



Aspects and Approaches of Spectrum Sensing Techniques in Cognitive Radio Network: A Survey

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Abstract: The changeover of communication applications from the domain of voice-only to multimedia type has necessitated an increase in the data rates. This exploits the concept of opportunistic usage of limited available spectrum dynamically. Thus, the problem of spectral congestion is overcome by further increase in its efficiency. However, present scenario of wireless vicinity strives to focus upon enhanced speed with increasing data rates and decrease in the overheads like cost per bit. To recapitulate this objective and refrain from the sporadic usage of spectrum bands, a challenging paradigm known as Cognitive Radio has been emerged towards resolving the bottleneck in spectrum utility. Different spectrum sensing methodologies are adapted as regards to spectrum detection mechanism and type of spectrum sharing methods in a variety of networking environment like homogeneous & heterogeneous. Current generation wireless network involved with varied range of high definition audio as well as video applications with QoS is greatly heterogeneous. Spectrum sensing comprises of studying the radio spectrum with its explanations in order to accomplish the knowledge of the licensed-transmission in the shared spectrum group. Thus, Spectrum sensing is a significant assignment in CR system that is very much essential in the IEEE 802.22 standard. We have analyzed the effects and impact of various spectrum sensing techniques in a wide range of wireless domain. The heterogeneity of a wireless link could be realized by a mobile device in assistance with multiple interfaces.

Keywords: CRN; Spectrum Sensing; QoS; DSA;

I. Introduction

Based upon the statistics of Federal Communications Commission (FCC), the temporal and geographical deviations as regards to the exploitation of licensed bands are from 15% to 85% [1]. This has necessitated the study of efficient spectrum utilization to combat the major bottleneck of the scarce radio resource in a wide environment of wireless applications. In this context, a new platform has been evolved for resolving the spectrum deficiency by means of accessing the spectrum dynamically and opportunistically known as cognitive radio network (CRN). Due to the time shifting characteristics of wireless channels, spectrum sensing seems to be a critical issue and serves as an essential component in cognitive radio systems. It needs secondary users to scrutinize the movement of primary system and give up the licensed band when the licensed/primary user requires utilizing for itself [2]. The first global standard based on CR technologies with the competence of wideband spectrum sensing and opportunistic spectrum utilization identifies the spectral efficiencies of wireless regional area networks (WRANs) in the range of 0.5—5 bit/s/ Hz. However, under the existing standard of IEEE 802, the base station coverage may range up to 100 km in WRAN (802.22) where the power would not be a limiting case [3]. In wideband opportunistic spectrum access (WOSA) method, the secondary/cognitive users at the same time sense all frequency bands, but utilize only those that are identified to be idle. The opportunity which is emerged for the unlicensed users to explore its further transmission dynamically by intruding the underutilized vacant spaces at a specific time and location is addressed as 'spectrum holes'. Thus, it is a vital task in a cognitive radio network (CRN) that follows on dynamic spectrum access (DSA) to increase network spectrum utilization [4]. Spectrum sensing may be visualized basing upon three methods. These can be described as primary transmitter detection, primary receiver detection, and interference based detection [5]. The flow of this paper is structured as follows. Spectrum sensing techniques based on detection mechanism is described in section 2, Role of spectrum sensing in different environment is discussed in section 3 followed by different approaches of spectrum sensing in section 4. Finally it ended with conclusion in section 5.

II. Spectrum Sensing Based on Detection Mechanism

A. Transmitter Detection

This is supported on the findings of a delicate signal from a primary transmitter in the course of local observations of secondary or cognitive users. Receiver uncertainty problem and shadowing problem [6] are two major limitations under this category. This faces the hidden node problem that limits its usability. Secondly, shadowing causes cognitive radio transmitter unable to distinguish the transmitter of licensed/primary user.

B. Primary Receiver Detection

Cooperative detection minimizes the possibility of interference. Nevertheless, the most capable way to discover spectrum holes is to sense the primary users (PU), which seems to be receiving data within the communication range of a cognitive user. Generally, the local oscillator (LO) [5] escape power released by the radio frequency of the primary receiver is utilized. However, as the LO leakage signal is classically weak, the application of a reliable detector is not insignificant. This process is only practicable in the findings of TV receivers.

C. Interference-Based Detection

Interference at the receiver is managed by designing some models basing upon the interference temperature limit [5]. Interference can be organized at the transmitter using emitted power, out-of-band emissions, position of individual transmitters and frequencies used by specific type of radio operations. This can be defined as measure of the RF power made by unwanted CR-emitters in addition with noise.

D. Based on Overall Signal Detection

Sensing methods can be categorized in terms of coherent and non-coherent as regards to signal detection. Further, exploiting the classification based on bandwidth of the spectrum it may be wideband and narrowband spectrum sensing. In coherent type of detection, the primary signal may be spotted by contrasting received signal with a priori information of the primary signals, where as in non-coherent no a priori information is needed [6]. As far as spectrum sensing in signal processing is concerned it can be either non-cooperative or cooperative detection. Cooperative spectrum sensing can waive out the likelihood of misdetection and false alarm, reduces sensing time thereby resolves the hidden node problem of primary user. It serves as a solution to the noise uncertainty [7]. In non cooperative detection types several spectrum sensing processes may be selected by specific SUs like match filter detection [8], Energy detection [9], and Cyclostationary detection [9]. Where, the secondary user has the ability of differentiating the appearance of primary user and secondary user [10, 11]. All these methods do come under primary transmitter detection. These replicas are considered for sole SUs to process their local spectrum observations. But their performance is restricted without concern of spatial diversity [12]. Hence many schemes way out to cooperative type of detection where the uncertainty in the individual unlicensed user's detection may be appreciably reduced. Thus it is further perfect than non-cooperative detection. The benefit of cooperative sensing aims at increasing the effectual signal-to-noise ratio (SNR) adequately as the measure of cooperating SUs increase [12] which inevitably helps to lessen the spectrum-sensing charge of each individual SU or the number of compressive sensing measurements. As far as data fusion methods are concerned cooperative detection model can be categorized as centralized and decentralized fusion [13] [14, 15, 16, 17, 18]. Centralized fusion experimentally served globally optimal solution. However, decentralized fusion methods supersede centralized one in terms of reduction of power consumption [16, 17, 18, and 19].

III. Role of Spectrum Sensing in Different Environment

The status of the spectrum sensing in a cooperative as well as non-cooperative CR network has been discussed.

A. Cooperative Spectrum sensing (CSS)

To accomplish sensing accuracy and conserve energy the nodes allocate sensing outcomes between themselves recognized as cooperative spectrum sensing. The cooperative spectrum sensing studies basically emphasize two strategies that every unlicensed users may distribute the similar possession of primary users, i.e. homogeneous system or practically unlicensed/secondary users at unusual locations may access different bands as they may be either inside or away from the range of primary users characterized by heterogeneous systems [2]. Spectrum sensing being a prerequisite and indispensable component for a CR, intensive studies and its issues need to be analysed. Moreover, all the nodes in a networking environment consume maximum energy. Cooperative sensing can sort out the problems of hidden PUs, shadowing fading and multipath fading by exploiting multiuser diversity there by outperforms the detection problem of non-cooperative sensing or traditional spectrum sensing (single user spectrum sensing) [20].

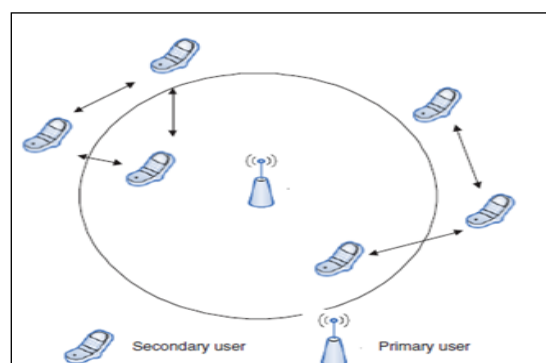


Figure1. Heterogeneous cognitive radio system [2]

Though CSS improves the sensing ability, but due to its energy consumption characteristics the life time of the network gets affected. Rigorous study and analysis in this regard motivates towards an approach of establishing a cognitive radio sensor network (CRSN). This is characterized as an energy constraint network that can preserve and protract the life time of the network by minimizing the number of cooperating nodes where as safeguarding a good possibility of detection under the specified energy constraints [21]. This presents user selection scheme and a design model to minimize the overhead energy consumption basing upon binary knapsack problem where the best nodes are to be selected among the prospective nodes provided to the consideration of the advantages under performance-energy tradeoff features [21]. Cooperative spectrum-sensing methods are needed for implementation that reduces the exposure time and develop the possibility of accurate discovery in a distributed network [22, 23, and 24].

Cooperation amongst multiple sensing users is necessary for establishing cooperative spectrum sensing. Where, the co-operation benefit is maximized conditionally. However, the prerequisite condition of gathering the sensing particulars from all unlicensed/secondary users to reach the fusion center without any loss may not be always guaranteed to be fulfilled. Thus, initiating a sense of adopting two types of sensing approaches i.e., cooperative multiuser sensing along with soft/squashy information fusion and hard/strong information fusion [25].

In response to accurate detection of primary users more precisely, in a CRN the secondary users can be synchronized to achieve cooperative spectrum sensing. In view of the sensing performance deterioration due to fading effect in the coverage channel, a cluster-based cooperative/supportive spectrum sensing technique may be applied to recover the sensing performance. All the unlicensed users are separated into a few clusters, thereby the most favorable one is chosen as the cluster head to report a common receiver [5]. Thus the spatial diversity gain could be enhanced.

B. Non cooperative Spectrum sensing

In a heterogeneous environment both the cooperative sensing (CS) and Non-cooperative sensing (NCS) seems to be very much unreasonable and ineffective as far as far as opportunity detection is concerned. Moreover, the efficient spectrum sensing process may be broadly divided into three categories to grab the spectrum opportunities as: temporal, spatial and spatial-temporal spectrum sensing.

Temporal spectrum sensing is based on an assumption testing among existence and nonexistence of Primary users. Spatial spectrum sensing can be is originated as the estimation of the location and transmission power of the primary transmitter [26]. Here, the presence of SUs whether inside or outside the range of a PU is based on the received signal strength. The PU has been always assumed to be in an active or ON state, but, in practice, PU may alternate its state in between ON and OFF status. Since, appropriate and enhanced spectrum detection seems to be predictable and serves as a vital component after sensing the spectrum, to develop the opportunity detection performance in spectrum sensing, performance metrics have been defined to guide the spatial-temporal opportunity detection followed by a proposal. Thus, a two-dimensional sensing (TDS) have been framed out [20]. Maximal ratio combination (MRC) is hypothetically proved to be approximately finest in low SNR region, a typical scenario in the situation of cognitive environment [27].

IV. Different Approaches of Spectrum Sensing

A. Multitask Spectrum Sensing

In order to enhance the spectrum detection ability along with reduction in the enforcement of fading ISI channels a collaborative spectrum sensing seems necessary to implement. That in turn takes an advantage of spatial diversity among multiple SUs. This comes out with a progressive approach towards the difficulty of detection failure and hidden terminal problem. Several challenges like high spectrum sampling rate, high communication cost causing node failure etc could be over-ruled by enabling the cooperative decentralized spectrum sensing thereby considering a cluster based CRN [1].

Assimilating two burning issues under sensing surroundings i.e. compressive sensing and spectrum sensing in CRN environment to realize low-overhead spectrum sensing, it intends in minimization of spectrum restoration inaccuracy supported on linear regression method [1]. In order to address the sampling rate limitation observed in spectrum sensing circuits and the interference range of PUs being inadequate, various clusters in the CRN may not be able to share a common thin spectrum. Thus a novel approach of multitask spectrum sensing technique have been proposed based on spatiotemporal data mining process. Hidden Markov model along with viterbi algorithm is used for precise spectrum decision for each SU. Findings of proposed algorithm achieved elevated sensing presentation in provisions of standardized/normalized mean square error, probability of accurate detection as well as probability of false alarm [1]. Proposal of spatiotemporal data mining schemes of low-cost spectrum sensing in CRNs is a multitask spectrum sensing algorithm. A high probability of correct detection reduces the interference to the Pus. The scenario of wireless access of mobile users constituting macro as well as micro cell in a heterogeneous networking environment has been figured out [28].

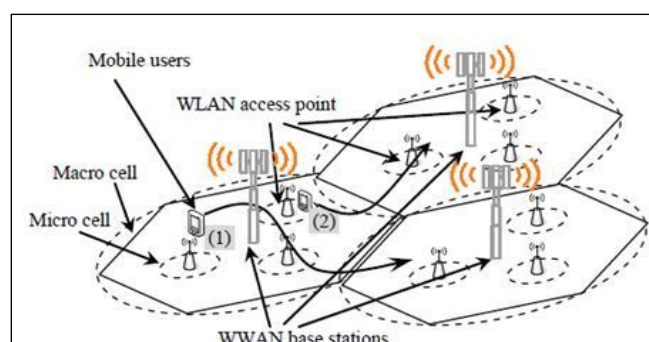


Figure2. Wireless Heterogeneous scenario [28]

B. Spatial -Temporal Opportunity Detection

A combined spatial and temporal opportunity detection model is formulated to confront critical issues and problems as well as challenges experienced in spatial-temporal opportunity detection. A two-dimensional sensing structure has been proposed. The outcome of the proposed work envisages analogous performance as the CS scheme in the spectrum-homogeneous environment but, it achieves noticeably better result than the traditional NCS and CS schemes in spectrum heterogeneous environments. The corresponding findings of this paper are lessening the constraints of sensing sensitivity and a perceptible enhancement of the spectrum utilization there by a progressive approach in framing out competency in spectrum utilization in a heterogeneous environment [20].

Focusing upon transmission techniques in CR network, Spectrum- heterogeneity has been explored towards the scheming of resource allocations as well as access approaches [5]. The SUs take advantage of only the temporal opportunity in absence of Pus activities in an overlay pattern where as in underlay technique the SUs access the licensed band even in presence of Pus. However, a prerequisite of interference constraint to guarantee PU performance is inevitable [29]. Considering the probability of PU activity, it is revealed that the underlay model supersedes the overlay method only when the probability of PU's activity is high. However, under lowest probability of PU's activity the reverse scenario would exist [30]. A combining approach in access models has been proposed to make use of spatial-temporal opportunities [20, 31].

C. Imperfect Spectrum Sensing

In view of entire utilization of spectrum resources, dynamic allocation of spectrum vis-a-vis sharing functionalities is very important. A model access control protocol and control channel management have come up as designing principle to restrain the dynamic spectrum environment along with collision avoidance primary user. A good spectrum handoff mechanism has been in process to provide secondary users with smooth frequency transition and minimum latency. Secondary users' transmission power ought to be cautiously controlled under such scenario [32].

Taking into consideration that spectrum sensing techniques may be practically difficult to realize in the sense of perfectness, its performance may be characterized by probabilities of false alarm and miss-detection [33]. Though Spectrum sharing enhances spectrum utilization in terms of opportunistically access without interference where sensing seems to be too much essential, in overlay mechanism imperfect spectrum sensing may be the root cause of collision between the licensed and unlicensed user transmission by deteriorating the performance of primary user. Hence, to restore the quality of service (QoS) necessities enforced by the primary services, a threshold level has been judiciously evaluated to keep the maximum probability of collision below a noticeable range [33]. A channel coding technique has been employed to mitigate this limitation at the cost of reducing the data transmission time followed by increasing the sensing time. A rate- compatible Low-Density Parity- Check code has been proposed to safe guard the effective data rate of secondary users without channel coding.

Two effective methods have been explored to recover the performance deprivation of secondary service because of collisions with primary transmission. First technique is developed to take up the channel coding techniques and the next one to increase the sensing time. Both of these diminish the effective data rate. Results show sensible values of bit error rate (BER) and for a certain range of 'n' (amount of increase or decrease effective data rate) the ratio of sensing period to sensing time, the proposed channel coding outperforms the uncoded case [33].

D. Imperfect Spectrum Sensing For Partial Spectrum Shared Network

Currently researches are on hand to study the spectrum access of SUs within conditions of blocking and enforced termination probabilities [34] which undergoes a model of continuous-time Markov chain (CTMC). This model established the performance metrics in case of perfect spectrum sensing. All these events took place in an environment of spectrum sharing in an opportunistically manner between two licensed networks [35]. The impact of imperfect spectrum sensing as well as periodic sensing/ sensing periodicity becomes desirable to be analyzed through Markov chain analysis on the network performance. It is based on a background scenario with two

licensed network sharing the spectrum partially and opportunistically. To establish the capacity performance a cross-layer framework was designed taking into account spectrum sensing constraints at the Physical layer and that of at the MAC layer concurrently to optimize the throughput. A discrete- time markov chain (DTMC) model evolved to learn the unfinished spectrum sharing scheme during the existence of unsatisfactory spectrum sensing that is other way known as imperfect sensing. The partial sharing strategy can attain 20.8% and 7.4 % gains in throughput in contrast to the non-sharing strategies and hierarchical sharing strategies respectively [35,36].

E. Capacity and Power Allocation under Perfect and Imperfect Scenario

Focusing upon the drawbacks of underlay and overlay model, a mixed access strategy called as Hybrid method is considered.

Under IEEE 802.22 standard adjusting the parameters of the detector for estimation, a fast algorithm is proposed for power allocation in both ideal and deficient spectrum sensing scenarios. A novel approach estimates a lower bound for the capability. Then the correct value of the capability is simulated with an extensive search method. However, obtaining perfect channel state information seems to be difficult. So, by assuming that the SU is afforded with an imperfect evaluation of channel gain among the SU's transmitter and the PU's receiver [37,38] most favorable power allocation is calculated for the hybrid method under a status where no channel state information is on hand other than its probability density function (PDF). The algorithm was supported by a barrier method [36].

F. Spectrum Prediction Adopted For Spectrum Sensing

The capacity enhancement of CR gets obstructed due to a number of limitations. For example, outcome of transmission collisions observed in traditional spectrum mobility [39], non- negligible time delays [40], and undermining the efficiency of spectrum utilization [41]. Allocating suitable frequency bands to the bursty heterogeneous CR service requests result in extensive time delays making a sense of lower efficiency in spectrum sharing policies.

To prevail over these deficiencies, prediction based techniques have been extensively studied where, a CR user can omit the sensing task on some channels those are expected to be active simultaneously dropping the sensing time and power consumption [40, 42, 43, 44].

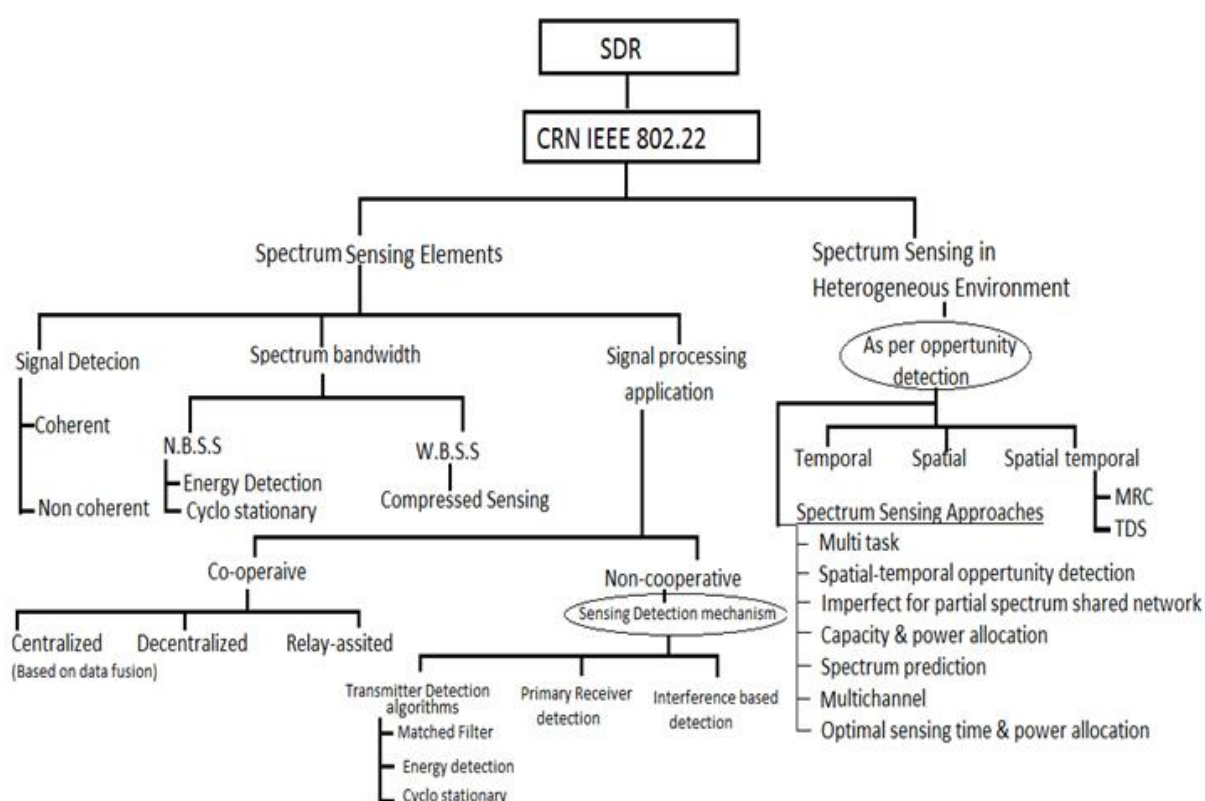


Figure 3. Spectrum sensing approaches in diverse environment

The commonly used prediction techniques are Hidden Markov Model, Neural Networks, Bayesian Inference-based prediction along with some graphical approach as model-based Autoregressive prediction and Static

neighbor graph- based prediction [45]. By overcoming the limitation of time delays followed by affecting the accuracy of the sensing result, efforts are made to rationalize spectrum estimation bottomed on channel state prediction that could offer a successful means to gear up the crisis. This is achieved by selecting a channel that is sensed and expected to be inactive. Secondary users can enhance the spectrum exploitation competence in parallel to diminish the interference with PUs. In multi-layer perception (MLP)–based prediction the future channel status for being idle is known and thus serves a better way to trim down the power consumption of secondary users [45]. In Bayesian inference (BIF) approach channel quality is predicted as per the inferred channel inactive period and sensing accurateness.

A simulated work of ordered sequence proved enhanced network performance such as throughput and time needed for resulting available channels. An upgraded version of prediction scheme known as Enhanced moving average-based prediction is used for improved performance in spectrum sensing. In auto-regressive model based prediction the parameters are estimated for using Yule-alker equations [45] to predict future channel states.

G. Multichannel Spectrum Sensing

Experimental study reveals that as the CR users may neither occupy a spectrum for a longer time nor does it satisfy their requirements, multiple non-contiguous spectrums could be sensed at the same time and utilized by CR users for the reason of improving throughput and communication reliability. But, a cost- efficient multi-spectrum sensing approach in a heterogeneous environment is a tough task [5].

Proposals are based upon spectrum sensing facts regarding the primary user's movement at the secondary base station for competent allotment of resources like communication time and power to SUs. The sensing details or information is acquired with the help of spectrum-aware sensors set up in the cognitive network coverage area, where in, a policy for the most favorable time-sharing and power allocation is offered to capitalize on the achievable capacity of fading CR broadcast channels. In this scenario transmission is inadequate by proper limitations on the interference received at the primary receiver and highest transmit power concerning to the secondary transmitter. Apprehending full soft- sensing information might be causing a severe load of feedback data along with system complications, a quantized spectrum sensing method is considered that takes into account only constrained intensities of licensed user movement [46].

H. Sensing Time Optimality and Power Allocation under inadequate Spectrum Sensing

The structural frame work employing spectrum sensing in a CR system consists of a time slot needed for sensing and a information/data communication slot. It indicates a tradeoff [47] between sensing time and data transmission time vis-a-vis implying the throughput of CR network. Thus in [48] an optimal sensing time for a single frequency band is studied which maximizes the sensing throughput. Subsequently, it was extended for a wideband environment where the throughput was maximized under the scenario of two different power constraints counteracting its previous work with a single constraint factor of possibility of exposure of the primary users. In [47] designing of optimal sensing and power allocation policy have been established to capitalize on the ergodic throughput that operates in WSSS and the WOSA scheme under multiband detection [49]. In order to safeguard the primary users from detrimental interference under imperfect spectrum sensing keeping an eye on both the above schemes, the results of usual transmit power and interference power constraint are discussed in a novel approach that attains the optimal sensing time as well as power allocation [47].

I. Sensing Technique for Differentiating Primary & Secondary Based On Queuing- Theoretical Framework

Multiple spectrum handoffs arise due to disruption of licensed users during the transmission period of cognitive user or secondary user. Channel usage is greatly influenced by spectrum sensing time, channel contention between multiple cognitive users, switching among various channels during hand-off etc. An approach based on queuing theory is introduced to distinguish the effects of these factors concurrently by means of incorporation of several system parameters [9]. A vital research way of spectrum sensing is carried out by considering the effects of missed detection as well as false alarm on its latency activity of primary and secondary users [50].

Due to channel outdated problem the extended information delivery time is increased. Hence, the target channel needs to be optimized to curtail the extended data release time as regards to various hand- off mechanism. Thus, it is experimented that the reactive handoff scheme serves better than the proactive handoff scheme under heavy traffic load. Proactive scheme results shorter extended data delivery time in comparison to the reactive handoff scheme during light traffic loads of the primary users. The former system reduces its unlimited data delivery time by keeping away from selection of a busy channel. This also performs sensing activity to find the idle channels instantly. However, the objective channel is explored by reactive spectrum sensing after handoff request policy is initiated. In contrast, the proactive mechanism saves the time of scanning the entire spectrum to establish the intended channel [9]. Consequent upon selection of target channels for spectrum handoff, the secondary

networks can be characterized as non- hopping and hopping. In hopping mode of network the secondary users possibly will require to execute spectrum sensing to find out the inactive channels [9].

V. CONCLUSIONS

The function of spectrum sensing is of greatest significance and to keep up of the QoS of the primary network intact, a good deal of object finding probability is essential. On the contrary, due to certain restrictions imposed on sensing procedure and the character of wireless communications, it is expected that there will be a possibility of missed detection. So, the unlicensed user will possibly identify that a frequency band is inactive and it will avail the charm of it. It's pertinent that CRN provides a high bandwidth to the end users by adapting the dynamic spectrum access techniques in a heterogeneous status of the environment including licensed and unlicensed bands. But, still challenges are on due to the dynamic spectrum environment and diverse QoS. It is highly desirable that the effects of two types of sensing errors as missed detection and false alarm are to be considered on the latency ability of licensed and cognitive users. These lead to an extension of the system time as a whole where, preliminary work on this has been experimentally verified by proposing analytical model with imperfect sensing.

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