A Survey of Cognitive Radio Reconfigurable Antenna Design and Proposed Design using Genetic Algorithm

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ABSTRACT
Cognitive radio network (CRN) is the latest paradigm of techniques for enhancing the utility and quality of radio communication systems by the efficient utilization of frequency spectrum. It is classified by overlay and underlay cognitive radio. Antennas that designed for the overlay scheme must have the capability to sense the channel and provide communication over a portion of it. Overlay antennas can be designed as two-port, where one port supports ultra wideband, and the other supports narrowband and are frequency reconfigurable. Moreover, they can be implemented as a one-port antenna, in which the same port is used for both sensing as well as communicating, and thus it must switch between wideband and narrowband modes. Evolutionary computation techniques like the genetic algorithm (GA) are efficient in designing new kinds of antennas with challenging designs. A binary genetic algorithm can be utilized to optimize the shape of an antenna to achieve maximum possible frequency reconfigurability with minimum number of switches for obtaining a wideband performance from a single cognitive radio antenna.

General Terms
Ultrawideband and narrowband antenna, Evolutionary algorithms.

Keywords
Cognitive radio networks, reconfigurable antenna, genetic algorithm.

1. INTRODUCTION
Conventional radio networks are designed to operate within a specified RF spectrum range. A cognitive radio is an intelligent antenna that can be programmed and configured dynamically. Presently, the increasing demand for mobile wireless services, like web browsing, video telephony, video streaming etc, all with various constraints on delay and bandwidth requirements, impose new challenges to be met by future generation wireless communication networks[1] On the other hand, the static RF spectrum allocation scheme has resulted in a limited efficiency of the spectrum utilizations.

2. COGNITIVE RADIO NETWORKS
Unlike conventional radios, cognitive radios (CRs) are designed to achieve purposeful utilization of the limited RF spectrum resource and to solve the spectral under-utilization problem. In a CR network, the intelligent part allows the unlicensed users or the secondary users to access spectrum bands licensed to primary users, while maintaining minimum level of interference with them. Two approaches of sharing spectrum between primary and secondary users have been considered: spectrum underlay technique and spectrum overlay technique. In the underlay approach, secondary users must operate below the noise floor of primary users, and thus strict constraints are imposed on the transmission power. Ultra-wideband (UWB) technology is very appropriate for this approach. In spectrum overlay CR, secondary users do search for unused bands of frequency, and use them for communication. To share the spectrum with licensed users without interference with them, and satisfy the various QOS requirements of applications, each CR user in a CR network should perform Spectrum Sensing, Spectrum intelligence or decision, Spectrum Sharing and Spectrum mobility. Spectrum sensing refers to sense and decide the portion of spectrum that is available free. Spectrum decision refers to selecting the available channel, and this is known as Spectrum decision and Spectrum sharing refers to let the other users share the available channel, and Spectrum mobility refers to make the channel free when a licensed user is detected. To perform these functions the antenna design must be cognitive, highly reconfigurable and organized.

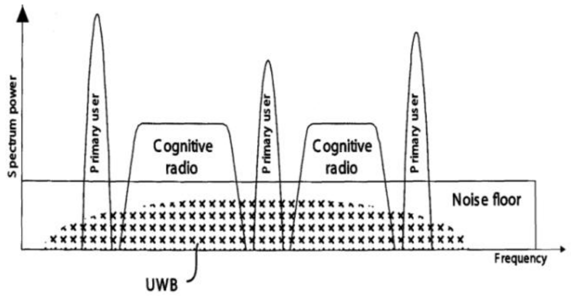

Fig. 1 Overview of Cognitive Radio Network

3. RECONFIGURABLE ANTENNAS
A reconfigurable antenna [2] is capable of modifying its frequency and radiation characteristics in a reversible and controlled manner. To provide a dynamic response, reconfigurable antennas integrate an inner mechanism such as RF switches, varactor diodes, mechanical actuators etc, each of which can change the intentional redistribution of the currents over the geometry of antenna surface and produce reversible alterations in its properties. Reconfigurable antennas are different from the commonly used CR smart antennas because the reconfiguration mechanism lies inside the antenna structure rather than in the external beam forming network [3]. Reconfigurable antennas are can be pattern reconfigurable, polarization reconfigurable and frequency reconfigurable antennas [4][5]. Frequency reconfiguration is achieved by modifying the antenna dimensions (physically or electrically) using switches, diodes, mechanical rotations, and tunable materials. Polarization reconfigurable antennas [6] are capable of switching between different polarizations modes Radiation pattern reconfigurability [7] is based on the modifying the spherical distribution of radiation pattern. Compound reconfigurability refers to tuning simultaneously several antenna parameters, for instance frequency and radiation pattern [8] and [9].

4. GENETIC ALGORITHM

Genetic algorithms (GA) which are a class of computational algorithms inspired by evolution were first introduced by John Holland in 1974. The GA can be used to find optimized solutions to search problems through the application of biologically inspired techniques [10], such as genetic inheritance, natural selection, mutation, and recombination or crossover. Using a GA, it is possible to define the desired performance of an antenna and allow the software to find the parameters for the design [11]. GAs are very useful in this field for several reasons, including:

1) Antenna current and voltage equations, which are based on Maxwell's equations, are very difficult to understand and grasp intuitively.

2) Antennas are developed using very fast antenna simulators, which require only seconds to produce accurate results.

3) The Antenna Search spaces are highly multimodal and difficult to optimize using other forms of numerical and hands-on optimization, yet finding good designs is important to industry.

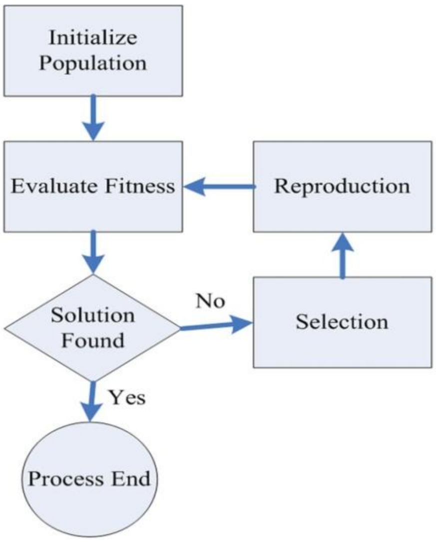

Fig. 2 Flow chart of Genetic Algorithm

5. COMPARATIVE STUDY OF COGNITIVE RADIO RECONFIGURABLE ANTENNAS

Cognitive radio antenna designing applications has been in research over the last few years. UWB antennas are required for underlay, and for sensing in overlay technique. UWB antennas were originally meant to radiate very short pulses over short distances. A great deal of research has been done in the field of underlay UWB antennas as proposed in [12] and [13]. The emphasis is either to design a frequency-reconfigurable antenna or to design a reconfigurable antenna with a sensing antenna in the band of interest. UWB sensing antennas along with the narrowband antennas were proposed in different ways in literature. Reconfigurable antennas without sensing antennas for CR application were presented in [14] and [15]. In [14], a reconfigurable printed Yagi-Uda antenna is presented for CR applications. A 46% frequency tuning bandwidth is achieved by loading the driver arms and four directors with varactor diodes. This design has a high-gain and a constant end-fire pattern constrained to be maintained while the operating frequency is tuned. Thin (1 mm width), long metallic strip lines are broken in short sections. The gaps between metallic sections are bridged with very high value surface mount resistors. The short strips are set to have a wavelength equal to free space wavelength corresponding to the highest operating frequency and also they are connected with resistors. 1MΩ resistors are placed in gaps of the metallic sections, which produces ohmic losses. The power handling capacity of the varactor diode is a major limitation on the maximum input power to the antenna. Also, the nonlinearity of diodes generates high-order harmonics and inter modulation components, which introduces interference in the system.

In [15], a MEMS based CR reconfigurable antenna was presented. The quad-band antenna has a radiation pattern in four frequency bands,

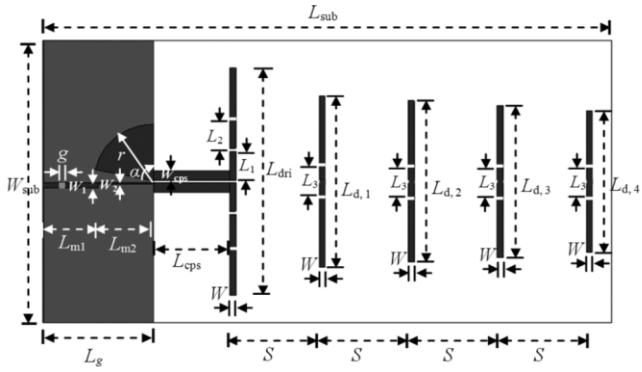

Fig. 3 Reconfigurable Yagi Antenna proposed by [14]

800–900 MHz, 1.7–2.5 GHz, 3.3–3.6 GHz, and 5.1–5.9 GHz, i.e. it covers all spectrums for existing wireless applications, such as GSM, WCDMA, Wi-Fi, and WiMAX. The operating frequency of the antenna can be adjusted by the use of a MEMS switch. A two-element antenna array is developed to boost the antenna gain at about 9–11 dBi over all four frequency bands. The isolation between the ports is an issue of consideration in this case because one pair of radiator may increase the noise level received by next pairs due to high order resonance and coupling. Poor isolation among B1-B2, B3-B2, B3-B4, and from B4-B2 shows the need for isolating the components such as switches to reduce the noise formation.

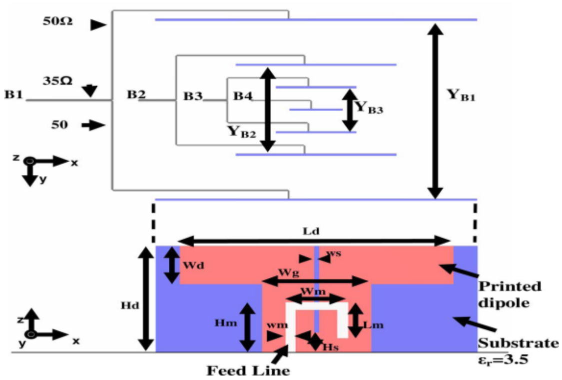

Fig. 4 Quad band antenna proposed by [15]

In [16] and [17], two port reconfigurable antennas were presented embedding a sensing antenna with frequency bands above 2.1 GHz for both reconfigurable and the sensing antenna. In [16], a new antenna design for cognitive radio communication is presented. It has two structures embedded together into the same substrate. The first structure a UWB antenna covering the spectrum from 3.1–11 GHz for channel sensing. Other is a frequency reconfigurable triangle shaped patch for communication with another RF device. The reconfigurability is obtained via a rotational motion. Since the "sensing" and the "communicating" antennas are both incorporated into the same substrate, coupling is crucial between them. For future, "sensing antenna" can be designed to cover a higher bandwidth (700MHz-11 GHz), which requires more rotations to be incorporated into the design.

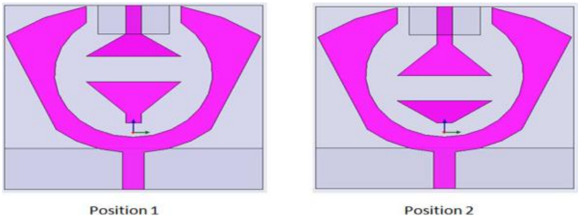

Fig. 5 Dual port Cognitive antenna structure comprising of both UWB and narrowband antenna, fig. taken from [16]

In [17], the antenna incorporates both a sensing and a reconfigurable antenna on the same substrate. The sensing antenna covers the band from 2-10 GHz, while the reconfigurable antenna can tune its operating frequency through the whole band covered by sensing antenna. Reconfigurability is achieved by feeding at different times, different antenna patches and the frequency tuning is obtained by physically changing the patch shape. A circular substrate holding five different antenna patches is rotated using a stepper motor. A 50Ω stripline connects the rotating section to guarantee a contact between the rotating circular substrate and the feed line. At each rotation stage, stripline excites a different patch and a different output frequency is achieved. A 12 V power supply is required for the stepper motor. The stepper motor at the back of the rotating antenna section is connected to the controller circuit, which shows that complex circuitry makes the antenna bulky for use on the RF front end. In [18], an antenna is presented with two microstrip lines fed monopoles. These two antennas share a common ground and are 20.5mm apart, from center to center. The sensing antenna is an egg-shaped patch, obtained by combining a circle and ellipse at their centers. The conglomeration of the patch, the partial ground plane, and feed matching section guarantees a UWB response of the sensing antenna. The communicating antenna is a 40mmx1mm microstrip line connected to a 50Ω feed line.

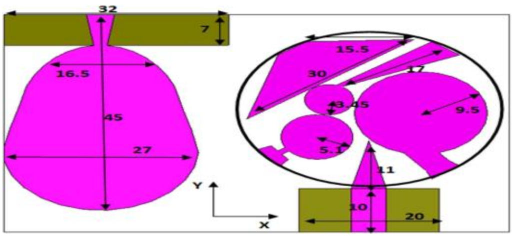

Fig. 6 A rotatable frequency reconfigurable dual port antenna for cognitive radio taken from [17]

This structure yields multiple resonances in the 3.1−10.6 GHz UWB frequency range. Two 1mm2 electronic switches are used in a frequency reconfigurability scheme. By controlling the position of these switches, the length of the antenna can be changed, thus leading to various resonant frequencies. More switches can be used to obtain more resonances, as only two electronic switches provide us limited available bandwidth to use.

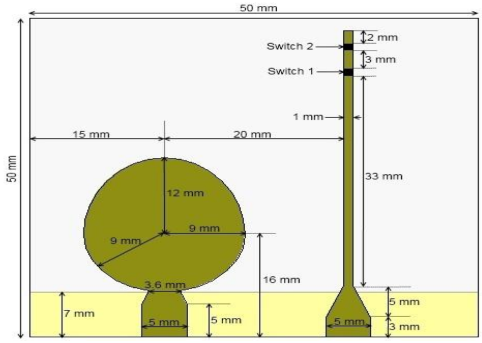

Fig. 8 Dual port UWB and narrowband antenna for CR proposed by [18]

In [19], an antenna suitable for underlay and overlay CR is proposed. The antenna can be operated as UWB, for underlay CR and for sensing in overlay CR, and is reconfigurable in a sense that it has the ability to selectively have a band stop in the WiMAX and WLAN bands, to get prevented by interference to primary users operating in these bands, when used in overlay CR mode.

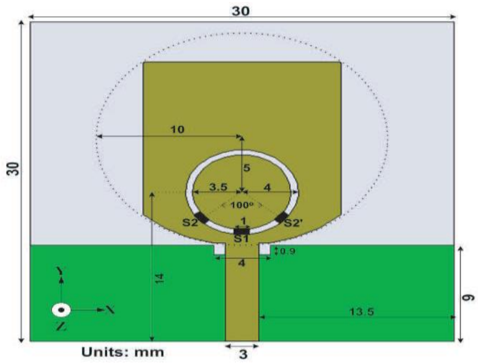

Fig. 9 Single port CR Antenna with a reconfigurable band notch, fig. taken from [19]

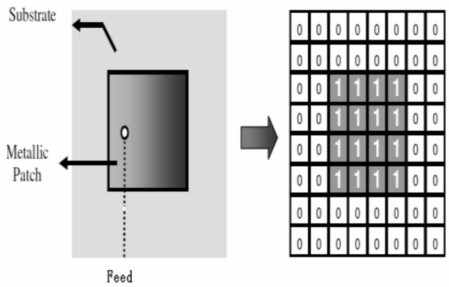

Fig.10 Encoding of patch shapes for antenna shape optimization, fig. taken from [21]

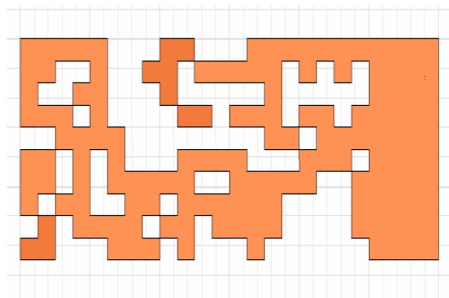

Fig.11 The top patch's shape of PIFA obtained by GA, fig. taken from [21]

Each of the antennas described in [20] demonstrated a different quality of genetic algorithms as applied to wired antenna design. The Yagi antenna which is optimized for the Arecibo Feed problem shows how the GA can modify the conventional designs, to solve unconventional problems. The crooked-wire genetic antenna shows the power of the GA to output not just an optimized design for an application, but a new software design with minimal help from the engineer. In [21], a technique for combining genetic algorithms (GA's) with method of moments (MoM) for integrated antenna design is shown and explores two applications as an example of the GA/MoM approach. In DMM a "mother" structure is chosen and its corresponding impedance or Z matrix is filled just once prior to beginning the GA optimization process. The GA then optimizes the design by creating substructures of mother structure as shown by the corresponding subsets of the original mother Z-matrix. Applications of DMM with GA/MoM reduce the total optimization time by avoiding multiple Z-matrix fill operations. In [22], a numerical code for antenna design using multiple frequencies has been presented. This code employs MoM and GA to design the optimal shape for PIFA patches, beginning from a rectangular geometry discretized with a user-defined detail level. Depending on the dimensions of the patch and on the discretization scale

In [23], the design of a low volume small multi band microstrip patch antenna for GSM900, GSM1800, GSM1900, UMTS1920, LTE2300, and Bluetooth 2400 applications by using a genetic algorithm (GA) is proposed. The GA method divides the overall patch area into different cells. Genetic algorithm together with finite element method (FEM) is used to optimize the patch geometry, the feeding and the shorting position. The optimized MPA has dimension of 46mm x 57mm with an air gap of 10 mm. It has a reflection coefficient less than -10 dB at all 6 bands and it can be useful for a base station antenna.

6. PROPOSED DESIGN USING GENETIC ALGORITHM

A great variety of antennas have been designed for the cognitive radio applications with different parameters of reconfigurability, and different frequency ranges. The reconfigurability in [14],[15],[18][19] and [20] is obtained using pin, varactor , and RF-MEMS switches. While the antennas of [16] and [17] uses rotatable patches moved by stepper motors. The amount of reconfigurability and in turn the number of possible states of the antenna is determined by the total number of configurations possible by the switches or the number of states occupied by the antenna for each rotation. While a detailed survey of the above papers, we have come to the following problem statements:

Table 1. Challenges in the various antenna designs

Paper	Type Of The Antenna	Number Of Switches/ Rotation To Attain Reconfigurability	Number Of Frequency Bands Possible	Challenges
In [14] by Y. Cai et al	Single port Yagi-Uda	12 Varacter diodes as switches	6	1 MΩ resistors are used to bias 12 diodes producing significant ohmic losses
In [15] by Terence Wu et al	Four port Microstrip with switchable multiband radiators	4 MEMS switches	4	Poor isolation between switches need filters to remove noise
In [16] by Y Tawk et al	Dual port Rotatable microstrip patch	2 Rotation of the antenna using stepper motor	2	Difficult to suppress coupling that occur on multiple antennas mounted on the same substrate
In [17] by Y Tawk et al	Dual port printed monopole antenna and a reconfigurable patch printed on the same substrate	5 Rotation of the antenna using stepper motor	5	Lossy connections between feed line and the rotating part
In [18] by M-Al Husseini et al	Two microstrip line fed monopoles on the same substrate	2 Electronic switches	3	Difficult to suppress coupling that occur on multiple antennas mounted on the same substrate
In [19] by M-Al Husseini et al	Rectangular patch with ring slot and single port	3 Electronic switches	3	Fast switching between UWB and narrowband configurations which increases complexity

While a cognitive radio cycle sensing and decision process, after receiving the current unused band from the wideband antenna, the narrowband antenna starts transmitting and receiving on this band. The numbers of frequency bands on which the narrowband antennas show significant gain are dependent on the number of total configurations of the switches. For Example, if there are 2 switches in the antenna, the total number of frequency bands possible is 4 or less.

For a successful cognitive radio, we require a large number of frequency bands so that the all the unused bands are exploited and improved spectrum efficiency is achieved.

For a large number of frequency bands to be utilized, we must increase the number of switches in the [14],[15],[18]and[19], or we can increase the total number of antenna configurations achieved through rotation in [16] and [17].But increasing the switches will increase the complexity, cost and losses of the system. For rotatable case, the antenna designed must be modified with great precision for increasing number of configurations achieved through rotation.

Optimization is a technique to find the best possible outcome from a problem having a set of constraints. Global optimization algorithms like Genetic algorithm can be used to develop the best possible antenna design while satisfying required constraints. Using GA we can optimize the antenna geometry, with the help of methods that are proposed in [20]-[23]. The approach will be to design the narrowband antenna with minimum possible switches or minimum possible changeable states to minimize the losses and then optimizing the structure using binary genetic algorithm for best possible gain and radiation parameters. So that it can operate on a more number of frequency bands by using minimum number of switches.

7. CONCLUSION

In this survey paper, we have discussed the design of antennas for reconfigurable Cognitive Radio applications. Cognitive Radio is a revolutionary frequency assignment technology which allows unlicensed users to use spectrum bands which are licensed to primary users, while satisfying the interference constraints. Spectrum underlay and spectrum overlay are the basic two approaches to share frequency spectrum between the primary and the secondary users.

Ultrawideband antennas are needed for sensing in overlay cognitive networks, and for communicating in underlay networks. Our aim is to design a reconfigurable antenna which is optimized by genetic algorithm. The target is to achieve maximum bandwidth for the communication antenna by using a minimum number of switches or other methods that can be used for achieving reconfigurability.

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