Cognitive radio Research and Implementation Challenges

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***Abstract*— Future mobile terminals will be able to communicate with various heterogeneous systems which are different by means of the algorithms used to implement baseband processing and channel coding. This represents many challenges in designing flexible and energy efficient architectures. Using the sensing phase, the mobile can sense its environment and detect the spectrum holes and use them to communicate. Current research are investigating different techniques of using cognitive radio to reuse locally unused spectrum to increase the total system capacity. They aim also to develop efficient algorithm able to maximize the quality of service (QoS) for the secondary (unlicensed) users while minimizing the interference to the primary (licensed) users. However, there are many challenges across all layers of a cognitive radio system design, from its application to its implementation.**
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I. Introduction

Observing that in some locations or at some times of day, 70 percent of the allocated spectrum may be sitting idle, the FCC [1] has recently recommended that significantly greater spectral efficiency could be realized by de-ploying wireless devices that can coexist with the primary users, generating minimal interference while taking advantage of the available resources. Thus, the discrepancy between spectrum allocation and spectrum use suggests that this spectrum shortage could be overcome by allowing more flexible usage of a spectrum. Flexibility would mean that radios could find and adapt to any immediate local spectrum availability. A new class of radios that is able to reliably sense the spectral environment over a wide bandwidth, detect the presence/absence of legacy users (primary users) and use the spectrum only if the communication does not interfere with primary users is defined by the term cognitive radio [2]. Cognitive radios have been proposed as a mean to implement efficient reuse of the licensed spectrum. The key feature of cognitive radios is their ability to recognize their communication environment and independently adapt the parameters of their communication scheme to maximize the quality of service (QoS) for the secondary (unlicensed) users while minimizing the interference to the primary users.

II. Cognitive radio approach

The potential for Cognitive radio is a novel efficient methodology, extension of software-defined radio, to transmit and receive information over various wireless communication devices. Being aware of the existing operators in the environment, Cognitive radio choses the best available option based on performance for each application. The different performance measuring parameters include frequency, power, antenna, transmitter bandwidth, modulation scheme etc. This means that the said radio has to deal with different RF spectrum and baseband varieties at the same time, thus requiring a more robust, efficient and reconfigurable hardware architecture. Clearly, the introduction of this revolutionary paradigm poses many challenges across all layers of a cognitive radio system design like spectrum sensing, interference management, resource allocation, RF design and implementation issues.

A. Sensing

One of the defining functions of a cognitive radio is the ability to sense the radio channel in order to find opportunities in spectrum and adapt the radio parameters. Recent measurements have shown that the spectrum usage is concentrated on certain portions of the spectrum while a significant amount of the spectrum remains unused. These holes can be classified into three types [3] :
1. Black spaces, which are occupied by high power interferes some of the time,
2. Grey spaces, which are partially occupied by low power interferes,
3. White spaces, which are free, no one send information on this band, but it is occupied by natural and artificial forms of noise(e.g. thermal noise, transient reflections...).
Black spaces is obvious forbidden to send on it because of the high power interferes, so the whites and the Grey spaces are the candidates for use by unlicensed operators. Spectrum sensing has been identified as a key enabling cognitive radio to not interfere with primary users, by reliability detecting primary users signals. So sensing requirements are based on primary user modulation type, power, frequency and temporal parameters. Spectrum sensing is often considered as a detection problem. Many techniques were developed in order to detect the holes in the spectrum band. Focusing on each narrow band, existing spectrum sensing techniques are widely categorized into energy detection [4] and feature detection [5]. However, the performance of the energy detector is susceptible to unknown or changing noise levels and interference. In addition, the energy detector does not differentiate between modulated signals, noise, and interference but can only determine the presence of the signal. It does not work if the signal is direct-sequence or frequency hopping signal, or any time varying signal. On the other hand, cyclostationary models have been shown in recent years to offer many advantages over stationary models. Thus, cyclostationary feature detection performs better than the energy detector. However, it is computationally complex and requires significantly long observation time [6]. Recent work has shown that the ability to sense weak signals based on sub-space analysis[7].

The biggest challenge related to spectrum sensing is in developing sensing techniques which are able to detect very weak primary user signals while being sufficiently fast and low cost to implement.

B. Interference management and resource allocation

Spectrum utilization can be improved by making a secondary user to access a spectrum hole unoccupied by the primary user at the right location and the right time. In current cognitive radio protocol proposals, the device listens to the wireless channel and determines, either in time or frequency, which part of the spectrum is unused. It then adapts its signal to fill this void in the spectrum domain. Thus, a device transmits over a certain time or frequency band only when no other user does [8]. The contribution of some recent studies [9] and [10] has extended the cognitive protocols to allow the cognitive users to transmit simultaneously with the primary users in the same frequency band. This is exactly the question to tackle : How we can allow the secondary user to transmit simultaneously with the primary user as long as the level of interference with the primary user remains within an acceptable range.

III. IMPLEMENTATION ISSUES

A. RF design

A primary technological concern in cognitive radio architectures, whether it be for wideband sensing procedures or wideband multi-band communication mechanisms is the ability to design linear and spectrally-agile components and architectures in the radio-frequency front-end of the transceiver.

In a conventional radio design, some assumptions are made on the interferers and, based on worst-case scenarios, the performance of the RF front-end is specified with respect to selectivity and linearity. Conventional radios typically utilize a pre-select filter at the receiver input to limit the interferers, which the active part must be able to withstand. However, for a cognitive radio this approach is not very practical due to its inherent need to flexibly select the radio frequency. Removing or relaxing the pre-select filter selectivity significantly exacerbates the problems due to interferers. All RF front-end specifications cannot be directly mapped to circuit blocks without information on the interferer scenarios. Some of the error generation mechanisms are complex and, in general, it is a fairly involved task to find out the building block requirements that lead to adequate receiver performance under all expected conditions. The fact that, in a cognitive radio, neither the RF frequency nor the bandwidth is known in advance complicates the situation considerably. Following the well-proven methods of receiver design and frequency planning will lead to excessive circuit block requirements particularly in absence of a pre-select filter at the receiver input. In order to deal with the more stringent performance requirements, a cognitive radio should be designed to take advantage of its inherent capabilities. It should use the information it possesses on the interferer situation and its own non-idealities to select the RF frequency, not only based on spectrum occupancy, but also on the suitability of a given frequency for communication. This will help in relaxing the circuit block requirements, so that they do not become excessive, while not forcing the initial radio design to limit the capabilities of the cognitive radio.

B. Sysem On Chip Implementation

Designing the digital baseband processing of such an extremely agile system is a very challenging task. The required processing power is huge in most of the functional unit and the memory needs and memory bandwidths are also usually very high. But the two most difficult aspects are probably :

- the partitioning of the system in hardware and software processing units,
- the system integration and the design of the embedded software

The partitioning implies a deep study of the basic algorithms involved. The different variations of a given function must be identified. As in most cases there are many different implementation options, the design space to be explored is a large one. The output of this algorithmic analysis is a set of highly parameterizable and flexible functional entities. The design of these entities is less challenging. However, it strongly depends on the selected target technology as we will show with the example of a Xilinx Virtex V target.

The system integration phase is also a critical issue. Scheduling of the hundreds of different tasks running on very different operating units requires an accurate modeling of their dependencies, of their parallelization possibilities and of their timing-related constraints. The entire platform is controlled by a complex embedded software application running on a set of embedded CPU cores. The challenges here are those of a real-time constrained application in the context of a multi-processor System on Chip architecture.

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