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Realization of Spectrum Sensing Controller using FPGA

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Abstract— ***Spectrum sensing is a pivotal part of any Cognitive Radio Networks (CRN's) that resolves the problem of inefficient spectrum utilization by enabling secondary user to opportunistically utilize the unused licensed bands. The prime functionality of cognitive radio is spectrum sensing in which presence of the primary users is accurately detected. Opportunistic unlicensed access to the (temporarily) unused frequency bands across the licensed radio spectrum is currently being investigated as a means to increase the efficiency of spectrum usage. Such opportunistic access calls for implementation of safeguards so that ongoing licensed operations are not compromised. The control part of the spectrum sensing algorithm is defined using Finite State Machine (FSM) for energy based single and co-operative spectrum sensing. The implementation was done in Spartan 6 FPGA board (XC6SLX16) and the hardware results have been validated.***

Index Terms —***component; Cognitive radio; Decision Fusion;Data Fusion;Finite State Machine (FSM); EGC rule.***

I. Introduction

The available electromagnetic radio spectrum is a limited natural resource and getting crowded with the emergence of new wireless devices and applications, and the compelling need for broadband wireless access, this trend is expected to continue in the coming years. In autocorrelation based spectrum sensing architecture on FPGA with dynamic offset compensation, there exist the different non-idealities which deteriorate the performance of spectrum sensing algorithms developed for cognitive radio applications [1]. According to the FCC study of the spectrum utilization shows that licensed spectrum with utilization ranges from 15% to 85% in the bands below 3GHz, which indicates that there is a significant scope of improving spectrum utilization. It has been also found that the allocated spectrum is underutilized because of the static allocation of the spectrum. The relatively low utilization of the licensed spectrum suggests that spectrum scarcity, as perceived today, is largely due to inefficient fixed frequency allocations rather than any physical shortage of spectrum.

The conventional approach to spectrum management is very inflexible in the sense that each wireless operator is assigned an exclusive license to operate in a certain frequency band. And, with most of the useful radio spectrum already allocated, it is difficult to find vacant bands to either deploy new services or to enhance existing ones [2].

In order to exploit spectrum in a dynamic fashion, cognitive radios must have a sensing mechanism for identifying spectrum opportunities and avoiding interference with licensed primary users.

Spectrum Sensing Techniques

Spectrum sensing performs the following tasks (1) detection of spectrum holes, (2) determination of spectral resolution for each spectrum hole, (3) estimation of the spatial directions of an incoming interfering signal, and (4) signal classification the detection of spectrum holes is probably the most important task, and is explored through a binary hypothesis-testing problem.

Cognitive Radio Networks

The operation of a cognitive radio for dynamic spectrum access involves two main components: spectrum sensing and spectrum opportunity exploitation [3]. The individual decisions of each CR are integrated in the fusion center using different fusion rules. Due to fading and other hidden terminal effects in the transmitted channel, single node is unreliable in the detection probability. For implementing cooperative spectrum sensing, the algorithm uses one of the fusion rules hence reducing the efficient detection [4].

i)*Spectrum Sensing*: The radio environment and the available spectrum band are monitored. Their information is captured and spectrum holes are detected.

ii) *Spectrum Analysis*: The characteristics of the spectrum holes detected are estimated.

iii) *Spectrum Decision*: The appropriate spectrum band is chosen according to the spectrum analysis and characteristics and user requirements: data rate, bandwidth, and transmission mode.

Due to hardware limitations and energy constraints, a cognitive radio may be unable to sense the entire spectrum simultaneously. Hence, a sensing policy that defines when

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and which frequency band to sense must be implemented either individually or collaboratively. In spectrum sensing based energy detection for cognitive radio, the algorithm works in FPGA with operating frequency range between 110MHz-138MHz (maximum).The result shows the reduction in probability detection. It impedes discrimination between sources of received energy namely primary signal and interference from other cognitive radios. It also has bad performance under low signal to noise ratio (SNR) regions [5].

In addition, we must assume that the sensing periods have already been synchronized among different cognitive radios, because simultaneous transmission and sensing on the same frequency band is generally inefficient.

In this paper, the control part of the spectrum sensing algorithm are defined using Finite State Machine (FSM) for energy based single and co-operative spectrum sensing.

The rest of the paper is organized as follows. In section II the spectrum sensing algorithm basics are discussed. It is followed by section III which describes the energy detection algorithm for single node and co-operative sensing. In section IV provides the hardware implementation results followed by conclusion in section V.

II. Spectrum Sensing Algorithm

Spectrum sensing is broadly classified into 3 types. They are matched filter, cyclostationary detection and energy detection. Matched filter is the best method if the PU waveform is known and CR is implemented only in selected PU bands. Cyclostationary detection is more suitable if the noise uncertainties are not known energy detection is preferred if the noise uncertainties are known.

A. *Energy detection*

Energy detection (also denoted as non-coherent detection), is the signal detection mechanism using an energy detector (also known as radiometer) to specify the presence or absence of signal in the band. The most often used approaches in the energy detection are based on the Neyman-Pearson (NP) lemma. The NP lemma criterion increases the probability of detection (Pd) for a given probability of false alarm(Pa). Energy detector is the most popular way of spectrum sensing because of its low computational and implementation complexities. The receivers do not need any knowledge about the primary users. An energy detector (ED) simply treats the primary signal as noise and decides on the presence or absence of the primary signal based on the energy of the observed signal.

B. *Proposed Single Node Spectrum Sensing*

In single node spectrum sensing, a single CR is used to sense and detect the presence of PU.

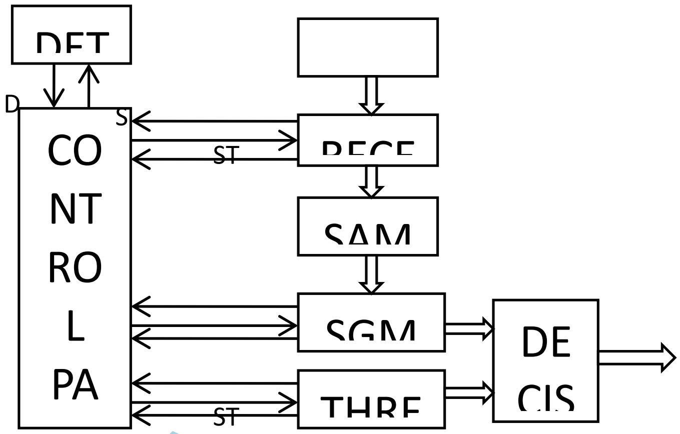

Figure 1 Single node spectrum sensing

The schematic of the proposed architecture is shown in Figure 1. The input ports of the architecture are the clock input (clk, 1-bit), input signal port, activate (ACT) and false alarm probability input (Pf) and binary decision output (y) denotes the output port. The architecture functions are designed using Finite State Machine form. The architecture constitutes of various blocks with different functionalities like Detection Profile, Threshold Computation, Reception block, Statistic Generator Module (SGM) and the Decision block. Each module operates as a state of the finite state machine whose state sequence is governed by the control signals issued from the Control part of the architecture. The state diagram is shown in Figure 2. The Control part provides a 'Start' signal to a module for enabling the initialization. After the completion of the task, it sends back a 'Done' signal. The detection profiles are loaded and stores them into the profile storage. Threshold is calculated using look up table approach. For a particular noise environment, the threshold values for acceptable Pf range (.01 to .08 at .001 intervals) are stored in an on chip RAM based look up table. The Signal reception block then senses the input signal samples and stores them into the Sample memory. The SGM now reads the contents of the Sample Memory one by one, squares it and adds them up to determine the average value for the calculation of test statistic. Finally, the Decision block compares the test statistic with the calculated threshold to give a 1-bit binary output indicate the presence or absence of PU in the channel. The decision block holds the responsibility for the indication of the presence or absence of PU.

C. *Cooperative Spectrum Sensing Hardware*

Cognitive radio cooperative spectrum sensing occurs when a group or network of cognitive radios share the sense information they gain. This provides a better picture of the spectrum usage over the area where the cognitive radios are located.

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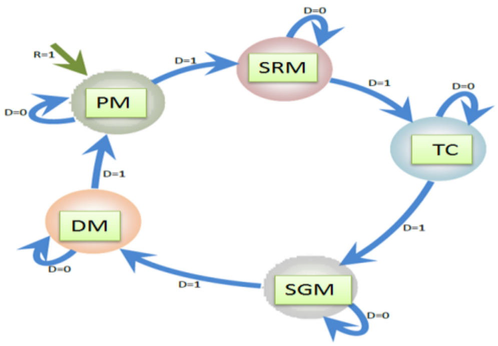

Figure 2 Finite state machine model

The modular structure of the proposed ED hardware as shown in Figure 2 and its FSM based execution imparts flexibility to the architecture. It can be very easily remodelled to implement energy based cooperative spectrum sensing algorithms. The basic structure remains same. The profile memory (PM) is used to load all the profiles to be detected. Once it receives the control signal, the state is switched to Signal Reception Module (SRM) state. Here, the indication about the reception of the signal is facilitated. Based on the probability of false alarm and probability of detection, the threshold values are computed. In next state, the threshold value is compared. The switching of state Threshold Computation (TC) to state Statistics Generator (SGM) occurs where the test statistics for the signal is computed.

In cooperative sensing, multiple CRs are used to independently sense and detect the presence of PU and, their decisions are combined in a fusion center (FC). This FC utilizes the independent decisions from the participant CRs and combines the decisions to determine the presence of PU.

To implement cooperative spectrum sensing consisting of n SUs, n parallel SGMs are implemented. Each SGM accepts signal samples from a particular SU through a signal input port (in_sig1, in_sig2...) and would calculate the test statistic for that SU when it is active. The Energy based Cooperative spectrum sensing using AND, OR, Majority (decision fusion rules) and EGC (data fusion rule) are implemented. In case of decision fusion rules, the DM compares the test statistic values from each of the TSMs with the pre-calculated threshold value. For a particular noise environment, the threshold values for acceptable Pf range (.01 to .08 at .001 intervals) are stored in an on chip RAM based look up table. Then the decision about the PU activity for each SU and finally combines the decision to implement one of the decision fusion rules. The individual decisions are obtained at the decision outputs (y1, y2... yn) and the combined decision is obtained.

On the other hand, for implementing EGC, DM calculates the average of the test statistics obtained from different TSMs and compares with the threshold value to give the one bit binary decision output about the presence or absence of the PU in order to efficiently utilize the free spectrum by the SU.

III. SOFTWARE SIMULATION

The process flow of the energy detector is, the received signal is passed through the ADC then calculate the FFT coefficient values then squared those values and average over the observation interval. The simulation was performed using MATLAB Simulink and the results are validated.

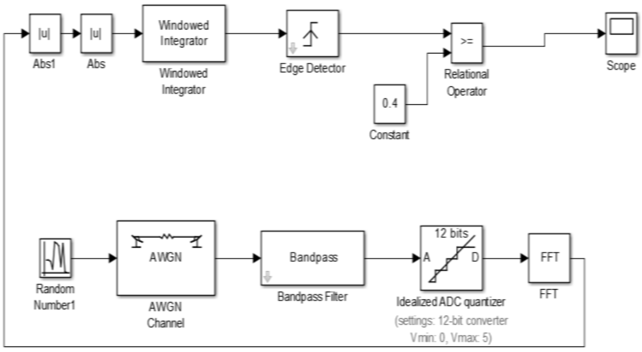

Figure 3 Simulink model for Energy Detection

Then the output of the detector is compared to a pre defined threshold value to decide whether the primary user is present or not. The threshold comparison is modeled using simulink as shown in Figure 3.

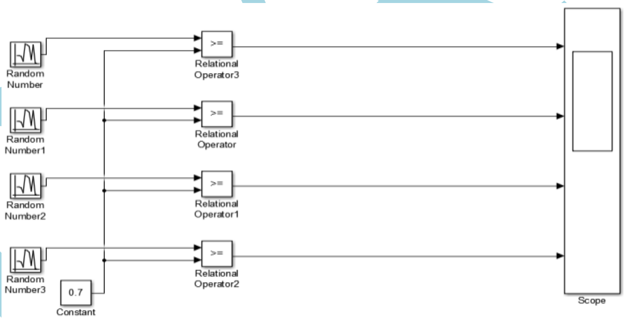

Figure 4 Simulink Model for Threshold Calculation

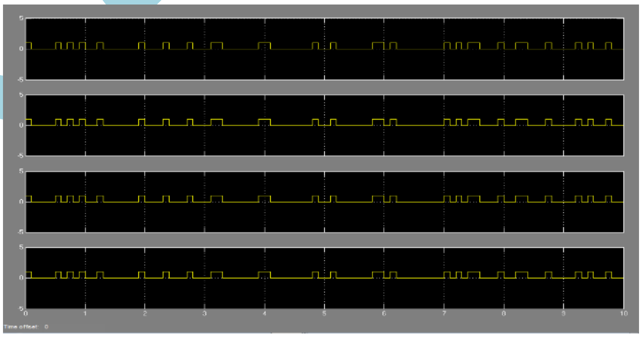

Figure 5 Simulink output for Energy Detection with 4 users Comparison

Figure 5 shows threshold comparison of 4 users using energy detection (ED) method. There are 4 users with different signal values which are compared with threshold value and its output is shown in Figure 6.

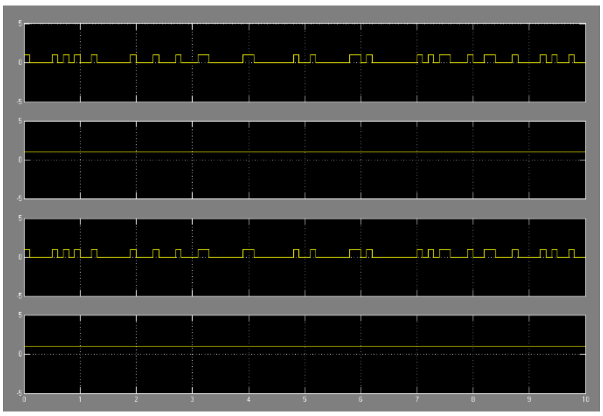

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Figure 6 Simulink Output for Threshold Calculation

Threshold value is set at 0.7 and is generated using constant block. Relational Operator compares the input signal value with threshold signal value as shown in Figure 6 and the difference of both values shown on Scope.

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IV. Hardware implementation

The Finite State Machine design for enhancing the control part of spectrum sensing was simulated using Modelsim 6.4a software. The cognitive radio detects both the presence and absence of primary user (PU) efficiently.

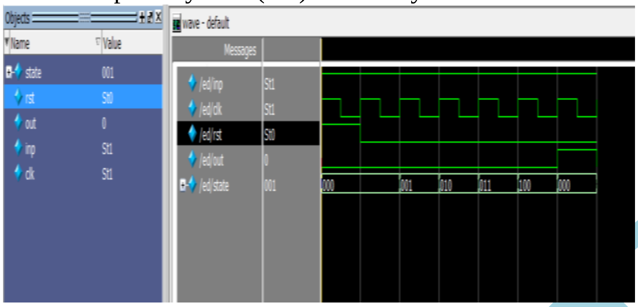

Figure 7 Simulation Output

In the design, each module is represented as an individual state in FSM architecture as shown in Figure 7. The control unit provides the control signal atach stage. The modules are assigned with following state assignments.
000–PM(Profile Module),001 – SRM (Signal Reception),010 – TC(Threshold Computation),011 – SG (Statistics Generator),100 – DM (Decision Module).

The output of SGM, the decision module state provides the one bit binary decision output. The decision implies the presence of the licensed user if the output reads 1 and if it reads 0 indicating the absence of the licensed user. The implementation was performed using Spartan 6 and the Xilinx summary has been reported in Figure 8.

Figure 8 Xilinx Report

The Xilinx summary provides the details about the

Slice Logic Utilization	Used	Available	Utilization
Number of Slice Registers	27	18,224	1%
Number used as Flip Flops	27	-	-
Number of Slice LUTs	25	9,112	1%
Number used as logic	24	9,112	1%
Number using O5 output only	21	-	-
Number using O5 and O6	3	-	-
Number used exclusively as route-thrus	1	-	-
Number with same-slice carry load	1	-	-
Number of occupied Slices	7	2,278	1%
Number of MUXCYs used	24	4,556	1%
Number of LUT Flip Flop pairs used	25	-	-
Number of fully used LUT-FF pairs	25	25	100%
Number of unique control sets	2	-	-
Number of slice register sites lost to control set restrictions	5	18,224	1%
Number of bonded IOBs	5	186	2%
Number of LOCed IOBs	5	5	100%
Number of BUFG/BUFGMUXs	1	16	6%
Number used as BUFGs	1	-	-
Average Fanout of Non-Clock Nets	1.88	-	-

resources such as number of slices, LUT's, flip flops etc. The availability and the utilization is inferred from the Xilinx summary report.

V. Conclusion

Energy detection is a non-coherent blind signal detection because it does not require the prior knowledge of the primary user. It is based on the fact that energy of the signal to be detected is always higher than the energy of the noise. It detects the presence of a signal by comparing the received energy with a known threshold. Threshold selection is a challenge in energy detection method because it depends on the noise variance. The efficient utilization of spectrum is achieved only the probability of misdetection is reduced. Both implementation and computational complexity are relatively low. Research on spectrum sensing thus far has mainly focused on meeting the regulatory requirements for reliable sensing. An important venue for further research is the interplay of spectrum sensing and higher-layer functionalities to enhance the end user's perceived QoS.

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