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FPGA IMPLEMENTATION OF COGNITIVE ENGINE USING PARALLEL PROCESSING

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ABSTRACT

Cognitive radio (CR) is a one of the most intelligent radio that can be configured dynamically. Its transceiver is designed such that to use the best wireless channels. According to environment change cognitive radio, this can intelligently utilize the natural spectrum resource, and is able to reconfigure the radio parameters. So the radio automatically detects available channels in wireless environment, then accordingly changes its channel status parameters to allow more efficient wireless communications in a given spectrum band at one location. The focus of paper is to minimize delay and increasing throughput of decision making engine. In this paper, software design architecture and one of the application of Genetic Algorithm (GA) driven Field Programmable Gate Array (FPGA) based decision making engine for cognitive radio is presented.

Keyword: *Cognitive Radio (CR), Genetic Algorithm (GA), FPGA (Field Programmable Gate Array).*

I. INTRODUCTION

Nowadays, the available wireless network spectrum is assigned to fixed policy in that most of the spectrum is unused. Because of limited resource and inefficiency in the use of assigned spectrum commence a new technology to exploit wireless spectrum opportunistically. Cognitive radio (CR) technique concept has been proposed by Mitola in 1999 [1] to alleviate the apparent scarcity of available radio spectrum. CR techniques enable the user to share or reuse the spectrum in an opportunistic manner. Cognitive radio encloses all the features of conventional software defined radio (SDR) with its intelligence named as cognitive engine (CE). It has the ability to sense which portion of spectrum is unused, capability to learn from the observed spectrum and ability to reconfigure within any layer of radio communication system.

Recently, the implementation aspects of CE is an active area of research with various artificial intelligence (AI) techniques application to radio domain like genetic algorithm (GA), artificial neural networks (ANN), case-based systems, swarm intelligence and linear models [2]. Research conducted at Virginia Tech has also developed a genetic algorithm engine for cognitive radios [3, 4]. Their simulation results validate that their genetic algorithm implementation does in fact change the transmission parameters to different settings, based upon a set of objectives. Similarly, in [5, 6] their genetic algorithm implementation is realized in software does change the radio parameters. Little after, a group [7] has simulated the algorithm to evolve parameters for multi-carrier transceivers. The work presented in this paper describes the software design of genetic algorithm explained in [8] outputs a selection, but the execution of fitness functions that drive the GAs is carried out as VHDL approach. We are designed a decision making engine operate in wireless communication band in the range 800MHz to 2.4 GHz.

The structure of this paper is as follows: in section II, describes the cognitive radio parameters. Section III discusses the software design and architecture. Section IV discuss about the result and discussion. Finally, conclusion in section V.

II. COGNITIVE RADIO PARAMETERS

Developing a complete list of cognitive radio parameters is not possible because each radio engine is developed with unique objective feature. In adaptive CR systems, the inputs are environmental parameters whereas the transmission parameters will be the system outputs. The objective functions for the artificial intelligence (AI) tool are formed by mathematical equations exploiting the dependence of one over the other parameters. They allow the controller to tune the system to the required QoS. The list of transmission and environmental parameters are listed in table 1 and table 2 [6].

A. Transmission Parameters

TABLE I: List of Transmission Parameters

Parameter	**Name Description**
Transmit Power	Raw transmission power
Modulation Type	Type of modulation format
Modulation Index	Number of symbols for given modulation scheme
Symbol Rate	Number of symbols per second
Bandwidth	Bandwidth of transmission signal in Hertz

Cognitive radios takes advantage of the control parameters made available by the underlying software-defined radio system. These control parameters are input to a fitness function along with the environmental parameters. These parameters convey the information about transmission channel status, performs optimization towards predefined objectives, and finally outputs optimal decisions on the transmitting parameters which are considered as knobs to the CR system.

B. Environmental Parameters

Environmental measurements inform the system of the surrounding environment characteristics. These characteristics include: internal information about the radio operating state, and external information representing the wireless channel environment. It provides the knowledge to the cognitive controller on making decisions and to be inputs to the objective functions of artificial intelligence tool. These parameters are also considered as dials to the CR system.

TABLE II: List of Environmental Parameters

Parameters	**Name Description**
Noise power	Size in decibels of noise power
Battery life	Estimated energy left in battery
Power consumption	Power consumption of current configuration

C. Objective functions for Cognitive Radio

In wireless communication system there are several desirable objectives that the radio system may want to achieve. Defining a complete list of decision variables to generate a generic fitness function usable by all radios is not possible. Radios are developed independently, each possessing a unique list of parameters used to control them. As mentioned in literature [8], we followed the three single objective fitness functions for decision. They are power consumption minimization, BER minimization and throughput maximization.

The fitness function of power consumption minimization, BER minimization, throughput maximization is defined as

$$f_{min-power} = 1 - \frac{P}{P_{max}} \quad (1)$$

$$f_{min-BER} = 1 - \frac{log_{10}(0.5)}{log_{10}P_{be}} \quad (2)$$

$$f_{max-throughput} = \frac{log_2(M)}{log_2 M_{max}} \quad (3)$$

Where,
P is the average transmits power of all sub carriers.
Pmax is the maximum available transmit power.
Pbe represents the average BER over all the channels.
M is average modulation index of all the sub carriers.
Mmax is the maximum modulation index.

The possible modulation types include BPSK, 4, 16, and 64QAM, and the BER of AWGN channel is considered. The three signal-objective fitness functions are in conflict with each other, for example the minimization of power consumption usually results in an increase of the BER. Therefore, the actual results of optimization should strike a balance between these signal objective fitness functions, which can meet the communication requirements of the system and improve the other performance as high as possible. Therefore, we can define the multiple-objective fitness function of the whole network as

$$f = \omega_1 * f_{min-power} + \omega_2 * f_{min-BER} + \omega_3 * f_{min-throughput}$$

Where the weight vector ω determines the importance of the three control objectives, and it should meet the requirement ω1+ω2+ω3 = 1. The weight vectors determine the searching direction of the cognitive engine, and the selection of the proper weight vector should follow the requirements of the communication system.

III. SOFTWARE DESIGN ARCHITECTURE

Genetic Algorithm is class of natural reasoning which utilizes the biological techniques like natural selection, crossover and mutation. Solutions to the genetic algorithm used here can be represented in the form of binary 0s and 1s.

A. Overview

In 1975, Genetic Algorithm was introduced by John Holland to describe the natural selection processes [10]. Genetic algorithm is an intelligent search strategy inspired by biological evolution. The theory of evolution was introduced by Charles Darwin to explain his observations of plants and animals in the natural ecosystem [11]. He noticed that every new generation was associated with some changes; hence the worst -fit individuals lost their survival in the competition. Thus, the basic principle survival of the fittest is adapted in all GA systems.

B. Genetic Algorithm

The terminology used in Genetic Algorithms is mix of both genetics and engineering [10]. All GA work on a population of solutions to the given problem [11]. Each individual in the population are named as a string or chromosome i.e. combination of frequency, modulation type, transmit power. Each individual are referred as genes coded with binary strings. For all iteration a new generation is evolved from the existing population in an attempt to produce good solutions.

The genetic algorithm begins with randomly selected population of chromosomes and evolves over several generations. In each generation the fitness of individual chromosomes is evaluated and checked against stopping criteria. If the adequate fitness has been achieved or time criteria have been met the genetic algorithm sends the appropriate set of transmission parameter to the radio.

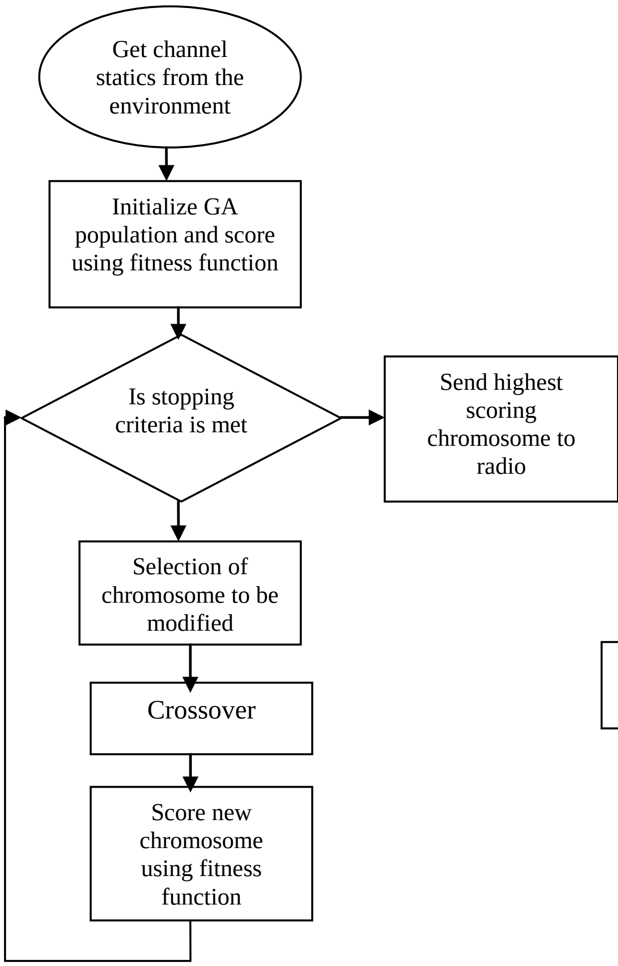

Fig 1- Block diagram of genetic algorithm [5].

If the stopping criteria are not met, multiple chromosomes are selected from current population in order to form new generation. The selection process chooses chromosomes based upon their fitness score where higher scoring chromosome have a better chance to be selected. Once the selected chromosomes have been chosen, they are modified by crossover, which combines two chromosomes into one. The new population is used in the next iteration of the algorithm.

C. Proposed Architecture for Cognitive Engine

The proposed cognitive engine architecture is as shown in fig 2. Initial random populations are generated by LFSR (Linear Feedback Shift Register) for the design. Separate LFSRs are implemented for generating values for various sub strings. Fitness module is block to find the fitness of each chromosome as per the required scenario of genetic algorithm (GA). Elitism based selection is adapted to improve the random selection. One point crossover method is designed by inverting the specific binary string. The flow of data form one module to other is monitored by the main controller as well as the initial population strength.

The main objective is fulfilled by using parallel processing architecture of cognitive engine on FPGA as shown below.

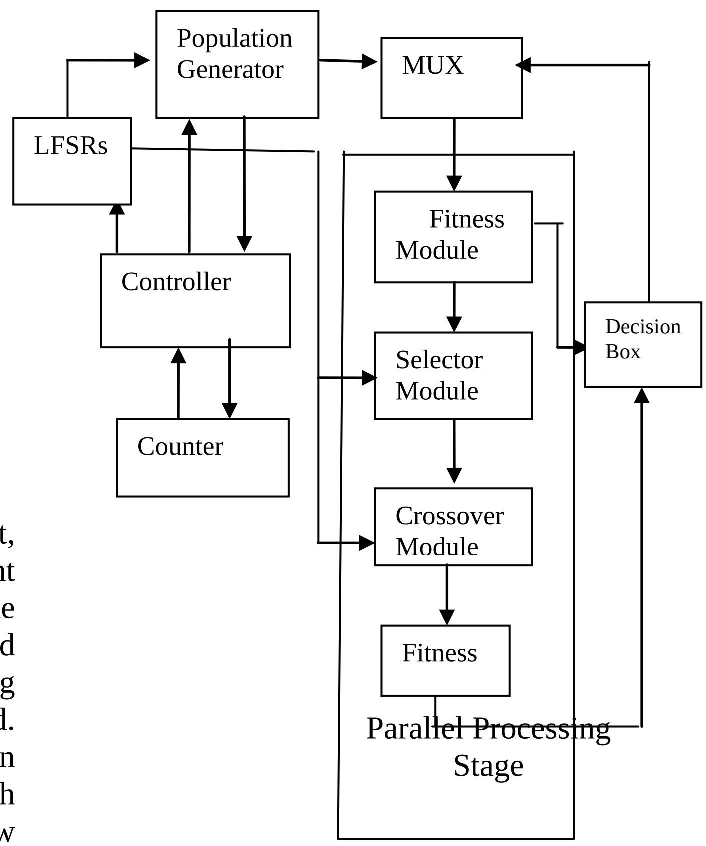

Fig 2 - Cognitive engine architecture [14].

IV. RESULT AND DISCUSSION

The stimulation of performance of cognitive engine is implemented in XILINX. So, stimulation result is shown below,

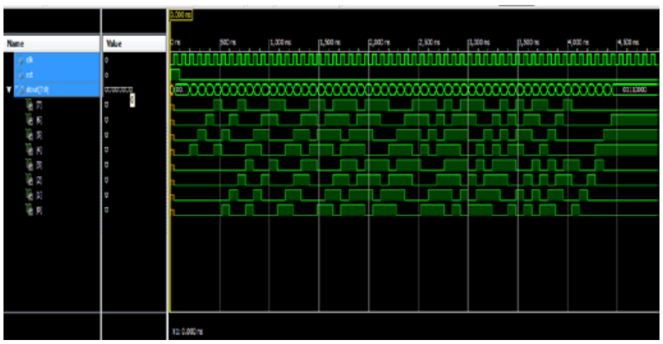

Fig 3- Simulation Output waveform

A multi-carrier system with 64 sub-carriers is simulated. Each sub-carrier is assigned a random attenuation value to simulate a dynamic channel. Here standard AWGN channel is used having average BER. BPSK, QAM, 16-QAM and 64QAM modulation schemes are considered. The maximum transmit range is 30 dB, whose maximum power value is selected since it is close to the specified maximum transmit power. In which the power of each sub-carrier is coded with 6 bits and the modulation index is coded with 2 bits. Elitism selection, single point crossover are used in both algorithm. The whole architecture was designed and tested on XILINX for functional verification as shown in fig 3. As cognitive radio decision making engine has a relatively high real-time requirement, the proposed software based approach can gain a much better result. The 8 bit chromosome is split into sub fields for transmission and environmental parameters representation for cognitive radio. The size of initial population affects the throughput of the system as it has to search all different combination of chromosomes.

V. CONCLUSION

The advantage of genetic algorithm over other algorithms is its multi-objective handling capability. The fitness module for cognitive engine is implemented by software approach. Initially the design is tested on XILINX. The whole system runs at 199MHz and optimum solution is obtained in 9.38 ns over the design. The main objective of the paper is fulfilled by parallel processing architecture of cognitive engine on software to reduce delay up to 10% over previous software design.

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