Determination of Medium Access Probability of Cognitive Radio under Different Fading Channels

Rezwan Ahmad, Md. Imdadul Islam, M. R. Amin

Abstract*: The correct decision in detecting the presence of the primary users is a vital requirement in cognitive radio network. Incorporation of spatial false alarm makes the derivation of probability of correct decision a difficult task. The previous literature performs the task only for the case of the received signal under Normal distribution of the fading channel. In this paper, we enhance the work for three small scale fading channels: Rayleigh, Rician and Nakagami-m Fading Channels to get the real scenario of a cognitive radio network in an urban area. The impact of fading parameters and sensing range on the profile of probability of correct decision is also investigated to optimize the performance of the network.

Index Terms: Cognitive radio, spectrum sensing, spectrum hole, medium access probability, spatial false alarm.

I. INTRODUCTION

With the advent of new high data rate wireless applications, as well as growth of existing wireless services, demand for additional bandwidth is rapidly increasing. To be available anywhere and anytime when needed, the wireless medium has to be exploited. Currently, spectrum allotment is operated by providing each new service with its own fixed frequency block. Demand for access to spectrum has been growing dramatically, and is likely to continue to grow in the foreseeable future. New services, such as unlicensed wireless Internet access and satellite digital audio broadcasting (DAB), are being launched and are quickly reaching hundreds of thousands of consumers. At the same time, most "prime" spectrum has been assigned, and it is becoming increasingly difficult to find spectrum that can be made available for either new services or to expand existing infrastructures.

Existing "command-and-control" spectrum allocations defined by government regulatory agencies prohibit unlicensed access to licensed spectrum, constraining them instead to several heavily populated, interference-prone frequency bands. As a result, there exists an apparent scarcity of transmission spectrum that is forcing a critical rethinking of

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how wireless communications is performed. Additionally, it may be difficult to gain access to a large contiguous block of frequency spectrum, which can be a major limitation for high data rate transmissions.

Even though much of the spectrum has been allocated, preliminary measurements indicate that usage of the frequency spectrum is sparse both spatially and temporally. As the spectrum is underutilized by the primary license holders, there exist spectrum holes that can be used by secondary users, yielding efficient utilization of the spectrum and eliminating the apparent spectrum scarcity. To ensure that existing services can continue to grow and evolve, it is important that efficient access to and use of the radio spectrum should be promoted [1].

As a significant part of frequency resources are already allocated to licensed systems, suspending new systems from being introduced. However, according to many measurement campaigns, spectrum utilization in these licensed bands is relatively low [1], [2]. To face this problem, new dynamic spectrum access policies are proposed, that allow a spectrum owner called primary user (PU) to lease part of the unused spectrum resources for unlicensed (opportunistic) use by the so-called secondary user (SU). The transceiver that can exploit such a spectrum scenario without causing a harmful interference to licensed users is named a cognitive radio (CR) [3]-[5].

There are four main functions of a CR and they are as follows: 1. Spectrum Sensing – finding unused spectrum; 2. Spectrum Management – finding the best available spectrum to use based on quality of service criteria; 3. Spectrum Mobility – allowing for the shift from one frequency to another; 4. Spectrum Sharing – scheduling and sharing spectrum in a fair manner.

In [6], the author has developed a theory to find expression for the medium access probability by including the effect of the conventional false alarm (CFA) probability and the spatial false alarm (SFA) probability. The paper explicitly discusses the probability of correct decision only for the case of received signal under Normal distribution of the fading channel.

In the present paper, we enhance the work of Han et. al. [6] for the following three small scale fading channels: Rayleigh, Rician and Nakagami-*m* fading channels to get the real scenario of a CR network in an urban area. The impact of the fading parameters and the sensing range on the profile of the probability of correct decision is also investigated to optimize the performance of the network.

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The paper is organized as follows: Section I describes the system model of the work, where sensing consideration in CR and SFA and medium access probability is described. In this section, a brief description is given about the application of the medium access probability for different fading channels. Section III describes the result of the investigation in details and finally the conclusion is given in Sec. IV.

II. SYSTEM MODEL

2.1 *Sensing Consideration in CR and SFA Problem*

The objective of conventional sensing in CR is to understand the real on-off status of a PU inside the SU's sensing range. To properly determine one of the above two hypotheses: PU off, access opportunity is available (denoted by $\mathcal{H}_0$) or PU on, access opportunity is unavailable (denoted by ($\mathcal{H}_1$) is obtained by analyzing the received signal x [7]-[10]:

$$\begin{aligned} &\mathcal{H}_0: \quad x[n]=w[n], && n=0,1,\Lambda\ ,N-1, \\ &\mathcal{H}_1: \quad x[n]=s_0[n]+w[n], && n=0,1,\Lambda\ ,N-1, \end{aligned} \tag{1}$$

where $x[n]$ is the received signal by the SU, $s_0[n]$ is the signal from the PU locating at the edge of the sensing region; and N is the number of samples. The distance between the PU and the SU is denoted by r and the sensing range is denoted by r_s which ensures the secondary receiver and primary receiver are not interfered by each of other relevant transmitter [11]. If the primary transmit power is S and the noise power is σ_n^2, then the relation between the target primary-signal-to-noise ratio (PSNR) $\tilde{\gamma}$ and the sensing range r_s is given by the following equation:

$$\tilde{\gamma}=\frac{Sh(r_s)}{\sigma_n^2}, \tag{2}$$

where $h(.)$ denotes, for a given distance, the power loss including the path-loss, shadowing, and also multipath fading [11].

As we know that SU is granted to utilize the idle primary channel dynamically if no busy PU is detected inside the secondary sensing range r_s. Another way we can say that a SU is permitted to access primary channel regardless of the transmitting PU outside the sensing range. In other words, a SU is granted permission to access the primary channel regardless of the transmitting PU resides outside the sensing range.

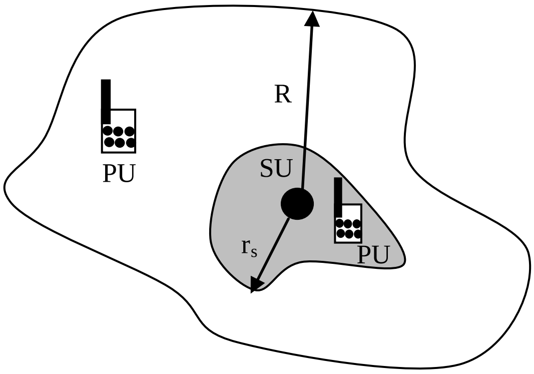

Fig.1 Sensing rage of a SU within a cell: Shaded part of the figure is the sensing rage of the SU.

The sensing range with respect to a SU (shaded region), the cell boundary and the location of the PUs within and outside the sensing region is shown in Fig. 1; where R is the cell radius and r_s is the radius of the sensing region.

However, in real situation, the scenario may be quite different. It was shown earlier that when the distance between the SU and the PU (denoted by r) is larger than the sensing range (denoted by r_s), the SU still can sense the presence of the PU with some detection probability [12]. It was shown that the detection probability does not decrease efficiently to a lower level in terms of the primary signal from the outside of the sensing range. This phenomenon is proved by the experiment performed in [12]. On the other hand, the area πr^2 increases rapidly as r increases. The larger area πr^2 means the higher probability to meet the PU. As a result, considering the detection probability ($r > r_s$) and the probability to meet a PU jointly, the SU can suffer from high probability to lose access opportunity.

2.2 *SFA and Medium Access Probability*

For a quantitative analysis and a practical scenario, let us consider that a PU is located at a distance R from the SU. We further consider that the PU has a probability p to be in the transmitting state at any instant of time. The small scale primary network is considered to be as follows: for the existence of a PU in a circular observed window, of which the area is πR^2, where $R > r_s$ [6]. Here the spectrum sensing is to properly determine the one of the two states $\mathcal{H}_0$ and $\mathcal{H}_1$, where $\mathcal{H}_0$ denotes the access opportunity is to be available; and $\mathcal{H}_1$ denotes the access opportunity to be unavailable. In addition, the state $\mathcal{H}_0$ is divided into two sub-states: $\mathcal{H}_{0,-}$ and $\mathcal{H}_{0,+}$. The sub-state $\mathcal{H}_{0,-}$ denotes that the PU is in the switching on state inside the sensing range and $\mathcal{H}_{0,+}$ denotes that the PU is in the transmitting state and residing at a point outside the sensing range. Thus, we can write

$$\begin{aligned} &\mathcal{H}_0: \begin{cases} \mathcal{H}_{0,-}: & x[n]=w[n], \\ \mathcal{H}_{0,+}: & x[n]=s_+[n]+w[n], \end{cases} && n=0,1,\Lambda\ ,N-1, \\ &\mathcal{H}_1: \quad x[n]=s_-[n]+w[n], && n=0,1,\Lambda\ ,N-1, \end{aligned} \tag{3}$$

where $s_-[n]$ is the primary signal when the PU is inside the secondary sensing region, and its power is given by $Sh(r)$, $r \le r_s$; while $s_+[n]$ is the primary signal when the PU resides outside the secondary sensing region, and its power is $Sh(r)$, $r > r_s$.

For the SU, the probability of access opportunity provided by the primary network is the probability that the spectrum hole is available for the SU, denoted by $P(\mathcal{H}_0)$, and is given by [6]

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$$P\left(\mathcal{H}_0\right)=1-p\,\frac{r_s^2}{R^2}, \qquad R>r_s. \tag{4}$$

The conditional probability, $P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,-}\right)$, denotes the CFA probability, and $P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,+}\right)$ denotes the SFA probability. Hence, the total access opportunity lost by sensing is the sum of $P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,-}\right)$ and $P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,+}\right)$, that is, $P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,-}\right)+P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,+}\right)$.

For $\mathcal{H}_{0,-}$ and including the CFA probability, $P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,-}\right)$, the medium access probability is given by the following expression

$$\begin{aligned} P_{MA-} &= P\left(\mathcal{H}_{0,-}\right)\left[1-P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,-}\right)\right] \\ &= (1-p)\left[P\left(T>\in \mid \mathcal{H}_{0,-}\right)\right], \end{aligned} \tag{5}$$

where $T=\sum_{n=0}^{N-1}|x[n]|^2/N$ is the test statistics with energy detection (ED) and $\in$ is the detection threshold [6]. Since $P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,+}\right)$ is the probability of the PU to be detected under $r>r_s$, thus for $\mathcal{H}_{0,+}$ and including the SFA probability, $P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,+}\right)$, the medium access probability can be written as

$$\begin{aligned} P_{MA+} &= P\left(\mathcal{H}_{0,+}\right)\left[1-P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,+}\right)\right] \\ &= p\int_{r_s}^{R}\left(1-p_D(r)\right) f(r)\,dr, \end{aligned} \tag{6}$$

where $f(r)$ is the probability density function (pdf) of the PU location and is given by $f(r)=2r/R^2$ as $f(r)$ should give $\int_0^R f(r)\,dr \equiv 1$ and $p_D(r)$ is the detection probability.

Thus the total medium access probability, P_{MA}, is the sum of P_{MA-} and P_{MA+} as given by Eqs. (5) and (6):

$$\begin{aligned} P_{MA} &= P_{MA-}+P_{MA+} \\ &= P\left(\mathcal{H}_{0,-}\right)\left[1-P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,-}\right)\right] \\ &\qquad + P\left(\mathcal{H}_{0,+}\right)\left[1-P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,+}\right)\right] \\ &= (1-p)\left[P\left(T>\in \mid \mathcal{H}_{0,-}\right)\right] \\ &\qquad + p\int_{r_s}^{R}\left(1-p_D(r)\right) f(r)\,dr. \end{aligned} \tag{7}$$

In the following, we briefly describe how to calculate the probability $P\left(T>\in \mid \mathcal{H}_{0,-}\right)$ and the detection probability $p_D(r)$ to evaluate the total medium access probability P_{MA} as given by Eq. (7). It is to be mentioned here that the upper limit of the integral in Eq. (7) is

$$R=r_s\sqrt{\frac{p}{1-P\left(\mathcal{H}_0\right)}}, \tag{8}$$

which is derived from Eq. (4).

2.3 *Medium Access Probability in the case of Nakagami-m, Rayleigh, Rician and Normal Distributions of the Fading Channels*

In this section we describe the medium access probability as given by Eq. (7) in the case of different distributions of the fading channel.

For the pdf $f_X(x)$ of X for a fading channel, the conventional false alarm probability appearing in Eq. (7), viz., $P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,-}\right)$ can be calculated as

$$P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,-}\right)=\int_{\in}^{\infty} f_X(x)\,dx, \tag{9}$$

where $\in$ is defined earlier. Thus the probability $P\left(T>\in \mid \mathcal{H}_{0,-}\right)$ can be obtained as

$$\begin{aligned} P\left(T>\in \mid \mathcal{H}_{0,-}\right) &= 1-P\left(\mathcal{H}_1 \mid \mathcal{H}_{0,-}\right) \\ &= 1-\int_{\in}^{\infty} f_X(x)\,dx, \end{aligned} \tag{10}$$

As an example, for Nakagami-*m* Channel, the probability $P\left(T>\in \mid \mathcal{H}_{0,-}\right)$ is given by the following expression

$$P\left(T>\in \mid \mathcal{H}_{0,-}\right)=1-\int_{\in}^{\infty} f_N\left(\alpha,\Omega_0,m\right)d\alpha, \tag{11}$$

where

$$f_N\left(\alpha,\Omega_0,m\right)=\frac{2m^m\alpha^{2m-1}}{\Omega_0^m\,\Gamma(m)}\,e^{-m\alpha^2/\Omega_0}, \tag{12}$$

where Ω_0 is the time-average power of the received signal and *m* is the Nakagami fading parameter, sometimes called shape factor of the Nakagami-*m* distribution. The value of *m* ranges between $1/2$ and ∞.

Taking the variation of the average signal strength with distance *r* as $\Omega(r)$, we can write the detection probability $P_D(r)$ as

$$P_D(r)=\int_{\in}^{\infty}\frac{2m^m\alpha^{2m-1}}{\Omega^m(r)\,\Gamma(m)}e^{-m\alpha^2/\Omega(r)}\,d\alpha. \tag{13}$$

For other fading cases, the appropriate pdf $f_X(x)$ should be used in Eq. (9) to calculate the CFA probability.

III. RESULTS

For each of the fading cases, we select two set of parameters: one for the case of the absence of any PU and the other for the case of the presence of the PU.

For Nakagami-*m* fading case, we choose the fading parameters, $\Omega_0=0.2$ and m = 2. For Rayleigh fading channel, the only parameter: $\Omega_0=0.2$. For Rician fading case, $\Omega_0=0.2$ and the peak amplitude of the dominant signal, A = 1. For the pdf of the Normal distribution, $\sigma_0=\sigma_1=\sigma=0.14$, $\mu_0=0.2$, $\mu_1=1$ [6]. The variation of signal strength with distance is considered as $\Omega(r)=kr^{-n}$, where n is the path loss exponent and we have taken k = 1.3 and n = 2.7. The value of p is taken as 0.7.

Figure 2 shows the variation of the medium access probability P_{MA} against the probability of access opportunity $P(\mathcal{H}_0)$ taking $\in = 0.12$ and $r_s = 3$. The condition of the network is better for the case when the received signal follows the Normal pdf. For other three cases (Rayleigh, Rician and Nakagami-m), the probabilities P_{MA} are very close to each other and each of them rises exponentially. When the access opportunity $P(\mathcal{H}_0) > 0.85$, the P_{MA} for Rayleigh, Rician and Nakagami-m fading cases are almost equal.

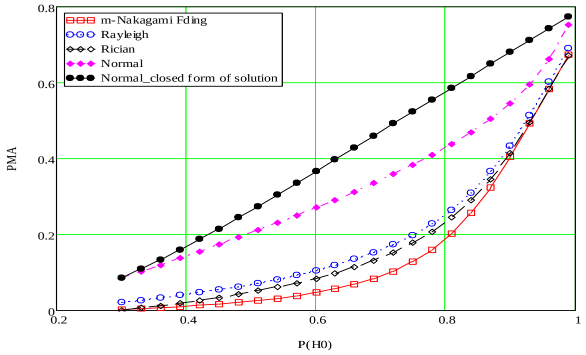

Fig. 2 The variation of medium access probability P_{MA} against

the probability of access opportunity $P(\mathcal{H}_0)$ taking $\in$ = 0.12, $r_s = 3$.

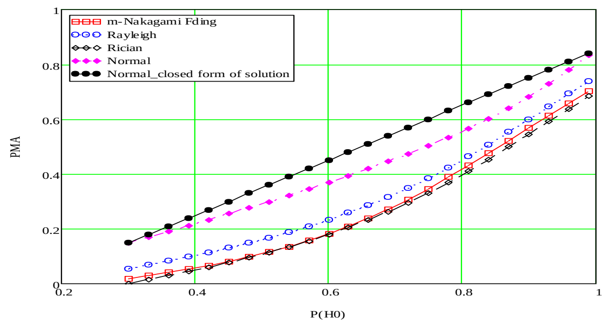

Fig. 3 The variation of medium access probability P_{MA} against the probability of access opportunity $P(\mathcal{H}_0)$ taking $\in = 0.2$, $r_s = 3$.

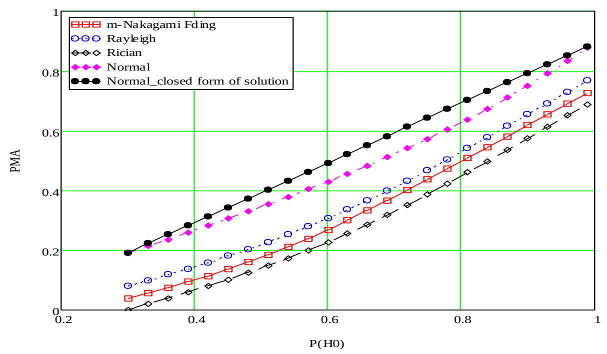

Fig. 4 The variation of medium access probability P_{MA} against the probability of access opportunity $P(\mathcal{H}_0)$ taking $\in = 0.25$, $r_s = 3$.

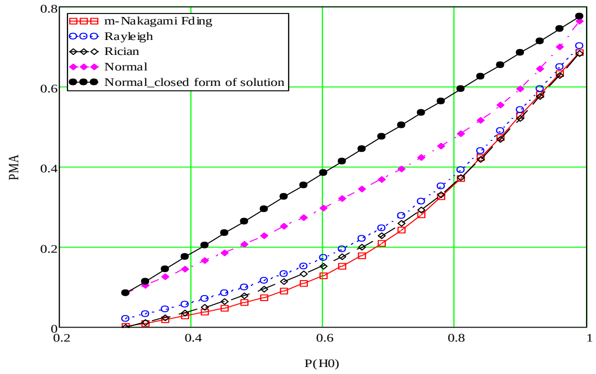

Fig. 5 The variation of medium access probability P_{MA} against the probability of access opportunity $P(\mathcal{H}_0)$ taking $\in = 0.12$ $r_s = 4$.

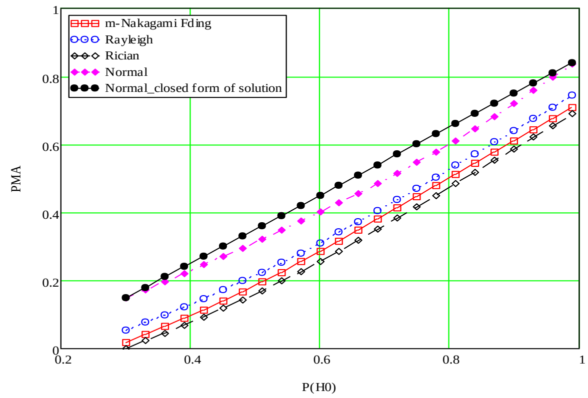

Fig. 6 The variation of medium access probability P_{MA} against the probability of access opportunity $P(\mathcal{H}_0)$ taking $\in = 0.2$, $r_s = 4$.

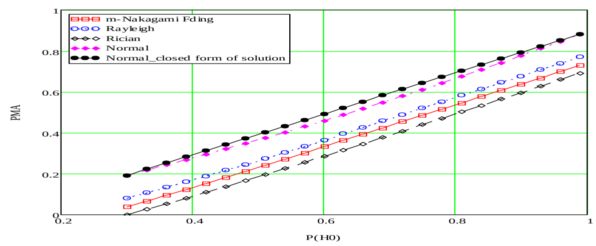

Fig. 7 The variation of medium access probability P_{MA} against the probability of access opportunity $P(\mathcal{H}_0)$ taking $\in = 0.25$ $r_s = 4$.

The impact of the threshold $\in$ is easily visualized from Figs. 2- 4, where the threshold is varied as $\in$ =0.12, 0.2 and 0.25. As is observed, a very little improvement is found for the case of the Normal pdf, but for the other three fading cases, the profile of the medium access probability, P_{MA}, rises. It is also observed from Figs. 5-7 that the profile of P_{MA} is heavily dependent on the parameter r_s, the sensing range. If the values 0.12, 0.20 and 0.25 for the parameter $\in$ are applied for $r_s = 4$, the increase in P_{MA} is found more prominent and the profile of all the curves approach to linear.

IV. CONCLUSION

The paper investigates the impact of fading condition of the wireless channel, sensing range and threshold value of the received signal on the medium access probability. The profile of the medium access probability changes from exponential to linear with the increment of the radius of the sensing region, r_s . The performance of the network is found to be the best for the case of normal fading but the situation is very poor for other three fading conditions. The impact of small scale fading is prominent in an urban area hence bad results of Rayleigh, Nakagami-*m* and Rician fading reflect the realistic scenario of the wireless network, which is the actual finding of the paper. Still, we have the scope of incorporating the Walfish-Ikegami model, Okumura-Hata model and Lee's Prediction model instead of the ordinary path loss exponent formula used in the present investigation. Even, including the adaptive equalizer or match filter with the detector can improve the performance of the network.

REFERENCES

1. S. Haykin, "Cognitive radio: brain-empowered wireless communications," IEEE Journal on Selected Areas in Communications, vol. 23, pp. 201-220, Feb. 2005.
2. D.Cabric, S.Mishra, and R.W.Brodersen, "Implementation issues in spectrum sensing for cognitive radios," in *Proc*. 38th *Asilomar Conf. Signals,Systems* and *Computers*, Pacific Grove,CA, 2004, pp. 772-776.
3. A. Ghasemi and E. S. Sousa, "Spectrum Sensing in Cognitive Radio Networks: The Cooperation-Processing Trade-Off," Wiley Wireless Commun. and Mobile Comp. Special Issue on Cognitive Radio, Software-Defined Radio, and Adaptive Wireless Systems, vol. 7, no. 9, pp. 1049–60, Nov. 2007
4. Jun Ma, Geoffery Ye Li, and Biing Hwang (Fred) Juang, "Signal Processing in Cognitive Radio," in Priceeding of the IEEE, May 2009, vol. 97, no. 5, pp.805-823.
5. A Ghasemi, ES Sousa, "Interference aggregation in spectrum-sensing cognitive wireless networks," IEEE J. Select Topics Signal Process., vol. 2, no. 1, pp. 41–55, 2008.
6. Weijia Han, Jiandong Li, Qin Liu, and Linjing Zhao, "Spatial False Alarms in Cognitive Radio," IEEE Commun. Lett.., vol. 15, no. 5, pp. 518 – 520, May. 2011.
7. Masha Derakhshani, Tho Le-Ngoc, "Aggregate Interference and capacity-Outage Analysis in a Cogitive Radio Network," IEEE Trans. Veh. Technol. , vol. 61, no, 1, pp. 196-207, January 2012.
8. Masha Derakhshani, Tho Le-Ngoc, "Beacon transmitter placement on aggregate interference and capacity-outage in a cognitive radio network," in 72nd IEEE Vehicular Technology Conference, Ottawa, Canada, Sep. 2010, pp. 1-5.
9. Marco Cardenus-Jaurez, Mounir Ghogho, "Spectrum Sensing and Throughput Trade-off in Cognitive radio under Outage constraint over Nakagami Fading," IEEE Commun. Lett., vol. 15, no. 10, pp. 1110-1113, October 2011.
10. A. Ghasemi and E. S. Sousa, "Collaborative Spectrum Sensing for Opportunistic Access in Fading Environments," in Proc. IEEE 1st Symp. Dynamic Spectrum Access Networks, Baltimore, MD, Nov. 2005, pp. 131–36.
11. F F. Digham, M.S. Alouini, M. Simon, "On the energy detection of unknown signals over fading channels," IEEE Trans Commun., vol. 55, no. 1, pp. 3575–3579, Jan. 2007.
12. D. Cabric, "Experimental study of spectrum sensing based on energy detection and network cooperation," IEEE Trans. Wireless Commun., vol. 7, no. 11, pp. 4502-4507, Nov. 2008.

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