Cyclostationary Feature Detection in Cognitive Radio for Ultra-Wideband Communication Using Cooperative Spectrum Sensing

Aparna P. S. and M. Jayasheela

***Abstract*—Almost 80 to 90 percent of the radio spectrum is left unutilized at any period of time, while at the same time some other regions of spectrum experience overcrowding. A cognitive radio is a smart radio that can identify the idle frequencies (also termed as spectral holes or white spaces) and allot them for the use of unlicensed secondary users. The basic functionality of a cognitive radio is to sense the spectrum accurately by avoiding any chances for interfering with primary or licensed users. Spectrum sensing can be performed either in cooperative or non-cooperative method. This paper, performs cooperative spectrum sensing, using the amplify and forward based relay technique. The idea is to utilize relay nodes to convey the signal transmitted from primary user to the fusion center and then estimate the presence or absence of primary activities in the spectrum. The cyclostationary feature detection is the spectrum sensing method used here. Bit error rates for the UWB channel models (CM1/CM2/CM3/CM4) are calculated and compared.**

***Index Terms*—Cognitive radio, cooperative spectrum sensing, cyclostationary feature detection, ultra-wideband (UWB) communications.**

I. Introduction

Cognitive radio is a novel approach for improving the utilization of one of the precious natural resource, the radio spectrum. The idea was first conceived by Joseph Mitola III. The cognitive radio (CR) can be considered as another type of software-defined radio. CR can be termed as an intelligent wireless communication system. It is intelligent because it is aware of its environment and learns from the environment and adapt to any statistical variations in the input stimuli. In doing so, the two primary objectives to be kept in mind are highly reliable communication whenever and wherever needed and an efficient utilization of the radio spectrum. The cognitive radio achieves these by the spectrum sensing methodology where a region of the spectrum is being sensed to detect whether it is already occupied or not. If it is found idle, it is temporarily used by the cognitive user (secondary user) to transmit its own signals before the licensed primary user returns.

Cooperative spectrum sensing is a more reliable method where multiple cognitive radio users share their decisions to form a common global decision, regarding the occupancy of the spectrum [1].

A global decision is more accurate since it avoids chances for multipath fading, shadowing etc. This paper deals with the cyclostationary based cooperative spectrum sensing method.

This paper is organized as follows. Section II discusses about the related works. Section III deals with cooperative spectrum sensing, its various types and the rules to be followed in the process of decision making. Section IV deals with cyclostationary feature detection method. Section V explains the UWB based cognitive radio while section VI gives the proposed system model. Simulation results are explained and discussed in the section VII where ROC and complementary ROC curves are plotted for different number of relays and for different values of SNR. Also the performances of different channel models of UWB are compared and discussed. Finally, the section VIII presents the conclusions derived and ends with some practical applications of the proposed system.

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II. Related Works

Reference [2] focus on a cognitive radio approach which is based on a non cooperative spectrum-sensing technique that is suitable for applications in detection and avoidance schemes (DAA) to allow coexistence between ultra wideband multiband and Worldwide Interoperability for Microwave Access systems. This would improve the spectral efficiency. The cyclostationary property of WiMAX signals due to the cyclic prefix is exploited. To ensure the coexistence between UWB–MB and WiMAX technologies using a DAA scheme, [2] has proposed a non-cooperative spectrum-sensing algorithm. Non cooperative spectrum-sensing technique has various problems like shadowing, multi path fading, hidden node problem etc [3], [4]. Cooperative detection is proposed instead. Cooperative behavior helps to overcome all the earlier cited disadvantages of non cooperative spectrum-sensing and will improve its agility and usability [5].

In [6], the cooperative spectrum sensing is performed. The sensing technique involved is energy detection. The detection results of multiple cognitive radios are combined to a global result with high reliability. So as to transmit the local decisions a signalling channel is required.

Reference [7] uses the energy detection method under two fusion strategies, data fusion and decision fusion. The results are extended to a multi-hop network. Analysis is validated by numerical and simulation results. The energy detection method has poor performance under low SNR

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values. In such times, it fails to distinguish between the noise and primary user signal and such an estimation error may degrade detection performance. In [7], the cyclostationary feature detection is proposed instead of energy detection which performs better because of its noise rejection ability. This is because noise is totally random and does not exhibit any sort of periodic behaviour. When there is no prior knowledge about primary user's waveform the best technique for sensing the spectrum is cyclostationary feature detection.

III. Cooperative Spectrum Sensing

Cooperative spectrum sensing can be done in many ways. These include centralized, distributed and relay-assisted methods [3]. In centralized cooperative sensing, a central node called fusion center (FC) controls the three-step process of cooperative sensing. First, the FC selects a channel or a frequency band for sensing and instructs all cooperating CR users to individually perform local sensing. Second, all cooperating CR users report their local sensing results to the FC via the control channel. Third and final, the FC combines the received local sensing information and determines the presence of PUs.

The distributed cooperative sensing does not rely on any FC for making the cooperative decision. In this the CR users communicate among themselves and converge to a common decision on the presence or absence of PUs. Based on a distributed algorithm, each CR user sends its own sensed data to all other users, combines its data with the received sensing data, and decides whether or not the PU is present by using some local criterion. If the criterion is not satisfied, then CR users send their combined results to other users and repeat this process until the algorithm is converged and a final common decision is reached. In this manner, this distributed scheme may take several iterations to reach a common agreeable unanimous decision.

The sensing channel and report channel may not be perfect in real case. In relay-assisted cooperative sensing, a CR user observing a weak sensing channel and a strong report channel and another CR user with a strong sensing channel and a weak report channel will complement and cooperate with each other to improve the performance of cooperative sensing.

The local decisions made by each individual CR users are fused to form a global decision. Decision fusion can be done by various soft, quantized soft or hard combining rules. Here we use the hard decision fusion in which the one bit local decision is send to the fusion center. Commonly used hard combining fusion rules are AND, OR and majority rules. Here AND rule is used as the fusion rule. The hard combining rule has an advantage that it requires much less control channel bandwidth when compared to the soft combining rules.

IV. Cyclostationary Feature Detection

Cyclostationary spectrum sensing method is the proposed method for spectrum sensing. This method deals with the inherent cyclostationary properties or features of a signal [2], [3], [4]. Such features with periodic statistics and spectral correlation are not found in any stationary noise or interference signals. Hence the proposed method possesses high noise immunity. In this method, cyclic spectral correlation function (SCF) is used for detecting signals present in a given frequency (f) and the cyclic SCF, (S_{yy}^{x}) of a received signal can be calculated as follows.

$$S_{yy}^{x} = \sum_{\tau-8}^{\infty} R_{yy}^{x}(\tau) e^{-j2\pi f} \qquad (1)$$

Here $R_{yy}^{x}(\tau)$ is the cyclic autocorrelation function and α is the cyclic frequency [4]. When the parameter $\alpha = 0$ the cyclic spectral correlation function, SCF becomes power spectral density. When the signal is present in the given frequency spectrum, the method gives the peak in cyclic SCF implying that the primary user is present. If there is no such peak, the method implies that the given spectrum band is idle or there is no primary user active at given time and location [8]. Based on this observation, CR users identify the status of absence or presence of primary users in the particular band in a given time and location.

V. UWB Based Cognitive Radio

Some of the features of UWB satisfy the basic requirements of a cognitive radio. These include negligible interference, dynamic spectrum, sensing capability, multiple access and security [9]. The modulation schemes involved are DS-PPM and TH-PPM of which the TH-PPM is used in this paper.

To reduce interference of UWB using a Cognitive Radio, consider the two chances for interference: either between the primary user and a cognitive relay or the mutual interference between two adjacent cognitive relays. As per the FCC's spectral mask, even though there exists any free band within same spectrum, UWB is advised to avoid using that band [10].

VI. Proposed System Model

The system model is illustrated in Fig. 1. Some random input is taken and TH-PPM modulated. This modulated signal is used as the primary user signal. The signal from primary user is relayed by multiple cognitive relays and the data from each relay unit is send to the fusion center. The relaying method involved is amplifying and forward. At the fusion center, any of the majority combining rules, AND, OR rules [11] etc can be used. This paper focuses on the results obtained using AND rule for data fusion.

After the transmission through the UWB channel (CM1/CM2/CM3/CM4), the fused data reaches the cyclostationary feature detector section. This section involves finding the fast Fourier transform, correlation, averaging and feature detection. Finally TH-PPM UWB demodulation is performed and obtained the bit error rate (BER) measurement. The TH-PPM modulator as well as the modulator is attached to a UWB pulse generator. The resulting BER is compared with the BER that is obtained while using AWGN as the channel.

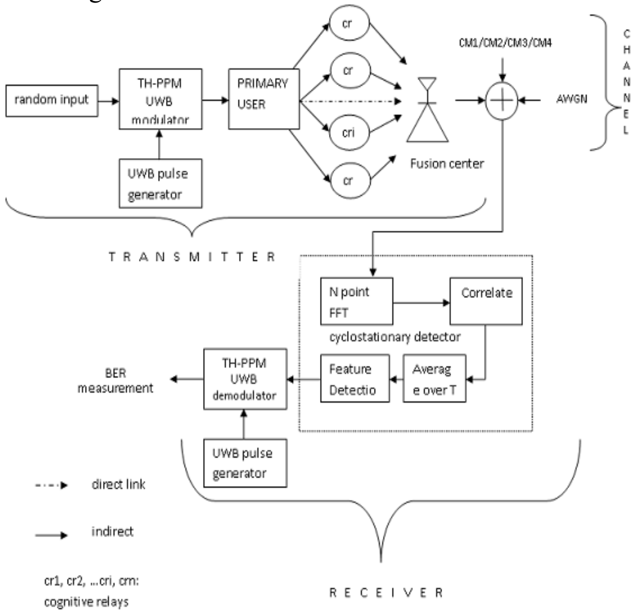

Fig. 1. Block diagram

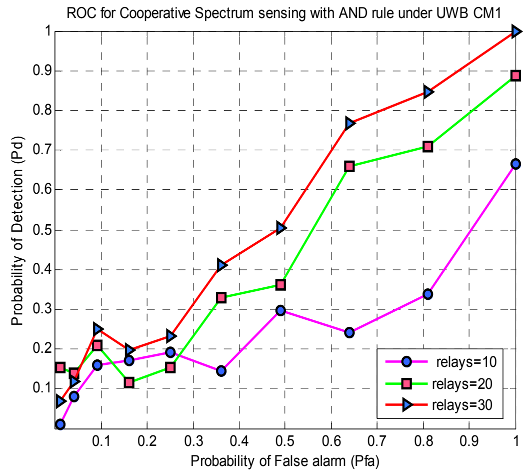

Fig. 2. ROC for different number of cognitive relays

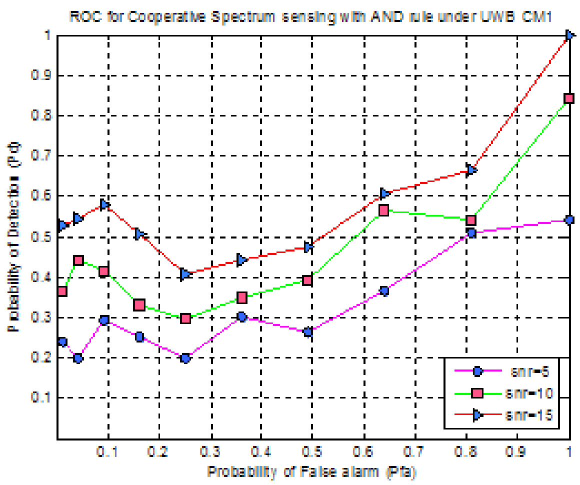

Fig. 3. ROC for different values of SNR

VII. Simulation Results & Discussions

The plot between probability of detection and probability of false alarm is termed as the receiver operating characteristics (ROC) [12]. ROC is the probability of the sensing algorithm (here the sensing algorithm is cyclostationary feature detection method) claiming that the primary signal is present. Thus the probability of detection (P_d) increases with increasing value of probability of false alarm (P_{fa}). Also probability of missed detection (P_{md}) decreases with increasing value of probability of false alarm (P_{fa}). Cooperative spectrum sensing is performed here by using 10, 20 and 30 cognitive relays. Relation of P_d with signal to noise ratio (SNR) is also investigated. SNR values considered here are 5, 10 and 15.

Fig. 2, Fig. 3 gives the ROC while Fig. 4, Fig. 5 gives the complementary ROC. In Fig. 2, corresponding to P_{fa} =0.5, the P_d value is 0.3 for 10 relays, 0.37 for 20 relays and 0.5 for 30 relays. Hence it can be concluded that P_d increases with increasing number of relays. In Fig. 3, for P_{fa} =0.5, the P_d value is 0.28 for SNR=5, 0.4 for SNR=10 and 0.48 for SNR=15. This shows that P_d increases with increasing SNR values.

In Fig. 4, corresponding to P_{fa} =0.5, the P_{md} value is 0.7 for 10 relays, 0.64 for 20 relays and 0.5 for 30 relays. Hence it can be concluded that P_{md} decreases with increasing number of relays. This means if more cognitive relays are used for the purpose of sensing the spectrum, then there is less chance for any missed detection.

In Fig. 5, for P_{fa} =0.5, the P_{md} value is 0.72 for SNR=5, 0.6 for SNR=10 and 0.52 for SNR=15. This shows that, P_{md} decreases with increasing SNR value.

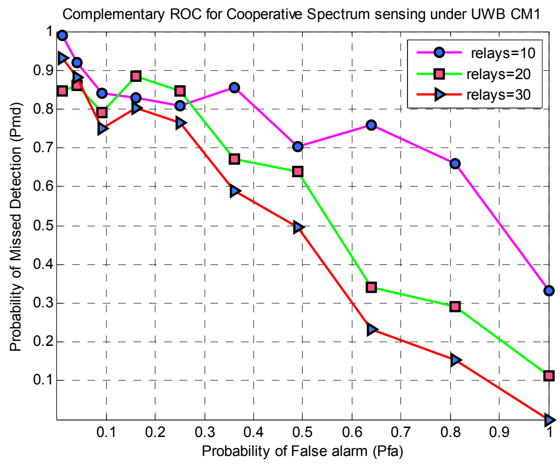

Fig. 4. Complementary ROC for different number of cognitive relays.

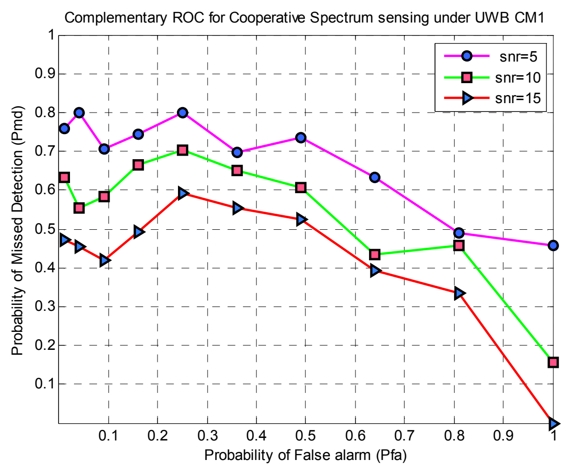

Fig. 5. Complementary ROC for different values of SNR

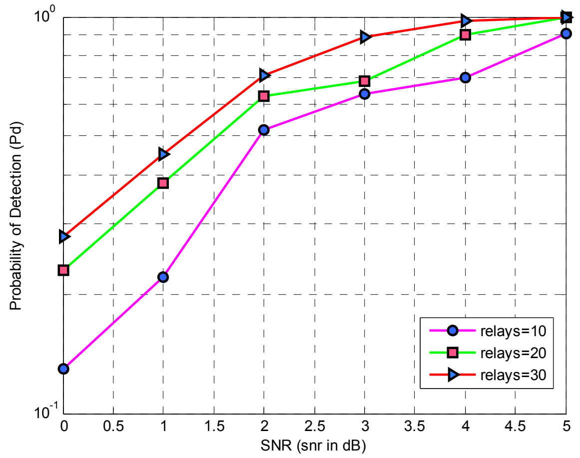

Fig. 6. Plot of SNR against P_d for 10, 20 and 30 relays with $P_{fa} = 0.1$

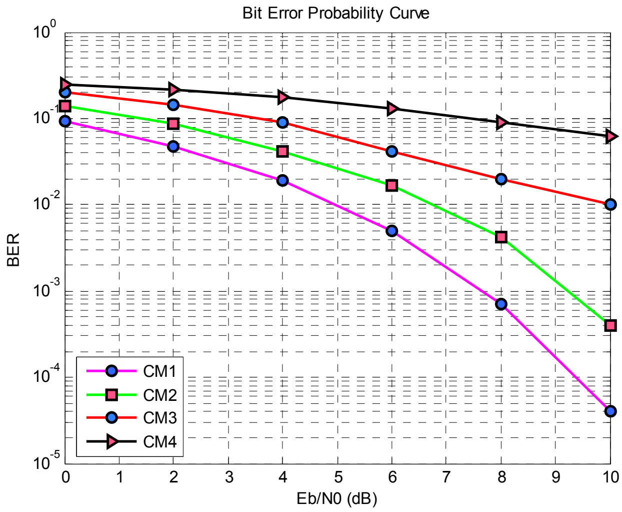

Fig. 7. Comparison of performance of the system under different channel models (CM1/CM2/CM3/CM4).

Fig. 6 gives the plot of SNR against P_d. At SNR=2dB, P_d value for 20 relays is greater than that for 10 relays, while P_d value being greatest for 30 relays. This shows that P_d increases with increasing number of relays for the same SNR value.

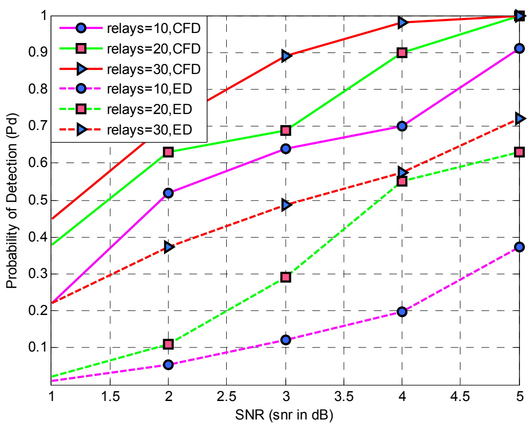

Fig. 8. Comparison of SNR against P_d plots for 10, 20 and 30 relays for both the detection schemes; cyclostationary feature detection (CFD) and energy detection (ED).

The final output of the TH-PPM demodulator in the block diagram is the bit error rate measurement (BER). Fig. 7. gives the comparison of the performance of the proposed system under the four different channel models of UWB (CM1/CM2/CM3/CM4). BER is most reduced when channel model1, CM1 is employed while channel model4, CM4 gives only a minor reduction in BER. Thus the best case is obtained with the UWB channel model1 while the UWB channel model4 gives the worst case.

Fig. 8. gives the comparison of the energy detection (ED) and the cyclostationary feature detection (CFD) schemes. It compares the SNR values with the probability of detection, P_d. Curves are plotted for different number of relays for both these spectrum sensing schemes. Considering the case of 10 relays, for SNR = 4, P_d value is 0.2 in energy detection method while it is 0.7 for the cyclostationary feature detection. Similarly for 20 relays, for SNR = 4, P_d value is 0.55 in the case of ED method while it is 0.9 for the CFD method. This shows the improvement in the performance when energy detection method is replaced by the cyclostationary feature detection method. The simulation result also shows that performance improves if the detection is performed with more number of cognitive relays.

VIII. Conclusion

The spectrum sensing can be performed most reliably and successfully by using the cyclostationary feature detection method. Even though this method increases the complexity of the system, it is worth the risk since its noise immunity is immensely high as when compared to the existing methods. Thus the cyclostationary based cooperative spectrum sensing is implemented onto the Ultra Wide Band region of the spectrum. Such an enhancement would be useful in applying the benefits of the cognitive radio onto many of the indoor applications. For example in a hospital environment which include many obstacles, due to the combined effects of cooperative sensing and the UWB communication channel, a secured, high speed, energy efficient communication is possible that can successfully coexist with other users in the same environment.

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