Cognitive Radio and green communications: power consumption consideration

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**Abstract:** Green Cognitive Radio (GCR) is a Cognitive Radio, which is aware of sustainable development and takes it as an additional constraint in the decision making function of the cognitive cycle. In this paper, we remind the Cognitive Radio concept, and then explain how the sensors distributed within the three layers of our model help to reach GCR. The use of these sensors, so as to make the correct decision and to comply with the sustainable development constraints, is explained through two examples related to power consumption.

1. Introduction

Since Resolution 42/187 of the United Nations General Assembly in December 1987, Sustainable Development (SD) has become an issue and an aspiration of our civilization. The most often-quoted definition of SD has been formulated by the Brundtland Commission [1] as the development that “meets the needs of the present without compromising the ability of future generations to meet their own needs”. The first paper related to cognitive radio, as a way of decreasing electromagnetic pollution (mainly from the human exposure point of view) has been presented several years ago in [2]. But, at that time, this type of preoccupation was not in the trend. Now, mainly due to global warming, it is in the limelight. Currently, 3% of the world-wide energy is consumed by the ICT infrastructure which causes about 2% of the world-wide CO2 emissions (which is comparable to the world-wide CO2 emissions by airplanes or one quarter of the world-wide CO2 emissions by cars). In parallel another challenge of future wireless radio systems is to globally reduce the electromagnetic radiation levels in order to have a better coexistence of wireless system (less interference) as well as a reduced human exposure to radiations. This last point was the main objective of [2]. These values of carbon footprint are very impressive. They have been confirmed by a lot of studies and reported in many conferences and workshops as the recent “Next Generation Wireless Green Networks Workshop”, held in SUPELEC in November 2009. Starting from the work presented in [3], we claim that Cognitive Radio, thanks to its sensors, is an enabling technology for Green Communications. IT is exactly what we named Green Cognitive Radio. In this paper we focus on power consumption issue and highlight that with adequate sensors as:

- Spectrum Hole detection sensor and Peak to Average Power Ratio (PAPR) sensor we can manage the High Power Amplifier (HPA) efficiency. In transmitters equipments (whatever the type of standard to be amplified) the major consumption is due to the HPA. It could reach during transmission up to 70% of the total consumption. So, saving a few percent regarding HPA efficiency is of great interest in the context of GC. This example is extracted from [4].

- Thermal sensor and area occupancy ratio sensor. This example describes how to migrate a function from a hot location (high consumption) to a cooler location (lower consumption) by means of both thermal sensor and area occupancy sensor. This example is extracted from [5].

2. Cognitive Radio
2.1. The Cognitive Cycle

Cognitive Radio (CR) relies on Mitola's work in [6] and [7]. Mitola argues that radio will become more and more autonomous, and thanks to the support of flexible technology (namely software defined radio SDR [8]) will acquire some self-autonomy to dynamically modify its functionality. As explained in Fig. 1, this relies on a cognitive cycle (part a) from [6]). Part b is a simplified view of the cycle, which can be summarized in three main steps [9]:

- **Observe:** gathers all the sensing means of a CR,
- **Decide:** represents all that implies some intelligence including learning, planning, decision making,
- **Adapt:** reconfigures the radio, designed with SDR principles in order to be as flexible as possible.

Cognitive Radio presents itself as a set of concepts and technologies that enable radio equipments to have the autonomy and the cognitive abilities to become aware of their environment as well as of their own operational abilities [6]. Thus it is a device that has the ability to collect information through its sensors and that can use the past observations on its surrounding environment, in order to improve its behavior consequently. Therefore the CR equipment adapts its behavior to the local context. We can conclude this very short description of CR by saying [3]: "CR is a decentralized view associated with a local optimization of needs and resources versus a centralized and static view based on the worst case scenario's needs".

![Figure 1: The cognitive cycle (a) and its simplified view (b)](image)

2.2. Multilayer sensors

In order to make appropriate decisions, cognitive radio equipments rely on the information gathered from a set of sensors. Consequently, designing simple, accurate and reliable sensors enable the CR equipment to adapt the best possible way to its surrounding environment. In [9], the concept of "Sensorial Radio Bubble" (SRB) for cognitive radio equipments has been introduced, in order to model and process the environment seen from the sensors of the equipment. Thus it can be seen as the smallest cluster associated to the CR equipment. Through this cluster, the SRB has to manage (discriminate, fusion, filter, etc.) the information collected at its different sensors, in order to send reliable and useful information to the decision making engine inside the equipment. All the information that can help the radio to better adapt its functionality for a given service in a given environment is worth being taken into account. Then as we make no restriction on the sensors nature, it is possible to draw the general approach exposed in Table 1, already presented in [9]. Sensors were classified in function of the OSI layers they correspond to, with a rough division in three layers. In the lowest layer of our model, we find especially all the sensing information related to the physical layer: propagation, power consumption, coding scheme, information related to the hardware execution platform, etc. At the intermediate level is all the information that participates to vertical handovers, or can help to make a standard choice, as a standard detection sensor for instance. The network load of the standards supported by the equipment may be of
interest also. It also includes the policies concerning the vicinity, the town or the country. The highest layer is especially related to the applications and all that concerns the human interaction with the communicating device. It is related to all that concerns the user, his/her habits, preferences, policies, profile. The equipment can be aware of its environment with the help of sensors such as microphone, video-camera, bio-sensors, channel estimation, battery level, etc.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper Layer</strong></td>
<td>Application and IHM: User profile: Price, Operator, Personal choices, etc. Sound, Video, Speed, position, Velocity, Security, Indoor/outdoor, etc.</td>
</tr>
<tr>
<td><strong>Intermediate Layer</strong></td>
<td>Transport, Network: vertical Handover inter/intra networks, Standards Recognition, Load on a link, etc.</td>
</tr>
<tr>
<td><strong>Lower Layer</strong></td>
<td>Physical, link, medium, running hardware: Access mode, Power, Modulation, Channel coding, Carrier /Symbol frequencies, horizontal Handover, Channel estimation, Direction of Arrival, Consumption, etc.</td>
</tr>
</tbody>
</table>

Table 1: The sensors according to the simplified three layer model [9]

3. Power consumption examples

3.1. PAPR sensor for High Power Amplifier efficiency

This section is based on the work published in [4] Future wireless reconfigurable multistandards equipments will amplify a lot of different standards, each one having each its PAPR. In order to amplify these signals with the same HPA, without modifying any hardware, the current solution is to take an Input Back Off (IBO) greater than the greatest PAPR of the standards. Therefore the efficiency of the HPA is very low (see Fig. 2). Another solution we proposed in [4] is to use an algorithm to mitigate the PAPR in order to amplify every signals with a high efficiency at a low IBO. That means whatever the PAPR of the signal is, it should be lower than the predefined IBO after mitigation. In the CR context, we proposed in [10] to use the Spectrum Hole sensor to detect the hole and to use part of it to convey the correcting signal to mitigate the PAPR. The other part of the hole is used for useful data. The PAPR sensor is used, in this example, to select the best algorithm to mitigate the signal PAPR under the IBO threshold.

![Figure 2: Amplification of different signals with different PAPR and its effect on HPA efficiency](image)

3.2. Function migration, in reconfigurable hardware, for temperature and power consumption management

This section is based on the work submitted in [5]. We measured and shown there is a strong connection between temperature of the FPGA block and the consumption of this block as it is presented Fig.3. Using this information given by the thermal sensor and using Partial Reconfiguration technology as described in [11], it is therefore possible to offer a strategy of migrating functions, as in [12], from hot blocks to cooler blocks as presented Fig.4. The area occupancy sensor informs if this cooler block is free to perform function migration.
4. Conclusion

This paper deals with Green communications from the equipment power consumption point of view. We shown through two examples, that using cognitive cycle with proper sensors, we can decide actions which decrease the power consumption. This strategy is what we called Green Cognitive Radio. Further work will demonstrate this strategy through real demonstrations.

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References