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Smart Transmitter for Cognitive Radio

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Abstract: The wireless data consumption is increasing rapidly due to increase in number of mobile devices which are connected through air. So there is huge demand for spectrum. Large chunk of spectrum is licensed which are expensive. Unlicensed users are prohibited access to licensed spectrum. To efficiently use the available spectrum and solve the spectrum shortage problem there is need of cognitive radio. Software defined radio is a building block of cognitive radio which is reconfigured according to the available spectrum. This project aims at building a reconfigurable smart transmitter which can change modulation scheme on the fly depending upon the bandwidth, power and probability of error requirements. The different modulation schemes and the decision making logic is simulated in MATLAB and then implemented on FPGA platform.

Keywords: Radio, Software Defined Radio, Partial reconfiguration (PR), Power Consumption.

I. INTRODUCTION

As the wireless communication devices are increasing rapidly demand of wireless spectrum also increasing .The spectrum available is fixed so there is need to utilize the available spectrum more efficiently. One way to achieve this is by using the technology which will adopt itself as per the environmental condition i.e. noise in the channel, channel bandwidth, signal energy .Cognitive Radio is the adaptive communication system who does the same job. It is explicitly designed to use available spectrum more efficiently.

Cognitive Radio works in cycle of three stages i.e. spectrum sensing, spectrum analysis and spectrum decision making. In this work we are working on spectrum analysis and spectrum decision making part of cognitive cycle. Spectrum analysis includes collection of parameter values like SNR, Energy of the signal, etc. from spectrum sensing circuit, then it analyze all parameters and finds optimal communication protocol for transmission (e.g. frequency, suitable modulation technique). After finding best matching protocol spectrum, decision making step comes into picture. In this step according to the spectrum analyzers result transmitter parameters (modulation technique-4QAM/8QAM/16QAM) are configured on the FPGA.

The main constraint while implementing cognitive radio is sensing period. To avoid interference between license user's signal and unlicensed user's signal there is need to sense the spectrum after some periodic interval (sensing period). Also once the empty channel is found transmitter have to adjust its parameters like frequency of operation, modulation technique to be used within no time. To achieve this we implement cognitive radio transmitter on FPGA by using partial reconfiguration technology. In this common logic of 4QAM, 8QAM, 16QAM modulation techniques are implemented on static memory of FPGA, and different bit files are generated for changing part of the modulation techniques. During the runtime with the help of ICAP (Internal Configuration Access Port) partial bit files are loaded into dynamic memory of the FPGA. \ Hence instead of configuring whole QAM modulation technique we configured change part of modulation technique power consumption and circuit configuration time gets reduced.

The rest of the paper is organized in following manner. Section 1 explains the proposed transmission system with various stages involved in the Cognitive Radio technique implementation. In section 2 results are discussed and in last section conclusion is made.

1. Proposed Cognitive Radio System:

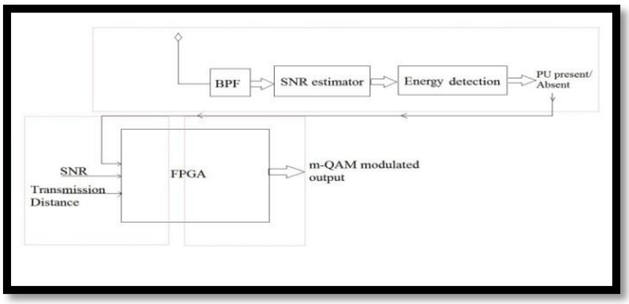

Fig. 1 Block Diagram of Proposed cognitive Radio System

1.1 Spectrum Sensing:

Spectrum sensing is an important part in cognitive radio in determining the availability of empty channel so that secondary user can utilize the empty channel without causing any harmful interference with the primary user signal. In this it analyzes the status of the spectrum and finds the presence or absence of primary user. There are various spectrum sensing methods two are described here[3].

1.1.1 Energy Detection Technique

The main advantages of Energy detection technique are it takes **short time** to identify the presence or absence
Of primary user and it does not require any prior knowledge about the received signal.

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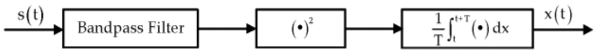

Fig.2 Energy Detector Block Biagram

In Energy Detection technique the output signal of bandpass filter with the bandwidth W is squared and integrated over the observation interval T. Finally the output of the integrator is compared with a threshold, to decide whether a licensed user is present or absent. [4]

In his paper [6] Mohammad Akbari has proposed modified Energy detection technique with two level model i.e. pre-filtering and data fusion. Pre-filtering is carried out with 3σ criteria method. In this method pre filtering is done by rejecting very small and very large node's values. In next level i.e. data fusion, in this all the data from pre-filtering level is analyzed and based on that hypothesis H0 (PU present) or H1 (PU absent) are made.

$$P\left(\frac{H_1}{\bar{E}}\right) > P\left(\frac{H_0}{\bar{E}}\right) \ldots.. H_1$$

$$P\left(\frac{H_1}{\bar{E}}\right) < P\left(\frac{H_0}{\bar{E}}\right) \ldots.. H_0$$

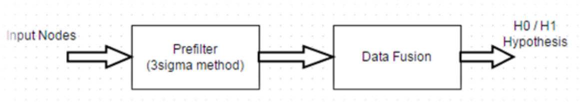

Fig. 3 Modified energy detection technique

As different modulation schemes have different distribution characteristics, based on order of modulation detection characteristics changes. Also in a scenario when there is no information available regarding primary user signal and only power of the random Gaussian noise is known to us, Energy detection technique is always efficient detection technique. The problem with energy detection technique is, it gives information about only presence and absence of PU and fails to explain what kind of signal it is, also at lower SNR performance of Energy detection technique degrades [5].

1.1.2 Cyclostationary Feature Detection:

Cyclostationary feature detection methods are more complex but more reliable methods of signal detection. Many systems used in communication system have periodicities in their second order stastical parameters due to the operations such as sampling, modulation, multiplexing and coding. [10]

These cyclostationary properties also known as spectral correlation features are used for signal detection. A signal has cyclostationary features if, its cyclic correlation function is non-zero for a non-zero cyclic frequency. The Fourier transform (FT) of a CAF produces the signal spectral correlation function (SCF) [11]. The cyclic autocorrelation function (CAF) is used for time domain analysis, which can be expressed as,

$$R_x^{\propto}(\tau) = \lim_{T\to\infty}\frac{1}{T}\int_{\frac{-T}{2}}^{\frac{T}{2}} X\left(t+\frac{T}{2}\right)X^*(t-\frac{T}{2})\ e^{-j2\pi\alpha t}dt$$

$$= X\left(t+\frac{T}{2}\right)X^*\left(t-\frac{T}{2}\right)e^{-j2\pi\alpha t}$$

And its SCF can be expressed as

$$S_x^{\propto}(f) = \int_{-\infty}^{\infty} R_x^{\propto}(\tau)\ \ e^{-j2\pi\alpha\tau}d\tau$$

$$= \int_{-\infty}^{\infty}\lim_{T\to\infty}\frac{1}{T}\int_{\frac{-T}{2}}^{\frac{T}{2}} X\left(t+\frac{T}{2}\right)X^*(t-\frac{T}{2})\ e^{-j2\pi\alpha t}dt$$

$$e^{-j2\pi\alpha\tau}e^{-j2\pi\alpha\tau}dtd\tau$$

$$= \lim_{T\to+\infty} S_{xT}^{\propto}(t,f)$$

According to SCF a detector could determine presence of the signal [10].

1.2 Spectrum Analysis and Decision Making

The spectrum sensing block senses the free channel frequencies available in the spectrum. It also calculates the noise level present in the channel. These two parameters are then analyzed by the spectrum analysis block and select the best modulation scheme. The logic of switching between different modulation schemes is implemented by spectrum decision making block.

The mathematical equation for choosing best modulation scheme based on the Signal-to-Noise ratio and maximum channel bandwidth available is expressed as below.

$$m = 10^{\frac{C*log2}{2*Maximum\ Bandwidth}}$$

Where,

Channel Capacity(C) = Maximum Bandwidth* log $(1+\frac{S}{N})$

m = Level of QAM modulation

The modulation scheme chosen is configured on the fly on FPGA with minimum reconfiguration time. Partial Reconfiguration feature of FPGA is used which reduces the power consumption and area occupied by circuit to a great extent.

1.3 Implementation

The different QAM schemes are designed and simulated in MATLAB 2013Ra using Xilinx Block set library. The design and simulated results are shown in figures below also all three modulation schemes are implemented as a single design. For all four design VHDL codes are generated which are used to implement the circuit on FPGA. Partial Reconfiguration feature is used to change the appropriate modulation scheme on the fly as chosen by spectrum analysis block. [12]

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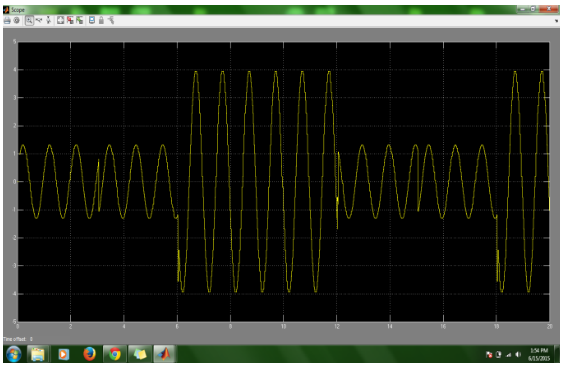

Figure 5 4-QAM Modulator output waveforms

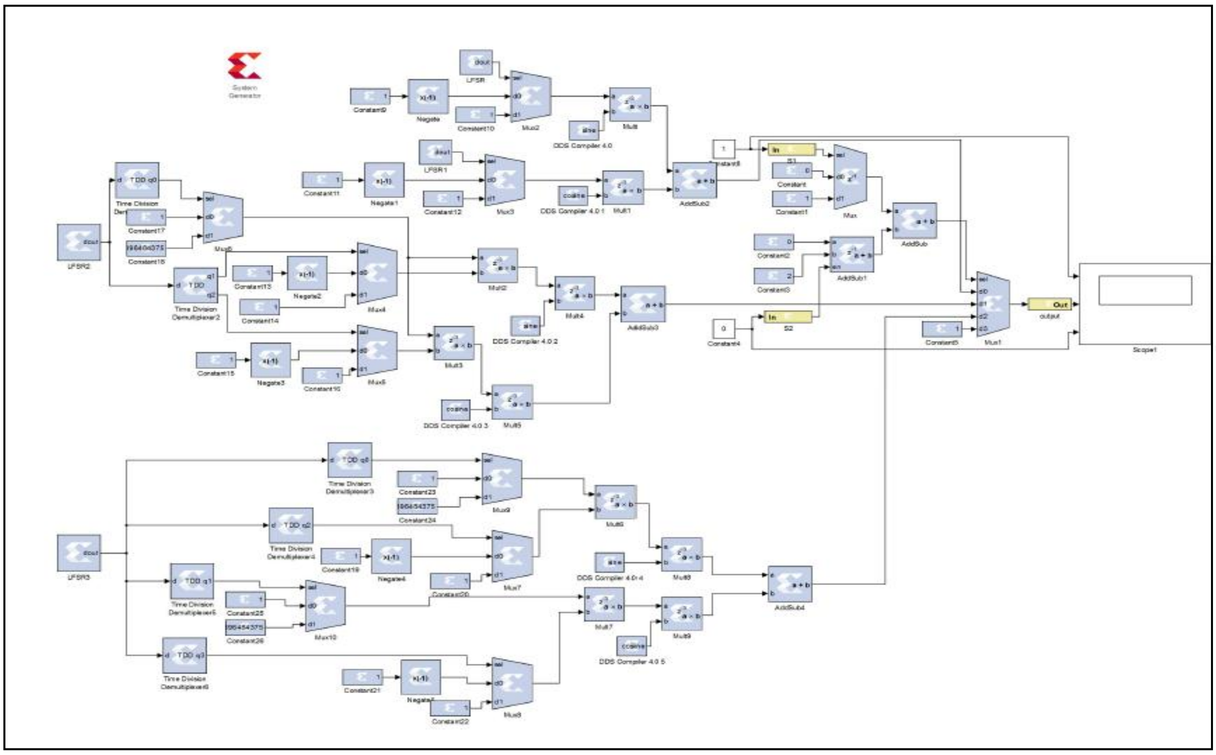

Figure 4 Combined QAM Model (4-QAM, 8-QAM, 16-QAM,)

Simulation Results for different modulation techniques are presented in below figures,

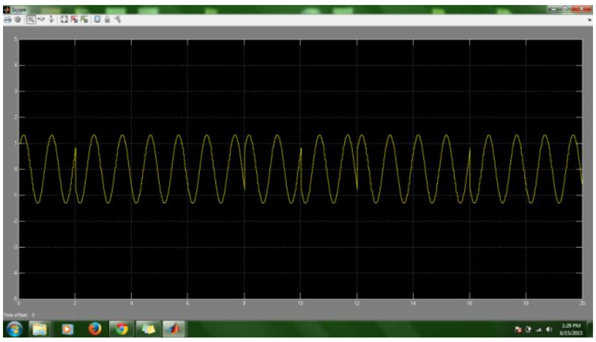

Figure 6 8-QAM Modulator output waveforms

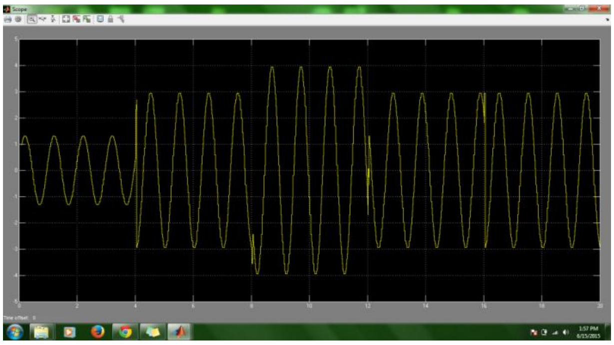

Figure 7 16-QAM Modulator output waveforms

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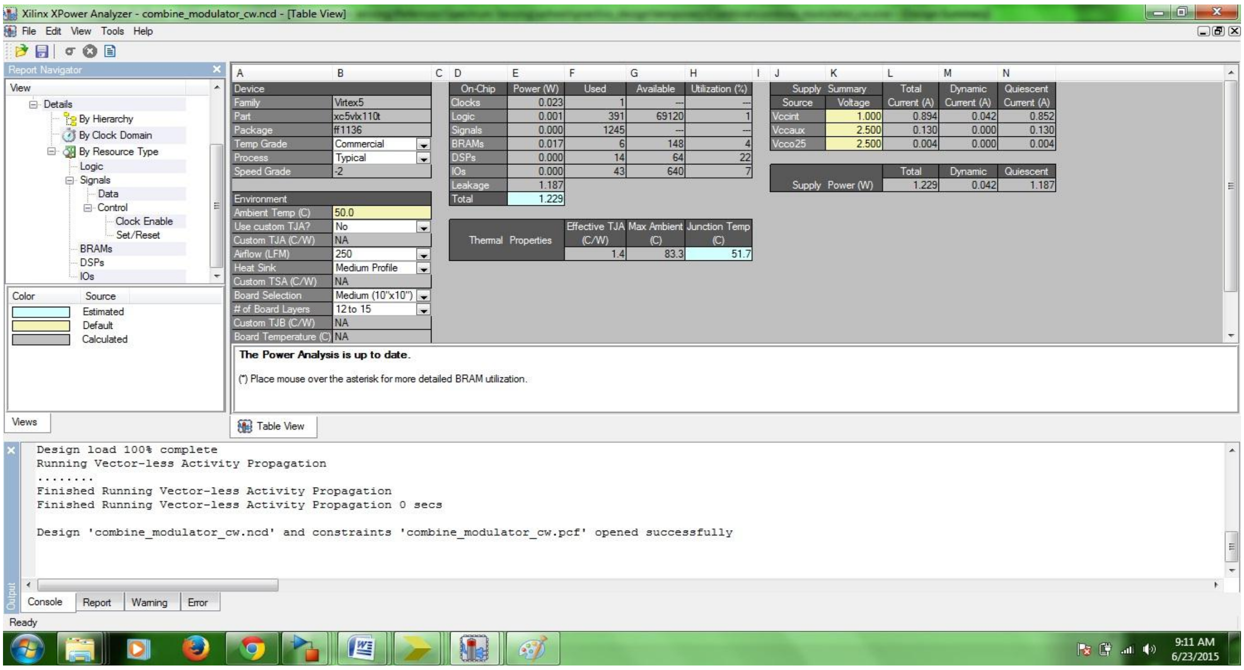

Figure 8 Xilinx Xpower Analyzer output of Combined Model

Supply Power for Combine Model (W) = 1.229 W

Supply Power for Model
Implemented by using PR technique = 1.198 W

Time require to configure
Model without PR technique = 9 nsec

Time require to configure model

With PR Implementation technique < 1 nsec

2. RESULTS AND DISCUSSIONS

The complete design consisting of all three modulation schemes and those implemented using PR are compared on the basis of area and power. The table below describes the device utilization of FPGA with and without PR.

Device Utilization summary(Without PR)			
Logic Utilization	**Used**	**Available**	**% Utilization**
Number of slice registers	375	69,120	1%
Number of slice LUTs	391	69,120	1%
Number of occupied slices	391	69,120	1%
Number of fully used LUT-FF pairs	223	543	41%
Number of Bonded IOBs	43	640	6%
Total memory used	108	5328	2%

Table 1 Device Utilization Summary without PR

Device Utilization summary(With PR)			
Logic Utilization	**Used**	**Available**	**% Utilization**
Number of slice registers	76	69,120	1%
Number of slice LUTs	197	69,120	1%
Number of occupied slices	84	17,280	1%
Number of fully used LUT-FF pairs	48	169	21%
Number of Bonded IOBs	43	640	6%
Total memory used	18	5328	1%

Table 2 Device Utilization Summary with PR

The power required for the configuration for complete circuit with three modulation scheme is 1.229 W and that for circuit configured with PR implementation technique is less than 1.198 W. Also area required for the implementation of complete circuit is always more than that required with PR technique.

3.CONCLUSION

In this paper, the m-QAM modulation techniques that must be supported in a cognitive-radio environment are outlined. The different operational steps in a cognitive-radio device are explained, and the transmitter parameters and design that change with channel conditions are presented and discussed. The objective is to analyze the

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space signals by observing the channel activity and making the appropriate decisions to reconfigure the cognitive-radio transmitter so that it dynamically optimizes its response. Even though the concept of cognitive radio is still under study, it is believed that the future of wireless communication is likely to be based on the key features of a cognitive-radio environment (Spectrum sensing, spectrum analysis & spectrum decision making).

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