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An Insight in the Recent Advances in Cognitive Radio Networks

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Abstract

Cognitive Network is an emerging field in the context of Mobile Communication.In the present scenario, when Covid pandemic has limited the human mobility, mobile, internet and data have become the topmost need of each individual. Cognitive networks will be the only solution to cater to the needs of the increasing system capacity. This paper is a review in the field of Cognitive Radio Network (CRN) starting from the initial phase of defining to implementing Cognitive Radio.It summarizes some major work been done and the different prospects in the field of CRN.After extensive literature survey and review, the findings are presented for new prospects for future research.

Keywords: Cognitive Radio, Energy Detection, Spectrum Sensing

1. Introduction

The major findings after rigorous survey of the available literature are presented below in the chronological order.

Cognitive Radio was first introduced by **Joseph Mitola III** in 1998 in a seminar at KTH (the Royal Institute of Technology in Stockholm). For the first time, he wrote acomprehensive description of the term "Cognitive radio" in his research paper. **Gerald Q. Maguire** was the co-author for the same.

In 2000,**Mitola** wrote his PhD dissertation on "Cognitive radio as a natural extension of the SDR concept". Mitola described the term cognitive radio as "the point in which wireless personal digital assistants (PDAs) and related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to detect user communications needs as a function of use context, and provide resources to radio and wireless services".

The Federal Communications Commission (FCC), USA published a report which was aimed at the changes in technology and the profound impact that those changes would have on spectrum policy in 2002.In 2005, IEEE launched project of 1900 series standard for next generation and spectrum management. In 2006, FCC established Rule and Order on "how to use CR devices in unused portions of the TV White Spaces by secondary basis".In 2011, IEEE 802.22 WRAN (Wireless Regional Area Network) was declared by IEEE as an official standard for Cognitive Radio.Finallystarted the era of individual research in Cognitive Radio Networks. In this paper, the review is initiated from the year 2005 when Simon Haykin published a brain storming paper on cognitive Radio.

2. Related Work

Simon Haykin 2005 defined "cognitive radio as an intelligent wireless communication system that is aware of its environment and uses the methodology to adapt to statistical variations in the input to provide highly reliable communication and efficient utilization of the radio spectrum". The research

worked on measuring the interference temperature thereby estimating channel state information and designing a predictive model of the channel. This work addressed the emerging technology of cognitive radio.

Amir Ghasemi and Elvino 2008discussed the trends, features and challenges in cognitive radio In this article various regulatory requirements such as sensing periodicity, detection sensitivity etc are discussed. Various challenges faced in spectrum sensing viz. channel uncertainty, noise uncertainty, interference uncertainty are taken into account. Further the authors outlined the design tradeoffs that are needed to be made to enhance systemperformance.

TevfikY¨ucek and H¨useyinArslan 2009 presented a survey of various spectrum sensing methods for cognitive radio. They explained the problems encountered in spectrum sensing introduced multi-dimensional spectrum sensing. This paper explains the concepts of cooperative sensing and the forms in which it can be used. They discussed many sensing algorithms including external sensing etc.Statistical modelingof the network traffic and channel utilization for studying the primary user behavior is explained by the authors in their paper. Finally they enumerated the current wireless standards been used.

Akyildizetal. 2011 wrote in their survey paper about the different spectrum sensing techniques that are used for spectrum detection. They analyzed the different elements of cooperative sensing. These elements include cooperation models, hypothesis testing, sensing techniques, data fusion, types of channels and knowledge base. The factors affecting the gain and overhead achieved in cooperation are presented. They considered a number of factors viz. sensing time, energy efficiency, cooperation efficiency, security, mobility and wideband sensing. The research challenges limiting the performance of cooperative sensing are also discussed.

SamanAtapattu 2011assessed the detection performance of energy detection under Rayleigh fading and log-normal fading. The work focused on single and multiple cognitive relays and extended to mutihop relays. They worked on the K out of N fusion rule. The performance increases for the case of multiple relays however degrades drastically in case of multihop cognitive relays. The performance is limited by the errors due to imperfect reporting channels.

R. Suresh Babu and M. Sugandhi 2012 reviewed energy detector being a popular sensing method without the need to estimate channel information. This study summarizes energy detectionunder Additive White Gaussian Noise, Rayleigh fading and Nakagami fading channels. Energy detection with decision fusion is also studied for different number of cognitive nodes with multiple antennas. Their results show how the probability of missed detections decrements with the increase in the number ofantennas at cognitive nodes.

Teguig et al. 2012 bridged the gap between the hard fusion and soft fusion rules studying them together. This paper presented different fusion schemes that can be implemented in fusion center. The work proposed a quantized fusion scheme that gives a goodtradeoff between detection performance and the computational complexity. They also analyzed a quantized combination scheme based on athree-bit quantizationand demonstrated a comparative performance with the classic fusion rules.

SrinivasNallagonda etal. 2013 described how cooperation helps to enhance the accuracy of detection of the PU. In this paper energy detection based cooperativespectrum sensing using soft combination of theenergy values obtained from different cognitive radios is considered. The performance of many soft data fusionschemes is implemented at fusion center. Different sensing channelsviz. AWGN, shadowing, Rayleigh and Rician fading channels are considered for analysis. Different parameters viz.time-bandwidth product,average channel SNR and number of users. The performance for CSS is indicated in terms of missed detections.

S. Maleki et al.2013authored a censored truncated technique designed for spectrum sensing aimed to save energy-efficiency. This technique can be designed by limiting the average energy consumption of each sensor. This is done by putting alower bound on probability of detection and an upper bound on false alarm rate. By doing so the interference to the primary user can be controlled to an extent and the network throughput can be increased.A fixed sample size censoring scheme is used to for low power cognitive radios, The authors claim that their scheme outperforms all existing techniques in terms of energy efficiency under different cases.

Md. ShamimHussian etal. 2013 worked on classic hard fusion sensing. This paper assessed the performance of cooperative user based on the spectrum sensing using the classic energy detection method in both the non-fading channel and the fading channels. This paper presents the analysis of these fading channels using hard decision combining fusion rules. Fusion rule is performed at fusion centerto arrive at the final decision about the presence of PU. It is found that spectrum sensing becomes harder in presence of Rayleigh and Nakagami fading. The authorsverifiy that Ricean fading channel provides better sensing results.

Eftekhari A. et al. 2013 formulated a simple strategy based on correlation for approximating the amplitude and delay of a signal using a number of randomly chosen noisy frequency domain samples. The output of the proposed work labeled as compressive matched filter is modeled as a random process withscaled mean and the autocorrelation function shifted of the given template signal. Following the empirical procedures the work proves that the maximum deviation of this procedure from its mean sharply decays with the increase in number of measurements. The probabilistic tail dependent on the expected maximum deviation is derived in the proposed work. The minimum number of measurements required is decreased for guaranteeing that the expected empirical maximum of the formulated random process occurs significantly near to the maximum of its mean function. The work states that for a class of signals the proposed methodology would successfully approximate the latency by using a random 50number of frequency-domain samples that inversely scale with the SNR and logarithmically in the observation bandwidth.

Huang et al. 2014 proposed many different spectrum sensing schemes viz. cooperative, non-cooperative, centralized and distributed algorithms. They aimed to obtain a global sensing result which is normally not possible due to heterogeneous spectrum availability in widespread area. The authors proposed an intelligent non-parametric Bayesian learning model named Hierarchical Dirichlet process used for cooperative spectrum sensing. They worked on cluster based sensing in which common sparse spectrum is sensed within each group. This compensates for the hidden node problem. Finally concisely distributed information system is designed in which intracluster and intercluster sensing information is exchanged for global decision.

Doha Hamzaetal. 2014worked on equal gain combining (SEGC) for cognitive radio. The reporting channels used for cognitive radios to transmit theirsensing results to the fusion center are undergo multipath fading. Cognitive radios estimate the phases of theirreporting channels and use them to combine their sensing results.FC takes a global decision by comparing the received signal with the threshold. The authors concluded that the performance of SEGC is superior to maximum ratiocombining.

Ning Zhang et al. 2014 describeddynamic spectrum access in multi-channel cognitive radios.They revisited the fundamental issues in DSA and spectrum sharing. In this case the channels inhibit different usage characteristics and the detection performance of the secondary users varies. Firstly the spectrum sensing is considered where multiple SUs coordinate cooperatively to sense the channels of the primary users.As far as the PU's interests are concerned the performance of cooperative spectrum sensing is betterPUs. While when the SU's interests are concerned the objective was to maximize the expected free time while maintaining the interference level to the PUs under a specified level. Based on the problem transformation they proposed a solution through the channel selection algorithm.

NareshGunichetty et al. 2015proposed a novel two stage sensing method in which energy detection is used in the first stage and the second stage is a combination of cyclostationary feature detection and maximum minimum eigen value detection (CMME). The threshold for the dual stage is adjusted to maximize the detection capability. CMME stage estimates the noise variance and feedback to energy detector thereby enhancing the overall performance. But detection performance needs to be checked using real-time measured data.

Ranjeeth and Anuradha 2015considered square-law combining diversity technique over non-cooperative sensing when wireless users are affected by different types of fadingviz. Rayleigh, Rician,Nakagami, Hoyt andWeibullchannels. Performance is evaluated using receiver operatingcharacteristics (ROC) curves drawn for various parameters viz. number of diversitybranches, time bandwidth product, SNR and fadingparameters. It isnoticed thatWeibullshows better performance than otherfading channels when SLC is used.

MeenakshiSansoy and Avtar Singh Buttar 2016 in their paper proposed a cyclostationaryspectrum sensing technique in multiple antenna cognitive radio by using Maximal Ratio Combining (MRC) method. Cyclic analysis is performed by computing the Spectral Correlation Density (SCD) by FFT Accumulation Method (FAM). Simulation results reveal that CFD is good at lower SNR in detecting the primary user with a probability of approximately 90 percent at 20 dB.

Furtado et al. 2016 focused on the interference caused due to multiple SUs located outside the sensing region. The interference is then formulated as gamma distribution. The results show that the sensing degrades when the SUs have a single link for sensing and transmission. The maximum attained throughput is bound by the participating SUs and number of radio links.

Pankaj and Brahmjit 2016worked on both hard and soft fusion schemes.They showed how soft decision schemes perform better than hard fusion but at thecost of increased bandwidth. So they proposed a semi-soft scheme in which each cognitive radio makes a 1-bit local decision and sends one or two-bit data to the fusion center. At the fusion center the received data is used to determine the global

test metric which is compared to a threshold to form the final decision. They also derived the average bandwidth cost in thisscheme. The authors verified that the performance of their proposed fusionscheme is optimum.

AsmaaMaali et al. 2017presented a comparative study of Maximum EigenvalueDetection (MED) and the Energy Detection (ED). Theperformance of these two methods is evaluated in terms of theirReceiver Operating Characteristics and theirdetection probability for different values of Signal to Noise Ratioand smoothing factor L. The results of their study are discussed in terms of probability of detection.

Sk.MShabber et al. 2018 did comparative study on energy detection and match filter detectionidentify underutilized spectrum with characterizing interference and achieving reliable and efficient operation. In this paper energy detection and matched filter based spectrum sensingis discussed in detail. The performance over a Rayleighfading channel is evaluated through Receiver operating characteristic curve with Probability of detection vsProbability of False alarm.

Sara Gmiraet al. 2018 conducted a study onthe resources access problem in cognitive radio networks when used by alargenumber of secondary users. They established a cooperation coalitionalgame.The utilityfunction in the gaming algorithm depends on the transmission power and the noise level. The authors proposed a distributed coalition algorithm which is used by the SUs to decide when to join or leave a coalition. This decision is basedon the maximal coalition utility value. The tradeoff between the energy efficiencyand the targeted throughput is maintained. The authors validated the overall throughput and energy efficiency of the network.

MeenakshiAwasthia et al. 2018in their work optimized the energy efficiency for cooperative spectrum sensing in cognitive radio network. A novel mathematical formulation for maximizing energy efficiency by varying the number ofsecondary users, time taken for sensing and transmission time is evaluated. An iterative sub optimal algorithm is described to obtain optimal values of sensing time andtransmission time. Results and plots demonstrate the authenticity and optimality of their algorithm.

A Tony Cladia etal. 2018 defined Cognitive Radio Sensor Network. They explained the concept as a circular system of radio sensor hubs which can sense remote intellectual. These sensors can cooperatively convey their records over an accessible range groups in a multicastfashion to achieveparticular applications. The main problem caused due to spectrum sensing is that it degrades the primary user throughput. Here this paper proposed a new spectrum sensing method which improves the spectrum sensing performance and the energy efficiency. Also it provides fast transmission to secondary users using dijkstra algorithm. This algorithm calculates the shortest path to the destination so the energy spent in transmitting the data through this shortest path is reduced to an extent. Interference can be avoided by providing protection to primary user. The SU adaptively perform the second spectrum sensing with respect to the first sensing result. Therefore the proposed method increases the energy efficiency and reduces the interference to the primary users. Results show the comparison of existing and proposed method based on the energy efficiency. The authors performed the simulation using Network Simulator.

ChhaganCharan and RajooPandey 2019used the doublethreshold eigenvalue detection scheme that performs well at low SNR but is not reliable under deep fading and hidden node problem. They detected

spectrum holes using artificial intelligence techniques. In this paper a double threshold based cooperative sensing scheme is proposed. The threshold is obtained from ratios of eigenvalues obtained from the covariance matrix. The results show that the proposed scheme performs better than conventional eigenvalue and energy detection methods.

YounessArjoune and NaimaKaabouch 2019 aimed to give an in-depth survey of the recent advances in spectrum sensing, This article covers the development of cognitive radio from its inception to the current advances. The authors highlighted the benefits and demerits of both wideband and narrowband spectrum sensing techniques. A numerous research papers are reviewed and the challenges and future research topics are discussed. This survey paper is helpful for new researchers in the cognitive radio field. It explains the concepts of spectrum sensing and spectrum management.

FaroqAwinet al. 2019 proposed an adaptive algorithm by combination of fusion rules to balance between the detection performance and the transmission overhead. In their work they described combined hard and soft clusters of CRs. Each cluster use a different strategy. The authors provided various combination strategies using adaptive threshold. The proposed algorithms are studied under the influence of Rayleigh fading model. The results prove that the adaptive threshold algorithm outperforms the fixed threshold and other conventional fusion algorithms.

Krishan Kumar et al. 2019 illustrated the advantages of compelled cooperation for increasing the efficiencyof spectrum sensing in cognitive radio. This paper proposed a sensing scheme that reduces the detection time and improves the activity gain. This is done by the permission of the cognitive radio of the same band to compel cooperation. Results recorded shows that the proposed scheme is perfect for a case of two users with reduced delay and increased activity gain.

Yan Caietal. 2019 in this article have cited deliberate energy efficiency and spectrum efficiency in cellular systems with basic D2D communication capabilities including device-to-device single-hop (D2D) communication mode and two-way amplified relay communication mode (AF) D2D. The average energy efficiency and spectrum efficiency are analyzed, and under the influence of Rayleigh fading channel, path loss and co-channel interference, two closed modes of D2D communication mode are obtained. The result of the analysis was verified by numerical simulation. Obtaining the simulation results, the outcome of interference, the position of the relay nodes on energy efficiency or the distance between the D2D pairs or the efficiency of the D2D communication spectrum are considered. The optimal D2D transmission power of these two modes is also studied to maximize energy efficiency.

Anu Maria Joykutty and B. Baranidharan 2020 gave a survey on wireless networks and cognitive radio. They defined a wireless network as a number of wireless nodes thatcommunicate with each other without having been bound to anyregular infrastructure. Wireless networks can have irregular topology.As thenumber of wireless devices is increasing day by day, it is becoming a challenge to the limited wirelessspectrum. The efficient usage of limited spectrum resources can be done by opportunistic spectrum access by cognitive radios. Taking advantage of the fact that thechannels assigned to the primary users may be wasted inidle time. Cognitive radios can sense the unused channelspace and temporarily assigns to the secondary users. This paperdiscusses the recent advancements in the area of spectrum sensing and spectrum security.

Julian Martinaez et al. 2020 proposed a solution to shared resources to improve the under- utilization problem. In this article a review of the current state of spectrum sharing is discussed. They reviewed a number of published articles on mobile networks and TV. Many studies and simulations proposed sharing of spectrum efficiently. The current studies reveal that there has been a significant growth in this research area.

Gerges M. Salama and Sarah A. Taha 2020 used decentralized uncoordinated sensing technique. They studied energy detection with ANDand OR hard fusion rules. The authors plotted the signal at various instances. They studied power spectral density of the signal and noise.

Ojo et al. 2020 in their paper proposed an Enhanced EGC (EEGC) for CRN. The modulation used is BPSK scheme and propagated over Rayleigh flat-fading channel. Highest SNR branch is selected from the received signals through three antennas using three Selection Combiners. The outputs of these SCs are combined using conventional EGC. The output of from the EGC is used as an input to energy detector to determine the energy of combined signal. The proposed technique is simulated and the results obtained show that EEGC gives better performance with lower sensing time, higher detection probability and lower miss detections.

Gaoyu Chen et al. 2020showed howthe accuracy of spectrum sensing is affected by uncertainty factors viz. multipath fading, channel signal-to-noise ratio, shadow effect, hidden terminal etc. Cooperative spectrum sensing makes use of the spatial gain attained by sensorsplaced at geographicallydistant places. They demonstrated how combination of decision results show accurate decisions than single node.Data fusion strategies play an important role inthe perceptionof results and increases system reliability. The authors summarized many data fusion schemes in cooperative spectrum sensing and their performance.

3. Conclusion

This paper presents the major findings in the field of cognitive radio networks after an extensive literature survey and review over a long period of time. Observations show how CR can be the solution to the underutilized radio spectrum. The white spaces can be used to accommodate a large number of users. The CR facilitates smooth handoff and better QoS by smartly adapts itself to the available bandwidth conditions. A lot of research is been performed in CRN. Major work lies in finding the spectrum holes, sensing time, energy efficiency and optimization of sensing accuracy.

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