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A SURVEY REPORT ON SPECTRUM SENSING TECHNIQUES IN COGNITIVE RADIO

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ABSTRACT

A software Radio which exploits unused spectrum spaces without causing much interference to licensed spectrum users and thus optimising the use of available radio frequency is, by its virtue of its intelligence, called Cognitive Radio. By judging the current trends in wireless technologies it can be predicted that Cognitive Radio will be a critical part of many future radio systems and networks. Cognitive Radio uses any of the three techniques – Spectrum Sensing, Spectrum Database and Cognitive Pilot Channel to acquire information about spectrum usage. Spectrum Sensing is the inherent ability of Cognitive Radio to autonomously perform required calculations and detect unused spectrum which can be used for a multitude of purposes. Due to its advantages many studies have been focussed to improve and implement Spectrum Sensing effectively in Cognitive Radio and this lead to development of many spectrum sensing schemes. This paper provides an insight into various Spectrum Sensing technologies and also analyses the advantages and drawbacks of each.

Keywords:- *Cognitive Radio, MIMO, Spectrum Sensing, Spectrum Sharing, Dynamic Allocation*

1. INTRODUCTION

The term “Cognitive Radio” was first coined by Joseph Mitola III in his article with Gerald.Q.Maguire, Jr., in 1999 describing it as a software –defined radio which can change its parameters depending on the need and user requirements. While this remains the core idea with which research on cognitive approach began, a few alterations to the idea were perceived and implemented. Depending on the parameters considered a distinction can be made between Cognitive Radios as 1) Fully cognitive radio, which takes into account every possible parameter and 2) Spectrum Sensing radio, which considers only the Radio Frequency spectrum. Cognitive Radio has four main functions which are-Spectrum Sharing, Spectrum Management, Spectrum Mobility and Spectrum Sensing. At the heart of the Cognitive Radio lies the Cognitive Engine which can understand and make decisions based on the spectrum environment. The unique idea which distinguishes Cognitive Radio is its ability to learn about the spectrum environment and locate frequency spaces or frequency holes which can be allocated to services in need of Radio Frequency Spectrum. The need for Cognitive Radio technologies rose sharply due to the shortage of spectrum for wireless services, as a result of traditional spectrum management schemes.

Spectrum Sensing used as a means to detect unused radio resources and estimate the interference level is a vital element in Cognitive Radio. Spectrum Sensing relies completely on the Secondary User to detect spectrum holes or “white space” in the RF spectrum. Spectrum Sensing schemes allow secondary users to monitor the licensed frequency bands and opportunistically utilize the frequency band when not used by the primary user while ensuring that the interference level is below the

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acceptable limit. Spectrum Sensing can be classified on the basis of the manner of detection – Cooperative Detection; Interference based Detection, Receiver Detection and Transmitter Detection. While many spectrum sensing schemes exist, an optimal spectrum sensing scheme or algorithm should have a good trade-off between the efficiency in allocation of spectral spaces to Secondary users and mitigating the interference to Primary users below a certain permissible level. [1] is a complete reference to what CR is and how the various technologies were developed and the terms were coined. A brief history of CR and its potential uses in the civil and military field are discussed. This survey figures out the pros and cons of various spectrum sensing techniques proposed by the researchers. A survey on various physical layer techniques of spectrum sharing in CR is catalogued [2] and reviewed the possibility of using wavelet transform for spectrum sensing. A review on dynamic spectrum sharing is made in[3] and the authors categorized the dynamic access and evaluated and compared the different techniques. The research challenges, signal processing techniques of spectrum sensing in CR network is presented in[4]. This survey report consolidates the spectrum sensing techniques in CR network and with MIMO configuration.

2. SURVEY ON SPECTRUM SENSING TECHNIQUES FOR CR

In [5] various spectrum sensing techniques were studied and two main metrics were considered – speed and accuracy of estimating the appropriate spectrum. The best spectrum sensing techniques are those which offer a trade off between time – frequency resolution , and they have a few drawbacks like leaking and large variance in power spectrum estimates. MTSE and FBSE overcome these but they lack keys to adjust t-f resolution. The authors suggest that the best possible method would be using wavelets as demonstrated by ‘ Z.Tiar and G.B.Gianmikis in their paper “ Wavelet approach to wideband spectrum sensing for cognitive radio”. Wavelets have certain interesting properties that can be used for spectrum sensing.

- Paper [6] discusses a method for Spectrum shared Cognitive Radio by considering a sensing function on both the Primary (Carrier sense of Wireless LAN) as well as Secondary systems and analyzing spectrum sharing techniques like Power Control and Time Sharing. Power Control methods limit interference at primary system but they also reduce secondary capacity as the secondary system gets closer to primary and Time sharing methods limits the area by the sensing level of primary system. It has been discussed that the appropriate sensing technique can be selected by maintaining enough sensitivity at primary and secondary nodes as high capacity is obtained by orthognality of primary and secondary systems by time separation.

- paper[7] proposes a method to determine the sensing threshold and minimum distance for the secondary users called Energy Detective method. By which the secondary user controls its sensing threshold and transmission power to guarantee the minimum decodable SINR for the primary receiver. By numerical analysis of interference to both systems using this method shows that coexistence of both systems is possible if the secondary users locate outside the minimum distance decided. This method is found to be most suitable where primary user’s parameters are unknown.
- An opportunistic spectrum sharing technique has been proposed in [8] based on a user solution algorithm along with a 2fb technique and water filling power allocation. It selects Secondary User which are nearly orthogonal to primary user and selects this list of Secondary User only those which are mutually near orthogonal to themselves in order to reduce interference with Primary User. Numerical results prove that high throughput can be achieved while not interfering with Primary User. This method can be extended to MIMO with a Receive Antenna solution to reduce Conceptual Feedback Complexity. This result is based on perfect channel state information at transmitter which may not be a practical assumption.

- In [9] the Spectrum sensing problem is treated as a Composite Hypothesis test problem. By exploiting statistics of the Received Signal and from information of the channel, two algorithms can be used 1) Iterative 2) Non Iterative GLRT sensing algorithm are developed for slow fading and fast fading channels respectively. These iterative sensing algorithms having high complexities and are used only as benchmarks for performance comparison. It is found that the simple non iterative algorithm is the best for both fast

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fading as well slow fading channels and also for MIMO and OFDM systems. Thus non iterative method outperforms several other sensing methods and is a more efficient method to be used.

- In [10] weighted sum rate maximization is considered where the SU are subjected to not only a sum power constraint but also interference power constraint. The multi constraint problem is transformed into its equivalent form with single constraint multi auxilary variables. A duality result is found for the form and an algorithm converts this convex bc problem into a sequence of convex MAC problems . This algorithm converges to the globally optimal solution.

- Pre-partitioning and weight driven approaches have been discussed in [11] to prove an efficient learning process for Cognitive Radio. Pre-partitioning involves randomly reserving a subset of available spectrum. It has potential to reduce the hidden terminal problem. Since transmission of different users will quickly converge to different channel sets in this case. Therefore users in a local area will avoid each other and the probability of hidden terminals is reduced. It is found that approximately 25% of more activations are expected in exploitation phase compared to uniform random exploration scheme. Weight driven exploration uses input from exploration to guide the exploration process itself and ensures exploration by merging randomness into action selection. Weight Driven exploration gives 40% higher number activation during exploitation.

- Weighted co-operative sensing method is a way of detecting the PU where the weight is designed by the PU signal energy and noise power. Paper[12] shows that the effect of weight depends on fading of signal significantly , to address Rayleigh fading plural antenna is used. Computer simulation show that usage of plural antenna elements is very efficient while estimation period is reasonably long.

- Paper [13] discusses a method to have optimum spectrum sensing by decreasing the average number of sensing bits, which are the bits used to represent sensing data , without actually decreasing the performance of sensing. Bits which have appropriate proof of a spectrum being present.

- In [14] a novel way of quantifying the detection information with variable length to save the spectrum resource is discussed. This Variable Length Quantification scheme employs trade-off between detection performance and overhead volume can make co-operative sensing more efficient and maintain the overall overhead within a limit. BY using Numerical Analysis it is proven that detection performance of this scheme is much higher than "OR" combination scheme and is similar in performance to the Optimal Linear Combination Scheme.

- In [15] a simplified model of primary user interruptions are considered as a Markov Chain . queuing analysis is carried out for two cases – two server single queue and single server two queue. For the 1st case a semi analytic expression for the generating function of queue length is obtained and for the 2nd case equations were obtained to determine the average queue length , which helps in determining the average waiting time according to Little's Law. In order to judge the stability of the queuing system numerical simulations are used to obtain the maximum arrival rate for stabilizing with respect to different service rates and interruption parameters.

- There are very few research works which take into account the impact of mobility on network design. [16] deals with key issues of mobility at different layers of protocol stack are discussed in detail. A quantitative assessment of mobility impact is calculated based on a case study on Ultra Wide bands. Currently existing methods of mobility management are compared. It is suggested that mobility can be handled more effectively by taking advantage of co operation between network terminals and information related to mobility of single terminals as well as groups of terminals can play a key role in design of solutions for mobile cognitive networks.

- A multi channel cognitive radio system with sensing limits at the secondary users and interference tolerance limit at PU And SU are considered in[17]. First the case of perfect PU detection is considered -With identical primary

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and secondary traffic statistics optimal fraction of licensed users lies between two extremes of fully licensed and fully opportunistic users and is equal to traffic duty cycle. Then the case of imperfect sensing is considered which provides similar results and in both cases the optimal number of secondary users is found to lie between complete regulation and autonomy. Numerical Analysis proves that the optimal number of SU increases as sensing ability of secondary node increases. It is also found that the sensitivity of sum goodput to primary user sensing is found to decrease as interference tolerance at primary and secondary nodes increases.

- Co-operative spectrum sensing reduces the effects shadowing and fading but it also generates a lot of overhead traffic which consumes more power. Censoring scheme for spectrum sharing is discussed in [18]. Two co-operative censoring test statistics are proposed based on cyclostationarity. Their asymptotic distributions have been established using numerical inversion of the characteristic functions. Simulation results reveal that the proposed strategy gives equal performance to a non censoring scheme. It also observed that the reductions in transmission rates are highest in the low SNR regime and in cases when the primary user is not present.

- This [19] discusses the various aspects of a distributed approach to spectrum sensing and preliminary results are shown. The use of cycle feature-based methods of signal detection and classification are discussed is shown that such methods provide reliable detection even at low SNR ratio scenarios.

  - A unified optimisation technique to resolve Dynamic Channel and Power Assignment (DCPA) problem is proposed in [20]. The effectiveness of the algorithm is evaluated through simulation.
  - The outage portability is evaluated in [21] for a Rayleigh fading CR model where, the secondary user is allowed to use the Primary channel during both the active and idle state provided Primary User can maintain the outage at a particular rate. The secondary user compensates interference with Primary User by sending to its receiver a combined message of both PU AND SU using superposition coding; Results show that cognitive user can communicate reliably by compensating interference to PU up to 10% outage portability.

3. SPECTRUM SENSING TECHNIQUES FOR MIMO CR SYSTEMS

The benefits of MIMO techniques in broadband systems are demonstrated in many scenarios[22 23 24 25] and now the focus is made on the Cognitive Radio network

In [26] a CR transmission strategy is discussed which is divided in to 3 stages

1) Learning – They listen to PR transmissions and apply blind algorithms to estimate spaces that are orthogonal to pr channels. Then beam forming is done to restrict interference of PR.
2) Channel Training – The channels are tested, training signals are sent to Receiver and linear mean square error is used to correctly find the channel with least error
3) Data Transmission

Considering that the estimation in stage 1 and 2 were imperfect the lower bound or Ergodic capacity was found. In order to maximize this, Algorithms were developed to find optimal power and time allocation for different stages. A closed form solution was found for the power allocation for a given time allocation and optimal time allocation was found using 2-D searching over a confined set.

- The uplink of cognitive radio has been considered in [27] with respect to Joint user selection and quantized power control schemes . The main aim is to maximize the sum rate capacity under constraint that interference with PU should be within a tolerable range. Two low complexity algorithms 1) Interference aware capacity algorithm which selects incremently , one user with suitable power level that has maximum single user capacity and total interference is less than interference constraint value. 2) Iterative user scheduling with interference minimalization, which with each iteration selects one user that induces minimum interference to the PU. Both methods have performance close to exhaustive Search.

- [28]describes an antenna system for portable lightweight cognitive radios employing opportunistic spectrum access. The 3- element E3SPAR antenna which is a frequency agile narrow band antenna capable of sensing over a

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wide bandwidth, unlike the classical 3 element ESPAR, exploits the mutual coupling between PEs and the central active element for running the operational subband rather than for maximizing the SINR. The resonant frequency is varied by controlling the varactor diodes. Apart from this the narrowband beam-patterns are controlled in the analogue domain allowing the tunable cognitive antenna system to exploit the extrememly important spatial resource.

- In [29] CR systems and their requirement of a physical layer are discussed, and the OFDM technique is implemented transmission technology for CR systems. By applying OFDM technique in CR systems, more adaptive aware and flexible systems can be made. Challenges which arise due to the use of OFDM in CR are identified and are labelled as areas for future research. This report also gives a few examples of OFDM-based standards that utilize cognitive features.

- In [30] different multicarrier techniques have been reviewed for the physical layer of CR. The performance of OFDM is analyzed and filter banks for multicarrier communication are introduced. The multitaper method has been proposed as an effective method for spectral analysis. It has been found that OFDM suffers from leakage issues and with TDD the issues of OFDM does not matter much. In the case of FDMA/FDD operation filterbanks may be preferred over OFDM. It is demonstrated that as a communication technique filterbanks provide better results than OFDM. And when used in spectral analysis filterbanks are equal optimal multitaper method. Thereby proving that they are better candidates for spectrum sensing in CR systems but the amount of understanding of OFDMA systems is far greater than filter banks.

- The design issues of low power Wireless Personal Area Network with Cognition in spectrum allocation is discussed in [31]. Concluded that cross layer optimisation for CR networks are still to be improved, protocols for low power design is to be updated.

4. CONCLUSION

Cognitive Radio is rapidly becoming an area of intense research and study. With advent of many new wireless services over the past few years leading to an increased demand for spectral resources has been identified as a possible reason for this. Cognitive Radio provides a solution to this resource allocation problem by locating unused or underused spectrum spaces of Licensed users and granting Secondary Users to access them with minimal amount of interference to the Licensed users. One of essential functions of Cognitive Radio is Spectrum Sensing, the ability to possible opportunities in the spectrum for allocation to Secondary Users, which is of profound importance. In this paper we have compared and contrasted many spectrum sensing techniques and the merits and demerits of each being the focal point of our interests. The limitation of this study lies on the spectrum regulations of various of regions and countries. Since most of the spectrum sensing techniques are the proposed schemes with the simulations and an analytical proof, but for real time implementations many other parameters are to be incorporated with respect to the signal vicinity. This paper can be a useful means to understand the current technologies and also act as a basis for novel ideas in the field of Spectrum Sensing and Cognitive Radio.

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