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Performance Evaluation of Energy Detection in Spectrum Sensing for Cascaded Multihop Networks over Nakagami-n fading channel

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Abstract

The spectrum sensing is an important activity of cognitive radios over fading channels. A proper sensing performance depends upon the fading margin and number of relays within a wireless link. This paper evaluates the sensing performance of energy detector in multihop networks over Nakagami-n fading channels. The decode and forward relays are considered for the analysis because of their best performance characteristics. Further, digital communication is aided by digital relaying techniques to achieve better performance results. The results yield the optimum value of average SNR based on fading margin and number of relays. The results emphasize that multi-branch networks (Co-operation) is an important tool to combat the effect of fading and to improve the detection probability.

Keywords: *Energy Detection, Spectrum sensing, Multi-hop System, Performance Evaluation, Nakagami-n Fading, Cascaded systems*

1. Introduction

With rising demand and usage of radio spectrum, the efficient use of available licensed spectrum is becoming more and more decisive. To satisfy the dramatic increasing demand for radio spectrum, cognitive radio *(CR)* is proposed as a key technology to realize the dynamic spectrum allocation. The radio frequency is highly regulated and communication service providers are assigned licences, which give them exclusive rights to use portions of the radio frequency spectrum. Permitting unlicensed user access to licenced spectrum can greatly increase spectrum utilization efficiency, but it is essential that the secondary users do not cause harmful interference to licensed user [1, 2]. A cognitive radios is required to achieve this , typically through spectrum sensing and interference management. The purpose of this cognitive communication challenge is to investigate the specrum utilization issues associated with primary and secondary user system sharing common spectrum based on throughput performances [3]. The overall goal is to allow the unlicensed user to operate in the presence of the licensed user. Spectrum sensing is the main errands of the cognitive radio used for fulfillment of the goal. Number of spectrum sensing methods has been used. Some methods used for standard signals while others are more general. Depending on the knowledge of signal under detection, better performance is usually obtained when generic methods are used for rough estimate on channel usage. Among all the generic spectrum detection methods, energy detection is the most popular method [4]. In the literature, many research efforts have been expended to analyze the performance of energy detectors. In [5], by assuming a flat, band-limited, Gaussian noise channel, the author detects the presence and absence of an unknown deterministic signal and derived as non-central and central chi-square distributions, respectively. The key performance parameters of energy detectors like probability of

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detection (P_d) and probability of false alarm (P_f) are also derived. Kostylev [6] has consequent the average (P_d) and average (P_f) by single path communication without cooperation for Rayleigh, Nakagami-n and Nakagami-m fading channels. Different analytical approaches are also given in [7, 8] to calculate the performance of an energy detector with and without diversity for generalized fading environments. Different diversity combining techniques such as maximal ratio combining (MRC), selection combining (SC) and switch-and-stay combining (SSC) have also been implemented for performance analysis under Nakagami fading distribution. In [9] author derive the probability of detection (P_d) in Nakagami-m and in Rician fading channel, limiting to the unity time bandwidth product (u=1). Relay based spectrum sensing concept was introduced by [10], which abruptly increase the spectrum sensing performance. Further different decision fusion methods are discussed and implemented in cooperative sensing scenario over different generic flat fading channels. In spectrum sensing the accuracy is desirable and is very hard to achieve. Cooperative sensing has therefore been introduced for accurate and reliable detection [11, 12]. But principally all discussed the performance in two hop relay networks. To the best of our knowledge, CR has not been implemented on cascaded multihop relay networks with wireless link. Potential of broader coverage in low transmitting power makes multihop scenarios more powerful communication technology [13]. In cellular communications, transmission occurs only on last link between a base station and end user. Multihop scenarios are the best suitable example for practical radio transmissions. In the last years, numerous contributions addressed the performance of multihop relayed transmission. Multihop transmission is accomplished through several relays between transmitter and receiver. The multihop network with cascaded relays for communication is not much researched because of analytical constraints. In practice, cascaded communication is frequently used in cellular communications. The coverage area is dependent on channel conditions and fading severity. Wireless mesh networks has been planned as a multihop network for broadband internet service, without the need of exclusive cable transportation [14].Morgado *et al.*, [15] investigated end-to-end performance of multihop relay link over different fading channels. The multihop model with serial relays is less researched for the CR networks. Investigation of multihop wireless networks especially with serial relay arrangement over Nakagami-n fading is not been reported in the literature. Relays can be classified as regenerative and non-regenerative. In the regenerative system, relay fully decodes the received signal from its predecessor node, encodes and then retransmit signal to its successor node. This is referred as decode-and-forward *(DF)* [16, 17, 18] or digital relaying. Decode and forward relays are preferable where capacity and throughput are important issues. On the other hand non-regenerative relays are referred as amplify and forward relays *(AF)*. These relays are preferable where complexity and latency are significant issues. In *(CR)* application, *(DF)* relays are best suitable because of high demand for the coverage of available spectrum.

The remainder of paper is organized as follows: Section 2 briefly describes the basic energy detection mechanism used for spectrum sensing and channel model for composite fading with its equivalent SNR expressions is briefly explained. In Section 3, the cascaded multihop network and its equivalent point to point PDF of the end to end SNR is introduced. The Section 4 includes brief about multi-branch networks. The analysis of simulated results of performance of energy detection system in multihop network is done in Section 5. The analysis of simulated results of energy detection in multihop multi-branch network is done in Section 6. Finally, in Section 7, we summarize the conclusions of our studies.

2. Basic Energy Detection and Channel Model

The energy detector is a threshold device and the output decision depends on the comparison of the incoming signal energy with the threshold. The received signal is converted in energy signal and that detected energy is further compared with a predefined threshold which depends on the noise floor. The availability of spectrum depends upon the comparison of detected energy with the predefined threshold. The output of the energy detector act as the test statistic to test the two hypotheses H_0 and H_1.The detection is the test of the two received signals at an energy detector at time t and can be represented as:

$$\begin{aligned} y(t) &= n(t)\,; && H_0 \\ y(t) &= n(t)+ x(t); && H_1 \end{aligned} \tag{1}$$

Therefore, the PDF of the received signal for hypothesis H_0 and H_1 is given by [19]

$$f_Y(y) = \begin{cases} \dfrac{1}{\Gamma(u)2^u} y^{u-1} e^{\frac{-y}{2}} & : H_0 \\ \dfrac{1}{2}\left(\dfrac{y}{2\gamma}\right)^{\frac{u-1}{2}} e^{-\frac{2\gamma+y}{2}} I_{u-1}(\sqrt{2y\gamma}) & : H_1 \end{cases} \tag{2}$$

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 probabilities of detection (P_d) and false alarm (P_f) can be generally evaluated by $Pr(Y > \lambda | H1)$ and $Pr(Y > \lambda | H0)$. Probability of detection (P_d) depends on the SNR (γ), detection threshold (λ) and number of samples (u). Some parameters viz. 'λ' and 'u' are manually adjustable according to the given conditions. But as far as γ is concerned, it gets affected by channel conditions. To measure the received signal power, the energy detector is used as a non-coherent detection device because it is having a very low implementation complexity as it does not need any prior information about the primary user's signal.

2.1 Nakagami-n (RICE) fading channel

In this paper Nakagami-n channels with flat fading characteristics have been chosen. The baseband signal is averaged with Nakagami-n flat fading environment. It is often used to model propagation paths consisting of one strong direct line of sight component and many random weaker components due to multipath. The Nakagami-n distribution [20] is habitually used fading model with strongest LOS lane accompanied with many arbitrary weaker components. Channel fading amplitude X is distributed as

$$p_X(x) = \frac{2\left(1+n^2\right)e^{-n^2}x}{\Omega}\exp\left[-\frac{\left(1+n^2\right)x^2}{\Omega}\right] I_0\left(2nx\sqrt{\frac{1+n^2}{\Omega}}\right) \quad x \geq 0 \tag{3}$$

Where, n is the Nakagami-n fading parameter. Its range lies between 0 and ∞. The Nakagami-n distribution has the range from Rayleigh fading ($n = 0$) to no fading (stable amplitude) ($n = \infty$). This type of fading is observed in the first resolvable LOS paths of microcellular urban and suburban land-mobile, pico-cellular indoor, and factory environments. The instantaneous SNR per symbol γ, is distributed according to the non-central chi-square distribution given by,

$$p_{\gamma}(\gamma)=\frac{\left(1+n^{2}\right)e^{-n^{2}}}{\bar{\gamma}}\exp\left[-\frac{\left(1+n^{2}\right)\gamma}{\bar{\gamma}}\right]I_{0}\left(2n\sqrt{\frac{\left(1+n^{2}\right)\gamma}{\bar{\gamma}}}\right)\quad \gamma\geq 0 \tag{4}$$

The MGF associated with this fading model is given by,

$$M_{\gamma}(s)=\frac{\left(1+n^{2}\right)}{\left(1+n^{2}\right)-s\bar{\gamma}}\exp\left[\frac{n^{2}s\bar{\gamma}}{\left(1+n^{2}\right)-s\bar{\gamma}}\right] \tag{5}$$

3. Multi-hop System Model

Rapid increase in the cellular subscribers and services require high capacity and coverage extension. The limited power source at the mobile terminal put constraint on transmitted power. System designers suggested multihop communication to be the key to encounter these problems. It is important to design and analyze the performance of multihop networks under fading scenario which could otherwise lead to the issues like link failure, poor quality of service (QoS), high infrastructure deployment and reduced revenue. Accuracy in sensing is the key parameter and is very difficult to achieve. Sensing accuracy is dependent upon many important factors like channel distributions, AWGN noise in wireless channels and hidden node problem. Improvement in such factors leads to the better spectrum sensing accuracy for cognitive radios. Further, sensing accuracy can be improved achieved by replicating the sensing process on time division basis over wireless link. Under severe fading conditions, primary user signal with lower signal strength is received at the receiver. The sub-channels between different relay nodes are independent. The different relay protocols can be assumed to transmit the transmitted signal. For simplicity, the cascaded multihop transmission link can be reduced to an equivalent point-to-point link and the PDF of the end-to-end SNR [21].

The *L*-hop system model with (*L-1*) intermediate relays between source *S* and destination *D*, R_1, R_2,...,R_{L-1} respectively is considered, as shown in Figure 1. The system is such that primary user transmitter *(PU-Tx)* and primary user receiver *(PU-Rx)* cannot see each other. All the communication between *(PU-Tx)* and *(PU-Rx)* take place via intermediate nodes. All the nodes are placed equidistant to each other to ease analysis. The corresponding SNR at each hop are $\gamma_1, \gamma_2, ..., \gamma_{L-1}$. The relays are *(DF)* following time division principle and operating in half-duplex mode. The wireless channels between successive relay nodes are slow varying and frequency non-selective Nakagami-n fading channels in our investigations. The practical scenario with independent and identically distributed *(i.i.d)* channels is considered. Following the model, this contribution develop framework for exact performance analysis of decode-and-forward relay link having arbitrary number of hops. We consider average detection probability and false alarm probability for performance analysis. The analytical results are validated by the Monte-Carlo simulations.

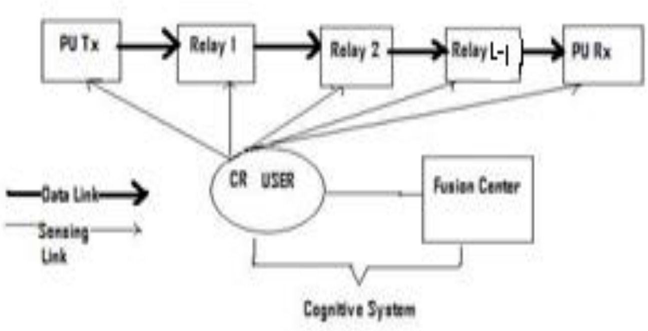

Figure 1. Schematic of a multihop transmission link via *L-1* intermediate relay nodes

4. Multipath Multi-branch System Model

The property of transmitted signal is rising broader in the frequency spectrum. The transmitted signal reflects, refract, diffract or interfere with the different objects within wireless link which results in multiple wave-fronts of the transmitted signal at the receiver. This is basic idea behind multipath propagation. Multipath scenarios results in implementation of diversity. Multipath networks are based on idea that multiple independent paths have a low probability of signal degradation due to channel fading conditions. So, using multi-path networks the similar information signal is transmitted over independent fading paths. At the receiver, these multiple independent paths are combined to reduce the fading effect. For multi-branch network several CR users are required to sense the presence of PU in different branches which results in cooperation. The final decision taken by fusion center is dependent on cooperation. Cooperative sensing improves the efficiency of spectrum sensing and reliability by sharing their information with each CR users. However, once the probability of sensing for a single branch is found, the same method can be applied for any number of diversity branches. Multi-branch networks improve the system performance by minimizing the channel variations due to fading.

5. Performance Analysis and Simulation Results for Multihop System

Based on the system model, the simulation results are given in this section .The results shown in this section are for average detection probability between two consecutive nodes. Each relay node act as a pseudo random bit sequence generator (PRBS). The PRBS is modulated by digital modulation techniques for the simulation. The modulated information is transmitted in the channel as symbols. Each symbol is assigned specific energy E as per the transmitted power requirements. The transmitted symbol is corrupted by AWGN and Fading effects in the channel. The AWGN is additional to the transmitted symbol to set required $\frac{E_b}{N_0}$ (SNR) over the wireless communication link. The symbol with SNR $\frac{E_b}{N_0}$ is multiplied by random Nakagami-n fading coefficients generated from the Nakagami-n distribution. Further, energy detection can be used to analyze the spectrum availability. The symbol in the channel is now faded according to the Nakagami-n fading. The MATLAB package is used to carry out simulations. The AWGN can also be added to the symbol as per required SNR with the help of dedicated function.

Figure 2 indicates the (P_d) verses (P_f) for four hop cascaded multihop system with different values of average SNR. As the value of average SNR within hops are increased, the (P_d) starts increasing. The interesting fact is the value of targeted (P_d) 0.9 is reported at average SNR of 14dB with Nakagami-n fading severity parameter $n=2$.

We also have analyzed the spectrum sensing with different values of fading severity parameter n. The (P_d) has direct relation with the severity parameter n. Figure 3 shows, as the value of severity parameter *'n'* start increasing, the (P_d) also increasing within a four hop wireless link. The value of targeted (P_d) 0.9 is reported at severity parameter $n=5$ for average SNR of 12dB. Further, we analyze the spectrum sensing with number of hops in cascaded multihop network.

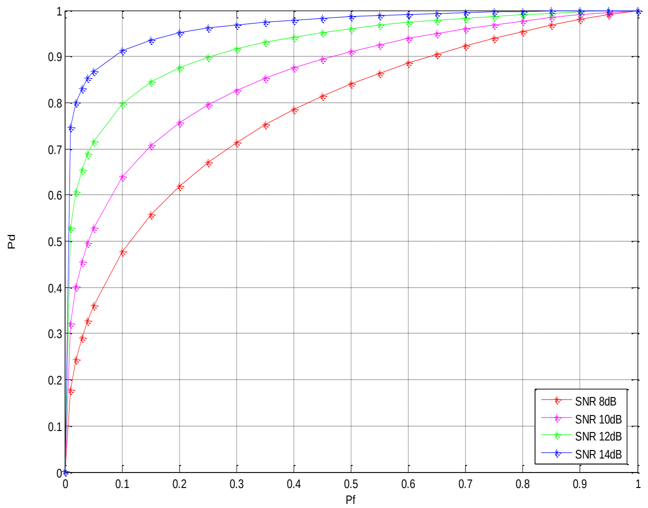

Figure 2. ROC analysis in Nakagami-n fading with different Average SNR in four hop system

Figure 4 shows an interesting fact that if direct transmission takes place i.e. no relay $(L=0)$ is placed between *(PU-Tx)* and *(Pu-Rx)*, then we get the lower bound value of (P_d). If one relay $(L=1)$ is placed between (*PU-Tx*) and *(Pu-Rx)*, there is an abrupt change in (P_d) for the fixed value of (P_f) =0.2. That value of (P_d) act as an upper bound value. As the relays within a wireless link starts increasing, the value of (P_d) lies in between the upper and lower bound (P_d) values.

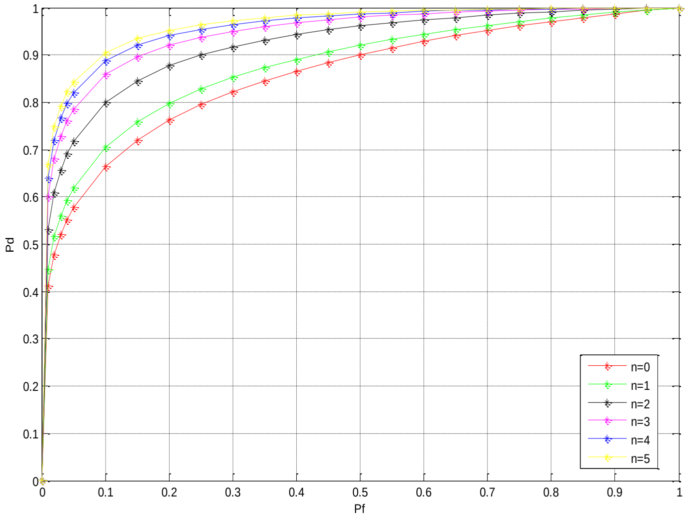

Figure 3. ROC analysis in Nakagami-n fading with average SNR = 12dB for four hop system

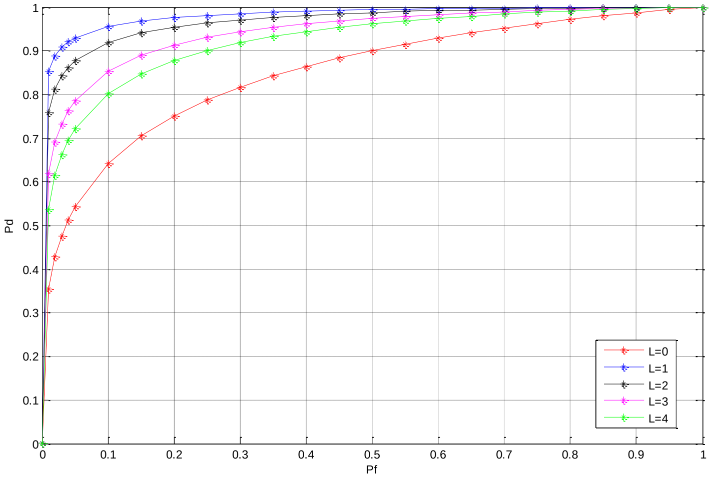

Figure 4. ROC analysis in Nakagami-n fading with average SNR = 12dB for four hop system

6. Performance Analysis and Simulation Results for Multi-branch System

Multi-branch networks discussed in Section 4 are implementing for spectrum sensing in cascading multihop networks. Depending upon the system performance the number of branches can be varied. We have analyzed the results for various numbers of branches. In this paper, improved results with multi-branch system implementation have been reported. Figure 5 shows that as the number of branches goes on increasing, the value of (P_d) also increases for fixed value of (P_f).

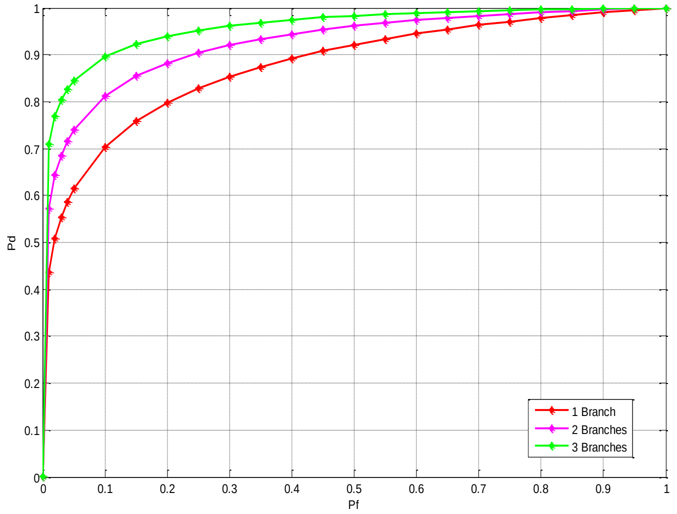

Figure 5. ROC analysis in Nakagami-n fading with different number of branches at average SNR = 8dB for two hop system

In depth analysis of graph shown in Figure 5 represents that by increasing the number of branches, the value of (P_d) increases from 0.7 to 0.9 for a three branch cascaded multihop system for the fixed value of (P_f) =0.1. Hence, the modified implementation provides a significant improvement in probability of detection.

7. Conclusion

Multihop communications networks play an important role in cellular communications. In spite of deployment complexity, the less transmitted power, high capacity and increased coverage area are the chief advantages of such networks. The cellular networks, sensor networks and ad-hoc networks are multihop in nature with each intermediate node acting as relay. The smaller number of hops reduces path loss and less power is need to be transmitted in multihop networks. Estimation of system performance against channel impairments dominated by multipath fading is one of the prerequisite to design such networks. We have deliberated the multipath multi relay based spectrum sensing with an energy detector for a cognitive radio network. The analysis covers the receiver operating curves (ROC). It is shown that the spectrum sensing employed in the cognitive radio network depends upon channel distributions. For good channel conditions higher number of hops can be used for targeted detection probability. The significant improvement in probability of detection appears with multi-branch networks.

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