

**DEVELOPMENT OF ADAPTIVE SENSING ALGORITHM FOR MINIMIZING
ENERGY AND BANDWIDTH CONSUMPTION IN COOPERATIVE SPECTRUM
SENSING TECHNOLOGY**

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Abstract

Optimized consumption of energy and bandwidth is crucial for efficient utilization of the limited electromagnetic spectrum for telecommunication purposes. Cognitive radio is one of the dynamic spectrum management applications with numerous benefits related to the management of available spectrum. But it has the challenge of high energy and bandwidth usage when the cooperative scheme of spectrum sensing is applied for accurate sensing. In this paper, an adaptive spectrum sensing algorithm is developed to minimize energy and bandwidth consumption in cognitive radio spectrum sensing while ensuring accurate spectrum sensing. The adaptive algorithm was developed based on the signal-to-noise ratio conditions of the channel. Results reveal that the energy and bandwidth usage by the cooperative spectrum sensing can be significantly reduced without negatively affecting the performance and detection of the cognitive radio in varying noisy conditions.

Keywords: Cognitive Radio, Cooperative Spectrum Sensing, Energy and Bandwidth Consumption.

1 INTRODUCTION

The electromagnetic radio spectrum is a limited treasured resource which exists naturally. Utilizing it efficiently for wireless communication has become a huge challenge due to the growth and advancement of wireless systems, services and devices in recent years (Goldsmith, 2005; Kakalou *et al.*, 2018; Riya Paul, Pamoli Nath and Soumyasree Bera, 2018). This growth has increased the energy and bandwidth requirement of these devices and services to ensure optimum connectivity (Gupta, Verma and Dubey, 2016; Wang *et al.*, 2018). Moreover, the conventional spectrum allocation policy does not permit full utilization of the radio spectrum. A dynamic rather than static usage of the spectrum must be encouraged to increase the availability of frequency spectrum (Lee, Kim and Kim, 2012; Sahu, Singh and Nandakumar, 2018). This would aid channel capacity expansion since cell occupancy varies with traffic load. Cognitive radio which applies the concept of dynamic spectrum access is utilized to exploit the spectrum holes in order to ensure more efficient spectrum utilization (Riya Paul, Pamoli Nath and Soumyasree Bera, 2018). Cognitive radios are aware of their surroundings and bandwidth availability and are able to dynamically tune the spectrum usage based on location, nearby radios, time of day and other factors (Goldsmith, 2005).

Transmitter detection techniques (otherwise called single user detection techniques) especially the energy detection technique suffer severely from fading and path loss effects (Lee, Kim and Kim, 2012). This makes it unreliable in low signal to noise ratio conditions (Sahu, Singh and Nandakumar, 2018). It therefore necessitates the inclusion of

more cognitive radios to improve on the sensitivity and accuracy of report (Zou, 2010). This process of including more cognitive radios to improve detection accuracy can be referred to as cooperative spectrum sensing. The cooperative sensing technique was developed to boost the Quality of Service (QoS) of the network and to improve on the results obtained from single user detection techniques. But it has a major challenge of consuming additional energy and bandwidth thereby increasing communication overhead (Sobron *et al.*, 2015; Kakalou *et al.*, 2018).

There is therefore a need for a more efficient and adaptive sensing algorithm that can reduce the overall energy and bandwidth consumption of the cooperative sensing technique to the barest minimum without a negative toll on the performance of the cognitive radio system which is the aim of this research. The objectives worked on to achieve this aim include: simulating and studying the detection performance of the single user and cooperative sensing using an improved energy detection algorithm under varying signal to noise ratios, evaluating the effect of change in probability of false alarm on detection and then making the cooperative sensing adaptive based on the SNR threshold set with respect to the results obtained from the first set of objectives. This is carried out through a supervised mode of learning.

The scope of the work is limited to cooperative spectrum scheme of cognitive radios with focus on energy and bandwidth optimization for improved performance of cognitive radio systems.

2 RELATED WORKS

Tsiaflakisa, Yi, Chiang and Moonen (2007) noted that dynamic spectrum management (DSM) design when initially proposed had mainly been focused on maximization of data rates (Tsiaflakisa *et al.*, 2007). However, reducing the total power had become a main target as IT power consumption has been identified as a significant contributor to global warming (Santhanam and Keller, 2018). In their paper, traditional DSM design was extended towards a much wider power-efficient scope and how to tackle the corresponding optimization problems identified. The technique developed helped to save about 50% power alongside improved data rate performance. Sun (2011) contributed significantly to the energy efficiency of spectrum sensing sharing while ensuring simplicity and robustness using a Multi-rate Asynchronous Sub-Nyquist Sampling System (Sun, 2011). Rognsvåg (2008) worked on the improvements that could be made to the algorithms employed in DSM. Decentralizing the coordination of power to make it more distributed to minimize cost and complexity was a major focus of the research effort (Rognsvåg, 2008). The results showed admirable improvement in the capacity of the system as compared to Static Spectrum Management (SSM). Lee, Kim and Kim (2012) proposed a sensing method which chose between single energy sensing and cooperative energy according to the received signal's Signal to Noise Ratio (SNR) from Primary User (PU). The simulation using conventional energy detection technique produced results which showed that the adaptive spectrum sensing produced efficiency and improvement in cognitive radio systems (Lee, Kim and Kim, 2012).

Some adaptive systems have been developed such as the adaptive random access technique developed by Lee (2015). A heuristic approach was utilized to improve the sensing data collection. This along with another adaptive system proposed by Sobron *et al.* (2015) focused on detection sensitivity, not focus on the energy and bandwidth consumption. Gupta, Verma and Dubey (2016) employed an adaptive threshold for each CR in cooperative spectrum sensing scheme based on the Neyman Pearson theorem (Huber and Strassen, 1973; Yan and

Blum, 2001). Rauniyar and Shin(2018) also utilized an adaptive threshold for each cognitive radio in the cooperative sensing. These produced better performances for the cooperative spectrum sensing, but was placed more computational demand on each cognitive radio before the collation of information at the fusion point. Salahdine *et al.*(2016) also utilized a dynamic threshold for detection but used matched filters which require prior information of the PU signals with more complexity. A recent survey of sensing algorithms for cognitive radio networks (Kakalou *et al.*, 2018)revealed that the majority of the sensing algorithms employed in research are energy based sensing algorithms due to the low implementation complexity and the fact that they do not require prior information of the PU signals. However, there is still a need for adaptively aimed reducing energy and bandwidth consumption specifically when cooperative spectrum sensing is utilized. This is the need which this paper addresses. It proposes a method to minimize the energy and bandwidth consumption at the fusion point during cooperative sensing while making consideration for low SNR conditions.

3 METHODS

3.1 Proposed Model

The adaptive spectrum sensing algorithm is proposed to solve the problem of increased energy and bandwidth consumption by the multiple cognitive radios in cooperative spectrum sensing. The algorithm is meant to be adaptive based on the secondary user's SNR status. If the secondary user has sufficient SNR to detect reliably, single user sensing is employed. Otherwise, cooperative sensing is utilized. This is done using a supervised mode of learning to ensure that the communication overhead is reduced considerably.

Each of the cognitive radios employed in the adaptive sensing algorithm utilizes the improved energy detection technique introduced by(Lopez-Benitez and Casadevall F., 2012). This ensures higher sensitivity in the single user and cooperative sensing algorithms compared to the conventional sensing schemes.

The adaptive spectrum sensing works with two hypotheses: H_1 (signal plus noise hypothesis) and H_0 (noise only hypothesis) to indicate the presence and absence of the primary user respectively. If an H_1 cell is beingtested, the probability density function (PDF) of the received signal $y_c(k)^i$ at the i^{th} CR user can be expressed as used in Lee *et al.*, (2012):

$$f_{Y_F}(y|H_1) = \frac{1}{\sqrt{2\pi M \sigma_F^2}} e^{-\frac{(y - \bar{S}_F)^2}{2}} \quad (1)$$

where

$$\bar{S}_F = \sum_{i=1}^M \bar{S}_F^i \quad (2)$$

$\bar{S}_F^i$ = mean value of the transmitted signal from the i^{th} CR user.

$\bar{S}_C$ = mean magnitude value of the transmitted signal at the primary user.

And if a H_0 cell is being tested, then the PDF of $y_c(k)^i$ can be expressed as:

$$f_{Y_F}(y|H_0) = \frac{1}{\sqrt{2\pi M \sigma_F^2}} e^{-\frac{y^2}{2}} \quad (3)$$

After each CR user determines whether there is the primary user or not, the results are retransmitted to the fusion center over wireless channel. Then, the fusion center makes the final decision by combining the received signals from M CR users. When the H_1 and H_0 cells are being tested, the PDFs of the combined result $y_F(k)$ at the fusion center are expressed in line with Lee *et al.*(2012)in equation (1) and in equation (4) as follows:

$$f_{Y_F}(y|H_0) = \frac{1}{\sqrt{2\pi M \sigma_F^2}} e^{-\frac{y^2}{2}} \quad (4)$$

The detection probability for a given value of the decision threshold is defined as the probability of the event that the output decision variable corresponding to the H_1 cell exceeds the decision threshold, which can be obtained as:

$$P_D = \int_{\gamma}^{\infty} f_{Y_F}(y|H_1) dy \quad (5)$$

$$P_D = \int_{\gamma}^{\infty} \frac{1}{\sqrt{2\pi M\sigma_F^2}} e^{-\frac{(y-\bar{S}_F)^2}{2}} dy \quad (6)$$

where

P_D represents the detection probability of the H_1 cell.

Let

$$z = \frac{y-\bar{S}_F}{M\sigma_F^2} \quad (7)$$

Then the detection probability can be expressed as:

$$P_D = \int_{\frac{\gamma-\bar{S}_F}{M\sigma_F^2}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} dz \quad (8)$$

$$P_D = Q\left(\frac{\gamma-\bar{S}_F}{M\sigma_F^2}\right) \quad (9)$$

where

$Q(\cdot)$ denotes Q function.

Since the transmitted signal of primary user is random signal, the improved energy detection technique is utilized. Various techniques such as Equal Gain Combining (EGC), Maximum Ration Combining (MRC), Selective Combining (SC) and many more could be used to combine the signal from multiple antennas. In EGC, each signal branch weighted the same factor irrespective of the signal amplitude. EGC is simpler to implement than MRC and channel amplitude estimation is unnecessary. In this work each local sensing result is combining employing EGC due to the advantage of using the same factor in combining for each cognitive radio.

3.2 Algorithm for Adaptive Cooperative Spectrum Sensing

An improved energy detection (IED) algorithm (Lopez-Benitez and Casadevall F., 2012; Olatunji, Fajemilehin and Opadiji, 2019) is utilized for each of the cognitive radios in the cooperative sensing scheme. The adaptive mechanism is then implemented based on the SNR status of the channel. The procedural flow for this mechanism is illustrated in Figure 1. It should be noted that the procedure for the simulation of the IED is similar to the Conventional Energy Detection (CED), except that an additional check of the immediate past sensing event ($T_{i-1}(y_{i-1})$) asides just the immediate signal energy check and the check for the average energy of the former sensing episodes ($T_i^{avg}(T_i)$) is included.

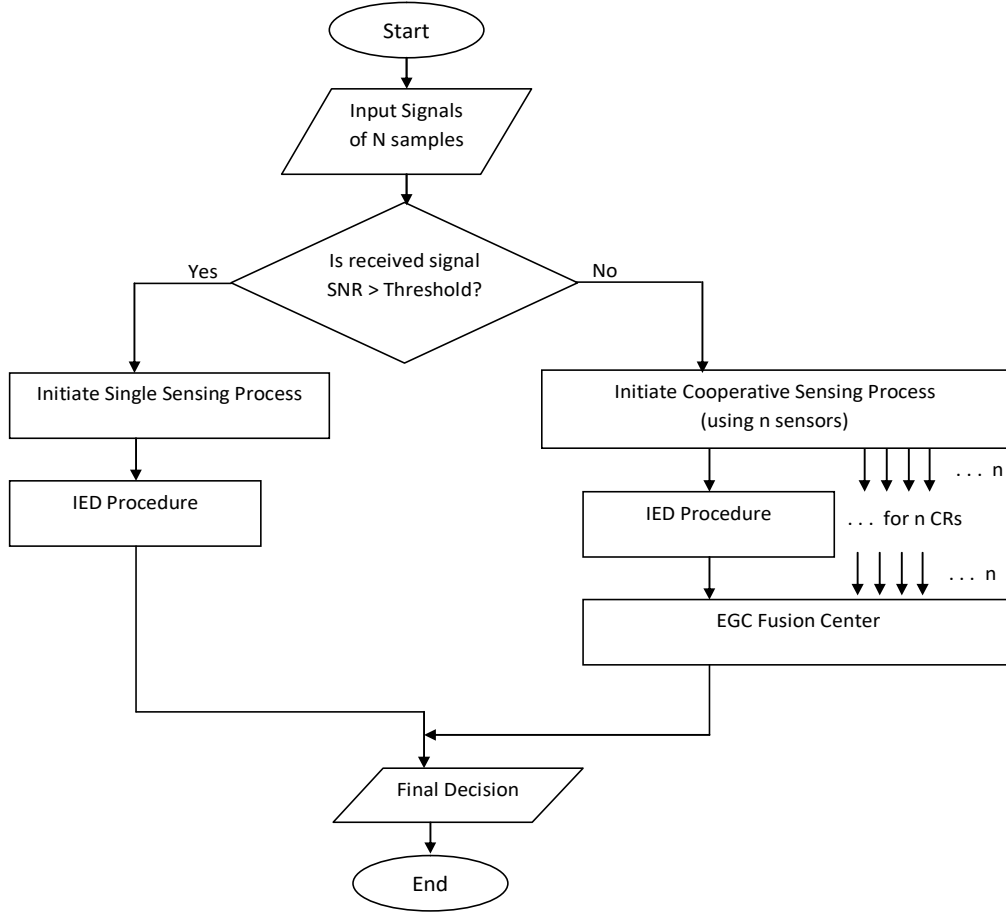


Figure 1: Flowchart for Adaptive Spectrum Sensing

The objective of the paper is to cut down on the energy and bandwidth consumed by the several cognitive radios introduced to achieve cooperative spectrum sensing. The approach suggested to achieve this has been discussed earlier which entails making the number of cognitive radios employed for sensing adaptive based on the Signal to Noise Ratio (SNR). Therefore, when the SNR is poor, several cognitive radios are utilized to ensure accurate sensing, else just one cognitive radio is utilized for sensing the simulation was first done with one cognitive radio using the IED procedure to observe the performance under varying SNR conditions. The number is then increased to two and then five and later ten to observe the performance of cooperative sensing using IED scheme under varying SNR conditions.

4 SIMULATION AND RESULTS

Simulations were carried out using MATLAB (R2017a) with a total of ten (10) cognitive radios employed to simulate the cooperative spectrum sensing technique. The results obtained are presented in Figures 2 and 3.

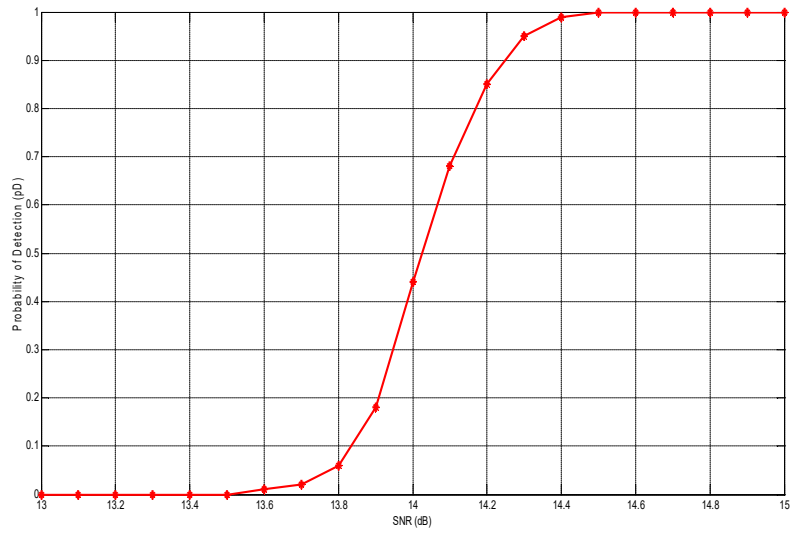


Figure2: Spectrum Sensing using IED Scheme with a Single CR

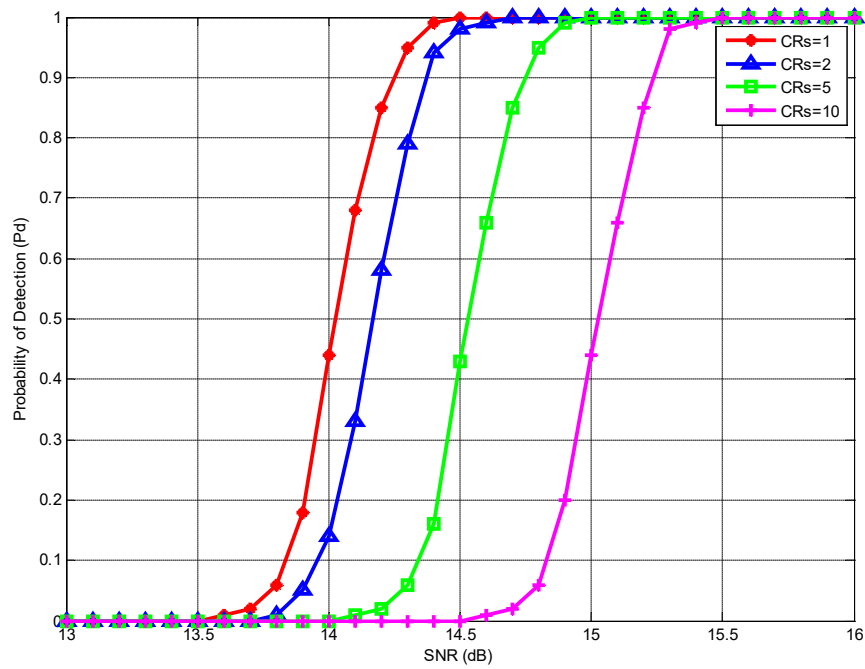


Figure3: Performance of Cooperative Sensing using IED Scheme

It should also be noted that these performance simulations were performed with the probability of false alarm (P_{fa}) fixed at 5%. But changing this value has effect on the detection probability values. The result shown in Figure 4 reflects the effect of change in the probability of false alarm on the detection probability.

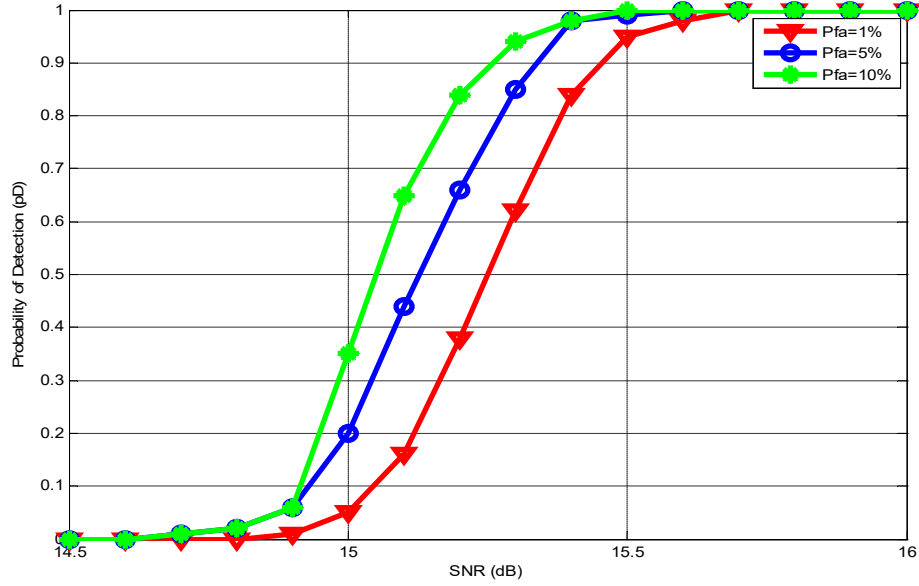


Figure4:Cooperative Sensing using IED Scheme with various Pfa

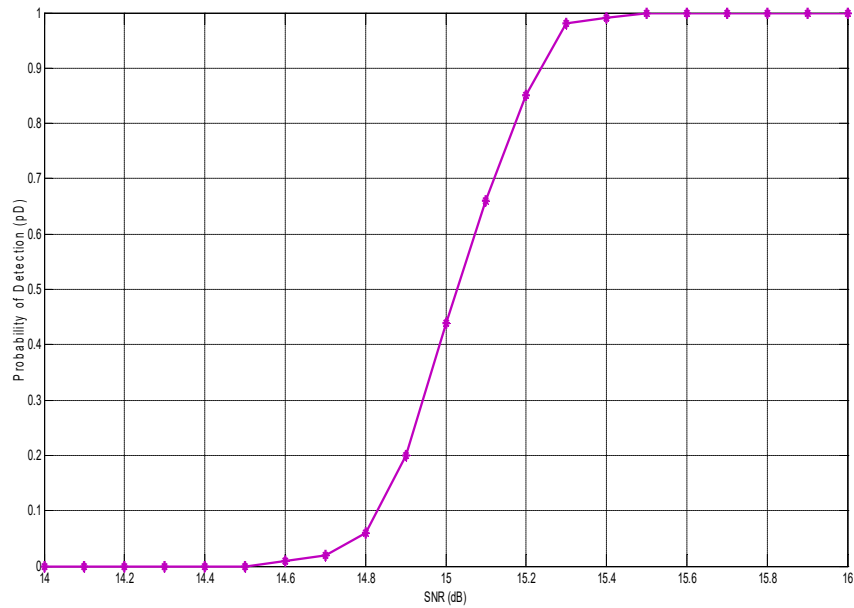


Figure 5:Adaptive Cooperative Sensing using Single and Multiple CRs

The result for the adaptive spectrum sensing algorithm to cut down on energy and bandwidth consumption is presented in Figure 5.

5 DISCUSSION

5.1 Performance of the Cooperative IED under varying SNR conditions

The result presented in figure 2 shows the performance of the IED scheme when only one cognitive radio is employed in sensing. The scenario represents a very noisy environment where the noise level has been raised. Yet it is still observed from the result that detections

begin from about 13.6dB and increases rapidly to maximum detection probability within a range of about 1dB. This validates the sensitivity of the IED scheme.

Furthermore, the performance improves as the number of cognitive radios used in sensing is increased to ten as seen in figure 3. The result compares the performance of cooperative sensing with single user sensing working with the IED algorithm. The result validates the fact that multiple sensors give a more accurate result since the individual reports of each of the cognitive radios are collated before the final decision is taken. Hence, cooperative sensing done with a greater number of cognitive radios had truer detections than those with a smaller number of cognitive radios. This therefore means that some of the detections observed between 13.6dB and 14.5dB could have been false alarms. This is confirmed from the result using ten cognitive radios where the true detections began at 14.5dB. This therefore implies that the higher the number of cognitive radios employed in sensing, the better and more accurate the detection result.

5.2 Effect of change in Probability of False Alarm (PFA) on Detection

The result presented above in figure 4 reveals the effect of changing the probability of false alarm. The simulation was done for ten cognitive radios equipped with IED algorithm. The result shows detections starting from 14.6dB when the probability of false alarm is set to 1% which is about the same point where detections begin when it is set to 5%. But detections did not commence until about 14.8dB when the probability of false alarm is increased to 10%. It is also observed that detections when Pfa is 1% rise higher and at a faster pace than the higher values of Pfa which is expected and logical. This therefore confirms the fact that the higher the probability of false alarm, the lower the detection probability.

5.3 Performance of the Cognitive Radios using the Adaptive Algorithm

The result in figure 4 reveals that the detection using a single cognitive radio commences before that of cooperative spectrum sensing. This is understandable, bearing in mind that the detection done by a single sensor may be infiltrated with missed detections and false alarms. But the same detection was obtained for both schemes at about 15.5dB. Therefore, the adaptive cooperative spectrum sensing result shown in figure 4 is developed such that when the SNR was poor (<15dB), cooperative sensing is employed. Then when the SNR improved, a single cognitive radio is used. This gave accurate detections as shown in figure 5 while reducing the energy and bandwidth consumption by about 31% as seen in figure 6.

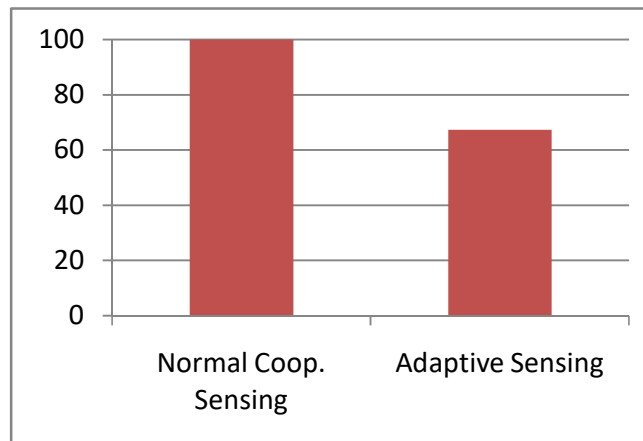


Figure6:Comparison of Percentage Energy and Bandwidth Consumption for Conventional and Adaptive Cooperative Sensing

6 CONCLUSION

The adaptive cooperative spectrum sensing developed using supervised learning helped set a threshold which is adaptive to the noise level. At this threshold, both cooperative and uncooperative spectrum sensing perform efficiently. The adaptive scheme activated the single sensing technique when the SNR condition was above this threshold. When the channel SNR conditions were equal to or lower than this threshold, cooperative sensing was activated. This cut the energy and bandwidth requirement by about 31%. The results show considerable conservation of resources for further needs in the network. Only in poor SNR scenarios would full cooperative sensing be employed. This adaptive technique employed IED algorithm for the individual cognitive radios in the cooperative sensing scheme which ensured accurate spectrum sensing sensitivity. The adaptive cooperative spectrum technique developed proved to be energy and bandwidth efficient after testing. Future work would explore evaluating this adaptive scheme in other forms of fading channels such as Rayleigh and Nakagami with varying signal conditions. The outcome of this present research suggests, that the developed adaptive cooperative technique will be effective in such channels as well.

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