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Sensing Performance Evaluation over Multihop System with Composite Fading Channel

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Abstract

Cognitive radio has been demonstrated for improved spectrum utilization by secondary users in the presence of spectrum holes. In this paper, a Cognitive Radio (CR) network is implemented over the cooperative multihop wireless link. A multihop network is a collection of relay nodes within transmitter and receiver. A fixed infrastructure based multihop architecture is assumed for the performance analysis of energy detection algorithm for spectrum sensing in CR. System performance estimation against channel impairments dominated by fading and shadowing effects is one of the prerequisite for performance analysis of such networks. An effort has been made for exact performance analysis of multihop wireless network over composite fading channels. The investigation lead to the findings i.e., *for a given value of fading or shadowing parameter, the preferable detection probability is always dependent upon the optimum number of hops. Depending upon SNR a three- or five- hop link may perform better. For severe fading conditions,* the *one-hop link performs best.*

Keywords: *Energy Detection, Spectrum sensing, Multi-hop System, Performance Evaluation, Composite Fading channel*

1. Introduction

Radio frequency is a natural resource but unlike other resources it will not deplete when used. Most of its usable or beneficial part has been allocated to different services or has already been licensed by the government agencies in respective countries. Therefore there exists an apparent spectrum scarcity for new wireless services. It has also been noticed that licensed users rarely utilize all the allocated frequency bands at all the time and at different geographical locations. The underutilization of allotted frequency bands occurs and spectrum usage becomes inefficient. Such spectrum underutilization has motivated cognitive radio (CR) technology. Spectrum detection and spectrum traffic allocation are the main two challenges to enhance the spectrum utilization. The unlicensed users first sense the primary user's activities, *i.e.*, detecting the presence of signals in the frequency spectrum is spectrum sensing. The motto behind the development of CR technology is primary user detection with better transmission opportunity exploration [1, 2]. Spectrum holes are the unused frequency bands allocated to primary user at any point of time [3]. The performance of energy detection based spectrum sensing has been principally discussed for two hop relay networks [4, 5]. The recent studies illustrated that the cooperative relaying protocols can be used to fulfill all the basic requirements of CR networks [6, 7]. Many authors have been proposed that the cooperative spectrum sensing with accurately chosen fusion method will significantly improve the probability of detection [8]. CR has not been implemented on cascaded multihop

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relay networks over wireless link with composite fading characteristics. The potential of broader coverage in low transmitting power makes cooperative multihop scenarios more powerful communication technology [9]. In the last few years, numerous contributions addressed the performance of multihop relayed transmission, Hasna and Alouini [10-12] and Karagiannidis *et al.*, [13] studied average bit error rates and outage probability for different types of relays over Rayleigh, Nakagami-m fading channels. A relay network is thus expected to provide an improved return on assets, which means higher average revenue per user with superior grade of service at low incremental cost. The idea behind this approach is to split up the wireless link into multiple shorter hops, so that the source communicates with the destination only indirectly via a set of intermediate relay stations. Since the individual hops are generally much shorter than the distance between source and destination, the detrimental effects of path loss can be mitigated and therefore the total transmit power might be reduced compared to systems without relays [14]. If less transmit power is used, this also leads to a reduction of both the inter- and intra-cell interference level and might facilitate a cell capacity gain since multiple nodes within one cell might transmit data at the same time if they are far enough apart. Further, multihop relaying gives better trunking efficiency at aggregation points. Such networks are well suited for deployments in emergency and disaster scenarios. Also in rural areas, where traffic density is low and population is sparsely distributed, it may not be economically viable to build traditional cellular access networks with full fledged base stations (BS), rather a network architecture with a BS flanked by relay nodes to improve capacity and range extension may be a more flexible approach. The channel condition within all the hops of a cascaded multihop network does not remain same. In a wireless link, the data to be transferred from the sender to receiver has to propagate through air. During this propagation, the signal (data) gets distorted due to several phenomenon’s that occur within the wireless link. Issues like hidden terminal problem, multipath fading, shadowing and noise all makes it difficult to detect and extract the exact transmitted signal at the receiver. Also, the spectrum bands that lie above the 2GHz frequency are affected severely by these environmental conditions.

The remainder of paper is organized as follows: Section 2 describes multihop systems and spectrum sensing in cognitive radios. Section 3 briefly describes the composite fading channel chacteristics over multihop network. In Section 4 provides performance analysis and simulation results. Finally, in Section 5, we summarize the conclusions of our studies.

2. Multihop Systems and Spectrum Sensing

To meet the objective of low cost radio network deployment, for wide-area coverage, multihop transmission is likely to play important role in future wireless communication systems. Wireless relays help overcome current dependencies on wired backbones and enable cost-effective enhancement of coverage, throughput and system capacity of cellular networks as well as a fundamental enabling-technology for wireless ad-hoc and sensor networks.

Motivating by the practical deployment, an infrastructure based multihop wireless network with the relays is considered for the performance analysis. The simple multihop technology is synonymous with packet radio networking, MANET and mesh networking. The *L*-hop system model with *(N-1)* intermediate relays between source *S* and destination *D*, R_1, R_2,...,R_{N-1} respectively is considered, as shown in Figure 1. Relays are equipped with wireless communication devices to exchange the information between source to destination. In fact relay nodes do offer high flexibility in placing base stations, allowing fast network roll-out and adaptive traffic capacity engineering. The system is such that source *S* and destination *D* are away from each other and does not follow line of sight mechanism. All the nodes are placed equidistant to each other for the ease of analysis. The corresponding SNR at each hop are $\gamma_1, \gamma_2, ..., \gamma_{L-1}$. The relay is capable to receive radio signal from its predecessor and retransmit to its successor in a multihop network. The relays may operate in different possible schemes, depending upon how the received signal is processed: Amplify and Forward (AF) and Decode and Forward (DF). In the Amplify and Forward (AF) scheme (Analogue Repeaters), the relay node just amplifies and re-transmits the input symbols. The received signal is deteriorated by link fading and additive receiver noise. The degraded signal and noise are amplified and forwarded, thereby raising the noise level of the system. Serial relay transmission is used for long distance communication and range-extension in shadowing. It also provides power gain. In this topology signals propagate from one relay to another relay and the channels of neighboring hop are orthogonal to avoid any interference. In Decode and Forward (DF) Relay Protocols (Digital Repeaters), the relay demodulates and decodes the received signal before the retransmission. In this case, the forwarded signal does not contain supplementary filth, but degrade the system performance by symbol errors. Following the model, the exact performance investigation of (DF) and (AF) relay links having random number of hops has been accomplished. The wireless channels between successive relay nodes are slow varying and frequency non-selective composite fading channels in our investigations.

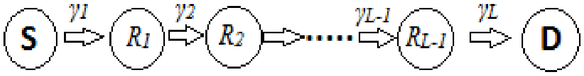

Figure 1. Schematic of a multihop network with source *S* is transmitting towards destination *D* via *N-1* intermediate relays

This paper perform the spectrum sensing in such a infrastructure based networks and shows that the probability of detection will also varies w.r.t the number of relays between source to destination. Spectrum sensing identifies unused spectrum and provides awareness regarding to the radio environment. The performance of spectrum sensing is investigated by means of energy detection technique and using their comparison property. Energy detector acts as a non-coherent detection because it is having a very low implementation complexity as it does not need any prior information about the primary user's signal. Such features make the energy detector the most commonly used detector in spectrum sensing. In spectrum sensing the accuracy is very much desirable. We consider detection probability (DP) and false-alarm probability (FP) for the analysis. The DP is defined as the probability of correctly detecting the Primary user (PU) when it is actually present and the FP is probability of incorrect detection of PU when it is not present. The vacant spectrum detection mainly depends upon the SNR condition of the wireless link and the sensing time. CR user need to sense the presence of PU, and transmit their data within same time duration, if the channel found to be free. In a infrastructure based multihop network such as shown in Figure 1, where the defined number of nodes are in between the transmitter and receiver, the repetitive sensing will lead to maximizing the sensing time. Which further results in lesser data transmission time with more power consumption. In this paper, the cooperative spectrum sensing is not incorporated, but single time sensing within the last hop and destination is accomplished, by keeping the view in mind that the signal to noise ratio at the last hop is dependent upon the probability of outage of first *(L-1)* relays within a wireless link . To simplify the analysis, cascaded multihop transmission link can be reduced to an equivalent point-to-point link and the PDF of the end-to-end SNR is given as [15].

$$p(\gamma) = N\delta(\gamma) + (1-N)\, p_{\gamma_L}(\gamma) \qquad \textbf{(1)}$$

Where, N represents probability that outage occur with first ($L-1$) link, $p_{\gamma_L}(\gamma)$ is the SNR of last hop. Assuming channels of L hops independent and relays in Fig.1 are separated by sufficient distance, the SNRs γ_l, l=1, 2…, L are mutually independent. The probability N can be expressed as

$$\begin{aligned} N &= 1 - \Pr\left\{\gamma_1 > \gamma_{th}, \gamma_2 > \gamma_{th}, \ldots, \gamma_{L-1} > \gamma_{th}\right\} \\ &= 1 - \prod_{l=1}^{L-1} \Pr\left\{\gamma_l > \gamma_{th}\right\} \\ &= 1 - \prod_{l=1}^{L-1} \left[1 - P_{\gamma_l}(\gamma_{th})\right] \end{aligned} \qquad \textbf{(2)}$$

Where, $P_{\gamma_l}(\gamma_{th})$ is the cumulative distribution function (CDF) of γ_l.

The longer sensing time reduces the data transmission time that degraded the channel efficiency. The energy detector is used to test the two different conditions of received signals (hypotheses H_0 and H_1) at time t and can be described as:

$$y(t) = n(t)\,; \qquad H_0$$

$$y(t) = n(t) + x(t); \qquad H_1$$

The PDF of the received signal for hypothesis H_0 and H_1 is given by [16]

$$\begin{aligned} Y &= \chi^2_{2u}, H_0 \\ Y &= \chi^2_{2u}(2\gamma), H_1 \end{aligned} \qquad \textbf{(3)}$$

Where $\Gamma(.)$ is the gamma function , $I_v(.)$ is the vth order modified Bessel function of the first kind, and $u = TW$ is the time bandwidth product. γ is the signal to noise ratio at the cognitive coordinator. The detection probability (P_d) and false alarm probability (P_f) can be generally evaluated by $Pr(Y > \lambda|\ H1)$ and $Pr(Y > \lambda|\ H0)$. Spectrum sensing performance mainly degraded when, channels within hops experiences deep fading and shadowing.

3. Composite Fading Channel Model

The wireless channels with slow varying and frequency non-selective characteristics are considered. For a composite fading channel, the received signal envelops of the N-hops X_1, X2,…, X_N are random variable with composite Nakagami-lognormal PDF given by [17]. By change of variable $t = \frac{\ln y_l - \mu_l}{\sqrt{2}\sigma_l}$, the PDF in can be expressed as

$$p_{X_N}(x_N) = \frac{2{m_N}^{m_N} {x_N}^{2m_N - 1}}{\sqrt{\pi}\,\Gamma(m_N)} \int_{-\infty}^{\infty} e^{-t^2} h(t)\, dt \qquad \textbf{(4)}$$

Where, $x_l \geq 0$, m_l is the Nakagami fading parameter, μ_l and σ_l represent mean and standard deviation of lognormal shadowing respectively. $\Gamma(.)$ is the standard gamma function. The m_l parameter is inversely related to the severity of the fading, m_l=1 for Rayleigh case and m_l=∞ for no fading case. σ_l is associated with the shadowing, σ_l=0 for no shadowing. $h(t)=e^{-m_l(\sqrt{2}\sigma_l t+\mu_l+{x_l}^2 e^{-(\sqrt{2}\sigma_l t\ +\mu_l)})}$, The integral form in Eq. (4), $\int_{-\infty}^{\infty} e^{-t^2}h(t)dt$ is a Gauss-Hermite integration, approximated as:

$$\int_{-\infty}^{\infty} e^{-t^2}h(t)dt \approx \sum_{i=1}^{N} w_i h(t_i) \tag{5}$$

Where t_i and w_i are the roots of Hermite polynomial of degree N and the weight factors of Gauss-Hermite Integration for the lth hop, t_i and w_i for different values of n are available in [18]. Therefore, Eq. (4) can be re-written as:

$$p_{X_l}(x_l)=\frac{2{m_l}^{m_l}{x_l}^{2m_l-1}}{\sqrt{\pi}\Gamma(m_l)}\sum_{i=1}^{N} w_i h(t_i) \tag{6}$$

An equivalent approximation for Eq. (6) is given by [14]

$$p_{X_l}(x_l)=K\sum_{i=1}^{N} a_i {x_l}^{2m_l-1}e^{-b_i{x_l}^2} \tag{7}$$

Where $x_l \geq 0$, $a_i=\frac{2{m_l}^{m_l}w_i e^{-m_l(\sqrt{2}\sigma_l t_i+\mu_l)}}{\sqrt{\pi}\Gamma(m_l)}$, $b_i = me^{-(\sqrt{2}\sigma t_i+\mu)}$,

$K=\frac{\sqrt{\pi}}{\sum_{i=1}^{N} w_i}$, K is the normalization factor. Based on the amplitude distribution in Eq. (7) PDF for the random variable γ_l can be evaluated as

$$p_{\gamma_l}(\gamma_l)=\frac{K}{2\rho^{m_l}}\sum_{i=1}^{N} a_i {\gamma_l}^{m_l-1}e^{-b_i\frac{\gamma_l}{\rho}} \tag{8}$$

$p_{\gamma_l}(\gamma_l)$ in Eq. (8) is a Mixture of Gamma Distributions [19]. For the PDF in Eq. (8), CDF of the SNR per hop $P_\gamma(\gamma)$ can be evaluated as

$$P_{\gamma_l}(\gamma_l)=\frac{K}{2\rho^{m_l}}\sum_{i=1}^{N} a_i \int_0^{\gamma_l} t^{m_l-1}e^{-\frac{b_i}{\rho}t}dt$$

The CDF of received SNR is rewritten by using [20]

$$P_{\gamma_l}(\gamma_l)=\frac{K}{2}\sum_{i=1}^{N}\frac{a_i}{b_i^{m_l}}\gamma\left(m_l,\frac{b_i\gamma_l}{\rho}\right) \tag{9}$$

Where, $\gamma(.,.)$ is the incomplete gamma function.

4. Performance Analysis and Simulation Results for Multihop System

The simulations are done for Nakagami-lognormal fading within the hops of wireless link. For simulations, MATLAB software is adopted. In simulations, it is assumed that wireless channels for each hop are independent and not identically distributed (i.n.i.d.). The signal to noise ratio (SNR) at the receiver is dependent upon the distance between source to destination and number of hops in a wireless link. Figure 2 clearly represents the receiver operating characteristic curve (ROC) analysis with various number of hops in case of cascaded multi-hopped network over composite fading channel. The direct link with average SNR of 8 dB is also included in performance analysis. Figure clearly reveals that the detection probability is dependent upon the number of relays/hops in a cascaded wireless link. As the number of hops starts increasing the detection probability gets decreased.

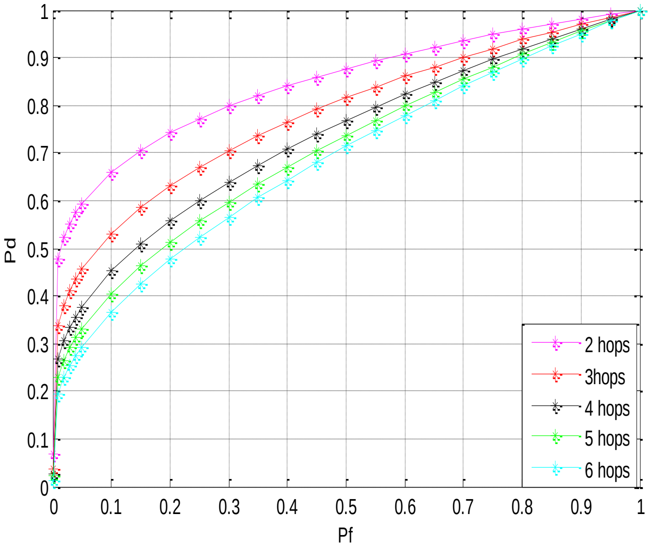

Figure 2. ROC for six-hop link for different number of hops at *m=1* and *σ = 8.* With Avg.SNR=8dB.

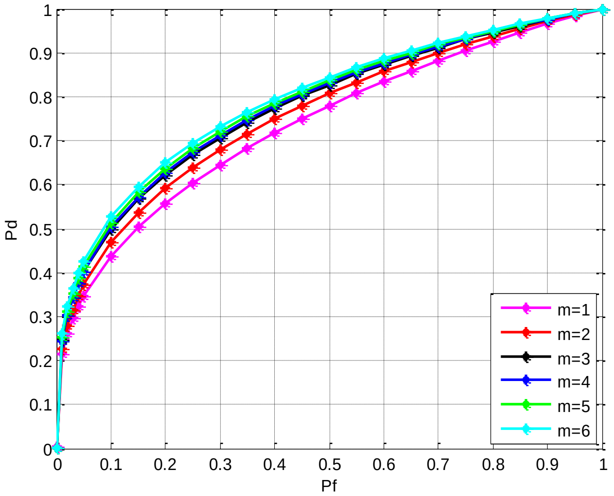

Figure 3. ROC analysis in Nakagami-lognormal faded (i.i.d) channel with different values of fading parameter (m) in a three hop network

In Figure 3 the simulations are carried out for 3 hop scenarios with the average SNR between each link is assumed to be 8 dB and the value of *u* is set to be 2. For the simulation the Receiver operating characteristic curves (ROC) has been drawn for the variable value of nakagami-m parameter having fixed value of standard deviation σ=8. From the figure it is revealed that as the channel conditions improve, the detection probability also improves significantly. Further, there is not significant improvement in detection probability for the values of *m* greater than 5

Figure 4 also represents the equivalent results, but the simulations are carried out for 5 hop network, assuming the average SNR within between each link is not identical. For the simulations, it is assumed that the average SNR goes on increasing as with the number of hops. The simulations are carried out for 5 hop scenarios with the average SNR between each hop are assumed to be (5dB, 8dB, 12dB, 15dB and 18dB).

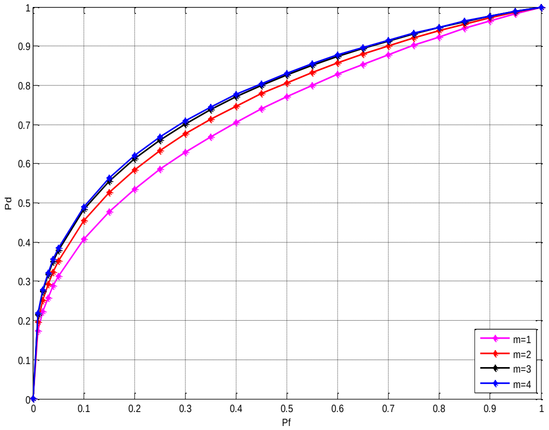

Figure 4. ROC analysis in Nakagami-lognormal fading (i.n.i.d) channel with different values of fading parameter (m) in five hop network

In depth analysis of graph shown in Figure 5 represents that the variation in P_d with standard deviation (σ) in (i.i.d) wireless links. Figure clearly describes that the as shadowing severity increases, the detection probability decreases for composite fading channel with *m*=2. Both the parameters follow the inverse relation property. The simulations are carried out for 3 hops network with each hop carries wireless links with an average SNR of 8dB. Similar analysis can be performed for 4 and 5 hopped networks with different average SNR within channel.

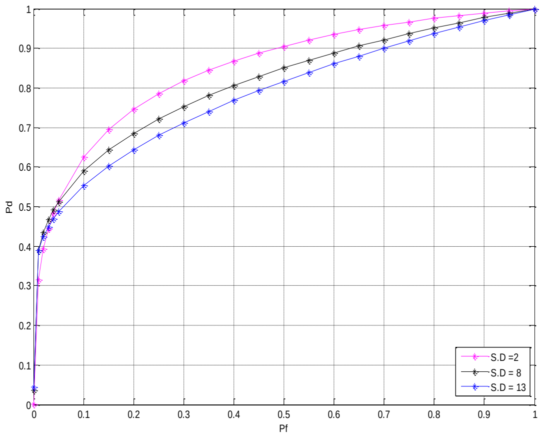

Figure 5. ROC analyses in Nakagami-lognormal faded (i.i.d) channel with different values of shadowing parameter (σ) in a three hop network

Similar analysis has been also been performed in Figure 6 by considering (i.n.i.d) wireless channels within hops of 4 hop network. The SNR within hops are the variable parameter with the assumption that it goes on increasing as the number of hops. For the simulations the direct channel with SNR 5dB is also associated with multihop network. The SNR within hops are assumed as (8dB, 12dB, 15dB and 18dB) respectively. It is clearly revealed from the both the Figures 4 and 5 that the shadowing severity affects the detection probability irrespective of the type of channel and number of hops.

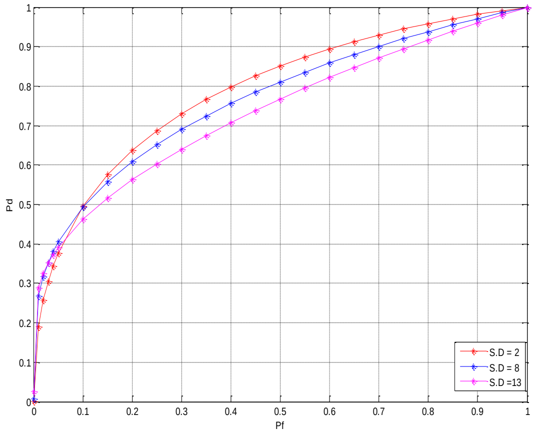

Figure 6. ROC analysis in Nakagami-lognormal faded (i.n.i.d) channel with different values of shadowing parameter (σ) in a four hop network.

Figures 7 and 8 represents an interesting fact that the type of relay within a multihop network also affects the sensing performance. The value of *Pd* is greater for the fixed value of *Pf*, in case we take up DF relays rather than the AF relays within a multihop wireless link. In Figure 6 we have analyzed the spectrum sensing with different types of relays by considering Nakagami-lognormal faded (i.i.d) channel with 8dB average SNR and having fixed value of standard deviation σ=8 within hops of the three hop network. Similar analysis has been also performed in Figure 7 by considering (i.n.i.d) wireless channels within hops of 3 hop network. The direct channel with average SNR 8dB is also associated with multihop branch. The SNR within hops are assumed as (8dB, 12dB and 15dB) respectively.

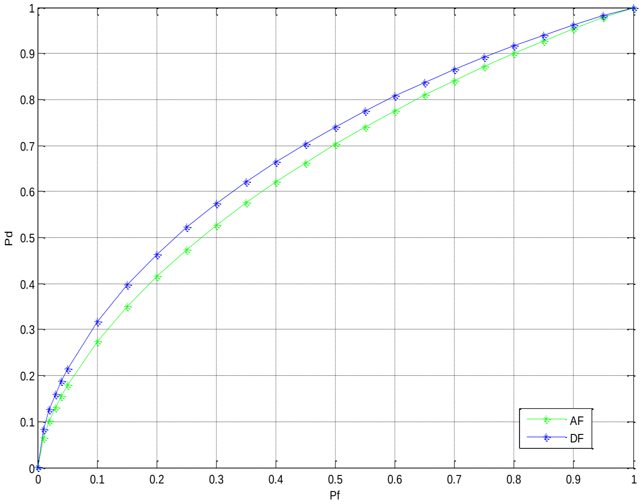

Figure 7. ROC analysis for Nakagami-lognormal faded (i.i.d) channels within 3 hop network

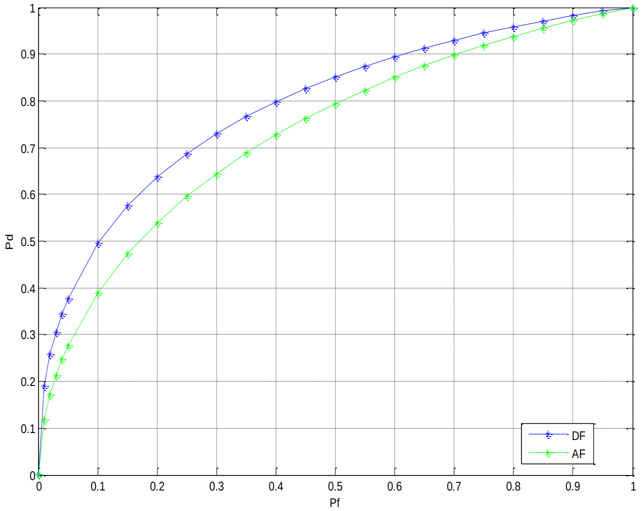

Figure 8. ROC analysis for Nakagami-lognormal faded (i.n.i.d) channels within 3 hop network

5. Conclusion

We have deliberated to do the spectrum sensing with an energy detector for a cognitive radio network with composite fading channels. All the wireless transmission systems are characterized by inefficient static spectrum allocations, imperfect channel distributions, fixed radio frequency bands, random distance between source to destination and imperfect network coordination. In wireless networks, as the distance between sources to destination keeps on increasing, for better reception it is necessary to incorporate relays within a link. The lesser power is need for transmission in multihop networks, but smaller number of hops reduces path loss. The analysis covers the receiver operating curves (ROC) representing detection probability for cascaded multihop link. It is also shown that the spectrum sensing employed in the cognitive radio network depends upon channel conditions. For good channel conditions higher number of hops can be used to achieve desired detection probability. Further for future work, the single branch multihop network can be augmented to multi-branch multihop network for the performance analysis with different diversity combining techniques at the receiver.

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