
Optimization of Spectrum Sensing Time in a Cooperative Cognitive Radio

By

A. M. S. Tekanyi, J. Raymond, and A. D. Usman

Faculty of Engineering

Department of Communications Engineering

Ahmadu Bello University, Zaria, Nigeria.

Email: raymondjerry5@gmail.com

ABSTRACT

The practical application of Cognitive Radio (CR) is to address the problem of spectral Radio Frequency (RF) under-utilization for wireless communications. One of the basic operation of the CR is the spectrum sensing. This task is associated with challenges of accuracy of detection as a result of Hiding Terminal Problem (HTP) and collision between Secondary Users (SUs) during data transmission process when there is no channel controller. The Cooperative Spectrum Sensing (CSS) deployed to mitigate the HTP, also introduces an additional communication overhead as a result of long sensing and reporting times. The longer the sensing time the more the communication overhead. The reduction in the communication overhead reduces the Total Error Rate (TER). In turn, when the TER is reduced the throughput is automatically increased. This paper presents the optimization of Spectrum Sensing Time in a cooperative CR Network and proposes a better way of achieving an improved Spectrum Sensing Time to efficiently utilize the RF spectrum.

Key words: Cognitive Radio, Cooperative Spectrum Sensing, Spectrum Sensing Time, HTP, probability of collision, and Throughput.

INTRODUCTION

Some of the most important components of CR concept is its ability to measure, sense, learn, and be aware of the parameters such as distance, signal strength, node velocity, operating frequency, protocol, availability of unused spectrum related to the radio channel characteristics, availability of spectrum and power, radio's operating environment, user requirements and applications, available infrastructures and nodes, local policies and other operating restrictions [1]. Report by Federal Communication Commission (FCC) pointed out that more than 70% of the RF spectrum is underutilized [2]. Spectrum scarcity is not due to lack of spectrum, but as a result of static spectrum allocation and much of the licensed spectrum remains unoccupied for large periods of time [3]. Therefore, there is need to effectively utilize this spectrum (RF) to improve its efficiency by allowing unlicensed users to utilize licensed bands whenever it would not cause any interference [4]. The CR is faced with a major challenge of Hidden Terminal Problem (HTP). The HTP in spectrum sensing is subjected to destructive effect of shadowing and deep fading, which lead to false alarms and misdetection problems causing interference the PUs [5]. The HTP occurs when a node is visible from access point but cannot communicate to the node within the communication distance [6]. Hence, this HTP has to be resolved so that the PUs performance is

not impaired and collision between SUs during data transmission is mitigated for a better throughput. Cooperative transmission can greatly improve the spectrum access opportunity as well as sharing efficiency for SUs with the help of cooperative relay nodes [7]. Cooperative Spectrum Sensing (CSS) in CR systems has not only enhanced the reliability of detecting PUs but it is also proven to be a powerful method for addressing HTP in fading or shadowing environments [2]. When HTPs are reduced, Total Error Rate (TER) is also reduced, and throughput increases automatically in a CR network [2]. 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 [8]. This cooperation to eliminate HTP introduces additional communication overhead [9].

The cooperation communication overhead generally increases with the number of cooperating users due to the increased volume of data that needs to be reported to and be centrally processed by the Fusion Centre (FC). The CR model using fusion method performs more accurately and efficiently when experienced with low Probability of false alarm (P_f) and low Probability of missed detection (P_m) [10]. Therefore, the CR network adopting collaborative sensing should manage the number of stations involve in the collaboration and the spectrum sensing time together in order to achieve better PU detection. If the sensing time is reduced, decision making at the FC is faster, and the sensing TER is reduced since the network is dynamic. A number of research has been done on spectrum sensing time among which is [11] addresses the tradeoff between sensing time and throughput during PU detection which leads to a longer sensing time and lowered the throughput. The research proposed a particle swarm optimization (PSO)-base scheme for an in-band 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. A fitness function was introduced to minimize probability of false alarm under constrain of the targeted probability of detection and fixed frame period. The fitness is a decreasing function $Q(.)$ and upper bounded by 1. The parameters of PSO search algorithms were fine-tune in advance to achieve the fastest convergence time. Also, [12] considered the collision which may occur between SUs during data transmission process when the SUs finds a spectrum.

The paper proposed a mathematical expression for collision between samples of the SUs using Poisson distribution to increase 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. The HBPSO was achieved by introducing a new learning rate to enhance exploration and exploitation, a global worst particle in the velocity update equation of SPO were introduced. Also, the acceleration coefficients were removed to improve optimal value and convergence speed of PSO. It is evident from the reviewed research works that CR network has opened more research areas of different challenges. This paper developed an improved technique using an Artificial Bee Colony (ABC) to improve the spectrum sensing time in a cooperative CR. The very fast convergence and very much reliable results of ABC in finding optimal solution, its optimization technique simplicity, less parameter handling, and simple analyzes of the problem are the main attraction of ABC over GA and PSO algorithms in finding

release policy of a reservoir [14]. Some of the advantages of using ABC are: the use of few control parameters (swarm size: the employed bees, onlookers, and scouts), both exploration and exploitation capabilities, ability to handle the objective cost and its high flexibility which allows adjustments. The convergence time of an algorithm characterizes how fast it enters its steady state. The fact of convergence speed implies faster learning and more efficient resource allocation. The group decision-making process used by bees for searching out the best food resources among various solutions is a robust example of swarm-based decision method.

The number of required samples to achieved a given pair of target probabilities (P_d, P_f) is given [12]:

$$N = \frac{1}{S^{\frac{1}{2}}} (Q^{-1}(P_f) - Q^{-1}(P_d) \sqrt{2S + 1})^2 \quad (1)$$

Considering the sampling time as τ , sensing time is derived [12]:

$$T_s = \tau N = \frac{\tau}{S^{\frac{1}{2}}} (Q^{-1}(P_f) - Q^{-1}(P_d) \sqrt{2S + 1})^2 \quad (2)$$

The larger sampling number results in the longer sensing time as seen in equation (2). The average achievable throughput of SUs is [12]:

$$R_n = P(H_0) \frac{T - T_s}{T} (1 - P_f) (1 + S_s) \quad (3)$$

where:

$P(H_0)$ is the probability that PU is inactive in the sensed channel

S_s is the received SNR of SUs transmission at the SU receiver.

When 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 [12]:

$$P_c = 1 - e^{-\frac{T_s}{T - T_s}} - \frac{T_s}{T - T_s} e^{-\frac{T_s}{T - T_s}} \quad (4)$$

The sensing time optimization problem is mathematically formulated as [12].

$$T_s = \frac{\tau}{S^{\frac{1}{2}}} (Q^{-1}(P_f) - Q^{-1}(P_d) \sqrt{1 + S_s})^2 \quad (5)$$

$$s.t \{ P_c \leq \underline{P_c} \quad R_n \geq \underline{R_n}$$

where:

$\underline{R_n}$ is targeted normalized throughput of SUs taken as 85% [12]

$\underline{P_c}$ is maximum allowable probability of collision between samples of SUs taken as 1% [12].

SPECTRUM SENSING

Spectrum sensing is a key function of a CR for identifying the spectrum usage status over a wide frequency range and its most critical performance requirements are accuracy and the time of spectrum sensing [17].

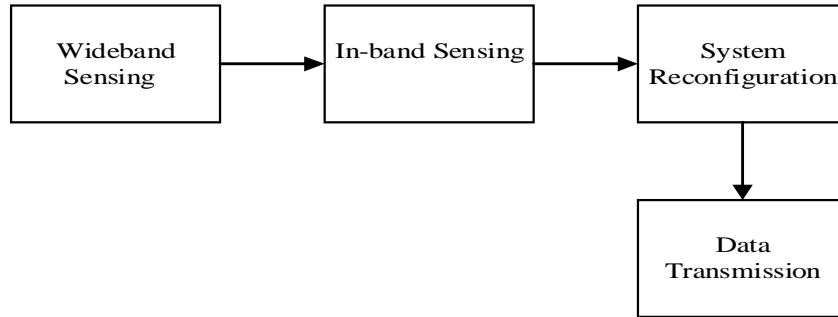


Figure. 1: Spectrum Sensing Stages [11]

Figure. 1 shows a spectrum sensing process of a CR network. CR performs a wideband sensing at its initial, and in the process it identifies a channel unoccupied by PU. Thereafter, in-band sensing is executed in compliance with strict FCC guidelines for protection of PUs [12]. FCC guideline permits unlicensed devices to make opportunistic or dynamic use of spectrum occupied by licensed user when it is temporary unused as long as their operation cause no harmful interference and the device does not generate emission or field strength levels greater than a specified level that is chosen to ensure that the devices generally would not cause interference [20].

Frame Duration

T is Frame duration of complete time of a channel allotted to an SU which comprises the sensing time T_s and the data transmission time T_d as shown in equation (7).

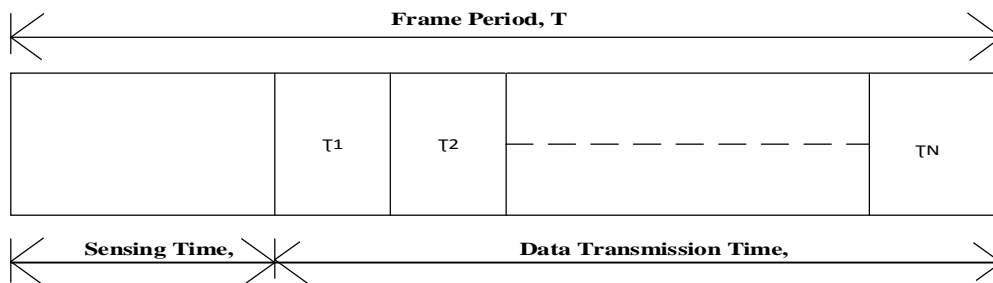


Figure 2: Frame Structure for CR Network [12]

After sensing operation is performed, the SU uses the rest of the time as T_d . During the data transmission of a CR network, the samples of SUs are transmitted following Time Division Multiple Access (TDMA) scheme for occupying a channel during the T_d . sampling times for N number of SU samples during the data transmission $\tau_1, \tau_2, \dots, \tau_N$ are sampling times for the number of SU samples, N as shown in Figure. 2. The frame duration represented as [12]:

$$T = T_s + T_d \tag{7}$$

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 among these candidate bands may be discovered through accurate detection. Sensing performance may be improved by sensing the band for a longer time, thereby increasing signal processing gain [21].

Energy Detection

Energy detection is a spectrum sensing technique that detects the presence/absence of a signal by measuring the received signal power. 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 [22] in Figure 3.

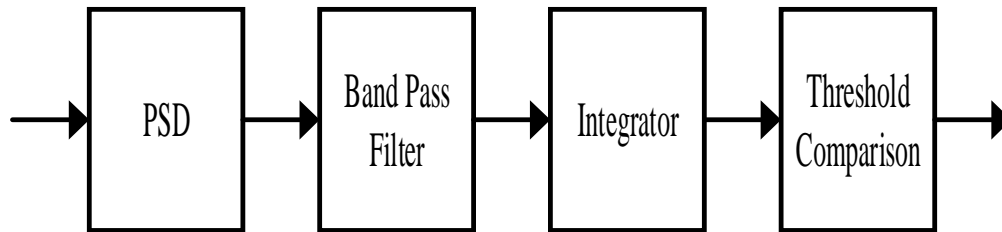


Figure 3. Block Diagram of Energy Detection Process [18]

The hypothesis test for the signal identification is expressed as follows [18]:

(i) H_1 is hypothesis for presence of PU,

$$Y[n] = hx[n] + w[n], \tag{8}$$

(ii) H_0 is hypothesis for absence of PU,

$$Y[n] = w[n], \tag{9}$$

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 H_0 and 1 under H_1).

$w[n]$ is the noise parameter.

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 [12]:

$$Z = \frac{1}{N} \sum_{n=1}^N (Y[n])^2 \tag{10}$$

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 SUs with the help of cooperative relay nodes [7]. Figure 4 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.

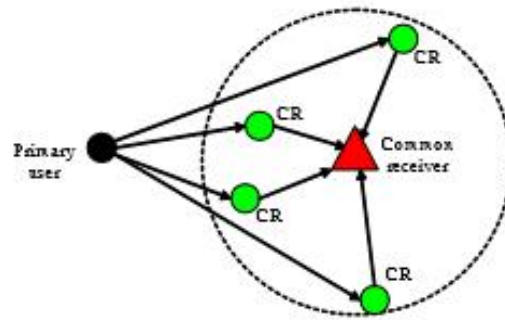


Fig. 4: Cooperative Spectrum Sensing Structure in a CR network [13]

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 [16]. To obtain an optimal sensing value under a given circumstance, optimization algorithms are applied [15]. Optimization can be defined as an effort of obtaining optimal solution to a problem under bounded circumstances [19]. ABC was used for optimizing a large set of numerical test functions and the results produced by ABC algorithm were compared with the result obtained by GE, PSO, DE, and ES. The ABC result was found to be better than those of the other population based algorithm with the advantage of employing fewer control parameters [11].

System Model of the Cooperative Radio

Here the ABC swarm size (the employed, onlookers, and the scout bee) represent the SUs, the food source represent the PUs, while the nectar amount which represent the Spectrum Power Density (SPD) of the PU are initiated on the MATLAB environment.

To achieve the FC, that is, the decision making engine which makes a timely assessment of SPD in terms of PU presence or absence of the available spectrum holes to be exploited by the SU. The allocation of an empty slot are achieved through the waggle dance. This is a method of communication used by the bees to inform other bees about food resources quality/quantity, distance and direction of the nest site. These are achieved by programming the bees to perform such functions. Figure 5 shows the flowchart representation of ABC algorithm for the sensing time optimization.

Simulation Parameters

Simulator	Matlab R2017a
Number of Time slots, T	100
Frame duration, T	224.25 ms
Sampling time, T	0.4 ms
Probability of detection, P_d	90%
Probability of false alarm, P_f	5%

Signal to noise ratio, S	-6 dB to -2.5 dB
Number of iteration	100
MNC	100
Limit	200
Number of required samples	50

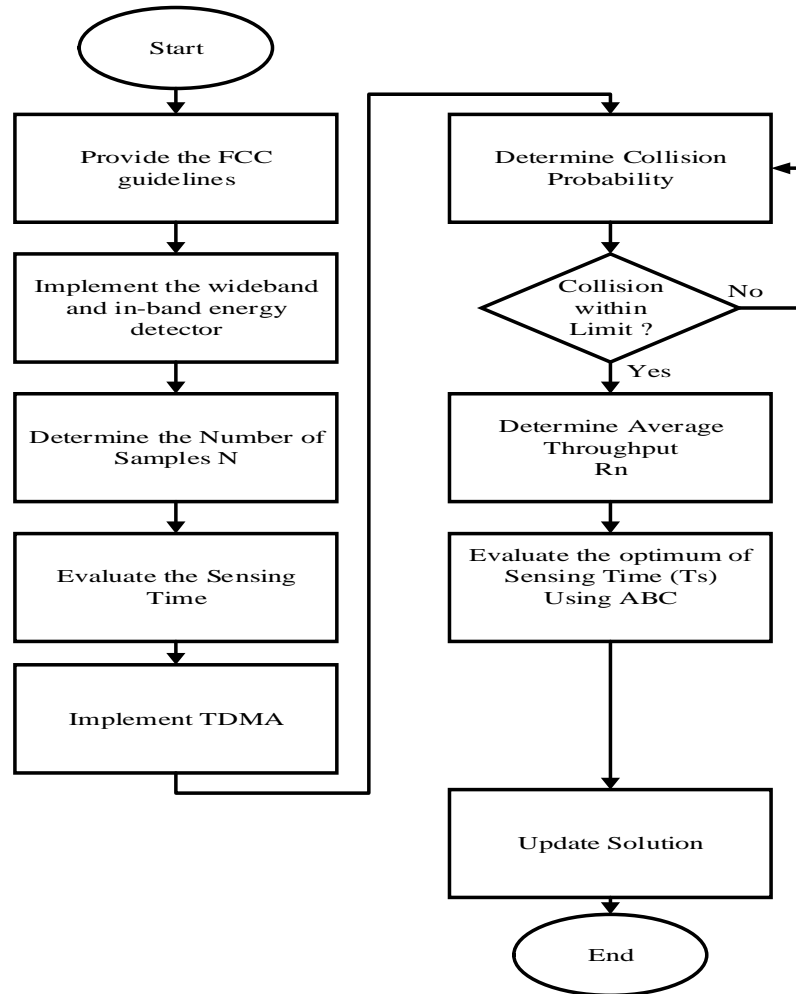


Figure 5: ABC Flow Chart for the Improved Spectrum Sensing Time Scheme

Simulation Results

Table 1 presents the summary of the result using ABC algorithm, the optimal value of sensing time obtained, and its corresponding values of throughput among the SUs and the probability of collision between samples of SUs. The optimal values are obtained by taking the average of each parameter in each of the column through simulation and has been compared with the results obtained by [12] in terms of the sensing time, throughput and probability of collision as performance matrices.

Table 1: Sensing Time Results obtained by ABC Optimization

Sensing Time, T_s (ms)	Probability of detection, P_d (%)	Probability of false alarm, P_f (%)	Sensing S (dB) (worst case)	Probability of collision between SUs, P_c (%)	Normalized Throughput, R_n (%)
13.89	90	2.91	-3.88	0.22	96.34

Figure 6 presents a bar chart showing a clear improvement by comparing the optimal sensing time result obtained by [12] and the result obtained from the developed improved spectrum sensing time scheme of the cooperative CR network as shown in Table 1. The sensing time is improved by 28.75%, that is, from 19.49 ms to 13.88 ms. The reduction in the value of the sensing time indicates a better improvement.

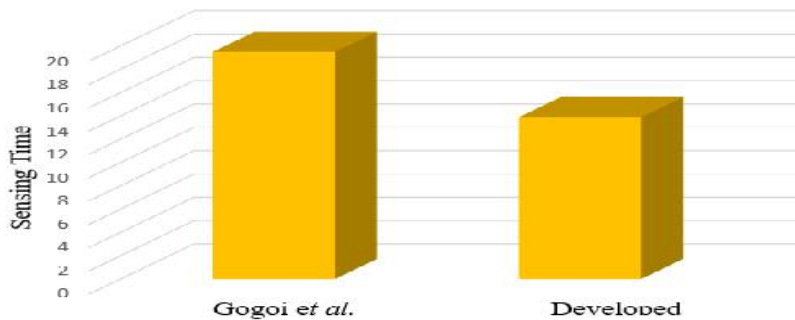


Figure 6: Comparison between the Sensing Time Results obtained by [12] and the Developed Algorithm.

Figure 7 depicts a bar chart illustrating a clear improvement by comparing both results of the normalized throughput obtained by [12] and from the developed scheme as shown from Table 1, the normalized throughput increases from 89.46% to 96.36% which is 7.72% improvement when compared to [12].

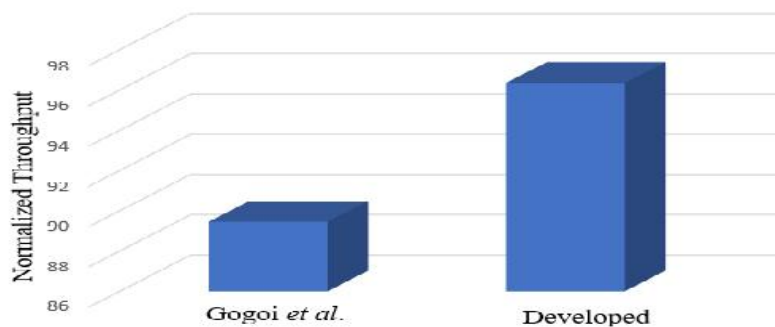


Figure 7: Comparison between the Normalized Throughput Results obtained by [12] and those from Developed Algorithm.

Figure 8 shows a bar chart indicating a clear improvement by comparing the Probability of collision result obtained by [12] and the result obtained from the developed scheme as shown

from Table 1. The probability of the collision among the SUs decreases from 0.57% to 0.22%. This shows an improvement of 61.40% when compared to [12].

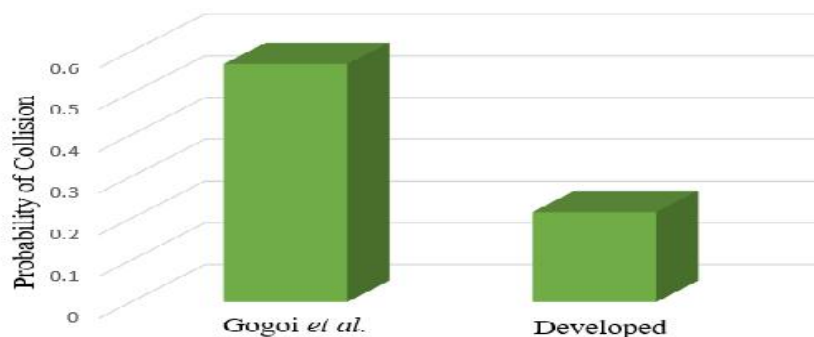


Figure 8: Comparison between the Probability of Collision Results obtained by [12] and the Developed Algorithm.

CONCLUSION

In this paper, an improved spectrum sensing time for efficient resource utilization has been developed using Artificial Bee Colony (ABC) in a cooperative cognitive radio. The ABC technique has improved the spectrum sensing time of the cognitive users, reduced the probability of collision among SUs and increased the average normalized throughput significantly.

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