relay to CC, while 'd_r' and 'd_d' are the distances between PU to relay and relay to CC respectively. 'n' is the path loss exponent and 'n_{p-r}' and 'n_{r-d}' are the AWGN's at the relay and CC respectively.

A_{fi} is the Amplification factor which is given as [1]:

$$A_{fi} = \frac{1}{\sqrt{|\, s_i(t)\, |^2}} \qquad (3)$$

B. *Double Threshold Energy Detection*

Double threshold energy detection technique is shown in Figure 2. Since single threshold detection has high interference problems, therefore, double threshold energy detection algorithm is considered in order to avoid the unwanted interference in cooperative-cognitive network.
In Figure 2, if the calculated $y(t) > \lambda_1$, then it means that PU is present; however, if $y(t) < \lambda_0$ then it means that PU is absent. When $\lambda_0 < y(t) < \lambda_1$, then re-detection is needed which means it has fallen in the undecided region.

The formulas for Probability of Detection (P_d), unavailable Probability (P_{ua}) and collision Probability (P_c) for double threshold energy detection algorithm are given in [2] and are expressed as:

$$P_d = P\,\{y(t) > \lambda_1 | H_1\} = Qu\,(\sqrt{2\Upsilon}, \sqrt{\lambda_1}\,) \qquad (4)$$

$$P_c = P\{y(t) < \lambda_0 | H_1\} = 1 - Qu\,(\sqrt{2\Upsilon}, \sqrt{\lambda_0}\,) \qquad (5)$$

$$P_{ua} = \frac{\Gamma\,(u, \lambda_0/2)}{\Gamma\,(u)} \qquad (6)$$

Where $Qu(...)$ shows generalized Marcum Q-Function, u is the Time bandwidth factor, while $\Gamma(.,.)$ and $\Gamma(.)$ are incomplete and complete Gama function respectively.

The spectrum efficiency of double threshold energy detection algorithm is less as compared to single threshold energy detection algorithm [11]. Further it is also shown that $P_c = P_m$ and $P_{ua} = P_f$ taken for single threshold energy detection algorithm. The interference between PU and SU is reduced for double threshold energy detection algorithm than the single threshold energy detection algorithm.

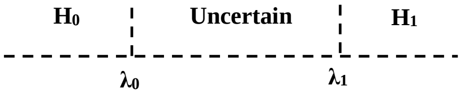

Fig. 2. Double threshold detection technique

III. OPTIMIZATION OF RELAY

The behaviour of detection probability changes with the Relay optimization. In the Figure 3, the system model for relay optimization is given [12] where 'd_0' is the normalized distance taken between source and destination and the separation between both relays are ½ d_0. The distance from source to R_1 and source to R_2 is d_1 and d_2 respectively.

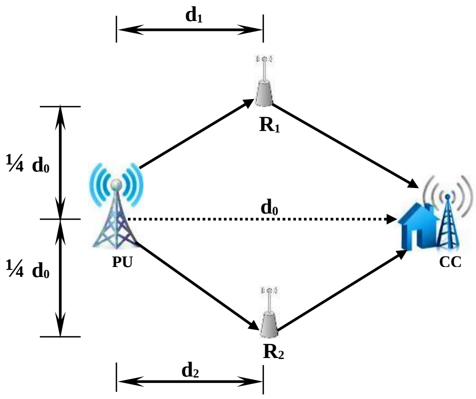

Fig. 3. Relay Optimization

IV. SIMULATION RESULTS

The simulation results taken for Raleigh and Rician channels are discussed in this section. Matlab has been used as a simulation tool. We have considered four scenarios for the model shown in Figure 3. The first scenario has one relay chosen at a distance ' ½ do' from the source. For the second scenario, two relays are taken with the same distance as ' ½ do' from the source. The third scenario has relays at a distance ' ¾ do' from the source and in the last scenario, the first relay is kept at a distance ' ¾ do' from source where the other relay is at a distance of ' ½ do' apart from source.

The parameters suggested for our simulation results are Path loss exponent = n = 3, time bandwidth factor = u = 1, SNR =1dB, $\lambda_0 = 0.8\lambda$, $\lambda_1 = 1.2\lambda$ and λ ranges from 0 to 100. The above parameters are taken for Rayleigh and Rician fading channels and k is assumed 1 for Rician channel.

A. *Probability of detection (P_d) vs threshold analysis in Rayleigh and Rician fading channels:*

In Figure 4 and 5, the Probability of Detection (Pd) vs threshold is shown for Rayleigh and Rician fading

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channels. We observe that with the increase in Threshold (λ), the Pd decreases. Similarly, it is shown that the Pd increases when the relay moves toward the source. The probability of detection is high in Scenario 4 as compared to other scenarios. It is clear from the Figures that in Rayleigh fading channel, the Pd for single threshold energy detection at λ = 30 is 58.31 % and decreases to 54.64 % in double threshold energy detection algorithm. The same trend is seen for Rician channel in which at λ = 30. The Pd for single threshold energy detection are 62.61 % and 58.37 % for double threshold energy detection algorithm. It is shown that the Pd in Rician fading channel is improved for both the energy detection algorithms over Rayleigh fading channels.

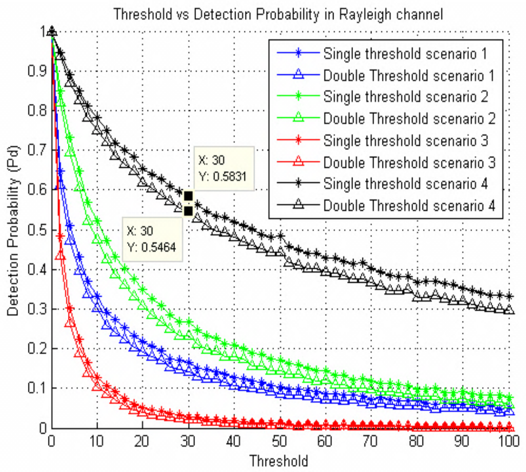

Fig. 4. Probability of Detection (P_d) vs Threshold (λ) in Rayleigh Channel

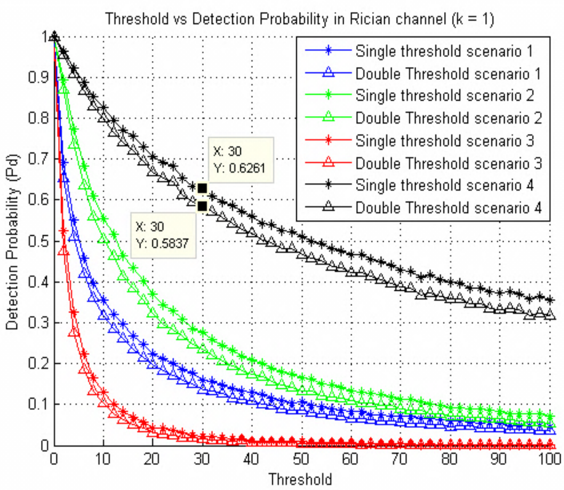

Fig. 5. Probability of Detection (*Pd*) vs Threshold (λ) in Rician channel

B. *Collision Probability (P_c) vs threshold analysis in Rayleigh and Rician fading channels*

In Figure 6 and 7, the Collision Probability (Pc) vs threshold are shown for Rayleigh and Rician fading channels. As the Threshold (λ) increases, the Pc increases and the collision probability decreases when the SU moves towards the PU. The collision probability is lowest in Scenario 4 as compared to other scenarios. The Figures show that in Rayleigh fading channel the Pc for single threshold energy detection at λ = 30 is 42.48 % and decreases to 37.82% in double threshold energy detection algorithm. Similarly, for Rician channel where the Pc for single threshold energy detection is 37.56 % at λ = 30 and 32.99 % for double threshold energy detection algorithm. The Pc in Rician fading channel is improved for both the energy detection algorithms than Rayleigh fading channel.

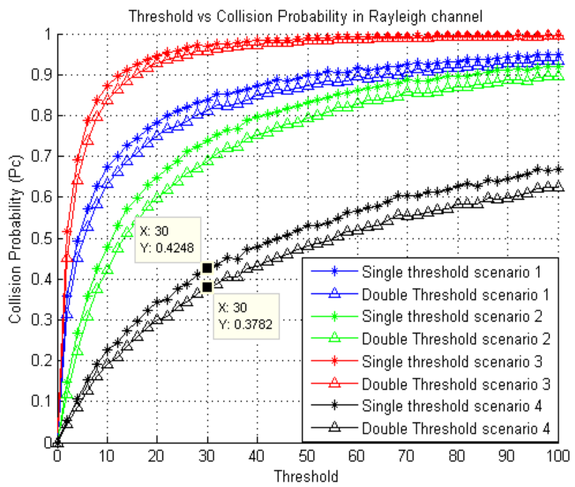

Fig. 6. Collision Probability (P_c) vs Threshold (λ) in Rayleigh Channel

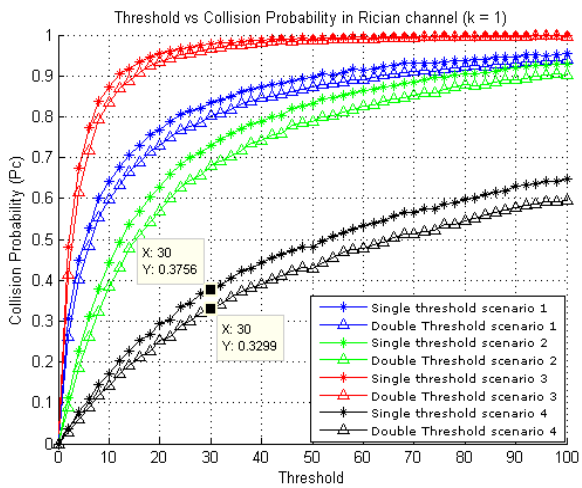

Fig. 7. Collision Probability (P_c) vs Threshold (λ) in Rician Channel

C. *Unavailable Probability (P_{ua}) vs threshold analysis in Rayleigh and Rician fading channels*

Figures 8 and 9 show the unavailable Probability (Pua) vs threshold for Rayleigh and Rician fading channels. It is shown that the Pua decreases with the increase in Threshold (λ), and increases when the SU moves towards the PU. Scenario 4 gives the highest Pua as compare to other scenarios. In Rayleigh fading channel the Pua for single threshold energy detection at

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λ = 30 is 48.37 % increases to 53.18 % in double threshold energy detection algorithm. Similarly, for Rician channel the Pua for single threshold energy detection is 52.29 % at λ = 30 and 57.34 % for double threshold energy detection algorithm.

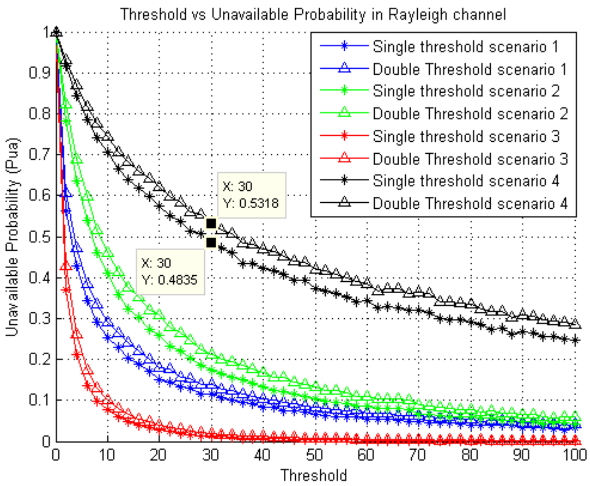

Fig. 8. Unavailable Probability (P_{ua}) vs Threshold (λ) in Rayleigh Channel

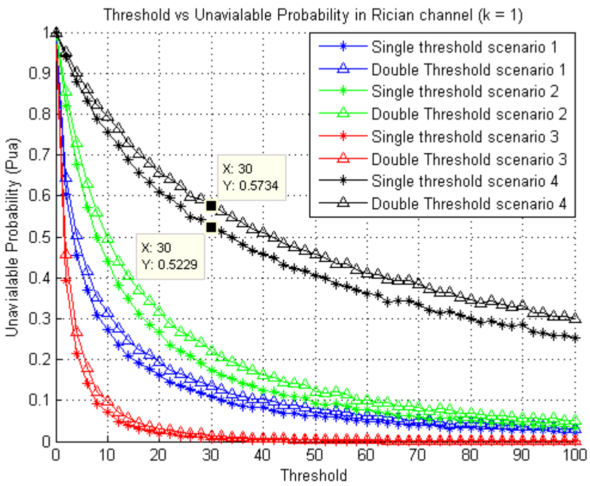

Fig. 9. Unavailable Probability (P_{ua}) vs Threshold (λ) in in Rician Channel

V. CONCLUSION

In this paper, we have analysed performance of double threshold energy detection in cooperative cognitive network over Rayleigh and Rician fading channels with path loss effect. Performance of the system has been examined in terms of Probability of Detection (P_d), Probability of collision (P_c) and unavailable Probability for different Relay positions between PU and CC. Simulation results show that the collision between PU and SU decreases by using Double threshold energy detection algorithm and the interference is also reduced between them. Moreover, the results also show a slight decrease in spectrum efficiency. It is noticed that the Rician channel decreases the spectrum efficiency more than the Rayleigh fading channel.

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