DEVOPS-AN OPEN ACCESS JOURNAL
Open Journal

Review

Improved Sensing Detector for Wireless Regional Area Networks

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Article information
Received: December 31st, 2022; **Revised:** March 25th, 2023; **Accepted:** April 3rd, 2023; **Published:** April 23rd, 2023

Cite this article
Kanti J, Tomar GS. Improved sensing detector for wireless regional area networks. 2023; 2(1). doi: https://doi.org/10.70705/ppp.doaj.2023.v02.i01.pp21-25

ABSTRACT

In wireless communication, noise and fading affect the radio signals. Multiple antennas one of the solutions to nullify these affects. In this paper, authors proposed an improved sensing detector for wireless regional area networks. The presented scheme uses two detectors concept, detectors imply multiple antennas, follows selection combination to select best signals. The proposed model not only improves the detection performance but also decreases the sensing time. Out of the two detectors the first one is energy detector with single adaptive threshold and second one is energy detector with two adaptive thresholds. The thresholds are adaptive as they are dependent on noise variance (σ2), and the value of this noise variance changes according to the noise signal. Both the detectors work simulta- neously and their output is then fed to a decision devise which takes the decision using OR rule. In the proposed scheme more than one antenna has been used and is compared with existing sensing techniques. Results show that the proposed an improved sensing detector technique while number of antennas (Nr) = 2, improves the detection performance by 24.6, 53.4, 37.9, and 49.6%, as compared to existing schemes (i.e. EDT-ASS-2015 scheme, ED and cyclo-2010, adaptive SS-2012, and conventional-ED) scheme at −12 dB SNR respectively. Meanwhile, proposed technique also decreases sensing time in the order of 47.0, 49.0, and 53.2 ms as compared to existing schemes (EDT-ASS-2015, Adaptive SS-2012, and ED and Cyclo-2010) scheme at −20 dB SNR respectively. Further, in cooperative SS the local decisions from each cognitive radio are transferred to a fusion center which makes the final decision and shares the decision to every cognitive radio. It is also found that the proposed detection technique with CSS when number of CR users (k) = 10, and Nr = 2, achieves spectrum detection performance in the order of 0.9 for SNR value of as low as −20 dB.

Keywords
Cognitive radio networks; Single adaptive threshold; Two adaptive thresholds; Two detectors; Cooperative spectrum sensing; Spectrum sensing.

INTRODUCTION

In present scenario, day-by-day technology is growing, and cognitive radio network (5-G technolo- gy) is one of the examples of this. In cognitive radio network (CRN), spectrum sensing plays an im- portant role. There are various techniques have been proposed by researchers to sense licensed signal. Such as in Maleki, Pandharipande and Leus (2010), authors have proposed two-stage spec- trum sensing technique (ED and cyclo-2010) to improve detection performance. This technique car- ried two detectors, first stage consisted energy detector and second stage consisted cyclostationary detector to give better sensing performance, however it was computationally more complex and required longer sensing time. Then, in Ejaz, Hasan, and Kim (2012), authors have proposed adaptive spectrum sensing scheme (adaptive SS-2012). In this scheme, out of two stages only one of the detection stage performed at a time, which was based on the estimated SNR. Presence of cyclosta- tionary detector in Ejaz et al. (2012) made system implementation more complicated. Furthermore, in Sobron, Diniz, Martins, and Velez (2015), authors presented energy detection technique for adap- tive spectrum sensing (EDT-ASS-2015). Here, authors focused on cost-function that depended upon a single parameter which, by itself, contained the aggregate information about the presence or ab- sence of primary users.

In this paper, we optimize detection performance using multiple antennas with two detectors, two detectors ED_SAT and ED_TAT perform sensing operation simultaneously. Thresholds are adap- tive that's why chances of occurring sensing failure problem is negligible (Liu, Hu, & Wang, 2012). The output results of detectors go to decision device (DD) who takes final decision using OR-rule, if the output of DD is 1 shows frequency band is busy (H1), otherwise free (H0). The main difference between this paper and others (Ejaz et al., 2012; Maleki et al., 2010; Sobron et al., 2015) are that none of these techniques focused on spectrum sensing failure (Liu et al., 2012), and fading problem. Adaptive threshold scheme reduces sensing failure

problem while multiple antennas mitigate fad- ing problem.

We further cooperative spectrum sensing scheme with an improved sensing detector (ISD). Here, all the CRs perform local observation by using ISD technique. The local decision will be made and reported to the fusion center (FC) in the form of binary bit i.e. 0 or 1. The FC will make a final decision using hard decision rule. In the proposed model we have used hard decision rule because it has bet- ter detection performance when the number of cooperating CR users is large (Akyildiz, Lo, & Balakrishnan, 2011), and provides slightly better performance at low probability of false alarm (Pf) (Teguig, Scheers, & Le Nir, 2008).

The novelty of this paper that proposed model is using multiple antennas to mitigate fading prob- lem, and detectors are using adaptive thresholds to mitigate sensing failure problem. Final decision makes by DD, simulation results show that the proposed model enhances detection performance at Pf = 0.1, performs well at low SNRs, and reduces sensing time as well.

The rest of the paper is organized as follows: Section 2 presents system description. Section 3 describes proposed system model. Section 4 shows the numerical results and analysis. Finally, Section 5 concludes the paper.

2. System description

There is a mathematical expression to detect the PU signal by using following hypothesis for received signal (Bagwari & Singh, 2012):

In Equation (1), r(n) is signal received by each CR user. x(n) is the PU licensed signal, w(n) is AWGN (additive white gaussian noise) with zero mean i.e. w(n) ~ □ (0, σ 2), σ 2 is noise variance, h is the gain of Rayleigh fading channel. H0 is the null hypothesis, shows the absence of PU and H1 is the alterna- tive hypothesis, shows that PU is present.

3. Proposed system model

3.1. An improved sensing detector

Figure 1 illustrates the proposed system model of an ISD. There are Nr number of antennas are imple- mented at each CR users. N is number of samples transmitted by PU. In Figure 1, Maximal-ratio combining (MRC) scheme is not considered since it has spectrum sensing overhead due to channel estimation. Moreover, a combining scheme based on the sum of the decision statistics of all anten- nas in the CR is not analytically tractable. Therefore, we assume that each CR contains a selection combiner (SC) that outputs the maximum value out of Nr decision statistics calculated for different diversity branches as x = max(x1, x2, x3, ..., xNr). The output of the SC is applied to upper stream and lower stream. In Figure 1, upper stream carries ED with single adaptive threshold, this detector is similar as conventional-ED, except adaptive threshold that's why detector is an advance version of conventional-ED. ED with single adaptive threshold calculates energy (X) of received signal (Bagwari & Singh, 2012) and compares with adaptive threshold (λ1), then generates output (L1) and passes to decision device (DD) in the form of binary bits. If the calculated energy (X) is greater and equal to adaptive threshold (λ1), then the output of detector (L1) is bit 1 else bit 0. Similarly, the lower stream carries ED with two adaptive thresholds (ED_TAT), this detector is different from the upper stream detector because it has two adaptive thresholds. Two adaptive thresholds concept is fruitful to re- duce sensing failure problem (Liu et al., 2012). Now, ED_TAT computes the energy, compares with thresholds (λ2) and produces output (L2). If computed energy is greater and equal to λ2, then the output L2 will be bit 1 else bit 0. The outputs of detectors (ED_SAT and ED_TAT) go to decision device (DD), further, DD adds L1 & L2 using OR-rule operation. According to OR-rule, if the sum of L1 & L2 is greater or equal to 1, shows H1 (channel is busy), else shows H0 (channel is free) as shown in Figure 1.

Suppose, xj(k) is the received signal at jth antenna for kth data stream, sensing channel between PU and CR is assumed to be Rayleigh fading channel, N is total number of samples to be sensed by CR and Nr is number of antennas. Hence, the overall output of a SC as follows:

It is seen from Figure 1 that individual antennas are allocated to cognitive radio. Now we consider that antenna branch which has maximum gain and passes to detectors for further process.

- Probability of detection of an ISD can be defined as:

respectively, PED_SAT and PED_TAT are the probability of false alarm of ED_SAT and ED_TAT detector respectively. Pr is the probability factor that a channel would be reported to ED_SAT and therefore, the probability that a channel would be reported to ED_TAT detector will be (1−Pr). Pr dependents on SNR of the channels to be sensed i.e. if Pr < 0.5 shows channel is very noisy, and Pr ≥ 0.5 shows chan- nel is less noisy or has a good SNR. Hence, the overall probability of false alarm and probability of detection directly depend on Pr. (0 ≤ Pr ≤ 1).

3.1.1. Energy detector with single adaptive threshold (ED_SAT)

Energy detector plays an important role in CRN in order to detect PU signal due to its simplicity and easy to implement (Urkowitz, 1967). Figure 2 shows the internal architecture of ED with single adap- tive threshold (ED_SAT). Here, input PU licensed signal received by square law device, which shows detected signal energy (X) and compared with single adaptive threshold (λ1) to make an output deci- sion to determine whether the PU is present or absent.

3.1.1.1. Expression of single adaptive threshold. The mathematical expression of single adaptive threshold (λ1) can be defined as (Tandra & Sahai, 2008):

where, N is number of samples, Nr is number of antennas, Q-1( ) denotes inverse-gaussian tail prob- ability Q-function, Pf is probability of false alarm, and σ2 is noise variance. Analyze Equation (7), threshold (λ) is directly proportional to noise variance (σ2), noise variance depends on noise signal, and noise signal is random in nature and change w.r.t. time, due to this noise variance (σ2) varies, and then threshold (λ1) also change. Threshold is adaptive in nature, therefore, at every time instant its value changes.

In Equation (9), N is number of samples, Q( ) denotes Gaussian tail

probability Q-function, and λ' is defined as ßf=ß1, where, λ is single adaptive threshold, σ2 is PU signal variance, and σ2 is noise variance.
3.1.1.1.2. Probability of false alarm for ED_SAT detector. The final mathematical expression of prob- ability of false alarm can be de- rived as (Sobron et al., 2015):

3.1.1.1.3. Total error probability for ED_SAT detector. The total error rate is the sum of the probabil- ity of false alarm (Pf) and the probability of missed detection alarm (Pm). Hence, the total er- ror prob- ability rate as follows (Bagwari, Kanti, Tomar, & Samarah, 2015):

3.1.2. Energy detecor with two adaptive thresholds (ED_TAT)
This is a simple kind of a circuit of ED except threshold. In this model we used two adaptive thresholds.

Figure 3 depicts internal model of ED_TAT in which firstly square law device (SLD) receives the sensed PU signal and computes signal energy (Y). Further SLD, there are two parts, in upper part if detect- ed energy values (Y) are greater than or equal to λ22, it generates bit 1, or less than λ21 gener- ates bit 0.

But, if detected energy values (Y) fall between λ21 and λ22 then it consider lower part as follow:

where Y1 is the output values of upper part and Y2 is the output value of lower part. After that values of Y1 and Y2 are added using adder.

Finally, using Equations (13), (15) and (16) the local decision (DD-II) of ED_TAT is expressed as:

Equation (17), equating the resultant value (Z) to threshold (λ2) to maintain overall system prob- ability of false alarm (Pf) 0.1. If Z is greater than or equal to λ2 then signal is present otherwise absent.

3.1.2.1. Two adaptive threshold scheme for spectrum sensing. In CRN, this is very difficult situation for detector to detect correct signal when noise and PU signal overlap to each other as shown in Bagwari and Tomar (2013a). To overcome this problem two adaptive thresholds are the fruitful solu- tion. The area comes under thresh- olds λ21 and λ22, known as confused region (Bagwari & Tomar, 2013a). λ22 is known as upper bound and λ21 is known as lower bound.

In Bagwari and Tomar (2013a), if the energy of received signal lies beyond λ21 or λ22, detector gen- erates bit 0 or bit 1 respectively, whereas, between λ21 and λ22, we divided the confused region into equal quantization level. We further, converted these levels into deci- mals. Now, correlating (Bagwari & Tomar, 2013a) with Figure 3, if X lies beyond λ21 or λ22, upper part of Figure 3 (ED_TAT) shows Y1.

3.1.2.2. Expression of two adaptive threshold. In the proposed double threshold decision, the value of maximum noise variance shows the value of upper threshold λ22 and the value of minimum noise variance shows the value of lower threshold λ21. Hence, the mathematical expression of two adap- tive threshold (λ21 and λ22) can be defined as:

Earlier, we have discussed that threshold is adaptive if it depends on noise variance, in above Equations (21) and (22) thresholds (λ and λ) depend on noise variance σ2. Q−1( ) denotes the inverse Gaussian tail probability Q-function. Assuming that the noise uncertainty in the wireless network environment is defined as [1/ϱσ 2, ϱσ 2], where ϱ is a constant parameter that computes the size of the uncertainty and ϱ > 1.

3.1.2.2.1. Probability of detection for ED_TAT detector. Suppose that ri is the normalized version of received sample r(n), the cumula- tive distribution function (CDF) of the ED_TAT, can be calculated as:

In Equation (23), a is an arbitrary constant, has value two. The ze- ro-mean primary signal r(n) with average power σ2 is independent of the circularly symmetric complex Gaussian noise w (n) with varance σ2, and h denotes the Rayleigh faded channel that is independent of w (n). Hence, |h | is
Rayleigh distributed with variance σ2/2. Thus, the Probability distri- bution function (PDF) of the ED_TAT detector for Hj (where j = 0, 1) is given as:

3.1.2.2.3. Total error probability for ED_TAT detector. The total error rate is the sum of the probabil- ity of false alarm (Pf) and the probability of miss-detection alarm (Pm):

3.1.3. Decision device
This device takes final decision whether PU frequency band is free or not, using OR-rule. The math- ematical expression is given as:

Figure 1 illustrates the working operation of ISD technique. In the given Figure 1, CR receiver sense received signal and perform the re- spective sensing operations using ED_SAT and ED_TAT detectors, and further makes final decision via decision device (DD) that PU band is available or not.

3.2. Cooperative spectrum sensiong with proposed an ISD
CSS technique is used to mitigate shadowing and fading in order to improve sensing performance of both local sensing performance and global sensing performance in a CRN (Bagwari & Tomar, 2013b, 2014; Do & Mark, 2012; Ling-Ling, Jian-Guo, & Cheng-kai, 2011). Here all CRs are using an ISD spec- trum sensing scheme to sense PU signal. Once all CRs have taken the local decision individually, they send their local decisions in the form of binary bit i.e. 0 or 1 to the FC over error free orthogonal chan- nels to take final decision. In Figure 4, let there are k numbers of CRs, all of them transmit local deci- sion Oi to a common single FC.
Finally, FC combines the binary bit decisions of all CRs where each CR have proposed scheme i.e. an ISDs, and makes global decision to show presence or absence of PU signal as follows
In Equation (38), D is the sum of the all local decisions Oi from the CRs. The FC considers a hard decision rule to decide whether PU signal is present or not. The hard decision rule states that a signal is

present only and only if any of the CRs sense a signal. As per the hard decision rule if O is greater or equal to 1, then signal is detected and if O is smaller than 1, then signal is not detected. The mathematical expression can be written as:

Finally, Equation (41) shows the global or final decision of FC. Now, the performance of overall proposed system can be analyzed via PD. Hence, using hard decision rule in CSS, the probability of detection (PD) of the FC can be expressed as follows:

In Equation (43), Pd is the probability of detection of individual CR users, can be calculated using Equation (3).

4. Numerical results and analysis

In our simulations we first evaluate the systems using QPSK modulation scheme and Rayleigh chan- nel. In this section, the proposed ISD scheme is compared with conventional energy detection, energy detection technique for adaptive spectrum sensing-2015 (EDT-ASS-2015) (Sobron et al., 2015), Adaptive spectrum sensing-2012 (Ejaz et al., 2012), ED and cyclostationary-2010 (Maleki et al., 2010), and hierarchical with quantization-2012 detection (Liu et al., 2012). The parameters used for simulation are given in Table 1.

In the following simulation given in Figure 5, we employ an ISD technique for 1,000 numbers of samples, we set the threshold for the system to achieve false alarm probability 0.1. In the simulation environment the value of λ1, λ2, λ21, and λ22 varies at every iteration. But in this case we have chosen
λ1 = 1.25, λ21 = 0.9, λ22 = 1.2 and λ2 = 1.014 as trade-off value.
In simulation environment, there is detection performance comparison between proposed an ISD scheme, EDT-ASS-2015 scheme, ED and cyclo-2010, adaptive SS-2012, and conventional-ED scheme. It can be seen from Figure 5 that when the number of antennas increases, probability of detection also increases. Proposed ISD scheme with number of antennas (Nr) = 3 outperforms Nr = 1, 2, EDT- ASS-2015 scheme, ED and cyclo-2010, adaptive SS-2012, and conventional-ED scheme by 9.0, 4.5, 29.1, 57.9, 42.4, and 54.1% at −12 dB SNR in terms of probability of detection respectively under constraint at probability of false alarm (Pf) = 0.1.

IEEE 802.22 states that if the value of Pf is set at 0.1, the minimum acceptable value required for detection probability is 0.9. It shows that proposed ISD scheme detects PU signal at approximately −12.5 dB SNR.

The spectrum sensing time defines the total time taken by cognitive radio users to detect licensed frequency band. Sensing time can be computed as:

Where, TISD is total time taken by proposed sensing technique for SS. TSC, TED_SAT and TED_TAT are the selection combiner (SC), ED_SAT and ED_TAT detectors SS time respectively. Therefore, the SC sens- ing time can be calculated as:
MSC is the number of samples during the observation interval, B is the channel bandwidth. Now, the ED_SAT sensing time can be calculated as:

S1 is the mean sensing time for each channel, in which MED_SAT is the number of samples during the observation interval, B is the channel bandwidth, C is number of sensed channels and probability factor Pr that a channel would be reported to the ED_SAT. Hence, the detection time of the energy detection is:

Similarly, the ED_TAT detector sensing time can be calculated as:

S2 is the mean sensing time for each channel, in which MED_TAT is the number of samples during the observation interval. (1 − Pr) is the probability factor that a channel would be reported to the ED_TAT detector. Hence, the detection time of ED_TAT detector is:
In Equation (52), M0 indicates the total numbers of samples during the observation interval, and channel bandwidth denoted by C.

Thus, the overall spectrum sensing time is calculated by substituting Equations (45), (48), (50), and (51) in Equation (44) as:

Figure 6 shows the graph of spectrum sensing time versus SNR. The proposed scheme at Nr = 2 re- quires lesser sensing time than the existing schemes. It is observed that there is an inverse relation between SS time and SNR. As SNR increases, sensing time decreases. We have used Equation (54) for potting the graph between sensing time and SNR. The value of parameters used in Equation (54) is defined in Table 1.

Now, at −20 dB SNR, proposed scheme at Nr = 2 requires approximately 46.7 ms while presently existing schemes (EDT-ASS-2015, Adaptive SS-2012, ED and Cyclo-2010) require around 47.0, 49.0, and 53.2 ms sensing time respectively. The SS time is directly related to the numbers of samples received by the CR user. The more sensing time is devoted to detecting, the less sensing time is avail- able for transmissions and hence degrading the CR throughput. This is known as the sensing effi- ciency problem (Lee & Akyildiz, 2008) or the sensing-throughput tradeoff (Liang, Zeng, Peh, & Hoang, 2008) in SS.

Figure 7 shows the graph of probability of detection (Pd) versus SNR between proposed CSS with ISD scheme, CSS-EDT-ASS-2015, and Hierarchical with Quantization-2012 scheme. In CSS we con- sider only three CR users. Simulation results show that Cooperative SS with ISD outperforms EDT- ASS-2015, and Hierarchical with quantization-2012. CSS with ISD improves detection performance around 12.5 and 19.1% as compare to EDT-ASS-2015 and Hierarchical with quantization-2012 at −12 dB SNR respectively. CSS with ISD achieves 0.9 detection probability at −12.5 dB with Nr = 2, while EDT-ASS-2015 and Hierarchical with quantization-2012 detection scheme achieves the same detection probability at −11 and −10.5 dB respectively.

In Figure 8, we have plotted the probability of detection (Pd) versus SNR plots for different number of cooperative CR users k = 3, 4, 5, 6, 7, 8, 9, 10, Pf = 0.1, Nr = 2, and N = 1,000. It can be concluded from Figure 8 that the value of probability of detection increases with increase in the value of SNR for different number of CRs. The probability of detection is maximum for k = 10, it's implies that for

N = 1,000, Nr = 2, and Pf = 0.1, only ten CR users are required for deciding the presence of the PU by using the ISD spectrum sensing scheme. When k = 10, Pf = 0.1 and SNR = −20 dB approximately, the proposed SS model can achieve probability of detection value 0.9, which is the SS requirement of IEEE 802.22 (Cordeiro, Challapali, Birru, & Shankar, 2005).

5. Conclusion

In this paper, an ISD for WRANs has been proposed. This scheme enhances detection performance, reduces bit error rate as well as sensing time. Numerical results show that proposed ISD scheme while Nr = 2 outperforms other existing schemes (i.e. EDT-ASS-2015 scheme, ED and cyclo-2010, adaptive SS-2012, and conventional-ED scheme), by 24.6, 53.4, 37.9, and 49.6% at −12 dB SNR re- spectively. It is also shown that the proposed scheme has lesser sensing time than EDT-ASS-2015, Adaptive SS-2012, and ED and Cyclo-2010 scheme in the order of 47.0, 49.0, and 53.2 ms at −20 dB SNR respectively. ISD has also been implemented with CSS scheme, it further shows that when k = 10, Nr = 2, and Pf = 0.1, proposed detector is able to detect PU licensed signal at −20 dB SNR. Finally, results conclude that the proposed scheme exhibits better performances than existing schemes.

Acknowledgment

The authors wish to thank their parents for supporting and motivating for this work because without their blessings and God's grace this was not possible.

Funding

The authors received no direct funding for this research.

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