Optimization of Spectrum Management Issues for Cognitive Radio

(Invited Paper)

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***Abstract* — Cognitive Radios have been proposed as the solution for the problem of underutilization of spectrum by licensed user. Various techniques have been put forward for calculating the spectrum sensing time. These techniques differ on the assumptions to be taken for the sensing time calculations, which lead to the variety of results. Since interference and false-alarms are the primary parameters in calculating the sensing time, hence they must be examined in depth. This paper emphasizes on the role of interference due to various sources and examine the main techniques for calculating the sensing time and also compares the results while keeping in mind the trade-offs that can be feasible.**

***Index Terms* — Cognitive radio, dedicated sensing receiver, sensing time, trade-offs, interferenc, false alarm probability**

I. INTRODUCTION

As the amount of traffic carried by wireless networks is constantly increasing due to rising number of users and new commercially emerging applications often have higher data-rate requirements. In contrast, a multitude of measurement campaigns carried out at various locations all over the globe have shown that spectrum is under-utilized in the time and space [1-3]. Cognitive radio has been proposed as a potential solution for aforementioned problems and its scenarios describe primary users, who hold official licenses to use spectrum band, and secondary users that opportunistically access that spectrum when it is not used by primary users [4]. Thus cognitive radio network is a multiuser system, in which different users compete for limited resources in an opportunistic manner, interacting with each other for access to the available resources. The fact that both users and spectrum holes can come and go makes cognitive radio networks a highly dynamic and challenging wireless environment [5]. In a cognitive radio network, the secondary users are allowed to utilize the frequency bands of primary users when these bands are not currently being used. To support this spectrum reuse functionality, the secondary users are required to sense the radio frequency environment, and once the primary users are found to be active, the secondary users are required to vacate the channel within a certain amount of time. Therefore, spectrum sensing is of significant importance in cognitive radio networks. There are two parameters associated with spectrum sensing is the probability of detection and probability of false alarm. Higher the probability of detection, better the primary users is protected. However, from the secondary users' perspective, the lower the probability of false alarm, the more chances the channel can be reused when it is available, thus the higher the achievable throughput for the secondary network. Various researches have focused on sensing capabilities, for continuous updating for the cognitive radio's knowledge of the environment. This knowledge of spectrum occupancy in time and in frequency domains helps the cognitive radio to better judge whether to use a particular bandwidth or not. The application of this model lies in applying cognitive radio's in specific geographical boundaries. [6]

The spectrum models (time and frequency) or sensing and reasoning algorithms have been presented to enable cognitive radio technology in practicality [7, 8]. This requires the cognitive radio to be able to sense the available frequency spectrum for primary users in addition to other cognitive radios and decide by a suitable transmission frequency. Moreover, once a suitable frequency is found the cognitive radio must be capable of vacating that frequency as soon as a primary user is detected [9]. This task of sensing cannot be assigned to the main receiver which is responsible for transmission and reception of the data. This would lead to a very large sensing time, and the concept of cognitive radio would not be possible, because, with the rising sensing time the probability of the spectrum being occupied again by the primary user would increase. This leads to the concept of a dedicated sensing receiver, also mentioned as the DSR. It can be appointed to choose a certain frequency at which the cognitive radio would transmit the data. Dedicated sensing receiver is solely focused on channel sensing and runs parallel with the main receiver. The dedicated sensing receiver can be a single separate antenna or it can also be an array of antennas working parallel for detection of spectrum holes [10].

In this paper, we have discussed the role of interference due to various sources and examine the main techniques for calculating the sensing time. We also compares the results while keeping in mind the trade-offs that can be

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feasible. This paper is structured as follows. The Section II explains the sensing techniques and elaborates the considerations in deciding a technique and how trade-offs can be made between two parameters (number of antennas and resolution frequency) for obtaining a desired result. The Section III elaborates the formulae for calculation of the sensing time and compares results through simulations. Finally, the Section IV concludes the work.

II. SPECTRUM SENSING TECHNIQUES AND POSSIBILITIES

There are many proposed techniques for spectrum sensing [11]. The basic possibility is to have a receiver which uses one of the various techniques for detection of vacant spectrum, such as energy or feature detection. This approach leads to a very high rate of false alarms [10]. Therefore we choose two-stage sensing methodology where the desired bandwidth is divided into coarse bins which are then further divided into fine bins. The receiver performs a cursory scan of the coarse bins in search of an idle channel. Once idle channels are detected, the receiver proceeds to a more thorough scan of the channels using improvised resolution in order to avoid misdetection or a false alarm, especially, when the primary users of the channel are operating at low signal-to-noise ratio (SNR) [12]. It has been observed that the sensing time is reduced to a great extent when we use a dedicated sensing receiver along with the conventional receiver within the cognitive radio. The responsibility of sensing the spectrum is equally divided among both the receivers. There is a Look-up-Table (LUT) [6] attached to the dedicated sensing receiver which updates the range of spectrum to be sensed. There are two types of sensing algorithms along with dedicated sensing receiver. (i) Course sensing [6, 13] where only those ranges of frequency are sensed in which the cognitive radio is allowed to operate. These ranges include military, aerospace and many other ISM ranges. This reduces a lot of time in sensing, and the other is (ii) Fine sensing [10, 13, 14] which senses the range of frequencies being specified after the coarse sensing is over. Coarse sensing depends on the information available in the LUT. The sensing receiver classifies the users as primary and secondary. It must be noticed that to have a dedicated sensing receiver, costs an undesirable cost in chip area and power consumption. Another approach would be to integrate the sensing hardware into the main receiver [7, 8]. But this proves to a hinder in our objective to reduce sensing time and rate of false alarms. Henceforth, all calculations and simulations in this paper have been done using a dedicated sensing receiver.

There are various detection techniques available in the literature [15]. We would first see to it that we understand the pros and cons of each before finalizing on a certain specific methods. Energy Detection and feature detection are the most commonly proposed techniques and give better results when we have a common receiver and no dedicated sensing receiver is used [7, 16]. Energy detection is an effective method of determining if energy is present within the measurement bandwidth. The measured energy does not differentiate between a modulated signal and noise. Feature detection on the other hand, exploits the periodicity in modulated signals. Cyclo-stationary feature detectors are used for this purpose. The modulated signal is riding on a carrier with built in periodicity. Hence its random processes characteristics also display periodicity. Cooperative sensing is the technique has lately gained the interest of the researchers. It defines two protocols. First is non-cooperative (NC) protocol, here all users detect the presence of primary user and the first one to detect informs the other users through the central controller (distributed sensing). The second protocol it defines is totally cooperative (TC) protocol, here two users patch up together and keep updating each others table for new status of different bandwidths. Although these techniques differ in implementation they sense all the coarse bins in series. At a given time and resolution only one bin can be scanned. Since dedicated sensing receiver is into play it may also happen that we have coarse sensing by one type of detection technique and fine sensing by another [17].Thus for fast scanning, dedicated sensing receiver uses non coherent energy detection to complete coarse sensing before it proceeds to fine sensing. The most common approach in fine sensing is to perform Fast Fourier Transform (FFT). As FFTs are computationally intensive [7], and with increase in the resolution the power consumption and the time taken for computations increases an adaptive FFT is used in which the number of FFTs vary with the operating conditions. Apart from these considerations, we have to consider various practical tradeoffs such as number of antennas, the appropriate coarse resolution bandwidth etc. Our first concern is - How the number of antennas impact the sensing time? It is logical that system should have as many antennas as possible. If the transmitter is considered, more number of antennas implies that higher data rates through spatial multiplexing. The disadvantage of increasing the number of antennas is a substantial penalty in chip area and power consumption due to the required replication of the transmit receiver chains [18]. Now, for the coarse resolution sensing bandwidth, we just need to focus on choosing the value of total number of fine bins (alpha) is the number of channels available for fine sensing after coarse sensing. Note, for a small number of antennas a large value of (alpha) is best and vise-versa. Next we analyze the number of FFT points. The FFT computation is one of the major contributors to the sensing time which implies that the FFT should have as few points as possible. The interferences which can be categorized into three categories as Co-channel, Adjacent channel and External Interference, play a major role. These interferences play spoilsport by causing false positive alarms in when sensing the bandwidth occupancy. Hence, a certain geographical specific threshold must be applied to account for the reduction in the number of false positive and yet maintaining a low sensing time. For example, the optimal number of coarse bins decreases with an increase in SNR and optimal number of fine bins increase with the increased interference in the band.

III. CALCULATION OF OPTIMAL SENSING TIME

We first describe the different notations required for the calculation of sensing time. The table below shows the practical values for certain parameters and describes the variables.

Now, the time taken by the system to perform one DFT (Discrete Fourier Transform) is given by:

$$T_{DFT} = \frac{1}{F_{DSP}}\left[4N\log_2(N) - 6N + 8\right] \qquad (1)$$

N here is the number of FFT points, or points that take inputs. If this is multiplied by the number of coarse bins and the number of FFT points in one coarse bin. We get the time for coarse sensing by:

$$T_{CRS} = \frac{B_{SYS}}{\alpha M N_{crs} F_{res} F_{DSP}}\left[4N_{crs}.\log_2(N_{crs}) - 6N_{crs} + 8\right] \qquad (2)$$

Once this has been accounted for, we do the same for fine bins, and the expression stands out as:

$$T_{FIN} = \frac{\alpha.\beta.\rho}{F_{DSP}.M}\left[4N_{fin}.\log 2(N_{fin}) - 6N_{fin} + 8\right] \qquad (3)$$

Now, the processor needs some initializing time and that is taken to be 1.1 ms [12]. We also need to account for the *phase lock loop* time for both fine and coarse sensing.

$$\begin{aligned} T_{SYS} = &\frac{B_{SYS}}{\alpha M N_{crs} F_{res} F_{DSP}}\left[4N_{crs}.\log_2(N_{crs}) - 6N_{crs} + 8\right] \\ &+ \frac{\alpha.\beta.\rho}{F_{DSP}.M}\left[4N_{fin}.\log 2(N_{fin}) - 6N_{fin} + 8\right] \\ &+ T_{init} + \frac{\alpha.\beta.\rho}{M} T_{PLL\_fin} + \frac{\beta}{M} T_{PLL\_crs} \end{aligned} \qquad (4)$$

Now, in the expression for phase lock loop time, we find it to be inversely proportional to the number of antennas. But we must consider the fact that as the number of antennas increase, the synchronization problem comes into play. Therefore as proposed by [10], we should not discard the phase lock loop time even for large number of antennas. We shall assume in case of large antennas this expression would account for the time wasted in synchronization, i.e. it will then be like a penalty metric.

TABLE I: SIMULATION PARAMETERS

B_{sys}	System frequency of operation
B_{crs}	Coarse sensing frequency bins
B_{fin}	Fine sensing frequency bins
F_{DSP}	DSP frequency
F_{res}	Sensing resolution
VCO control voltage	1V
PLL maximum phase jitter	1.0 deg rms
ρ	Percentage yield of candidate channels after Coarse sensing
Percentage of coarse-bins known as bad channels	30%
Number of fine channel scanned between frames during normal cognitive radio operation	100
N_{crs}	FFT points for coarse mode
N_{fin}	FFT points for fine mode
M	Number of antennas
F_{res}	10KHz
N_{crs}	128 points
N_{fin}	1024 points
T_{PLL_crs}	0.6 ms per channel
T_{PLL_fin}	0.35 ms for a single fine step of 10MHz

Now, we shall assign values to the above defined terms and run simulations accordingly to study patterns of how probability of false alarm affects the average detection time. Also we will see the trade off between number of antennas and the total system bandwidth. Eq. (1) represents the total time to perform a DFT [10] where F_{DSP} is the Digital Signal Processor's operating frequency. Eq. (4) represents the total sensing time of the receiver [19] .the following values have been assumed for our simulations. Further, we deduce the values of coarse and fine bins as follows:

$$\beta = \frac{B_{SYS}}{B_{cts}} = \frac{10GHz}{100MHz} = 100 \qquad (5)$$

$$\alpha = \frac{B_{crs}}{B_{fin}} = \frac{100MHz}{10MHz} = 10 \qquad (6)$$

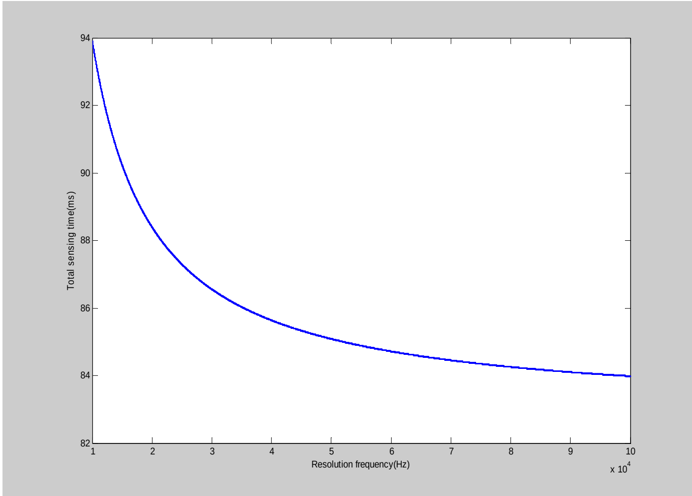
The number of coarse bins and fine bins are given by Eq. (5) and (6), respectively [6]. A quick search which is done via the analog detector, considers only 70 useful coarse bins. Considering that 40% of the measured channels are considered good, β is equal to 28. T_{init} which is the initial lock time is taken as 1.1 ms. Number of antenna is varied. F_{DSP} (Digital Signal Processor's operating frequency) is equal to 100MHz, then the fine sensing effort is equally divided by the main receiver and the dedicated sensing receiver. The total sensing time given by Eq. (4) is 93.9 ms for M=2. In Fig 1(a) it can be observed that as the resolution frequency starts to increase, the sensing time decreases, but as the sensing time decreases, the rate of false alarm may go very high [12]. Hence, to achieve a trade off between the two a multi resolution two stage sensing technique can be used.

Now, if we wish to keep the resolution high but do not want false alarms, we may increase the number of antennas. But at the expense of coupling effect, mentioned in Section 2. From Fig 1(b), it can be observed that as the number of antennas increases, the sensing time decreases. It must be noted that as the number of antennas increases the probability of false alarms does not increase. Hence, the drawback faced by increasing the resolution frequency is overcome. Therefore in Fig 2, we study the variation of sensing time with respect to number of antennas and resolution frequency**.** The reason to do so, can be understood as follows. In Fig 1(a) with M = 2 and resolution frequency at 10 KHz, we get the total sensing time as 94 ms, the same can be verified in Fig 1(b). We assume certain resolution frequency, Fig 1(a) gives us a desired value of total sensing time for that assumed value of resolution frequency. Similarly, we assume a certain number of antennas and Fig 1(b) will give us the value of total sensing time for that assumed value of number of antennas. But, we cannot infer what would be the value of the total sensing time if we use these values of number of antennas and resolution frequency together. These two parameters, resolution frequency and number of antennas behave differently when it comes to working as a one factor i.e. as a combination. It could be a possibility that we may require the sensing time to be of 94 ms but do not want the resolution frequency to be 10 KHz. For this, we have plotted a graph in Fig 2, from which optimal combination of number of antennas and resolution frequency can be deduced. We can observe that the total sensing time rises exponentially with the combination of antennas and resolution frequency. But with any one of the three axis values given, we can choose an optimal combination of the other two from Fig 2.

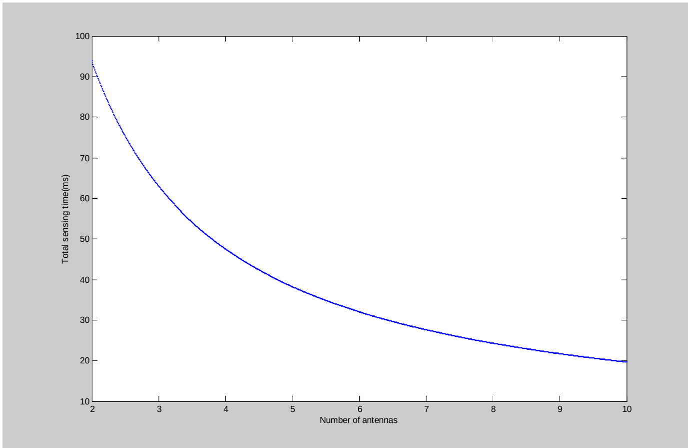
The combination of resolution frequency and number of antennas gives us a desired and practical combination of a total sensing time. We must also keep in mind that playing with resolution frequency has a direct relation with the probability of false detection. The resolution frequency would change the P_d (probability of detection), it would become virtually very high, i.e. even if there is a primary user present the spectrum would be detected as vacant. We can logically deduce that resolution frequency is directly proportional to probability of false alarm and indirectly proportional to P_d. Therefore, we see the effect of probability of false alarm on the average sensing time.The average sensing time (or detection time) is directly proportional to the probability of false alarms and inversely to the probability of detecting a vacant spectrum. It can be expressed as:

$$T_{\det} = \frac{(\beta - L)JP_{fa} + \beta}{P_d(L+1)} \tag{7}$$

Here, P_{fa} gives the probability of false alarm which is a gamma function dependant on the system bandwidth and time allocation for sensing [12]. J is the penalty matrix which accounts for the time wasted in initializing the system again once a false alarm is set, it is assumed to be 2. L is the number of vacant bins or idle bins, which is assumed to be 20 as 705 of the bins are available in a 30% loaded band (as assumed in the table). Similarly, P_d is calculated to be 0.7. Figure 3 reveals that average detection time has a liner relation with the probability of false alarm.



(a)



(b)

Figure 1 Variation of the total sensing time with (a) the resolution frequency and (b) the number of antennas of the cognitive radio network.

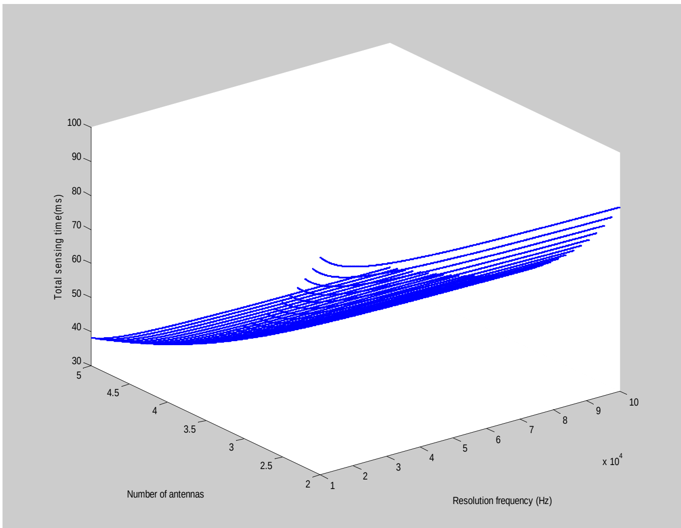


Figure 2 Variation of the total sensing time with the number of antennas and resolution frequency of the cognitive radio network

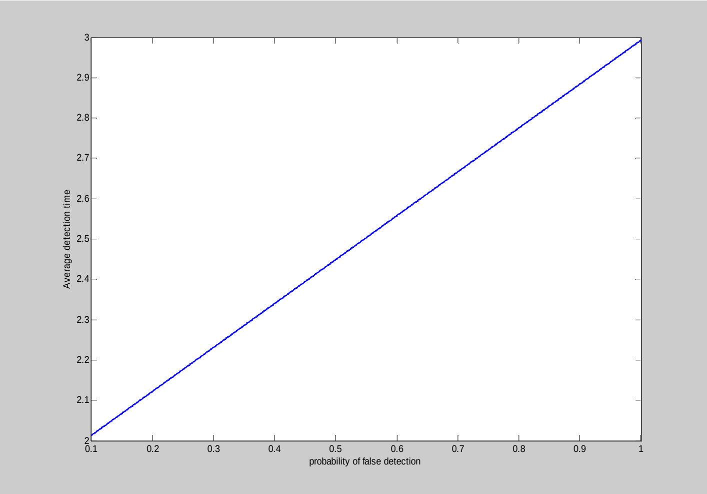


Figure 3 Variation of the average detection time with probability of false detection of the cognitive radio.

IV. CONCLUSION

In this paper, we have explored various issued related to the spectrum management of cognitive radios, as well as we worked out the tradeoff between resolution frequency and number of antennas. The relation between false alarm probability and average sensing time is explored and its relation with resolution frequency is examined. We have presented an analytical comparison of the multi-antenna and two antenna sensing techniques. Finally, the phase lock loop time in terms of total sensing time expression has been justified.

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