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Research Article

Performance Analysis of New Spectrum Sensing Scheme Using Multiantennas with Multiuser Diversity in Cognitive Radio Networks

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The spectrum detection (SD) is a critical step in cognitive radio (CR) to identify the available spectrum and avoid interference and harm to primary users (PUs). Nonetheless, the practical detection process is often compromised with problems of receptors uncertainty, shadows, and multipath fading. To overcome these problems, a cooperative SD scheme is proposed by exploiting the system multiantenna (MUA) with the multiuser diversity (MUD). The SD gives unlicensed secondary users (SUs) the opportunity to use the licensed spectral band until the PU makes its appearance. By allowing the cooperation between the SUs of the same spectral band, the time of the detection is reduced and increases the general dexterity, which is the strong point of cooperative SD. In this paper, we proposed an SD scheme using a new MUA design. The scheme proposed is a clear difference compared to other systems because in this design weight of quantification is multiplied by each receiving antenna. The scheme has the ability to detect low-level signals to facilitate sharing between the SU and PU system. The numerical results are made to prove the performance of the proposed system compared to the conventional system. The results obtained confirm the efficiency of the proposed scheme.

1. Introduction

1.1. Background. The rapid proliferation of smart mobile devices and the static management of the spectral band in the radiocommunication system have resulted in a shortage of frequencies. To overcome this problem in the wireless communication system, the concept of dynamic spectrum access through cognitive radio (CR) has become quite attractive today. Two categories of spectrum users are defined: the category of primary users (PUs) (i.e., those with a frequency band allocated by the authorities with high priority) and the category of secondary users (SUs) (i.e., those who come to share their bands with the PUs, under the condition not to create interference to the main users). This model is called model of hierarchical access and defines two approaches: the approach of simultaneous access and the approach of delayed access. The approach of simultaneous access allows SUs to access the spectrum at the same time as the PUs while respecting severe constraints in terms of emission power. The approach of delayed access, firstly proposed by Mitola [1], on the other hand, requires an SU to first verify that a channel is free (not in use by any PU) before it can transmit. Whenever the PU requests its band, then the SU must release and start again on a new free band.

Spectrum detection (SD) is an important technological step in the quest for dynamic spectrum access in the world of today's wireless communication system. However, the SD process often encounters some problems related to receiver uncertainty, multipath fading, and shadows. For this, a precise and fast SD technique in cooperative mode must be developed while using the multiantenna (MUA) system with multiuser diversity (MUD) to cope with this challenge. There are a large number of spectrum detection techniques, namely, energy detection, matched filter, and cyclostationary feature detection. Among the detection techniques, the energy detector (ED) is used because of its simplicity of implementation. ED uses the energy of the signal to carry out the signal detection without having beforehand the information about the type of modulation and the phase of the signal. To make the detector effective, a multiantenna system is used. Using multiple antennas a diversity gain can be achieved. One of the challenges in detecting PU is how to detect its low power, such as the noise sign below multipath channels. One of the solutions adapted to alleviate the fading channel bound by the multiple paths is the use of a diversity receptor.

SD in cooperative mode employs spatial diversity in wireless channels in order to tackle the unwanted actions such as hidden nodes and shading [2, 3]. There is evidence that the SD in cooperative mode improves detection yields [4, 5]. In the policy of detection in cooperative mode, each cognitive user (CU) independently performs its detection and then communicates its observations to a combination center (CC) [6, 7]. The CC, in turn, gives a final decision on the state of activity/inactivity of every channel by exploiting the rules of combination. The cooperation wholly demands that all detectors simultaneously perform SD in a short duration and declare their results promptly after the detection in order to guarantee timely and precise result [2]. In effect, a time or a period of silence is generally observed when all users of cognitive network cease their trial for the issuance of channels allocated and implement a cooperative SD. Concerning the secondary system, a long duration of silence can lead to an inefficient spectrum utilization [2], especially when there are a significant number of channels allocated. There are a number of solutions that could be implemented to reduce the duration of detection in order to guarantee maximum utilization of the SD and reliability of detection. One solution is to reduce the traffic load by playing on the size of the data of local detection or the number of detectors [2]. Another possible solution to facilitate the efficient operation of the bandwidth is exploitation of protocols of transmission and modulation such as time-division multiple access (TDMA) and code-division multiple access (CDMA). The minimization of the duration of detection can be achieved either by applying the techniques of advanced detection or by raising the number of detectors.

In wireless networks with the presence of fading, MUD by definition allows various users to know diverse conditions of fading channels and provide feedback to the base station of the individual channel states. The MUA system addressing this issue is discussed in [8–10] and this proposed system needed prior information on channel status between the PU and the SU. Generally, the SU has no knowledge of the PU channel; for this reason, we perform a new scheme with a suboptimal response to this question while applying the MUD with the quantization weights of the antennas.

In this paper, we present a distributed method concerning the SD in a temporal mode, which is focused on the MUD among cognitive users (CUs) in order to enhance the performance of detection in the cognitive radio networks (CRNs). Our work focuses on the detection of the temporal spectrum. However, the proposed new detection scheme can be incorporated into the SD space to obtain a spatiotemporal SD system [11, 12]. The proposed scheme of SD with the MUA is a framework of cooperative detection in order to overcome the shadowing and the low SNR. Unlike conventional MUD systems in CRNs, issues related to delay and equity are not considered during spectrum detection; this is due to the importance given to the probability of detection, which is considered as the only performance parameter.

We also present a MAC (medium access control) protocol based on the protocol of multiple access carrier detection (CSMA) to favor the transmission of data between cognitive users and the CC. The scheme uses a set of protocols to access media whereby a user needs to verify that the media are available prior to transmission of data. If a user detects transmissions on the channel by other users, it waits before making its own transmissions. The MAC protocol presented in this paper uses a different window in order to manage the MUD in CRNs. This MAC protocol is called CSMA cognitive MAC protocol, used for the purpose of monitoring the exchange between CC and SUs. Our results amply confirm that our proposed scheme achieves better performance compared to a conventional scheme that does not exploit the MUD. In addition, we demonstrate with great technique the importance of using multiantennas in SD.

In our simulations, we retain two scenarios: (1) the SUs are composed of several antennas and a simple antenna, and (2) the channel between the SUs and the PU is Rayleigh without and with shadowing.

To deal with the problems mentioned above, we retain the following plan: Section 2 presents the related work. In Section 3, the system model is described. Spectrum Sensing Using Energy Detector is discussed in Section 4. The performance parameters are described in Section 5. In Section 6, we analyze the performance of data combination techniques. Section 7 presents details of the mechanism of operation of multiantennas. The multiuser diversity is study in Section 8. CSMA using medium access control protocol, which facilitates exchanges between the combination center and the SUs, is described in Section 9. Simulation results are given in Section 10. Lastly, the paper is concluded in Section 11.

1.2. Contribution. The main contributions made in this paper are as follows.

(i) To improve the performance and capability of detection, SUs using MUA are proposed. By using MUA, it is easy to obtain diversity gain. In the detection of the PU signal, the major challenge is the detection of its low power as a noise level signal under the constraint of fading channels due to multiple paths. One of the most effective methods for avoiding fading channels due to multiple paths is to use a diversity receptor.

(ii) In this research, various compromises between some parameters are mentioned, for example, the number of antennas, the antenna quantization weights, and the detection time. The impact of increasing the number of quantization weights of the antenna is evaluated to improve the performance of the detector. The performances are evaluated using the different data combination techniques, such as maximal ratio combination (MRC), quantized combination, and hard combination (OR rule) by considering the Rayleigh fading channel.

(iii) We propose a MAC protocol based on CSMA that will provide the speed and reliability in transmitting observations of cognitive users at the CC level. The MAC protocol proposed uses a window of different return in order to exploit the MUD adhering to the secondary systems.

2. Related Work

The SD based on cooperation between SUs is a promising method to improve the accuracy of PU signal detection in CRNs by grouping their detection observations from different SUs. In SD in cooperative mode, the malicious SUs can alert false detection information in order to damage the final detection decision [13]. The SD in the CRNs can be done in distributed as in centralized [14]. In the centralized system, the SUs send their observations to a data combination center (DCC) and receive instructions from the DCC [15]. Regarding the distributed system, the SUs do not rely on a DCC to make the decision to access the channel, but it chooses itself the accessibility of the channel by conglomerating the results revealed by the other SUs. The data forgery attacks are often difficulties encountered in the SD in cooperative mode; the malicious SUs deliberately report false results to deceive decision-making. In [16], the SU detection data is weighted to increase the probability of detection of accessible channels under the constraint of a required false alarm probability. However, the system only takes into account the detection errors of SU, regardless of the malicious conduit of SU.

Spatial SD is studied in [17, 18], where the power of the maximum emission without the interference of a secondary user is estimated on the basis of intensities of the signal picked up by a collective of secondary nodes. To determine the maximum power of emission without the interference of a secondary node, the evaluations of the localization and the transmitting power of the main transmitter are evaluated cooperatively by a collective of secondary nodes. By exploiting these evaluations, every secondary node determines its power of maximum emission without approximate interference, which leads to a dimension limit of its space hole. The issue concerning the SD when the primary user is enabled or disabled is designated to detect temporal spectrum [19]. In [11, 12], joint spatial-temporal SD system is proposed which utilizes spatial sensing information to improve temporal sensing performance. Compared to both pure temporal and pure spatial, the scheme in [12] shows improved performance.

The study of SD in cooperative mode has been addressed in some research [19–21]. Detection in the cooperative mode between the secondary nodes can effectively combat: hidden terminals, weakening SNR, and shadowing [19]. In the cooperative detection, the cognitive users located in different places independently detect the frequency and communicate their observation to a combination center. They may send either a hard decision of a bit or the soft information on the canal in the CC [22]. The soft combination rule is derived in [22], where the weighting coefficients are similar to those for the combination of the maximum report.

To improve wireless communication network systems, the transmission relays have a cache technique that improves the system's transmission performance and reduces latency [23]. In [24], an improvement in spectral efficiency by introducing cooperative relay technology and multiuser diversity in CRNs was proposed. Cache-supported cooperative relay networks indicate that the cache can not only exploit the diversity of relays but significantly improve the transmission performance of the system [25]. The authors indicated that the cached system improves system transmission performance significantly compared to that without cache system, as it reduces data packet transmission time in wireless network systems [25]. They also mentioned that the order of diversity of the system can be quickly increased by using the cache. In addition, obsolete channel state information (CSI) degrades system performance by weakening the effect of multiuser diversity [24].

3. System Model

We consider that the PU system consists of MUA that operate in a bandwidth B and with the carrier frequency (fc). It is the same for the receiver SU system, which uses MUA. The CRN model is composed of a single PU and S SUs. Each user executes its own local SD in an independent manner then takes a binary decision based on the fact that the PU is present or not. All CUs send their decisions to a CC. The CC, in turn, combines the data and makes a final decision to determine the availability or absence of the principal user. At the level of CC, some combination rules are employed to give the final decision concerning the presence or the absence of PU. In addition, the structure works in a distributed mode in which CUs share their internal decisions to every user, as shown in Figure 1. Between the SUs and the CC, there is the presence of a MAC protocol based on the CSMA protocol which facilitates the transmission of data.

Taking into account the constraints of communication between the CC and the SUs, all CUs are not likely to send their data to the CC. We suggest that among the S CUs Z are likely to communicate with the CC. In effect, for the reason of the MUD, every CU presents different parameters concerning the channel of fading for a targeted observation time.

4. Spectrum Sensing Using Energy Detector

4.1. Problem Formulation. The problem concerning the SD hole is in the form of the binary hypothesis test, which consists in making a decision between two hypotheses:

$$\begin{aligned} H_0 &: u_i(n) = \mu_i(n) \\ H_1 &: u_i(n) = s_i(n) + \mu_i(n) \end{aligned} \tag{1}$$

Hypothesis 1 (H_1): a target is present.

Hypothesis 0 (H_0): no target is present.

For $n = 0, 1, \ldots, F$ and $i = 1, 2, \ldots, L$, $\mu_i(n)$ is considered as the additive white Gaussian noise (AWGN). signal samples of primary are indicated by $s_i(n)$. $s_i(n)$ is formulated as follows:

$$s_i(n) = \sum_{h=0}^{l_i} g_i(h)\,\hat{s}(n-h). \tag{2}$$

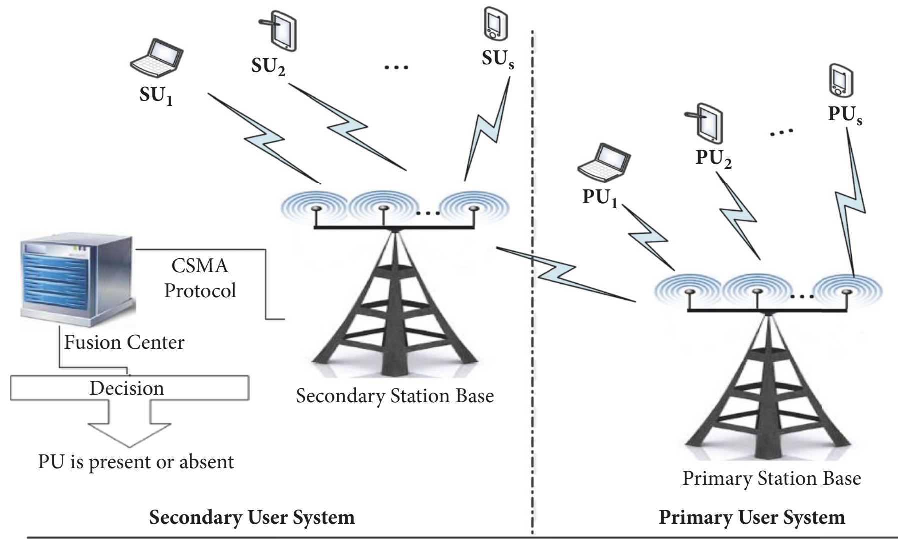

Figure 1: Synoptic scheme illustrating the mechanism of spectrum detection.

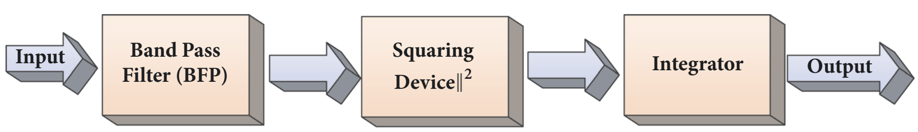

Figure 2: The synoptic block of energy detector.

$g_i(n)$ characterizes the response of the channel that exists between the receiving antenna i and the primary transmitter, $\widehat{s}(n)$ denotes the signal emitted by the primary transmitter, and the channel order is represented by l_i. We consider that the noise processes are zero-mean complex additive white Gaussian and independent at every receiving antenna. In addition, we assume equal variance ϑ_μ^2 for the noise processes at every antenna.

The signal to the entry $u(n)$ is filtered through a BPF (band-pass filter) in order to restrict noise and choose the useful bandwidth. The noise at the output of the filter performs a spectral density reduced in the band. The block diagrams (Figure 2) are composed of a device of an integrator of time-limited. The output of the device is squared and then processed by the integrator in order to obtain the discharge. In the end, to make a decision on a possible absence or presence of PU, the signal at the detector output must make a comparison with a detection threshold λ, in other words

$$\begin{aligned} R(u) &> \lambda : H_1 \\ R(u) &< \lambda : H_0 \end{aligned} \tag{3}$$

The statistical test of energy detection in MUA systems is proportional to the output of a square law combiner (SLC). Therefore, concerning F received signal samples and L reception antennas, $R(u)$ is calculated as follows:

$$R(u) = \frac{1}{LF}\sum_{i=1}^{L}\sum_{n=1}^{F} u_i^2(n) \tag{4}$$

As indicated by the primary signal, the channel model, and the noise previously presented, the test statistic $R(u)$ concerning the energy detection using MUA is disseminated as follows:

$$R(u) = \begin{cases} U_{2\eta}^2 & H_o \\ U_{2\eta}^2(2\varsigma) & H_1 \end{cases} \tag{5}$$

where $U_{2\eta}^2$ is considered as central chi-square distribution with 2η degrees of freedom. $U_{2\eta}^2(2\varsigma)$ is considered as noncentral chi-square distribution with 2η degrees of freedom and also a noncentrality parameter of (2ς). ς represents the SNR (signal-to-noise ratio) at the receiver level and is formulated as follows: $\varsigma = \vartheta_s^2/\vartheta_\mu^2$, where ϑ_s^2 represents the power of the PU signal. Referring to the central limit theorem, if F is large enough, the distribution of $R(u)$ can be approximated by the Gaussian distribution as follows:

$$R(u) \begin{cases} F\left(\vartheta_\mu^2, \frac{1}{LF}\vartheta_\mu^4\right) H_0 \\ F\left(\vartheta_s^2 + \vartheta_\mu^2, \frac{1}{LF}\left(\vartheta_s^2 + \vartheta_\mu^2\right)^2\right) H_1 \end{cases} \tag{6}$$

4.2. Noise Uncertainty. When there is not a limited time of detection and ϑ_μ^2 is well identified by the SU, the energy detector has the possibility of simultaneously making any probability of false alarm (Pfa) and the probability of detection (Pd) with any SNR value tested at the SU receptor. But in the practice, these assumptions do not hold for the following reasons. Firstly, the noise changes randomly in communication systems, more precisely when the SU changes its radio environment continuously. Thus, it is not easy to identify with certainty the value of ϑ_{μ}^{2} at a given time. Secondly, the limitation of spectrum detection time is imposed by the requirement of QoS by the upper layers related to the implementation of the system of CRNs.

Suppose that the noise power is included in this interval $[\beta^{-1}\vartheta_{\mu}^{2}, \beta\vartheta_{\mu}^{2}]$, with $\beta = 10^{(\sigma/10)}$, where the factor related to the noise uncertainty is designated by σ and is expressed in dB. In the case where λ is determined by considering that $\beta^{-1}\vartheta_{\mu}^{2}$ is the value of the expected noise power, at this time all the events related to the detection of the spectrum with $\vartheta_{\mu,true}^{2} > \beta^{-1}\vartheta_{\mu}^{2}$ with $\vartheta_{\mu,true}^{2}$, being the real noise power, will give a decision of presence of a signal, i.e., H1 regardless of the actual state of the primary user. With this methodology to define the detection threshold, the Pfa increases with respect to the noise uncertainty, in the light of the fact that the SU will be content to own the channel with greater probability when the noise uncertainty increases. In addition, when λ is defined with $\beta\vartheta_{\mu}^{2}$ as the expected noise power, then the Pd is reduced with the SNR decrease and the noise uncertainty increases. If the SNR value is low, the power of the attenuated PU signal does not give a significant component in the received signal. Therefore, it is not obvious to compensate for the noise fluctuation; in this way SU can pronounce as a busy channel (Ho) because the received power is less than the threshold of detection.

4.3. Noise Estimation Strategy. In wireless communication networks, noise estimation is a real problem. We distinguish several types of noise estimates. Among these different estimates, there are some that require prior knowledge of information commonly called data-assisted noise estimation. This type of noise estimation is not applicable especially when the prior information is not known, as was the case in cognitive radio networks. Therefore, we want to estimate the noise that does not take into account the prior information about the channel state, because this type of noise estimation is adaptable to CRNs.

In this subsection, we describe the estimate of noise in the guard band that focuses on maximum likelihood. The estimator uses the spectral band in the orthogonal frequency-division multiplexing (OFDM) signal guard band. The interference phenomenon is a recurring fact that occurs in the wireless communication system where the carrier frequency of every subband can interfere with others. To cope with this challenge, a guard band is used between the subbands and this can cause an increase in the noise in the guard band.

Ideally, the guard band is composed of noise but in the real fact, the guard band is composed of a fusion of the signal and the noise that migrates towards the spectral grade band. The performance of the estimator may be degraded as a result of spectrum leakage. This estimate requires knowledge of the quantity of the guard band. The proposed estimator is an efficient estimator that can affect the lower limit of the estimation error. Given that the guard band contains the noise spectrum, the estimator directly extracts these noise components. Then, the estimator determines the estimated noise power as it stands.

$$\vartheta_{z}^{2} = \frac{1}{2Q}\sum_{i=1}^{Q}\left|B_{i}\right|^{2} \tag{7}$$

where ϑ_{z}^{2} represents the estimated noise power, Q indicates the number of subcarriers available in the guard band, and B_i indicates the frequency zone of the subcarriers available in the guard band.

5. Performance Parameters

The estimation of the performance of the SD in cooperative mode can be summarized through overhead and cooperation. The cooperative gain gives the opportunity to improve the detection capacity resulting from its implementation. Key performance indicators are the probability of false alarm (P_{fa}) and the probability of detection (P_d), formulated by

$$P_{fa} = P_{r}\left(R\left(u\right) > \lambda; H_{0}\right) = \int_{R}^{\infty} q_{0}\left(u\right) du \tag{8}$$

$$q_{0}\left(u\right) = \left(\frac{u}{\vartheta_{\mu}^{2}}\right)\exp\left[\frac{-u^{2}}{2\vartheta_{\mu}^{2}}\right] \tag{9}$$

$$P_{fa} = \int_{u_t}^{\infty}\left(\frac{u}{\vartheta_{n}^{2}}\right)\exp\left[\frac{-u^{2}}{2\vartheta_{n}^{2}}\right] du = \exp\left[\frac{-u_{t}^{2}}{2\vartheta_{n}^{2}}\right] \tag{10}$$

where $q_0(u)$ represents the probability density function linked to the H_0 hypothesis, R denotes the detection threshold level, ϑ_{μ}^{2} denotes noise signal variance, and u designates the signal at the output of the detector.

$$P_{d} = P_{r}\left(R\left(u\right) > \lambda; H_{1}\right) = \int_{R}^{\infty} q_{1}\left(u\right) du \tag{11}$$

$$q_{1}\left(u\right) = \left(\frac{u}{\vartheta_{\mu}^{2}}\right)\exp\left[\frac{-\left(u^{2}+I^{2}\right)}{2\vartheta_{\mu}^{2}}\right] A_{0}\left(\frac{I_{u}}{\vartheta_{\mu}^{2}}\right) \tag{12}$$

$$P_{d} = \int_{p_1}^{\infty}\left(\frac{u}{\vartheta_{\mu}^{2}}\right)\exp\left[\frac{-\left(u^{2}+I^{2}\right)}{2\vartheta_{\mu}^{2}}\right] A_{0}\left(\frac{I_{u}}{\vartheta_{\mu}^{2}}\right) du \tag{13}$$

where A_0 indicates the Bessel function of the first order, $q_1(u)$ represents the probability density function linked to the H_1 hypothesis, and I_u designates the signal amplitude.

The main goal is to increase P_d through P_{fa}. The evaluation of the performance of different patterns of SD may be achieved by the comparison of P_d to a value of predetermined P_{fa}.

6. Performance Analysis of Data Combination Techniques

This section describes the rules for combining the observations of SUs that are exploited by the detector in order to make decisions regarding the presence or absence of PUs. We use a system of SD with a multiantennas in CRNs. We estimate that there are secondary nodes S, which is comprised of the same detector energy. The signal powers received are independent and identically distributed (IID) between pairs of secondary nodes, focused on a distribution of Nakagami or Rayleigh.

6.1. Hard Combination. In this system, each SU makes a decision whether there is an absence or presence of PU while transmitting in the form of the bit at the level of CC. This technique has an interesting advantage because it uses a limited bandwidth. There are three combination rules which are adopted at the CC level for data combination. These rules are the "OR rule", the "AND rule", and the "MAJORITY rule", which are defined in the following way: (i) OR rule: the band is pronounced accessible only when at least one user alerts that it is not used. (ii) AND rule: the band is pronounced accessible only when all users alert that it is not being used. (iii) MAJORITY rule (S out of Z): it makes the decision if at least S of Z users have detected a PU signal $1 \leq S \leq Z$.

6.2. Quantized Combination. Soft combination rules achieve good performance compared to hard combination rules. Low overhead and degradation of detection performance are recorded in the technique of combining hard decisions. The quantized combination is a lightened hard combining technique that takes into account multibit decisions compared to the hard combining technique that takes into account a 1-bit decision and offers a better compromise between overhead and detection performance. The 2-bit combination system was described in [28] where the author placed particular emphasis on the observed energy region, which is subdivided into four regions, and the observed energy models can be found in one of these regions. Every SU sends their observation data to 2 bits depending on the energy value observed. The threshold is then compared with the weighted sum, as follows: it is the responsibility of the CC to make a decision regarding the state of PU. In [29], the work proposes a quantized 3-bit combination system that gave a good result compared to that of a 2-bit system. The seven thresholds are equivalent to the 3-bit system, each SU signaling 3 bits of data focused on the energy region in which it is located. Quantified combination system performance is shown below:

(1) Bits number impacts: the quantified combination system has a good performance when the number of bits is increased to some extent. By increasing the number of quantization bits, this can result in two opposite effects on detection performance:

  (i) When the number of bits is high this also implies a high quantization level, which could lead to a higher quantization process, in other words, fewer quantization errors and this pleasantly increases the cooperative gain.

  (ii) Unlike the other case, when the number of bits is high the probability of binary error (BEP) created by the R channel could lead to a degradation of detection performance.

(2) Choice of quantization threshold: an appropriate choice of quantization threshold provides a good performance of cooperative SD. The low energy level obtained by a high quantization zone leads to an increase in the probability of false alarm and a high energy level obtained by a low quantization zone leads to an incrementation of the missed detection probability. Therefore, the quantization threshold choice should reduce the probability of missed detection rate and the probability of false alarm rate and increase the probability of detection rate to allow better performance.

6.3. Soft Combination. In the soft combining system, the SUs transmit their detection observations at the CC level without any local processing and the decision is made by combining the observation results at the CC level while using appropriate combination rules.

In the literature, the flexible combination rules applied at the CC level are as follows: maximal ratio combining (MRC), selection combining (SC), and square law combining (SLC).

(1) Performance analysis under AWGN channel: among the three combination rules, the MRC rule performs well than the others but requires information about the state of the channel. Unlike MRC, SLC does not impose channel status information and displays good result compared to SC.

(2) Performance analysis under fading channels: a performance analysis of soft combination systems under different fading channels has been studied in [30]. The performance of MRC is better under the channels such as Rayleigh fading, log-normal shadowing, and Rician fading compared to SC and SLC. It is important to emphasize that the greatest probability of detection is obtained under the Weibull channel for all the rules namely: MRC, SC, and SLC.

7. Mechanism of Operation of New Spectrum Detection Scheme Based on Multiantennas

To make our detection system more efficient and increase the detection capability, we deem it necessary to apply the MUA to the node of each SU. We also assume that the optimal design of the primary system is equipped with MUA, as shown in Figure 3. As the objective is to find the smallest signal level under the noise to allow the secondary nodes to detect the presence of PU, it is, therefore, a question of adapting the antennas to the PU system. In this work, we consider the SD technique with several receiving antennas at the secondary node level and unconditional on the CSI. We also assume that there is the presence of a fading channel and this channel is formulated by this expression:

$$g_i = \beta_i \cdot e^{j\theta t} \tag{14}$$

where g characterizes the response of the channel according to the Rayleigh distribution. β denotes the amplitude. θ indicates the phase and i represents the number of antennas.

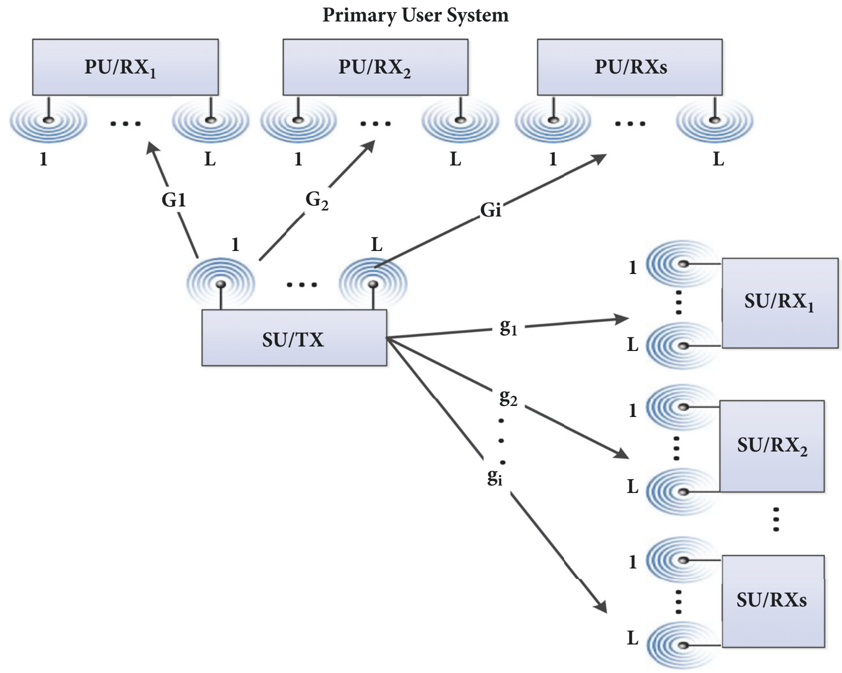

Figure 3: Illustration of antenna design between PU and SU.

In the detection mechanism, we make the combination of the signals of the antenna strands after multiplying by weights equivalent to the conjugate of the channel phase; the expression is formulated by

$$C_i = \frac{g_i^*}{|g_i|} = e^{-j\theta t} \tag{15}$$

Then, the combined signal is applied to the energy detector. In the detection mechanism, we assume that the CSI between the SU receiver and the PU transmitter is known. These multiple antenna channels are autonomous and are assumed to be Rayleigh fading channels. The AWGN with variance ϑ_μ^2 and a zero mean are autonomous in every antenna branch. The PU signal is considered as an independent and identically distributed process with variance ϑ_s^2. To facilitate understanding of the operation of our proposed system, we limit the number of receive antennas to three with the quantization weight also limited to four per receiving antenna. This model antenna uses the signal of the first antenna and is designated as a reference without duplicating any weight whatsoever. Regarding the rest of the antennas, i.e., the third and second antennas, each branch is multiplied by k_i, the number of predefined weights ($k_2 = k_3 = 4$). The weights include variables chosen in a coherent manner, the phase, distributed over the angles from 0 to 2 π. During the simulation, the weights are chosen in two nonidentical ways. The first strategy is to choose the weights fairly. The second strategy is to choose the random weights for the other antennas. This correlation is necessary to analyze the effect using various models of the antennas. However, the results show that both have a similar effect. As a result of the weighting of the antenna strands, we include the first signal with one of the four weighted signals of the second antenna strand plus one of the third weighted antenna strands. This same procedure is repeated for all other weights in the third and the second antenna. Therefore, the mechanism of this operation provides output signals k2∗k3. The derivative of the output signal of this model is designated by the following expression:

$$u_{ij} = u_1 + u_2 \cdot C_i + u_3 \cdot C_j \tag{16}$$

where u_1, u_2, and u_3 denote separately the signal received from the antennas 1, 2, and 3. C_i and C_j indicate the weights of antenna 2 and 3. Then, we operate (16) at the energy detector to acquire the test statistics. From this moment, we proceed to the comparison of output statistical test $|u_{ij}|$ while choosing the most extreme. In other words, to evaluate the noise-plus-signal value and select the maximum of them as it appears in [31]

$$\vartheta_{u_{ij}}^2 = \vartheta_{s_1+s_2'+s_3'}^2 + \vartheta_{\mu_1+\mu_2+\mu_3}^2 \tag{17}$$

The weighted signal is designated by s'. Following the selection procedure, the variance concerning the signal u max is expressed as follows:

$$\max\left(\left|u_{ij}\right|^2\right) = |u|_{\max}^2 \tag{18}$$

The maximum test statistic is then applied to the decision-making phase while making the comparison with the threshold in order to make a possible decision of the presence of PU.

8. Multiuser Diversity

The fundamental idea underlying the medium access control protocol (MAC protocol) is to use the CSI by interrupting the detection of the carrier, whereby the interruption time is considered a reduced function of the state of the channel [32, 33]. Only the sensor presenting the best transmission channel state is guaranteed by this system [34, 35]. The concept of a system of MUD must take into account two key issues, namely, the delay and fairness. In a perfect condition, when statistics about user fading are identical, the MUD has not only allowed increased individual user throughput but also the overall ability of the system. In addition, the CUs who are in the vicinity of the base station has a better SNR. A purely MUD strategy optimizes the average long-term rate of flow, without worrying about the required deadlines.

9. CSMA Using Medium Access Control Protocol

In this part, we discuss the MAC protocol focused on CSMA (carrier sense multiple access) for the SUs who communicate their data at the level of the CC. The MAC protocol suggested here is used to facilitate exchanges between the CUs and the CC during the period of SD. A protocol different from MAC could be used for exchanges between CUs during the period of the hole of the spectrum. Like previously stated, we suppose that there is a control channel dedicated which allows CUs to send information at the level of the CC. In addition, the physical layer that binds the user and the CC is supposed to be perfect. The MAC protocol discussed here is focused on the IEEE 802.11 MAC [36]. For our proposed scheme, the MAC protocol is exploited to allow exchanges between the CUs and the CC. As in our model, we have only one receptor, (i.e., the combination center); therefore it avoids the problem of the invisible terminal.

Every user is empowered to emit only at the beginning of every interval time and the time is subdivided into intervals. Before an SU sends its observation at the level of the CC, it must check the activity of the channel. If the channel is inactive during a given period of time, the SU sends its observation. If the channel is active, the user checks the channel status continuously until it becomes idle during a distributed interframe space interval. In this case, the user creates an interval of random interruption before transmitting so as to avoid a collision.

We choose the exponential system of interruption in the 802.11 standards such that it can be employed with MUD. A random interruption time is produced by the user i which is extracted from the interval $(0, w_i - 1)$ in accordance with a uniform distribution, where the integer number $w_i = WC_2$ is designated as the window of contention (WC) of the user S. After a successful transmission or at the initial transmission attempt, $w_i = WC_1$ if the observation obeys (3). On the contrary, case $w_i = WC_2$. After the failure of each transmission (absence of transmission), w_i is repeated until WC_{max} is reached, where $WC_{max} = WC_1 2^m$ if the observation obeys (3). On the contrary, $CW_{max} = WC_2 2^m$.

Table 1: Parameters representing the value used in the simulation.

Parameter	Value
The number of antennas used	1, 2, 3, 4
The probability of false alarm	0.1
Fixed weight for 4^{th}, 3^{rd}, 2^{nd}	3-3-3
Number of secondary nodes	4
Windows of contention	$WC_1 = 8$, $WC_2 = 64$
m	3
Number of samples (E)	25
SNR	-12dB

If the channel is inactive, the time counter of interruption is decreased, while if the channel is blocked, the time counter of interruption is said to be in the busy state. If the counter indicating the waiting time becomes zero, the observations of the users are sent to the level of the CC, and hence, we select $WC_1 \ll WC_2$. Consequently, users will arrive at the level of the channel with a strong probability and have a timer of random interruption much smaller. Whenever the CC collects data from the Z users, the CC issues the final decision. When the CC receives the data from the Z nodes, the CC transmits an information signal to prevent the transmission of data from the other nodes.

10. Simulation Result

In this section, we evaluate the performance of our proposed scheme. The evaluations are performed using the Matlab software. The main parameters selected for the simulations are listed in Table 1.

Figure 4 illustrates the detection performance when changing the quantization number by weight of each antenna with the OR combination rule based on receiver operating characteristic curves (ROC). The detection mechanism is based on the Rayleigh fading channel. It is noted in the figure that the performance is improved when quantization is adjusted by weight from 2 to 4 and that MUA is used. However, by adjusting to the number of weights greater than 4, we find that the performance of the system is reduced. Therefore, the number of antennas and the quantization weight of the antennas play a very important role in the improvement of SD.

Figure 5 shows the SD performance using the combination rule of maximal ratio combining (MRC). We use 1, 2, 3, and 4 multiple antennas with the same quantization weight of the antennas (C = 2). The detection mechanism is based on the AWGN channel. We find that the systems that use 3 and 4 antennas, respectively, have a better performance compared to the systems using the numbers of the antennas inferior to 3 with the same weights of quantification of the antennas.

Figure 6 characterizes the ROC curves of the SD performance while using the quantized bit number and the quantization threshold as well as the number of antennas used. We note that the 3-bit and 4-bit combination scheme with the presence of MUA (L = 3 and L = 4) offers better

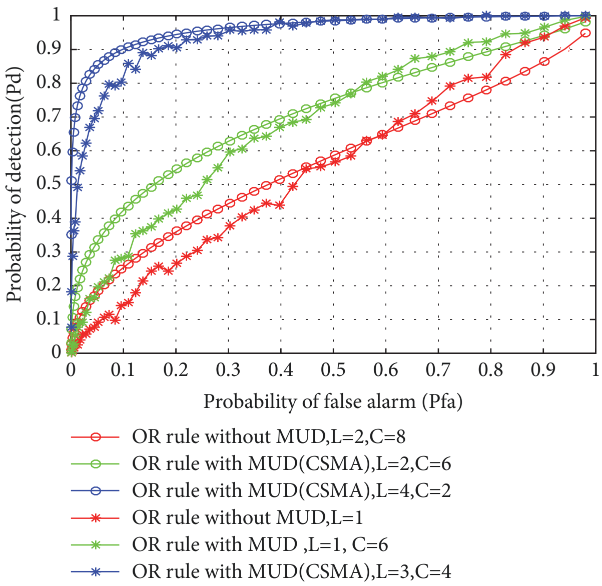

FIGURE 4: Performance of spectrum detection via Pd versus Pfa based on OR rule under Rayleigh fading channel for different antennas number and quantization weight.

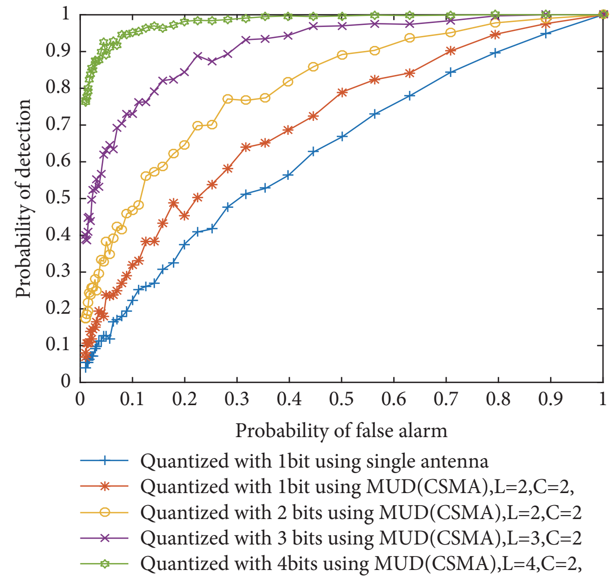

FIGURE 6: Performance of spectrum detection via Pd versus Pfa based on bits number for different antennas number and quantization weight.

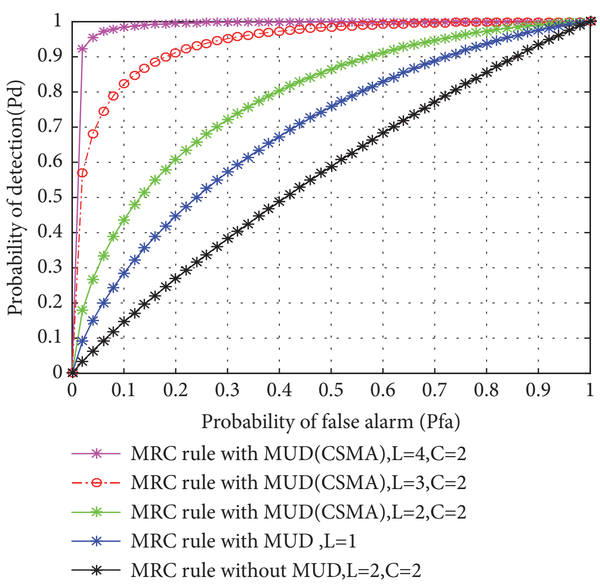

FIGURE 5: Performance of spectrum detection via Pd versus Pfa based on MRC rule under AWGN channel for different antennas number and quantization weight.

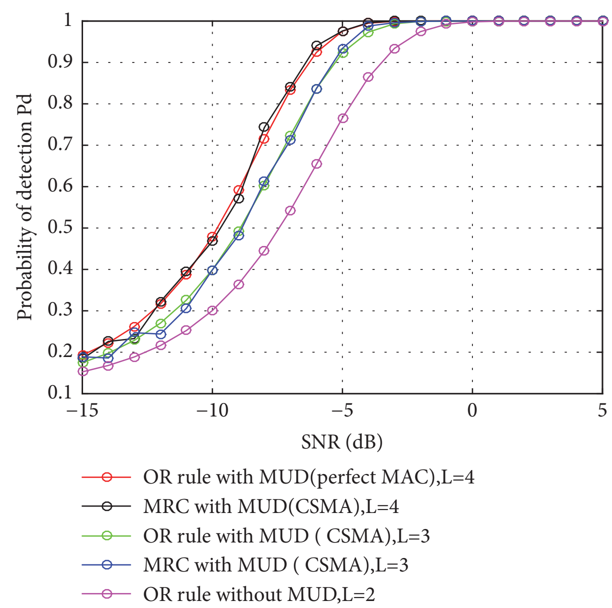

FIGURE 7: Performance of the OR rule and MRC rules for the proposed scheme and the traditional scheme.

performance than the conventional system scheme using the 2-bit combination with less than antennas.

Figure 7 presents the performance comparison between the SD focused on MUD and the classical SD scheme when the OR rule and the MRC rule are used at CC. We note that, in figure 7, the probability of detection of the spectrum based on the MUD has a better yield than that of the detection system of the classical spectrum, particularly when the SNR is low. The rule of hard combination (rule OR) and soft combination (MRC) using the MUD presents the good performance.

Figure 8 shows the performance gain in the detection of quantized rule using MUD compared to the classical SD schemes (i.e., without the MUD). We note that the probability of detection for the quantized rule with 4 bits and with 3 bits using MUD is greater than that of the rule of classical quantized, and the OR rule equally presents a high probability of false alarm at the level of every node. With a low value of SNR, the nodes that know a harsh fading may take bad decisions with regard to the presence of a PU. This could lead to a bad decision at the level of CC.

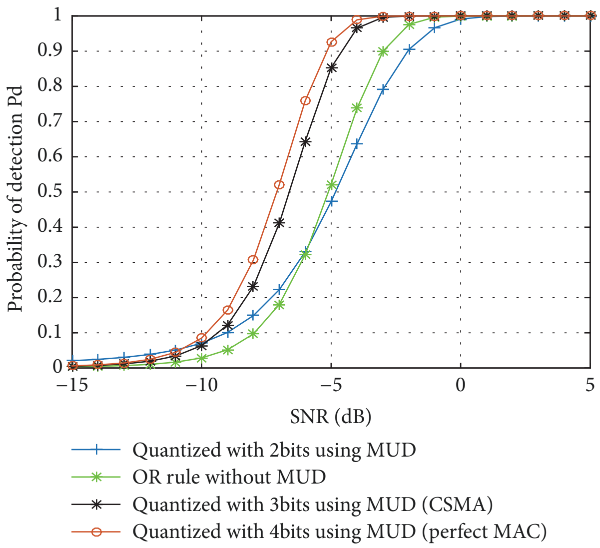

FIGURE 8: Performance of spectrum detection via Pd versus SNR using OR rule and quantized combination with different bits.

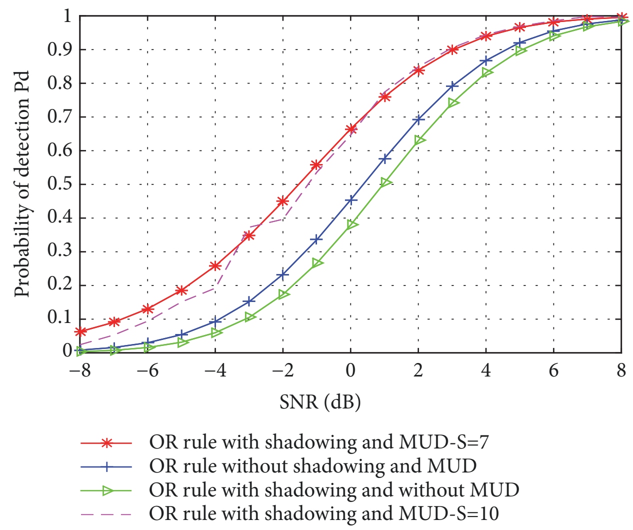

FIGURE 10: Illustration of the performance of the OR rule with MUD compared to the classical detection scheme, with the presence or absence of shadowing.

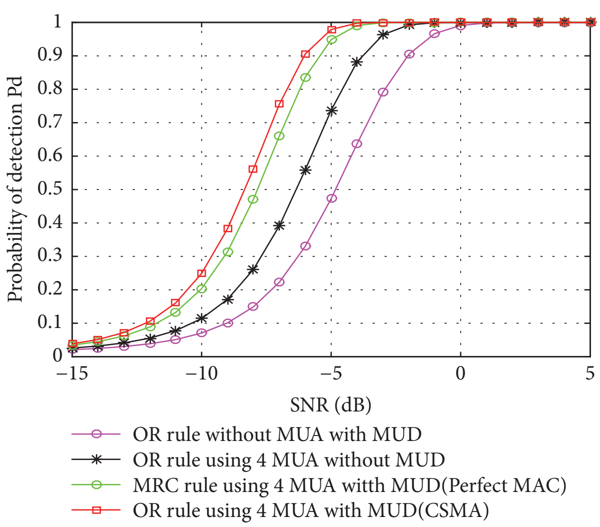

FIGURE 9: Performance of spectrum detection via Pd versus SNR based on different fusion rules with four antennas.

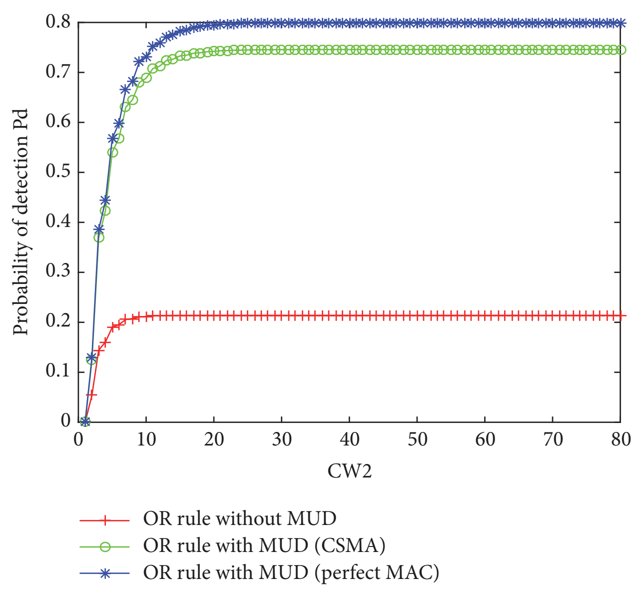

FIGURE 11: Performance comparison of the OR rule with and without MUD under different contention window settings WC2.

Figure 9 compares the performance of CUs using MUA with one using a single antenna. The MRC rule of the soft combination and the OR rule of the hard combination are utilized. Every MUA user is composed of 4 antennas. It is very obvious that the use of MUA has a good performance gain compared to the use of single antennas as shown in Figure 9. Also, it is evident that use of MUD in systems with MUA leads to improved detection performance.

Figure 10 illustrates the performance of our proposed scheme when shading and MUD are present and while using the OR combination rule. We observe in Figure 10 that the SD with the MUD gives the best performance in relation to the SD not using MUD, with the great value of SNR even in the presence of shadowing.

Figure 11 characterizes the performance of SD via Pd versus contention window with a perfect CSMA protocol based on CSMA and the OR rule. It is noted that the rule OR with the MUD linked to the MAC protocol gives a better performance concerning the probability of detection unlike that of the rule OR without MUD which gives a bad performance. It is also noted that when WC2 increases the MAC time also increases.

Figure 12 shows the detection probability obtained when the number of receiving antennas varies from L = 2 to 20. We observe a significant performance only when the numbers of antennas increase (L). The SC rule with contention window gives a good performance when L = 4.

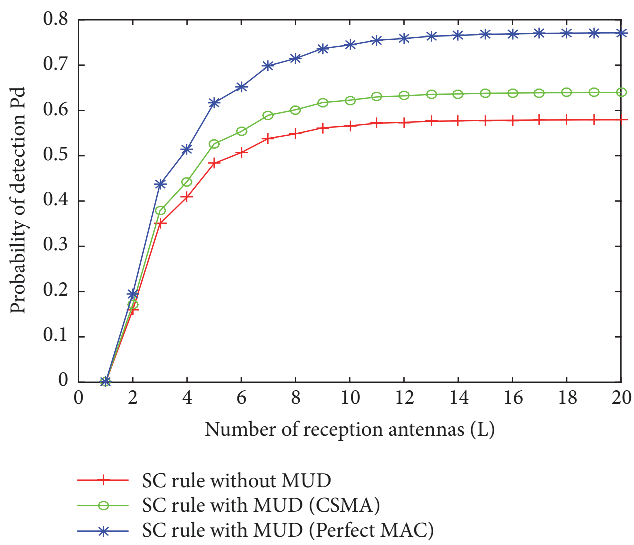

Figure 12: Probability of detection according to the number of receiving antennas for SNR = -12 dB.

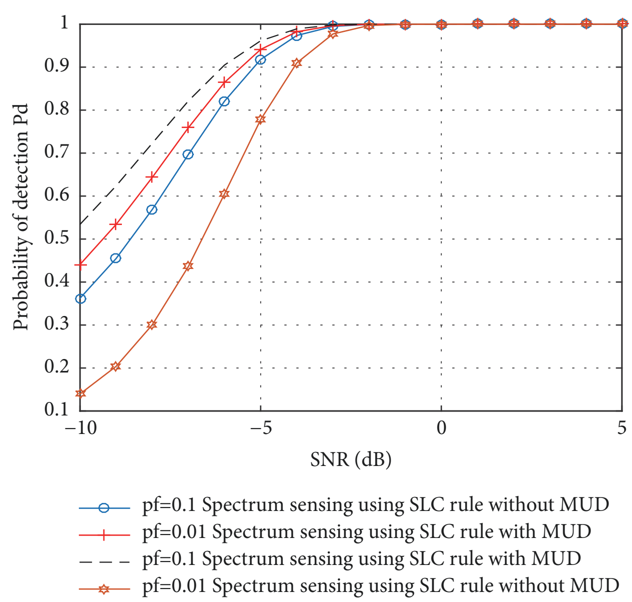

Figure 13: Performance of the SCL rule with the presence of Rayleigh fading, using different values of Pfa values.

Figure 13 gives us the comparison of the performance of the detection scheme with MUD and that of the classical detection the presence of shadowing and Rayleigh fading. The numerical results presented in Figure 13 confirm that the detection scheme with MUD significantly exceeds that of the classical SD. When SNR = -5 dB and P_f = 0.1, the MUD spectrum detection scheme attains probability detection near to 0.97 which is the requirement for the SD of IEEE 802.22 standard, employing solely E = 25 samples. In this condition, the probability of detection for the scheme without MUD is only around 0.7.

11. Conclusions

An effective contribution has been made in this work in the context of SD for CRNs based on the key points of cooperative detection and the different combination methods available. In this article, we evoked a new SD scheme while using new MUA structures. For this proposed system, quantization phases are used for each antenna weight. Our proposal aims to improve the SD capability in regions with low SNR and even when the energy detector operates under conditions of uncertainty. To achieve this goal it is important to improve the probability of detection while keeping the false alarm probability rate low and constant, even when there is the presence of noise uncertainty or low SNR. We described the mechanism of the proposed system and showed how to adapt this technique to energy detection. In this proposal, quantization weights are multiplied by each receiver antenna and consolidate these signals, then the upper maximum output is applied for energy detection. The performance of our schema is analyzed by performing simulations via the Matlab. The numerical results obtained confirm the good performance of our detection scheme. It is important to emphasize that the use of MUA is not only to make SD efficient, but also to facilitate opportunistic access to the spectrum when multiple channels are available.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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