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Weighted Sequential Energy Detector in Co-Operative Spectrum Sensing

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***Abstract* – Spectrum sensing is the primary essentiality to monitor the presence of primary user in cognitive radios. Among all the spectrum sensing techniques energy detection is preferable because it is simple and prior knowledge of primary user is not required, but conventional energy detection is not preferable in low SNR regions.**

In the confusion region we use a Weighted Sequential Energy Detection (WSED) method which considers a fixed number of past observations. Where the cognitive radios users uses previously received energy values until it detects a change in primary users activity. The probability of false alarm and probability of detection for the Weighted SED. The Weighted SED shows the better detection performance over the conventional co-operative energy detection technique.

***Keywords* – Weighted Sequential Energy Detection, Cognitive Radio, Spectrum Sensing.**

I. Introduction

Wireless And Mobile Communications

For each generation of wireless and mobile communications, many technologies have been improved and enabled higher data rates, better spectral efficiency. The move from analog to digital communication occurs in the transition from first generation (1G) to second generation (2G). With spread spectrum technologies, Wideband Code Division Multiple Access (WCDMA) becomes dominant in the third generation (3G) mobile communication. With Orthogonal Frequency Division Multiple Access (OFDMA), current 4G system supports higher data rates and better spectral efficiency over existing 3G system.

In order to further cope with an increasing demand, a new paradigm and technologies that can enhance spectral efficiency and improve spectrum utilization are needed for the next generation beyond 4G mobile networks. The concept for the fifth generation (5G) are highlighted in such that the 5G terminals will be equipped with various technologies, able to combine different technologies and adapt itself to the environment. Cognitive Radio (CR) is proposed and designed to tackle these challenges and it is one of the enabling technologies and solutions for the future 5G mobile networks in Large-Scale Propagation, Small-Scale Propagation

Introduction To Cognitive Radios

The word cognition means “the mental process of getting knowledge through thought, experience and the senses”. The term “cognitive radio”, Mitola defines a cognitive radio as “A radio that employs model based reasoning to achieve a specified level of competence in radio-related domains.”

The main function of the physical layer is to sense the spectrum over all available degrees of freedom (time, frequency and space) in order to identify sub channels currently available for transmission. CR user dynamically and opportunistically accesses the spectrum hole or the white space, while avoiding an access to the spectrum which is currently in use by the PUs.

Cognitive Radio Architectures

Cognitive Radio network architecture can be categorized into two groups, the primary network and the cognitive radio network. The primary network is an existing infrastructure which has an exclusive right over a certain spectrum band, for example, the cellular networks and TV broadcast networks. The components of the primary networks are

Primary User (licensed user): a user which has a license to operate in a licensed band. The PU operation should not be affected by the operations of CR users.

Primary Base-Station (licensed base-station): a fixed infrastructure network component with spectrum license. The CR network does not have license to operate in a licensed band and its spectrum access is allowed opportunistically. The components of the cognitive radio networks are,

Cognitive Radio User (unlicensed user): a user who has no license over the spectrum. CR user can access the spectrum opportunistically only when PU is not present and CR user must vacate the channel immediately when the PU is detected.

Cognitive Radio Base-Station (unlicensed base-station): a fixed infrastructure component with CR capabilities, providing a single-hop connection to CR users. In cooperative spectrum sensing, the CR Base-Station also serves as a fusion center to gather the information from cooperative users and make the final spectrum sensing decision.

Spectrum Broker (scheduling server): a central network entity that controls spectrum resource sharing among the CR users.

Cognitive Radio Characteristics: There are two main characteristics of cognitive radio, Cognitive Capability and Reconfigurability.

Cognitive Capability: CR’s cognitive capability allows CR to capture or sense the information from its radio

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environment. This task is functioned in three steps, which are referred as the cognitive cycle, shown in Fig. 1

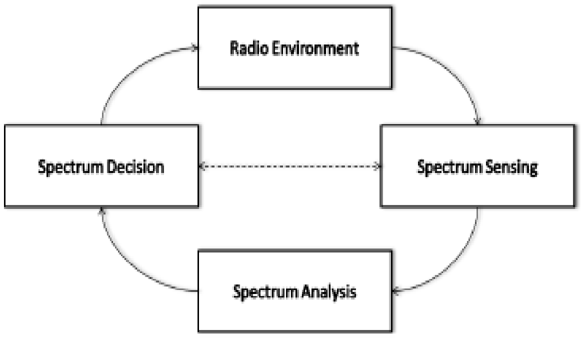

Fig. 1. Cognitive Radio Cycle

Spectrum Sensing: The radio environment and the available spectrum band are monitored. Their information is captured and spectrum holes are detected.

Spectrum Analysis: The characteristics of the spectrum holes detected are estimated.

Spectrum Decision: The appropriate spectrum band is chosen according to the spectrum analysis and characteristics and user requirements: data rate, bandwidth, and transmission mode.

Reconfigurability: CR's reconfigurability enables CR to be dynamically programmed according to the radio environment, to transmit or to receive on a variety of frequency and different transmission access. The configurable parameters in CR system are

Operating frequency: CR user can change its operating frequency depending on radio environment

Modulation: CR user can adapt its modulation scheme to user requirements and channel conditions

Transmission Power: CR user can reduce it transmission power to a lower level to allow more users to share the same channel and to decrease the interference.

Communication Technology: CR user can provide interoperability among different communication systems.

Spectrum Sharing: Based on the access technology, spectrum sharing can be classified as,

Overlay spectrum sharing: In this spectrum sharing technique, a portion of the spectrum that is not used by the licensed user is accessed by the CR users. As a result, interference to the PU is minimized.

Underlay spectrum sharing: This spectrum access technique exploits the spread spectrum techniques developed for cellular networks. CR user begins communication at the certain portion of the spectrum allocated by a spectrum allocation map with transmission power regarded as noise by the licensed user. This technique can utilize increased bandwidth compared to the overlay technique.

IEEE 802.22 WRAN Standard: IEEE 802.22 Wireless regional area network (WRAN) is the standard based on the CR technology. It focuses on utilizing and enabling un-licensed use on the UHF/VHF TV bands (54-862MHz).

II. Prior Works on Spectrum Sensing

With the aim to improve the detection performance in cooperative spectrum sensing, many novel techniques have been investigated and proposed. Various aspects and algorithms as well as the challenges for spectrum sensing are summarized. Cooperative detection with distributed sensors has been studied. A theory and application on detection of abrupt changes has been investigated.

Spectrum Sensing: CR user can access spectrum band only when the licensed user does not exist and it needs to vacate the channel immediately when the PU comes back. As a result, spectrum hole detection plays an important role in the CR system. There are various ways to detect the spectrum holes: transmitter detection, cooperative detection and interference based detection

Weighted Sequential Energy Detector: The weighted SED scheme exploits channel correlation by weighting and aggregating current and previous observations. In order not to include outdated observations, we employ the moving average model to combine energy observations. Then, the weighted output is compared to the threshold locally at the CR node, and the local decision is forwarded to the fusion center. At the fusion center, we choose the OR-rule for global decision making due to its simplicity and PU's protection purpose. Only one-bit CR's decision is forwarded to the fusion center and if any CR node detects the PU, all CR users will stop communication to protect the PUs.

Detection performance is often compromised with multipath fading, shadowing and receiver uncertainty issues. To mitigate the impact of these issues, cooperative spectrum sensing has been shown to be an effective method to improve the detection performance by exploiting spatial diversity. The optimal weighting is the one that can minimize the variance of T. The complexity involves minimizing the distributions at the same time. A sub-optimal approach is used to obtain the weighting vector by minimizing the variance of weighted received energy in each distribution separately. With SED, we can include past observations to vary the probability density function (PDF) of the weighted sum energy such that the shaded area is minimized. The can be achieved by separating the means, or minimizing the variance of the received energy in each distribution.

False alarm: A detector is said to have the property of constant-false alarm rate (CFAR), if its false alarm probability is independent of parameters such as noise or signal powers. In particular, the CFAR property means that the decision threshold can be set to achieve a pre-specified PFA without knowing the noise power. The CFAR is a very desired property in many applications, especially when one has to deal with noise of unknown power.

A cooperative spectrum sensing consists of multiple CR users and a fusion center. They are operated underneath a separate PU system, which does not cooperate with the CR system for Spectrum sensing. He CR users sense the spectrum, forward their local decisions to the fusion centre. The fusion centre makes the final decisions using a certain combining rule, such as OR-rule, AND-rule and majority rule. This will improve the sensing performance by overcoming fading and hidden terminal problem.

III. Block Diagram

In Weighted Sequential Energy Detector, a fixed number of past observations are taken for decision making. This method has better detection performance over the conventional cooperative energy detection technique. This method uses correlation by weighting and aggregating current and previous observations. In order not to include outdated observations, we use the moving average model to combine the energy observations.

In this method, there is a correlation between the previous and current received energy values. This channel correlation is affected by Doppler frequency. When Doppler frequency is low, channel gain is small. Conversely, high Doppler frequency leads to high channel variation, leading to low channel correlation. The sequential spectrum sensing technique is used to exploit the correlations. Each Cognitive Radio user senses the spectrum's in regular intervals.

Instead of deciding the primary user's existence only based on the current sensing period, it combines with the previously received energy value to improve detection performance. The Weighted SED scheme exploits channel correlation by weighting and aggregating current .The weighted output is compared to threshold locally at the CR node. At the fusion center, we choose OR_ rule for global decision.

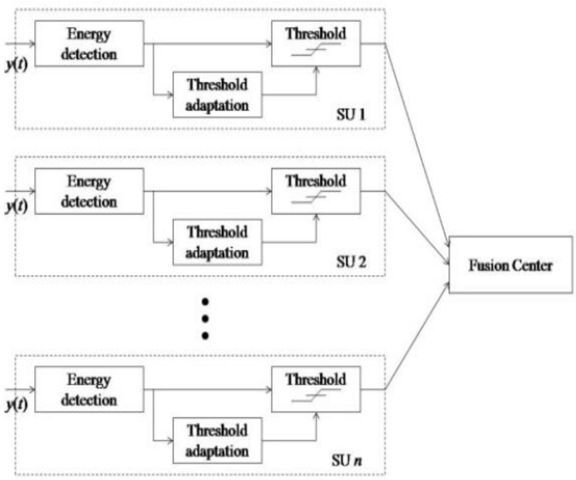

Fig.2- Block diagram of Weighted SED.

Energy detection has been used for multiband joint detection (MJD) in wideband sensing by employing an array of energy detectors, each of which detects one frequency band. The MJD method enables CR users to simultaneously detect PU signals across multiple frequency bands for efficient management of wideband spectrum resource at the cost of detection hardware.

Probability of False Alarm and Probability of Detection

The correctness of sensing signal availability is defined using quality parameters. This feature make up the performance metrics; among which are the probability of detection (PD), false alarm probability (PFA) and probability of missed detection (PM). PD specifies that a detector makes a correct detection that a channel is occupied, hence it is an indicator of the level of interference protection provided to the primary user. A large PD denotes exact sensing; hence a small chance of interference. An SU misses the chance to exploit a free spectrum when a false alarm event occurs. PFA should be kept as low as possible in order to prevent underutilization of transmission opportunities. This is an important measure in the study of a spectrum sensing technique.

The probability of declaring the spectrum space vacant H0, when it is indeed occupied H1, is referred to as the probability of missed detection (PM). A high PM implies an increase in the chance of interference between the PU and the SU. If the detection fails, or a miss detection occurs, the SU initiates a transmission, resulting in interference with the PU signal; contravening the opportunistic access concept. In essence, the spectrum sensing method should show a high probability of detection (low miss detection probability) and low probability of false alarm.

To quantify and depict receiver performance, use is made of receiver operating characteristics (ROC) curves. These graphs show relative trade-offs between detection probability and false alarm rates, (i.e. PD versus PFA), thus allowing the determination of an optimal threshold. There assist in exploring the relationship between sensitivity (detection probability) and specificity (false alarm rate). To plot ROC curves, one parameter is varied while the other is fixed. Using an energy detector, a test statistic is computed from discrete samples of the channel under investigation.

$$Y = \sum_{k=1}^{M} \left| x[n] \right|^2 \quad (1)$$

Y is the test statistic at the energy detector node; the number of samples under test is M. It is assumed that the noise power at the ED node is normally distributed with zero mean and unity variance. Thus, the received signal x(t) is normalized with respect to the noise power. Though the estimate of this noise power can be said to be uncertain, for this work however, this uncertainties are assumed negligible. From (1), the distribution of the received signal energy at the ED node is written as,

$$Y = \begin{cases} \chi^2_{2d} & H_0 \\ \chi^2_{2d}(2\gamma) & H_1 \end{cases} \quad (2)$$

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Sensing Procedures

The sequential sensing procedure is shown in Fig. The sensing period occurs periodically at the beginning of each packet, followed by the data transmission part.

The number of observation samples taken in the sensing period is defined by the time bandwidth product.

Primary User Activity

The PU activity is modelled according to a two-state Markov chain as shown in Fig. The parameter β and ά represents the probability of PU changing its state from active (H1) to idle (H0) and vice versa, while the notation 1− ά and 1− β represents the probability of PU remains in active (H1) and idle (H0) state respectively.

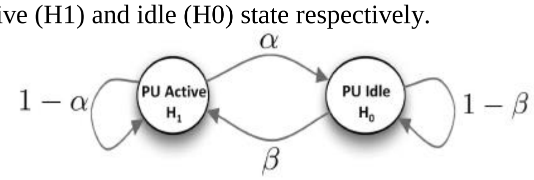

Fig. 3. Two-state Markov chain on primary user’s activity model

The energy observations are weighted and aggregated using the moving average model at kth sensing slot such that the decision is made by comparing weighted sum energy to the threshold. Finally the local decision is sent to the fusion centre to make a final decision using OR rule.

Weight computation: The weighting vector w is a key component of sequential cooperative sensing. Ideally under minimum error probability criterion, this vector should be optimized by minimizing the false alarm and miss detection probability. Hence it is complicated and optimal solution is difficult to obtain.

Sub-optimal weight vector: Since the optimal solution is difficult to obtain, a sub-optimal weighted calculation approach is proposed here. Considering the PDF of received energy when PU is idle (H0) and active (H1), the optimal detection approach is to determine the detection threshold that can jointly minimize the false alarm probability and missed detection. This can be achieved by separating or minimizing the variance of received energy in idle and active case.

IV. Simulation and Result

Energy distributions for weighted local observations with different number of past observations taken will be plotted by using MATLAB simulation.

Probability density function of received when PU is idle and active is plotted which will give the complete information about the spectrum sensing using Weighted SED. Here receiver characteristics (ROC) analysis for the signal detection theory to study the performance of the energy detector.

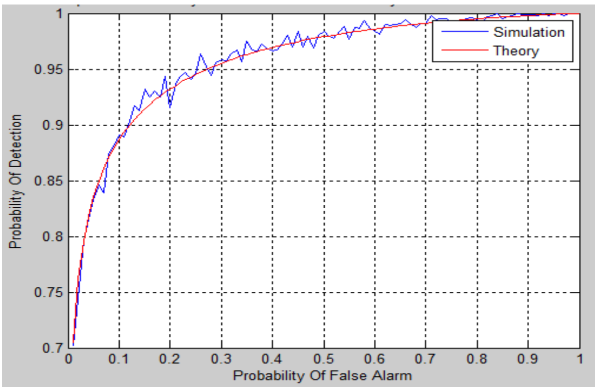

Fig. 4. Graph below shows probability of detection and probability of false alarm

SNR from 15dB to 25dB and *u*=100, 500, 1000 and 2000. It shows that when *u*=100, SNR from 17dB to 20dB is approximately good. When SNR is 21dB to 25dB, then detection probability is 1. In the case of *u*=500, then SNR from 20dB to 22dB is approximately good. When SNR is 23dB to 25dB, then detection probability is 1. In the case of *u*=1000, then SNR from 21dB to 24dB is approximately good and when SNR is 25dB, then probability of detection is 1. Again in the case of *u*=2000 and SNR =25dB, the detection probability is almost good. So when the time bandwidth factor is increasing, the probability of detection is decreasing. It also shows that SNR=25dB is approximately good.

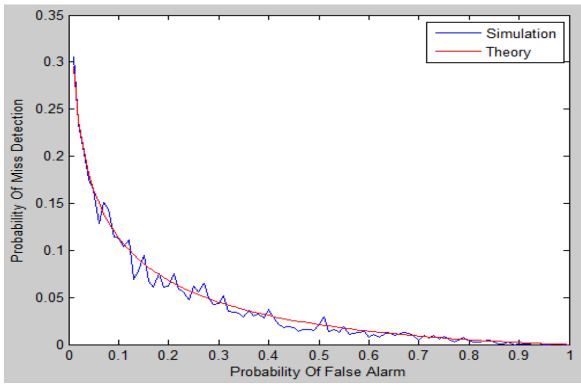

Fig. 5. Graph below shows probability of miss detection and probability of false alarm

If SNR<-10dB and increasing the u-value i.e. time bandwidth value, then we see the bad performance in detecting of energy. This probability of miss detection is opposite process of probability of detection. In this case, the performance is good.

For very less probability of false alarm increases, values for probability detection also increase. When values of SNR are increased, then there is dramatically increase observed in probability of detection at very few values of probability of false alarm. As values of the SNR increases, values for probability of detection also increases. When values are drawn for constant probability of false alarm and P_f increase, there is improvement in probability of detection observed.

V. Conclusion

In this paper, discussion of spectrum sensing based on energy detection in CR networks. ROC curves are used to plots of the probability of detection vs. the probability of false alarm. The probability of detection varies based on SNR, false alarm probability and various time bandwidth factors. SNR influences on the detection probability. When SNR increases, the detection probability increases and we also get SNR=25dB is better where detection probability 1. Again the detection probability varies depend on time bandwidth factor. If time bandwidth factor increases, the detection probability decreases. The false alarm probability also effects on detection probability. If false alarm increases, the detection probability increases. We also get the suitable SNR for the energy detector. So we almost get the final result of the spectrum sensing for cognitive radio based on Energy Detection as we expected.

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