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Cognitive radio in the context of internet of things using a novel future internet architecture called NovaGenesis

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ABSTRACT

Many Internet of Things (IoT) requirements are already at the core of next generation wireless networks, including 5G, cognitive radio and future Internet. There is a huge consilience that the majority of Internet devices will become sensors and actuators equipped over ordinary "things". As a consequence, the radio environment will increasingly become crowded with thousands of low-cost devices sharing the unlicensed frequency bands. This paper is regarding a convergent solution of future Internet and cognitive radio in the context of IoT. It proposes an embedded and low cost cooperative spectrum sensing solution, which has been experimentally implemented. Furthermore, we present a distributed software-controlled sector aware spectrum sensing architecture to store and analyze the spectrum usage information. Finally, the proposed approach has been integrated to a future Internet architecture called NovaGenesis. A proof-of-concept has been experimentally performed, demonstrating for the first time the convergence of IoT, future Internet and cognitive radio.

1. Introduction

The Internet of Things (IoT) has been challenging all existing information and communication technology (ICT) architectures in the last years, mainly due to the exponential growth in the number of connected devices, the diversity of possible technology stacks (heterogeneous networks) and devices connectivity issues [1,2]. The new scenario becomes even more challenging since many traditional networks had not been originally designed to offer adequate security and privacy for IoT [3,4]. Moreover, a significant portion of mobile IoT devices will require rebinding of devices' locators [2] and hundreds or even thousands of them will share the same radio frequency (RF) electromagnetic spectrum. The IoT requirements play an important role in the context of the next generation wireless networks, including 5G [5], cognitive radio [6] and future Internet [2]. For instance, Michailow et al. [5] have considered low power consumption and delay tolerant requirements of machine-to-machine communications in the context of 5G networks.

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Cognitive radios networks (CRNs) have been proposed as a key solution to define rules and techniques for using underutilized licensed RF bands [7]. One of its benefits is allowing users of congested unlicensed bands to offload their traffic to other parts of the RF spectrum, even the licensed ones. A CRN is able to identify when the legal owner of some RF spectrum portion, who is called primary user, is not making use of its licensed RF band. Cognitive networks may orientate secondary (opportunistic) users to make use of this part of the RF spectrum without interfering in the primary user communication [6]. As a consequence, a cognitive radio (CR) must identify – or sense – when the licensed RF band is unused and distribute this information for the secondary users that may be interested in establishing communication over this part of the RF spectrum. The tsunami of devices expected in IoT will push radio frequency spectrum control and management towards more opportunistic approaches, creating a straightforward link between IoT and CRN [1].

The latest piece of this puzzle is the strong relation between the IoT requirements and future Internet (FI) research [8]. The term future Internet was adopted in the first initiatives with the aim of rethinking the Internet, including the future Internet design (FIND) initiative [9] and the European future Internet assembly (FIA) initiative [8]. By FI, we mean any Internet-like network that could emerge in the future. This includes evolutionary approaches, in which the fundamental protocols of the current Internet are maintained and new ideas are incrementally introduced; or revolutionary approaches, in which the architecture is redesigned from scratch (also named "clean slate" proposals).

Examples of evolutionary FI architectures (FIAs) that encompass IoT scope are: FIWARE [10], SENSEI [11] and SmartSantander [12]. FIWARE provides a platform to integrate computer programs (or generic enablers – GE) via the next generation service interfaces (NGSIs). The NGSI-9/NGSI-10 is based on RESTful application programming interfaces (APIs) [10], as a consequence, it is dependent on the current Internet technologies. SENSEI is focused on the wireless sensor and actuator networks interoperation, creating a market for the sensed data also employing RESTful interfaces. Finally, SmartSantander is based on a platform for the smart city services integration using RESTful APIs.

To the best of our knowledge, those projects do not explore CRN approach to opportunistically perform spectrum control and management, by using a spectrum sensing technique. They also lack on supporting some FIA ingredients, such as: information-centric networking (ICN) [13], service-oriented architecture (SOA) [14], service-centric networking (SCN) [15], software-defined networking (SDN) [16], network function virtualization (NFV) [17], self-verifying naming (SVN) [4], identifier/locator (ID/Loc) splitting [2] and network caching.

Up to the current moment, we can conclude that none of the mentioned revolutionary approaches have being proper explored in the IoT state-of-the-art. In this sense, we idealized and developed a new FIA called NovaGenesis (NG) [18], which considers IoT and CRN as key players for future Internet. In this paper, we explore for the first time the convergence of IoT, CRN, and FI technologies, by means of three main contributions. Firstly, we report a successful implementation of a novel approach for cognitive radio in IoT scenarios based on a software-controlled, low-cost and an embedded cooperative spectrum sensing. Secondly, we present the concept and an experimental demonstration of a distributed, software-controlled and sector aware spectrum sensing architecture that employs current Internet protocols to store and analyze spectrum usage information. Thirdly, we extend NG with novel services to interoperate with the proposed CRN approach based on energy detection from spatially-distributed remote radio units by taking advantage of the NG FIA ingredients.

The remainder of this article will introduce our CRN based on energy detection from spatially-distributed remote radio units in Section 2. The proposed system is implemented using a low-cost hardware and GNU Radio as a processing platform. Section 3 presents NovaGenesis, including its fundamental concepts, implementation and two novel FI services to interoperate with our CR solution. Experimental results are reported in Section 4, including a proof-of-concept of the new NG services together with the embedded spectrum sensing. Finally, we conclude the paper in Section 5, giving direction for future works.

2. Cognitive radio network proposal: embedded low-cost cooperative sensing

The employment of a RF spectrum sensing technique is convenient, independently of the way that the unused RF band is going to be allocated by a secondary user, for this reason is considered one of the CR most important features [19]. CR may be placed alone in a non-cooperative environment or being part of a cooperative network, in which a channel allocation decision is based on the information collected by diverse CRs.

In the ISM bands, there is no licensed user, so the primary user is not formally present, but the benefits of the spectrum sensing and CR techniques are still valid. Regulation agencies stipulate that radios must implement some specific channel access techniques for certain RF bands, such as frequency hopping spreading spectrum (FHSS) or direct sequence spreading spectrum (DSSS). By applying FHSS, a radio pair keeps changing the communication channel frequency over time, spreading the transmitting power over a wider bandwidth. In a point to point communication, FHSS is very reliable and have been used for a long time. IoT applications, wireless sensor networks (WSN) and smart grid solutions typically demand low power consumption in order to enable communication among hundreds or even thousands of devices.

2.1. Cooperative spectrum sensing

The proposed cooperative cognitive radio network is presented in Fig. 1a. It is composed by the following blocks: sensing cell (SC); sensing cell controller (SCC); sensing information storage and analysis (SISA). The SC is responsible to acquire RF information, whereas the SCC detects users in the RF spectrum and SISA acts as a fusion center with the ability of