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A Review of Spectrum Sensing Times in Cognitive Radio Networks

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ABSTRACT

The introduction of Cognitive Radio (CR) to ensure the efficient utilization of radio spectrum resources, where the opportunistic unlicensed user called the Secondary User (SU) jumped into a temporary unused spectrum owned by the licensed user called the Primary User (PU) for data transmission without causing interference. The CR is the key enabling technology that enables next generation communication system also known as Dynamic Spectrum Access (DSA) networks to efficiently utilize Radio Frequency (RF) spectrum effectively. The CR has opened more research areas among which is the Spectrum Sensing and is the most crucial task for the establishment of CR based communication mechanism. CR has challenges of collision among SUs during data transmission and single user spectrum sensing is subjected to destructive effect of shadowing and multipath fading, which result to Hidden Terminal Problem (HTP). Cooperative Spectrum Sensing (CSS) was deployed to mitigate the HTP, but it also introduces an additional communication overhead as a result of long sensing and reporting times. The longer the sensing time, T_s, the more the communication overhead. The reduction in the communication overhead reduces the Total Error Rate (TER) and when the TER is reduced the throughput is automatically increased. This paper presents a review of Spectrum Sensing Times in Cognitive Radio Networks and proposes better ways of achieving an improved Spectrum Sensing Time to efficiently utilize the RF spectrum.

1. Introduction

Report by Federal Communication Commission (FCC) pointed out that more than 70% of the RF spectrum is underutilized over time and geographical location [1]. This means that spectrum scarcity is not due to lack of spectrum, instead because of waste due to static spectrum allocation and much of the licensed spectrum remains unoccupied for large periods of time [2]. Hence there is need to effectively utilize spectrum to improve spectral efficiency by allowing unlicensed users to utilize licensed bands as long as it would not cause any interference [3]. Radio Frequency (RF) spectrum is the segment of the electromagnetic band containing waves in the RF range which accommodates countless communication devices [12]. RF spectrum is a very valuable resource in wireless communication systems used for radio transmission and the available spectrum are limited. The demand for access to this spectrum resource will inevitably increase as society moves through the “information age,” creating a need for ever more “information bandwidth.” [11]. Energy detection may be used to perform a quick scan of a wide range of frequencies to identify a few possibly free bands called the white spaces or spectrum holes, which among these candidate bands the spectrum holes may be discovered through accurate detection. Sensing performance may be improved by sensing the band for a good optimal time, thereby increasing signal processing gain [4]. Cognitive Radio (CR) is designed to intelligently detect whether a particular segment of the radio spectrum is currently in use and to jump into the temporarily unused spectrum very rapidly without interfering with the transmissions of other authorized users [5]. The CR can operate under the overlay scheme, where users sense the channel for interference free usage before transmission if the channel is identified as idle. On the other hand, in the underlay scheme, SUs can transmit simultaneously with PUs if the amount of collision caused for PUs is below the interference temperature level [6]. Fig 1. Shows a considered CR and PU System model, “accessible sub-bands” indicates that all N PU’s sub-bands are accessible for opportunistic transmission [7]. The CR is faced with a major challenge of Hidden Terminal Problem (HTP) [8]. HTP in spectrum sensing is subjected to destructive effect of shadowing and fading, which leads to false alarms and misdetection problems causing interference to the PUs [7], [8]. The HTP occurs when a node is visible from access point but cannot communicate to the node within the communication distance. Similarly, the primary signal is present and difficult to detect, HTP can be caused by factors including severe multipath fading or shadowing observed by SUs while scanning for PUs’ transmissions as shown in Fig. 2 [1], [10], and [11]. Cooperative transmission can greatly improve the spectrum access opportunity as well as sharing efficiency for SUs with the help of cooperative relay nodes [9].

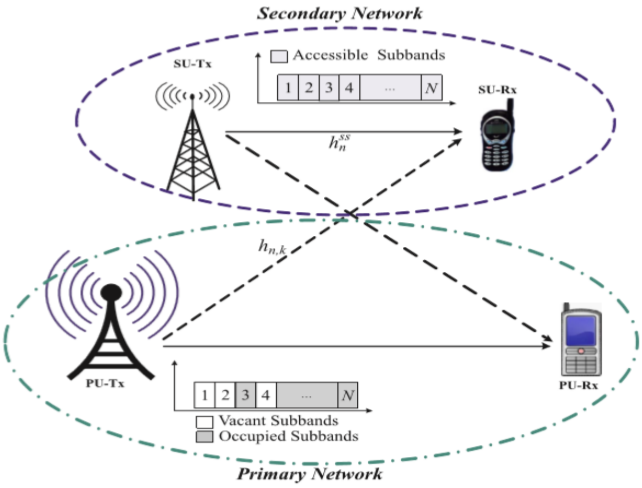

Fig 1: Considered CR and PU System model [7].

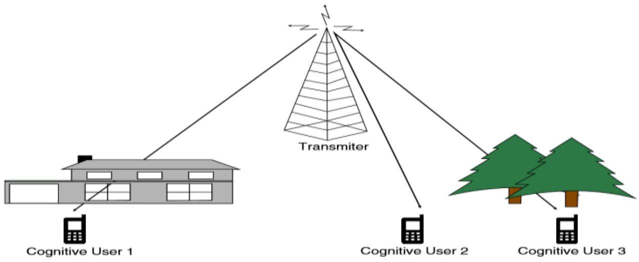

Fig 2: Shadowed Environment or Deep Fading Condition [1]

Cooperative Spectrum Sensing (CSS) in CR systems has not only enhanced the reliability of detecting PUs but is also proven to be a powerful method for dealing with HTP in fading or shadowing environment [1]. When HTPs are reduced, then Total Error Rate (TER) is also reduced, and throughput increases automatically in the CR network [13]. In the process of HTP elimination to detect the status of the PU at time, T_s, the CSS is useful since the group of CRs detect and allocate the spectrum efficiently [10]. Spectrum sensing technique is a key functionality for identifying the spectrum usage status over a wide frequency range and its most critical performance requirements are ***accuracy and time of spectrum sensing*** [14]. The main challenge in any CR system is to maximize SU's throughput while limiting interference imposed on licensed users. In this consideration, finding the optimal sensing, transmission timing strategies, and accurate sensing techniques are of great importance in a CR network [15]. The four major functions of CR are [16]:

(i) **Spectrum sensing**: refers to the capability of timely sensing of the spectrum holes [16].
(ii) **Spectrum management**: is the task of selecting the best available spectrum to meet user's communication requirements [18].
(iii) **Spectrum mobility**: is the process when a CR user exchanges its frequency of operation. The spectrum mobility deals with the handoff (transfer of connection to another unused spectrum band) in CR network [10].
(iv) **Spectrum sharing**: refers to providing the fair spectrum scheduling method, one of the major challenges in open spectrum usage is the spectrum sharing. It also helps in preventing spectrum overlap when multiple CR are involved in a network [17].

However, there are several factors that make spectrum sensing practically challenging such as [19]:

(i) Required Signal to Noise Ratio (SNR) for detection may be very low.
(ii) Multipath fading and time dispersion of wireless channels that complicate the spectrum sensing problem.
(iii) Noise level that changes with time and location which yields the noise power uncertainty issue for detection.

To overcome the aforementioned challenging factors, spectrum sensing methods using a wide scope of research are carried out in this area. These spectrum sensing methods can be classified as [16]:

(i) **Cooperative sensing**: The primary signals for spectrum opportunities are detected reliably by interacting or cooperating with other users, and the method can be implemented as either centralized access to spectrum coordinated by a spectrum server or distributed approach.
(ii) **Non-cooperative sensing**: Here each CR senses by itself and uses its sensing data to give a decision on channel state that is idle or busy. The CR will configure itself according to the signals it can detect and the information with which it is pre-loaded.
(iii) **Interference temperature detection**: In this approach, CR system works as in the ultra-wide band (UWB) technology where the SUs coexist with PUs and are allowed to transmit with low power and are restricted by the interference temperature level so as not to cause harmful interference to PU.

1.2 Cooperative and Non-Cooperative Cognitive Radio Networks

In this sub-section, the advantages and disadvantages of both cooperative and non-cooperative cognitive radio networks is discussed in Table 1.

Table 1: Comparison between Cooperative and Non-Cooperative Cognitive Radio Networks

	Cooperative Cognitive Radio	Non-cooperative Cognitive Radio
Advantages	(i)Improvement in detection probabilities, hence reducing overall detection time. (ii)No competition between cognitive users in CRN (ii)The cognitive users act as a single entity to maximize the total group utility (iii)It ensure efficiency as well as fairness among the cognitive users (iv)It formulate the interaction among cooperative cognitive users provided that the users can influence the action of others (v)Drastically reduce sensitivity requirements: channel impairments like multipath fading, shadowing and building penetration losses, impose high sensitivity requirement inherently limited by cost and power requirement (vi)It enhances link connectivity, which would lead to saving available resources. (vii)Hidden Terminal Problem (HTP), false alarms are significantly reduced (viii)More accurate signal detection, channel control and system synchronization are achievable. (ix)Primary signals for spectrum opportunities are detected reliably by interacting with other users. (x)Method can be implemented either centralized access to spectrum coordinated by a spectrum server or distributed approach implied.	(i)Cognitive users are selfish and each individual makes decision independently. (ii) The cognitive users have different (often conflicting) interests (iii)It has a considerably low data overhead [20], [21] and [22].
Disadvantages	(i)CR users need to perform sensing at periodic intervals as sensed information becomes obsolete fast due to factors like mobility, channel impairments etc. (ii)It considerably increases the data overhead; large sensory data; since the CR can potentially use any spectrum hole.	(i)Increase in sensitivity requirements (ii)Effect of Hidden Terminal Problem (HTP) is pronounce (iii)There is competition between cognitive users in CRN (iv)High collision probability among cognitive users during transmission process

In addition to the aforementioned advantages of cooperative CR sensing is the provision of the diversity gain achieved when CR users collaborate, bringing together sensing information of every SU in taking decision. The cooperating sensing will improve the detection performance and mitigate sensing error which may cause coexistence of SU and PU on same channel, and negatively affect the PU [27]. This implies that the accuracy of sensed information has a critical importance in the efficient utilization of RF spectrum, hence, the deployment of cooperative sensing. While sensing the spectrum, the following points should be considered [14].

(i) **Spectrum sensing bandwidth**: One of the issues associated with the spectrum sensing bandwidth is effectively knowing the number of channels on which the system will sense whether they are occupied.

(ii) **Transmission type sensing**: The system must be capable of identifying the transmission of the PU for the channel. It must also identify transmissions of other units in the same system as itself.
(iii) **Spectrum sensing accuracy**: The CR spectrum sensing mechanism must be able to detect any other signal levels accurately so that the number of false alarms is minimized.
(iv) **Spectrum sensing timing windows**: It is necessary that the CR spectrum sensing methodology allows time slots when it does not transmit to enable the system to detect other signals.

Spectrum can be assigned on an exclusive basis, or on a shared basis. That determines to a large extend the multiple access scheme and the interference resistance that the system has to provide. The spectrum usage are as follows [23].

(i) **Spectrum dedicated to service and operator:** A certain part of the electromagnetic spectrum is assigned on an exclusive basis to a service provider. The network operators buy or lease the spectrum on an exclusive basis, and due to this arrangement, the operator has control over the spectrum and can plan the use of different parts of this spectrum in different geographical regions, in order to minimize interference.
(ii) **Spectrum allowing multiple operators:** This can either be “spectrum dedicated to a service” or “free spectrum”. Spectrum dedicated to a service can be used only for a certain service (example, cordless telephones), but is not assigned to a specific operator. Rather, users can set up qualified equipment without a license. Such approach does not allow interference planning. Rather, the system must be designed in such a way that it avoids interfering with other users in the region. While the latter, free spectrum, is assigned for different services as well as for different operators. The Industrial, Scientific, and Medical (ISM) band at 2.45GHz is the best known example. It is allowed to operate microwave ovens, WiFi LANs, and Bluetooth wireless links, among others, in this band. And each user has to adhere to strict emission limits, in order not to interfere too much with other systems and users.
(iii) **Ultra-Wide Bandwidth Systems (UWS):** Here systems spread their information over a very large bandwidth, while at the same time keeping a very low-power spectral density. Therefore, the transmit band can include frequency bands that have already been assigned to other services, without creating significant interference.
(iv) **Adaptive spectral usage**: This approach relies on first determining the current spectrum usage at a certain location and then employing unused parts of the spectrum. This approach is also known as cognitive radio.

2. Spectrum Sensing

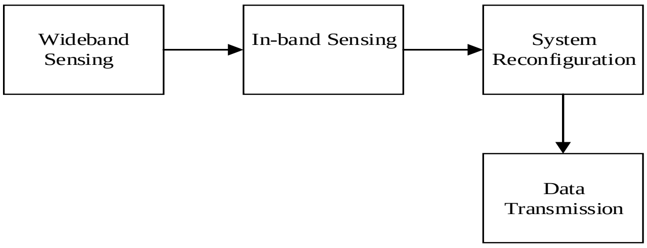

Fig 3. Spectrum Sensing Stages [24]

Fig. 3. Shows a spectrum sensing process of CR network. CR performs a wideband sensing at its initial, in the process it identified a channel unoccupied by PU. Thereafter, in-band sensing is

executed in compliance with strict FCC guidelines for protection of PUs [25]. FCC guideline permits unlicensed devices to make opportunistic or dynamic use of spectrum occupied by licensed user when is temporary unused as long as their operation caused no harmful interference and the device did not generate emission or field strength levels greater than a specified level that was chosen to ensure that the devices generally would not cause interference [26].

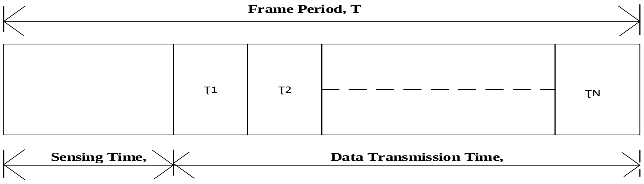

Fig 4: Frame Structure for CR network [25]

An SU is allotted a channel for a time frame of T within the frame duration, the SU senses the channel for duration of sensing time, T_s . After sensing operation is performed, the SU use the rest of the time as data transmission time, T_d . During the data transmission of CR network, the samples of SUs are transmitted following Time Division Multiple Access (TDMA) scheme for occupying a channel during the data transmission time, T_d . sampling times for N number of SU samples during the data transmission $Ʈ_1$, $Ʈ_2$, . . . $Ʈ_N$ are sampling times for number of SU sample, N. as shown in Fig. 4. [25].

$$T = T_s + T_d \tag{1}$$

Energy detection may be used to perform a quick scan of a wide range of frequencies to identify a few possibly free bands called the white spaces or spectrum holes, which among these candidate bands the spectrum holes may be discovered through accurate detection. Sensing performance may be improved by sensing the band for a longer time, thereby increasing signal processing gain [4]. Other techniques of detection for spectrum sensing are; cyclostationary detection, matched filter (MF) detection, and waveform detection [31] [32] [36].

2.1.1 Energy Detection

Energy detection is a spectrum sensing technique that detects the presence/absence of a signal by measuring the received signal power. This signal detection approach is quite easy and convenient for practical implementation because no prior knowledge is required and it has low cost. To implement energy detector, however, noise variance information is required. An imperfect knowledge of the noise power (noise uncertainty) may lead to the phenomenon of the SNR wall, which is a SNR level below which the energy detector cannot reliably detect any transmitted signal which increases the observation time. However, the SNR wall is not caused by the presence of a noise uncertainty itself, but by an insufficient refinement of the noise power estimation while the observation time increases. In this detection technique, the PU is detected based on the sensed energy, the received signal as Power Spectral Density (PSD) is passed through band pass filter and the band limited signal is then integrated over a time interval The time integrated signal is then compared with the predefined threshold to determine the presence of primary signal [31] as shown in Fig. 5.

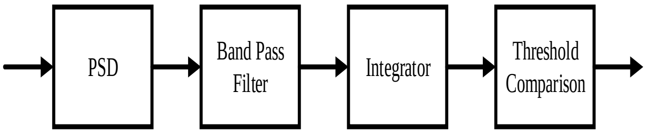

Fig. 5. Block Diagram of Energy Detection Process [32]

The hypothesis test for the signal identification is expressed [32]

(i) $H1$ is hypothesis for presence of PU,

$$Y[n] = hx[n] + w[n], \tag{2}$$

(ii) $H0$ is hypothesis for absence of PU,

$$Y[n] = w[n], \tag{3}$$

where:
$Y[n]$ is the signal transmitted by the PUs,
$x[n]$ is the PUs signal received by the SUs,
h is the channel gain (assumed to be 0 under $H0$ and 1 under $H1$.)
$w[n]$ is the noise.
n is number of secondary user samples, (1, 2, . . . N)

The energy detector takes input sample signals transmitted by PUs and accumulates them for power estimation and gives the output Z, which serves as decision statistics [25].

$$Z = \frac{1}{N} \sum_{n=1}^{N} (Y[n])^2 \tag{4}$$

The Probability of detection, P_d and the Probability of false alarm, P_f are defined as the probabilities that the SUs sensing algorithm detects a PU by comparing the output Z in equation (4) with a threshold γ [25].

$$P_f = P(Z > \gamma | H_0) \tag{5}$$

$$P_d = P(Z > \gamma | H_1) \tag{6}$$

The resulted P_f and P_d for a complementary distribution function of the standard Gaussian Q(.) is computed [25]

$$P_f = Q\left(\frac{\gamma - \mu_0}{\sigma_0^2}\right) \tag{7}$$

$$P_d = Q\left(\frac{\gamma - \mu_1}{\sigma_1^2}\right) \tag{8}$$

where:
γ is the threshold
μ_0 is the mean under the hypothesis H_0
μ_1 is the mean under the hypothesis H_1
σ_0^2 is the variance under the hypothesis H_0
σ_1^2 is the variance under the hypothesis H_1
Q is the complementary distribution function

The associated probabilities of false alarm and detection are defined in the complex valued Phase Shift Keying (PSK) modulated and circularly symmetric complex Gaussian noise cases as [25].

$$P_f = Q\left(\left(\frac{\gamma}{\sigma_w^2} - 1\right) \sqrt{N}\right) \tag{9}$$

$$P_d = Q\left(\left(\frac{\gamma}{\sigma_w^2} - 1 - SNR\right) \sqrt{\frac{N}{2SNR+1}}\right) \tag{10}$$

The number of required samples to achieved a given pair of target probabilities (P_d, P_f) of equations (9) and (10) is given [25].

$$N = \frac{1}{SNR^2} \left(Q^{-1}(P_f) - Q^{-1}(P_d) \sqrt{2SNR + 1}\right)^2 \tag{11}$$

Considering the sampling time as Ʈ, sensing time is derived as [25].

$$T_s = \text{Ʈ} N = \frac{\text{Ʈ}}{SNR^2} \left(Q^{-1}(P_f) - Q^{-1}(P_d) \sqrt{2SNR + 1}\right)^2$$

(12)

The larger sampling number results in the longer sensing time as seen in equation (12). The average achievable throughput of SUs is given as [25].

$$R_n = P\,(H_0)\,\frac{T - T_s}{T}\,\left(1 - P_f\right)\,\log_2(1 + SNR_{su}) \tag{13}$$

where:
$P\,(H_0)$ is the probability that PU being inactive in the sensed channel,
SNR_{su} is the received SNR of SUs transmission at the SU receiver.
If at least two samples of SUs transmit within any of the sampling time slots there may be a collision between samples of SUs, hence, the probability of collision (P_c) between samples of SUs is express as [25].

$$P_c = 1 - e^{\frac{-T_s}{T - T_s}} - \frac{T_s}{T - T_s}\,\boldsymbol{e}^{\frac{\boldsymbol{-T_s}}{\boldsymbol{T-T_s}}} \tag{14}$$

The sensing time optimization problem is mathematically formulated as [25].

$$\min_{SNR,\ P_f}\ T_s = \frac{\mathrm{T}}{SNR^2}\left(Q^{-1}\left(P_f\right) - Q^{-1}\,(P_d)\sqrt{1 + SNR}\right)^2 \tag{15}$$

$$s.t\begin{cases} P_c \le \overline{P_c} \\ R_n \ge \overline{R_n} \end{cases}$$

where:
$\overline{R_n}$ is targeted normalized throughput of SUs taken as 85%
$\overline{P_c}$ is maximum allowable probability of collision between samples of SUs taken as 1%,

2.1.2 Cyclostationary Detection

For any signal, cyclostationary features are caused by the periodicity or its statistics like auto correlation and mean. Also, to perform spectrum sensing, periodicity is intentionally induced. In this spectrum sensing technique, cyclic correlation function is used instead of power spectral density (PSD) to detect presence of primary user in a given spectrum. The cyclostationarity based detection technique differentiate primary user's signal from noise signal [31] [32]. In addition to this, cyclostationarity feature differentiates various types of transmissions and primary users. This spectrum sensing technique exploits the periodicity in the received signal to confirm the presence of primary users. At low signal to noise ratio (SNR) condition, cyclostationary feature detection technique outperforms the energy detection-based spectrum sensing technique [36].

2.1.3 Matched Filter (MF) Detection

When the transmitted signal is known, match filtering is the optimum method for primary user detection, in cognitive radio. As compared to other spectrum sensing techniques match filtering requires minimum time to achieve a particular value of probability of miss detection (PM) or probability of false alarm (PFA) [36].

2.1.4 Waveform Detection

In wireless systems, known patterns are used to support synchronization as well as for other communication tasks, these patterns are regularly transmitted pilot patterns, preambles, mid-ambles, spreading sequences etc. a sequence transmitted before each burst is known as preamble and a sequence transmitted in the middle of a burst of slot is known as mid-amble. If the known pattern is present, the received signal is correlated with a known copy of itself to perform spectrum sensing. This method of spectrum sensing is known as waveform based sensing or coherent sensing and it is applicable only to the systems where known signal patterns are available [36].

2.2 Cooperative Spectrum Sensing(CSS)

The primary signals for spectrum opportunities are detected reliably by interacting or cooperating with other users and the method can be implemented as distributive or centralized access to spectrum coordinated by a spectrum server. Cooperative transmission can greatly improve the spectrum access opportunity as well as sharing efficiency for SU with the help of cooperative relay nodes [9]. Fig. 6 shows a Spectrum Sensing Structure in a CR network with the assumption that each CR performs spectrum sensing autonomous and then the local decisions are sent to a common receiver called the Fusion Center (FC) which can fuse all available decision information to infer the absence or presence of the PU [13].

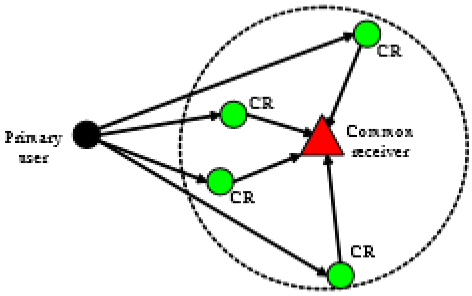

Fig. 6: Cooperative Spectrum Sensing Structure in a CR network [13]

2.3 Non-cooperative Spectrum Sensing

This technique of CR allowed each user to identify a white space individually and make decision if a particular channel is free or busy base on the sensing data information, then reconfigure the CR for data transmission. The various approach applicable are: matched filter (MF) detection, energy detection and Cyclostationary detection [31] [32].

2.4 Optimization in Cognitive Radio (CR)

The main challenge in any CR system is to maximize SU's throughput while limiting interference imposed on licensed users. In this consideration, finding the optimal sensing and transmission timing strategies and accurate sensing techniques are of great importance in a CR network [15]. To obtain an optimal sensing value under a given circumstance, optimization algorithms are applied [33]. Optimization can be defined as an effort of obtaining optimal solution to a problem under bounded circumstances, it aroused from the desire to utilize existing resources in the best possible way [34]. A comparative study of the performance of the standard version of Artificial Bee Colony (ABC) algorithm was compared with those of other well-known population-based algorithms employed for numerical optimization problems, that is Generic Algorithm (GA), Particle Swarm Optimization (PSO), Differential Evolution (DE), and Evolution Strategies (ES) optimization algorithms.

2.3 Comparing Artificial Bee Colony (ABC) with other well-known population-based algorithm.

Table 2. Provides a comparison between Artificial Bee Colony (ABC) with other well-known population-based algorithm for numerical optimization problems [35].

Table 2: Comparison between Artificial Bee Colony (ABC) with other well-known population-based algorithm

GA, DE, PSO, & ES	ABC
GA & DE employ crossover to produce candidate solutions from present once.	ABC produces the candidate solution from it presents by simple operation based on taking the difference of randomly determined parts of the present. This process increases the convergence speed of search into local minimum.
In GA, DE, & PSO, the best solution found so far is always kept in the population and it can be used for producing new solution in case of DE & GA, while producing new velocities in the case of PSO	In ABC, the best solution discovered is not always held in the population since it might be replaced with a randomly produced solution process between the candidate and the parent solution
GA has at least three control parameters (crossover rate, mutation rate,generation gap) DE has at least two control parameters (crossover rate, sealing factor) PSO has three control parameters (cognitive, social factors, initial weight)	The ABC has only one control parameter (limit). The description of the expression for determining the value of "limit" depend on population (colony size) and dimension of problem (MCN)
In GA or DE, mutation process creates a modification on randomly selected part of a solution to provide required diversity in the population	The ABC algorithm has mechanism that provides a global search ability and prevents the search from premature convergence problem by removing a whole solution in the population and then a new one produced randomly and inserted into the population by a scout.

3. Literature Review of Spectrum Sensing in Cognitive Radio Networks

[8] Proposed a novel network structure to separate the task of spectrum sensing from the SUs, and was aimed to overcome the major challenge in CR of HTP. The sensing devices were placed within the PU's networks for sensing the PU's activity to decide whether to admit SU and maintain the link quality. A low-interference-temperature handshake technique was proposed for communications between the SUs and the sensing devices to enable the handshake mechanism and prevent the conflict with the PUs. The problems of optimally locating a sensing device so that the collision probability was less than a threshold was analyzed using the theory of Lame curve and minimizing the number of sensing devices under the constraint of the maximal collision probability were studied and solved. The replacement of spectrum sensing device from the SU separately will increase communication overhead between the SUs and will reduce the system throughput.
[24] Addresses the issue of tradeoff between sensing time and throughput during PU detection which leads to a longer sensing time and lowered the achievable throughput. The research proposed a particle swarm optimization (PSO)-base scheme for an in-band local spectrum sensing by using methodological analysis, a fast convergence PSO (FC-PSO) scheme was derived by implementing a distribution-based stopping criterion subjected to detection performance, optimization time and SUs gain. The FC-PSO was said to have outperformed other optimization scheme in terms of convergence speed, and there was significant improvement of approximately 45% for sensing time, 70% for the probability of false alarm and 12% for achievable throughput compared with the non-optimal sensing scheme at SNR of 0dB. But cooperative spectrum sensing was not considered for decision making which may give a better sensing time and an improved system throughput.

[5] Considered the resolution of the HTP by using two models of the probability based primary signal detection and the Drake's equation models. The two models were designed to minimize the false alarms. This contribution includes the signal detection model by adjusting the parameters of Drake's equation to space occupancy of primary signal, and eliminating the HTP. The research reported that the Drake's model maximized the detection rate, but Drake's equation with probability-based model performed better than the basic probability-based model in detecting the weak signal (low strength signal). The accuracy of the signal detection can depend on the spectrum sensing time which will justify the effectiveness of the combined models in detecting the signal in terms of the system throughput, but it was not considered here.

[6] considered a channel access problem for PUs in CR network when there was no central controller in the network and proposed an Ordered Channel Assignment (OCA) and was achieved by searching the channels sequentially from the beginning, the first available channel was assigned when a request arrives from a PU. Optimal strategies based on Partially Observable Markov Decision Process (POMDP) framework was derived and three greedy policies were proposed for lower complexity but with less reward. The research reported that SUs obtained less benefit from unused channels, this may be as a result of absent of central controller which will lead to having collision among SUs and consequently reduce the throughput among SUs.

[27] Observed the challenges of reporting overhead which comes with CR network when collaborative sensing strategy is adopted. The research proposed to design a sensing management scheme for CR network, while taking the reporting overhead into account and first formulating an optimization problem that aimed at finding the optimal number of sensing stations which collaborate to maximized the PU detection probability for a given sensing/reporting time. The scheme coupled with the proposed collaborative sensing, where the sensing interval and the number of consecutive alarms for triggering channel switching are jointly optimized. However, the said efficient sensing management scheme could not show its effectiveness in terms of throughput between SUs during data transmission. Therefore, their work will experience communication overhead as sensing time is not taking into consideration and that will consequently reduce the network throughput.

[10] Proposed a cluster-based optimal selective cooperative spectrum sensing scheme which utilizes an efficient selective method for the best quality sensing data and a parallel reporting mechanism for reducing reporting time while maintaining a certain level of sensing performance. The said selective method, which was adopted in the cooperative communications, was applied in each cluster to implicitly select the best sensing node during each sensing interval as the cluster header without additional collaboration among cooperative users. Clusters were organized based on the identification of primary signal SNR value, and the cluster head in each cluster was dynamically chosen according to the sensing data qualities of CR users. For implementing the proposed selective mechanism in a cluster, all cooperative users (CUs) in a cluster have to monitor the control channel to determine the cluster header during the contention time. A parallel reporting mechanism based on frequency division was proposed to considerably reduce the time for reporting decision to fusion center (FC) of clusters. The FC would have combined all cluster decisions to make a final decision and broadcast the final sensing decision to the whole network. The work will experience large communication overhead as a result of monitoring the control channel by all CUs in each cluster and the high level sensing performance is not express in terms of the sensing time and throughput.

[14] proposed a system for spectrum sensing in CR using time domain method with the intention to compare the analysis and results obtained from the time domain and the on obtained from frequency domain using new threshold formula in energy detection method. The proposed system used energy detection method for the detection of signals which was independent of modulation and was used for transmission of signal, phase or any other parameter. It simply tells if the radio resource is available at any given time instant or not, parameter assumptions were made for their system modelling. The research work said the time domain analysis gave a best detection at a lower noise level for number of users as per threshold formula, as per analysis of probability of false alarm and as per analysis of SNR. But optimal value of the sensing time was not considered to show the efficiency of the energy detection method using time domain for the spectrum sensing.

[13] considered a CR network composed of CRs (secondary users) and a common receiver (Fusion Center, FC) by assuming that each CR performs spectrum sensing independently, and then the local decisions were sent to the FC which can fuse all available decision information to infer the absence or presence of the PU using a binary hypothesis-testing. The optimality of the cooperative spectrum sensing was investigated with an aim to optimize the detection performance in an efficient and implementable way to minimize the TER and eliminate the HTP. The optimal voting rule was derived for any detector applied to CSS with an expectation to find out the number of Value of voting rule (Ks). Also, detection threshold was optimized when energy detection is employed. Finally, a fast spectrum sensing algorithm for a large network was proposed which requires fewer than the total number of CRs in cooperative spectrum sensing while satisfying a given error bound. However, the sensing time was assuming to be smaller than the coherence time of the channel, while the sensing channel was viewed as time invariant during the sensing process, but this bases of comparison is not the best for validation and it should be justified by quantifying the value of the collision probability between SUs and the achievable throughput.

[29] considered the problem of cooperative spectrum sensing scheduling (C3S) in a CRN when there exist multiple primary channels, with a focus on scenario in which each SU has the freedom to decide whether to participate in CSS; if not, the SU becomes a free rider. Such a mechanism would conserve the energy for spectrum sensing at a risk of sacrificing the spectrum sensing performance. A coalition formation algorithm based on the channel status was developed, where each SU always chooses the coalition that brings the most information regarding the status of the corresponding channel, since there exist multiple primary channels, each contributing SU needs to determine which channel to sense, this method effectively reduces the uncertainty of the channel status. However, if an insufficient number of SUs participate in spectrum sensing, the sensing performance may not be guaranteed, which may result in poor throughput for all the SUs. Therefore, an optimal sensing time is required to enable a good number of SUs to participate in the spectrum sensing since an accurate sensing result will increase the certainty of the SUs.

[7] Proposed to investigate a wideband spectrum sensing for multiband CR to opportunistically detect spectrum holes without causing harmful interference to primary sub-channels by measuring the energy in the wideband. The research introduces a probabilistic spectrum access method, which assigns a probability for CR signal transmission over each primary sub-channel. Each primary sub-channel was classified into vacant or occupied via the definition of a spectrum access probability for CR transmission, in contrast to absolute sub-channel classification used in classical wideband energy detection. Then derived the secondary information rates achieved by their proposed spectrum sensing method and compare it to those provided by classical wideband spectrum sensing. An optimal power allocation was performed to maximize the CR achievable rates constrained on the total power and interference introduced to the primary network, sensing time was not considered in maximizing the CR achievable data rate which is key to the spectrum sensing and improving the throughput among the CR users.

[30] Proposed a solution for the problem of spectrum sensing in CRNs with the aim to increase the performance of the cooperative spectrum sensing. A cooperative spectrum sensing with detection based on two summary statistics was designed, including energy and first-order correlation of the received samples of the signal. The probabilities of detection and false alarm were obtained as criteria for evaluating the performance of the CRNs and presented through simulations. It was shown that the proposed method significantly improves the detection performance in cooperative spectrum sensing and highly decreases the probability of miss-detection in comparison with the traditional energy detection method. The effectiveness of the performance of the parameters of the scheme can also be justify on the spectrum sensing time which is not considered the work and be evidence on the system throughput.

[25] Considered the collision which may occur between SUs during the transmission process when the SUs finds a spectrum hole and can lead to decreased in the throughput of the samples of the SUs. To solve the said problem, the paper proposed a mathematical expression for collision between samples of the SUs using Poisson distribution with the aim of increasing the throughput of the samples of SUs. The optimization of the sensing time was done using a Human Behavior Based Particle Swarm Optimization (HBPSO) with the expectation of minimizing the probability of collision between sample SUs and achieving a high value of system throughput by approximately 90% under different SNR of the transmitter channel. Perhaps, pronounce collision between SUs is due to lack of cooperative scheme for the SUs and when cooperative spectrum sensing with a control unit is used, collision between SUs will be highly mitigated and throughput of SUs samples will be highly appreciated.

4. Conclusion

This paper presented a review of Spectrum Sensing Times in Cognitive Radio Networks, and has provided justifiable techniques for better ways to achieve an improved Spectrum Sensing Times for efficiently utilizing RF spectrum. CR network usually suspend normal data transmission during the sensing of channel and reporting result to FC in cooperative CR network, which can lower the channel utilization. Hence, it is critical to find the optimal levels for procession and cooperation by improving the sensing time T_s in energy detector-based sensing of the CR network which will mitigate the collision between the SUs and increase the throughput of the samples of SUs in a cooperative CR network.

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