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Towards faster spectrum sensing techniques in cognitive radio architectures

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Abstract

In the recent years, the subject of spectrum sensing techniques has been well studied in research community, highly motivated by the emergence of cognitive radio architectures. But in practice, given the complexity of proposed spectrum sensing techniques, the implementation of cognitive radio has become a tedious task. Unlike many papers in the literature, this paper focuses on implementation aspects of spectrum sensing. Especially, we attempt to reduce the time taken for spectrum sensing based on adaptive FFT approach employing statistical analysis. The first step of the many spectrum techniques is to obtain the FFT of input samples. Most of the existing spectrum analyzers like Tektronix RSA6000, Rohde & Schwarz FSVR etc employ detection and estimations algorithms based on the FFTs of the acquired samples. In this paper, we propose an algorithm to vary the FFT-size to obtain the spectrum information at a faster rate, applicable to cognitive radio environment. FFT size would be varied in accordance with statistical information obtained from the prediction engines. The proposed Adaptive FFT algorithm is studied as applied to the well known energy detection technique. Finally an implementation is carried out on USRP based on GNU Radio platform.

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Keywords: spectrum analyser;energy detection;adaptive FFT based algorithms;doubly cognitive radio architecture; dynamic spectrum access;

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1. Introduction

The term, "spectrum drought" coined by former U.S. Federal Communications Commission (FCC) chair William Kennard explains the severity involved in the scarcity of spectrum resources. This ever increasing demand for spectrum can be attributed to the explosion of smart wireless devices such as smart phones, tablets etc. These devices would require data rich content to be transceived (transmitted and received) on wireless channels at a very high data rate. Such high bandwidth applications consume huge amounts of spectrum, leading to spectrum scarcity. Envisioning the spectrum crisis problem, J Mitola proposed the concept of Cognitive Radio in 1999[1].Since its emergence, the cognitive radio concept has been the topic of vivid interest in the research community. In the entire cycle of cognitive radio, the most fundamental step is to precisely sense the spectrum. Before we discuss further, some of the terminologies that are used throughout the paper are depicted in nomenclature.

Nomenclature

CR	Cognitive Radio
PU	Primary User
SU	Secondary User
SS	Spectrum Sensing
ED	Energy Detection
SNR	Signal-to-Noise ratio
ROC	Region of Convergence
FFT	Fast Fourier Transform

SS techniques can be broadly classified into two approaches: data base centric approach and dynamic spectrum access approach. In data base centric approach, the spectral occupancy information is clearly defined.eg. Google spectrum database [12] and Specobs database from University of Washington [13]. A more complex and sophisticated approach is the dynamic spectrum access, where in the spectrum is dynamically sensed for the presence of the primary user. Till now, both these approaches are complementary to one another. In this paper, we try to enhance the pace of spectrum sensing by combining both the approaches. A prediction engine is employed to statistically analyze the spectral occupancy information (similar to data base), followed by dynamic spectrum sensing approaches to reduce the time taken for spectrum sensing.

SS is a critical aspect for the implementation of CR. The performance of the CR can be directly judged from the performance of the employed SS technique. There are many metrics to validate the performance of a SS algorithm, the standard metric being the ROC curves under different SNR conditions. In this paper, we would validate the algorithm from the system building view point by considering the overall latency of the system. That is, we would focus upon the time taken by for spectrum sensing as the metric to compare between two algorithms. This standpoint is valid and critical especially when the SS systems are built to sense the wider spectrum[4, 5]. A system that employs doubly cognitive architecture[6] is chosen. We then apply the adaptive FFT scheme to minimize the latency of the system, which is discussed in detail in the further sections. Simulations clearly show the improvement in the performance of the system without affecting the ROC curve performance.

A spectrum sensing algorithm can be implemented in any of the multiple dimensions[3]: frequency, time, space, code, angle etc. There are several algorithms proposed for each of these dimensions. Most of the techniques are difficult to implement in practice. Irrespective of the chosen dimension, the basic step in almost all the techniques is to sample the input and perform the FFT before any further processing. This suggests that the algorithm proposed in this paper can be applied to various categories of SS algorithms. In this paper, we confine our discussions to energy detection(ED) algorithm.

The rest of the paper is organized as follows: section 2 presents the motivation, the proposed algorithm with necessary simulations are presented in section 3, the implementation with results are presented in the section 4, followed by future work and conclusion in section 5 and section 6 respectively.

2. Background

2.1. Doubly Cognitive Radio Architecture[1]

The basic motivation behind our work is to improve the performance of the doubly CR system proposed in reference 11. The idea of doubly cognition can be summarized into two steps:

- Introducing a prediction engine, learning from the pattern of the ambient parameters with respect to various transmission parameters using machine learning techniques.
- Cognitively setting up the system parameters to achieve the optimum performance on SDR.

A complete test bed has been developed on USRP in 2.4GHz band and satisfactory results are obtained[11]. Energy detection technique was applied in the test bed. In the current paper, we attempt to reduce the latency of the implemented by using the statistical data obtained from the prediction engine. In particular, the fact that the length of the observation vector can be varied inversely in accordance with observed statistics (spectral occupancy probabilities) is the key finding. This is discussed in detail in section 3 and implementation is performed on USRP kits using GNU Radio platform (presented in section 4).

2.2. Statistically assisted multi resolution approach

Multi-resolution approaches for Cognitive Radio have been treated in the recent literature[7, 8, 9]. Although different methods have been applied in their papers, the basic idea is the same. The total bandwidth is first sensed using a coarse resolution. Fine resolution sensing is performed on a portion of the interested bands for Cognitive Radio. In such a way, CR avoids sensing the whole band at the maximum frequency resolution. Therefore, the sensing time is reduced and the power has been saved from unnecessary computations. Hur et al.[7] proposed a wavelet based multi resolution sensing technique in the analog domain. Neihart et al.[8] discuss an FFT based multi-resolution spectrum sensing for multiple antenna Cognitive Radio. The literature which comes closer to our algorithm would be reference 9[9]. While the reference 9 presents a progressive multi resolution approach, we propose an algorithm based on machine learning based prediction techniques.

3. Proposed Algorithm

3.1. System architecture

In our algorithm, the system under discussion is the doubly cognitive radio architecture proposed in reference 11. A simplified version of a spectrum sensing system with the important modifications (in order to implement the proposed algorithm) is presented in the fig. 1. While most of the blocks are same for any spectrum sensing system, the adaptive FFT resolution enabler block is imparted into the system to achieve our goal. This block contain two sub blocks, Mapper block and prediction engine. Prediction engine is spectrally trained SVM that provides spatial and temporal information about the spectral occupancy of the primary user (PU) in cognitive radio scenario. Mapper block maps the incoming samples to the corresponding resolution from the prediction engine. In practice, the enabler block is a software package.

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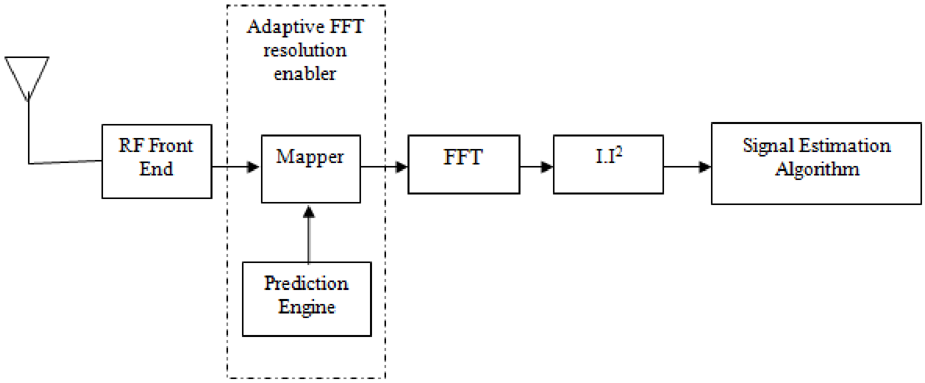

Fig 1: The system implementation of the statistically assisted multi resolution FFT based CR architecture

3.2. Algorithm

The fig. 2 depicts the proposed algorithm.

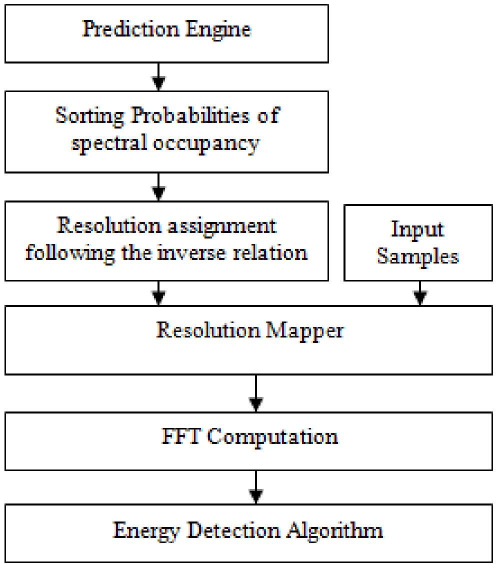

Fig 2: The proposed algorithm

The prediction engine outputs the probabilities of spectral occupancy of various bands available in the given spectrum. The probabilities are sorted in the increasing order. The FFT resolutions of each of the bands are assigned in the decreasing order. The mathematical reasoning in presented the section 3.3. Then resolution mapper maps the resolutions to the respective band samples. It is followed by FFT computation and energy detection algorithm. The implementation is presented in section 4.

3.3. Analysis employing energy detection technique

The standard energy detection technique[3] is presented in order to understand the importance of the observation vector N. Let us assume that the received signal has the following simple form.

$$y(n) = s(n) + w(n) \tag{1}$$

where s(n) is the signal to be detected, w(n) is the additive white Gaussian noise (AWGN) sample, and n is the sample index. The decision metric for the ED algorithm is given by

$$M = \sum_{n=0}^{N} \left| y(n) \right|^2 \tag{2}$$

where N is the size of the observation vector. Two hypotheses are defined based on the comparison between decision metric M and a fixed threshold $\lambda_{E.}$

$$\begin{aligned} H_0 &: y(n) = w(n) \\ H_1 &: y(n) = s(n) + w(n) \end{aligned} \tag{3}$$

Probability of detection P_D and probability of false alarm P_F are defined respectively as per (4) and (5).

$$P_D = \Pr(M > \lambda_E / \mathrm{H}_1) \tag{4}$$

$$P_F = \Pr(M > \lambda_E / \mathrm{H}_0) \tag{5}$$

In practise, a threshold is chosen in accordance to the noise variance level. If white noise and signal are modelled as a zero-mean Gaussian random variable with variances σ_w^2 and σ_s^2 respectively, the decision metric M follows chi-square distribution χ_{2N}^2 with 2N degrees of freedom and the decision metric M can be stated as

$$M = \begin{cases} \dfrac{\sigma_w^2}{2} \cdot \chi_{2N}^2 & H_0 \\ \dfrac{\sigma_w^2 + \sigma_s^2}{2} \cdot \chi_{2N}^2 & \mathrm{H}_1 \end{cases} \tag{6}$$

So we can infer that the metric has degrees of freedom dependent on observation vector N. In addition, in reference 10[10], the decision metric is the power level at the output of the FFT of an incoming signal is compared with a threshold value in order to identify the used TV channels, which is obviously dependent on the observation vector N. Since in a cognitive radio environment, the observation vector N can be varied in accordance with the spectrum scanning requirements, this feature can be exploited to decrease the overall latency of the system. A prediction engine is trained for the spatial and temporal information of the spectral occupancy. The output of the prediction engine is the probability of a sub band being occupied by the primary user ($P_{occupied}$). If $P_{occupied}$ is low, resolution need not be very fine since most of the spectrum is free. When $P_{occupied}$ is high, a finer sensing approach is performed by incrementing the observation vector N, thereby increasing the resolution. Hence

$$\mathrm{N} \ \alpha \ \frac{1}{P(occupied)}$$

The fine and coarse grain FFT approaches are already proposed in literature[7, 8, 9]. But none of these algorithms adapts the resolution of FFT based on statistical data given by the prediction engine as in our case. Simulations are carried out in MATLAB. The fig. 3 is the simulation result performed in reference 11 to show that the performance of the doubly cognitive radio architecture is almost comparable to that of reference 3.

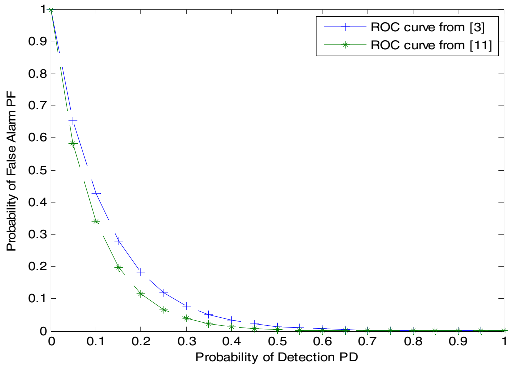

Fig 3: ROC performance curves: P_D vs P_F[3,11]

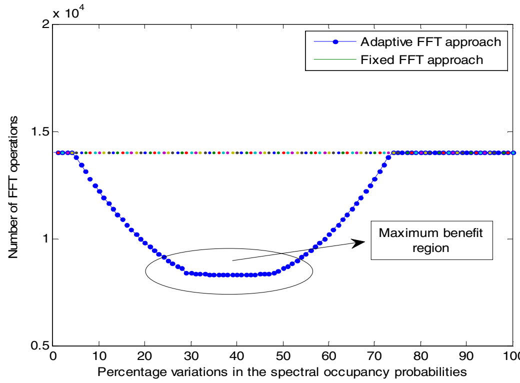

Fig 4: Number of FFT operations vs Percentage variations in the spectral occupancy probabilities. Maximum benefit region denotes the region there is a huge decrease in the FFT computations.

The fig. 4 depicts the performance of the current paper.. When there are huge variations in the terms of spectral occupancy, i.e., when some of sub bands are fully occupied by PU, while some bands are fully unoccupied, maximum benefit can be extracted out the proposed algorithm. It can also be inferred that the spectrum sensing time decreases in the maximum benefit region since the FFT operations come down.

4. Implementation

The implementation is carried out in 2.4 GHz band. We have chosen Universal Software Radio Peripheral (USRP), an FPGA based SDR transceiver and RF frontends from Ettus Research LLC for our implementation.

4.1. Prediction Engine

The prediction engine gives the probabilities of spectral occupancy according to the machine learning techniques based on the collected data. In our implementation, 2.4GHz band is considered and the sub bands are classified into low, medium and high regions according to the probabilities of spectral occupancy. A region with high probability of spectral occupancy will require a fine resolution and a region with low probability of spectral occupancy can have optimum FFT resolution. In our implementation, we assign 1024 point resolution to highly occupied regions and a resolution of 256 point FFT to spectral bands which are less occupied.

4.2. RF Signal Path

The fig. 5 represents the RF signal path. The captured samples of a band (inside which the spectral holes have to be identified) pass through a reconfigurable RF front end and are finally in a file. File serves as an input to the Mapper and further processed according to the algorithm given in fig. 2.

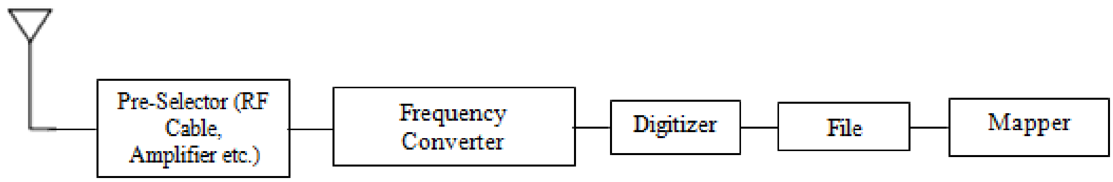

Fig 5: RF signal path

4.3. Results:

Based on the resolutions obtained from the experiment, we perform Decimation in Time 2-radix FFT to all the sub bands. The bar diagram in fig. 6 shows the number of complex additions and multiplications for each of the values of N.

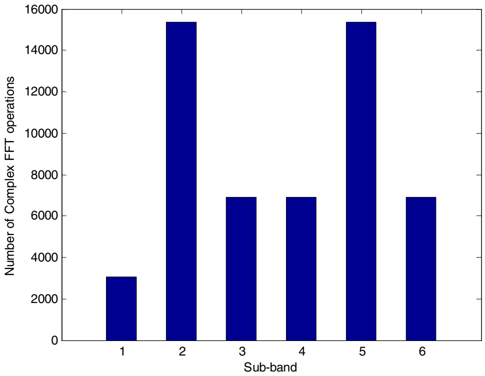

Fig 6: Number of complex additions and multiplications for different N

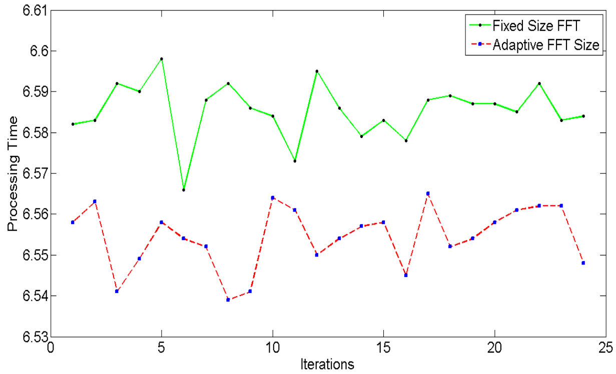

Fig 7: Spectrum sensing times for multiple iterations

The experiment was repeated for several iterations and the overall processing time for each of the iterations (in milliseconds) is plotted in fig. 7. We can observe the decrease in processing time in the order of few milliseconds. Better performance can be expected for the larger variations in N. The performance can be further enhanced by introducing the parallel and pipelining algorithms.

5. Future work

- Having obtained the satisfactory results, we would like to extend the present work to other cognitive radio engines.
- The latency can further be decreased by introducing the parallel architectures such as in reference 8.
- The wavelet based multi resolution approach can be coupled with the proposed algorithm in order to obtain the better results.

6. Conclusion

In this paper, we could show satisfactory performance by employing the statistical assistance based multi resolution approach. The reduction of overall latency is achieved. In addition, many times, while designing a spectrum sensing algorithm, system complexity is not taken into account. The system we considered, not only gave satisfactory performance but also easily implementable one. In addition, the adaptive FFT mapper block is designed to serve as independent module. It can be directly applied to any cognitive radio engine without changing the existing system.

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