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Coexistence server in Cognitive Networks: A real implementation

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ABSTRACT

In Cognitive Networks, coexistence is one of the main issues to be addressed. The release of TV White Spaces (TVWS) for use in various regions of the world presents an opportunity for better spectrum utilization and asks for new techniques of spectrum allocation. The IEEE 802.19.1 standard is designed to address the coexistence of secondary and primary users in TVWS. In this standard, two components are of paramount importance: the Coexistence Discovery and Information Server (CDIS) and the Coexistence Manager (CM). This paper describes a real implementation of a CDIS and a CM for cognitive networks in a central Coexistence Server. Results indicate that, with a coexistence server, it is possible to reduce the overall network interference, even in environments with unmanaged neighboring devices, with a throughput gain for managed and unmanaged devices.

1. Introduction

The limited availability added to the inefficient use of the frequency spectrum demands for new mechanisms and communication paradigms that exploit the existing spectrum more efficiently [1]. *Cognitive Networks*, also called Cognitive Radio Networks and Next Generation Wireless Networks [2,3], are a network technology that increases the efficiency of spectrum allocation through opportunistic access to given frequency bands. Some potential scenarios for Cognitive Networks implementation are: Vehicular Networks [4,5], Smart Grids [6–8], Sensor Networks [9–11], UAVs (Unmanned Aerial Networks) [12], Underwater Networks [13,14], Public Safety Communications [15] and Medical Body Area Networks [16].

Cognitive radio technology may access unused and underutilized frequency spectrum spaces, referred to as *white spaces* [17] (also called spectrum holes) in licensed and unlicensed bands for transmission [18,19]. If such bands start to be used by a licensed user, all cognitive radios must change its operating channel to another spectral hole, or remain in the same band, changing its transmission power or modulation scheme in order to avoid interference.

In search of alternatives for a more efficient use of the available frequency bands, regulatory agencies worldwide began to regulate the secondary use of the *TV White Spaces* (TVWS) [20–22], which refer to analog TV channels being released due to the deployment of digital TV broadcasts. These regulations permit the secondary use by unlicensed wireless devices as long as they always defer channel usage to the primary licensed user. This is one of the first applications of cognitive radios.

The potential benefits brought by TVWS communications are, however, as large as the challenge it imposes. Firstly, there is the issue of efficient and organized use of the VHF/UHF spectrum, which motivated several standardization efforts, as the creation of the IEEE 802.22 Working Group [23] for WRANs (Wireless Rural Area Networks), the IEEE 802.11af amendment [24] and the ECMA-392 standard [25] for WLANs (Wireless Local Area Networks). Secondly, non-technical questions arise from TV broadcasters strongly opposing the sharing of their dedicated spectrum (licensed) with secondary users [26].

In IEEE 802.11af, spectrum sensing is used to estimate TVWS availability. In IEEE 802.22, TVWS selection is based on queries in spectrum management database. If multiples networks operate on different standards (i.e., IEEE 802.11af and IEEE 802.22) in the same geolocation and in the same frequency, severe interference can be imposed [27,28].

Thus, a more recent challenge is to prevent harmful interference between multiple secondary networks who share the TVWS spectrum. This problem has attracted so much attention that the IEEE Wireless Coexistence Working Group (IEEE 802.19) created a subgroup specifically dedicated to define coexistence methods for TVWS, regardless of the radio technology (PHY or MAC layers) employed by the secondary

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user. The IEEE 802.19.1 standard [29] was published in 2014 and works in a high-level approach, in which new designs for physical and MAC layers are not considered. The standardization allows the production of compatible solutions by different vendors [30].

This article presents an architecture for coexistence of secondary TVWS wireless networks which adheres to the IEEE 802.19.1 architecture. The key element of the architecture is a central coexistence server that acts as:

1. Coexistence Discovery and Information Server (CDIS), which scans and stores coexistence information from different areas.
2. Coexistence Manager (CM), which redefines the channels and transmission powers of managed coexisting nodes in the network, considering radio environment characteristics, and the interference generated by elements that are not controlled by the architecture.

Practical results from a real implementation of the coexistence server are presented. Also, for contextualization, an overview of the problems of coexistence in TVWS is also provided in Section 2. The rest of this paper is organized as follows. Section 3 presents an overview of the IEEE 802.19.1 standard. Section 4 describes our real implementation of an IEEE 802.19.1 architecture, including novel algorithms to reduce network interference. Section 5 presents the results on a real testbed. A discussion about the results and the IEEE 802.19.1 standard is addressed in Section 6. Finally, Section 7 presents conclusions and future works.

2. Coexistence in Cognitive Networks

A natural consequence of multiple networks with cluttered access to TVWS is uncontrollable interference, resulting in the inability to coexist. The lack of effective coexistence can prevents the full exploitation of TVWS and significantly reduces their use.

Coexistence in cognitive networks is presented as a problem where two or more such networks use secondary spectrum bands concurrently. The major problem of the coexistence in these networks is the need to detect the primary user in the licensed frequency bands and, if detected, the complete removal of the secondary user activities from that frequency.

The coexistence problems can be classified into three categories: *detection of spectrum availability*, *interference mitigation*, *and spectrum sharing*. Open issues include regulatory requirements (limits of spectrum sensing) and heterogeneities in operating characteristics of secondary systems, including network architecture (master-slave, peer-to-peer, mesh), device category (fixed or personal/portable), transmission power limits, operating bandwidth, modulation/encryption schemes and MAC schemes (reservation or contention-based access) [31].

2.1. Detection of spectrum availability

The detection of spectrum availability refers to the identification of TV channels available for use without causing harmful interference to primary users. Furthermore, the detection of secondary networks is also important, especially to allow optimal decisions for channel selection [31].

- Primary Users Detection – The Cognitive Wireless Networks (CWNs) should apply reliable methods to detect available TVWS. For example, the FCC requires that the secondary systems determine a TV channel available primarily using a database of primary users, but spectrum sensing is also defined in the rules with very demanding requirements.
- White Space Database (WSD) is a central repository managed by a trusted authority. It stores information about the operations of the primary users, i.e., the primary users location, their requirements for transmission power, used channels, and expected usage duration [32]. The secondary systems query the WSD to determine the TV channel availability in its geographic region. Upon receiving a query, the WSD sends information about the available channels in the specified location and power levels allowed for transmission [23] on these channels.
- Spectrum Sensing is the process of radio frequency (RF) spectrum sensing in order to detect the presence of primary user signals, usually above a certain threshold of detection [33]. Reliable techniques for detection of spectrum to date are classified into five major categories [33]: energy detection, waveform sensing based, filtering combination, radio identification detection based and cyclostationary sensing based.
- Secondary User Detection – CWNs will also need to detect coexisting secondary systems that operate on the same or different TV channels. This will require the detection of potentially different interfaces. For example, it will be critical to IEEE 802.11af and ECMA-392 networks to detect the presence of nearby IEEE 802.22 networks, since they may impose severe interference, in addition.

2.2. Interference mitigation

Interference mitigation in TVWS is a difficult issue, especially in areas of limited channel availability and where network coverage overlaps. Currently, heterogeneous networks share the 2.4 GHz unlicensed frequency, and interference among them has been the subject of extensive research [34]. Interference problems will be similar in TVWS, however, interference situations between devices such as low power devices (e.g. IEEE 802.11af and ECMA-392) and high power fixed systems (e.g. IEEE 802.22) are new in TVWS. Moreover, the TVWS good propagation characteristics may also contribute to increase interference area. For example, urban WiFi networks typically operate in co-channel without serious performance degradation in the 2.4 GHz band due to spatial reuse, and could have greater interference when operating on TV channel, due to the larger scope. Last but not least, the primary interference, especially the high-power TV stations, is another problem specific to the TVWS.

Interference problems related to TVWS are classified into two categories [31]:

- Interference from/to Primary Users – In addition to the primary user detection, requirements to limit out of band transmissions are defined for all TVWS devices, additional constraints on the operation of the adjacent channels in order to reduce the likelihood of interference with operators. On the other hand, high-power primary users (broadcast TV stations between 20 and 1000 kW) may also interfere with the secondary systems. Local proximity, as well as minor differences in their operating frequencies will severely degrade the performance of a secondary device. A recovery protocol for primary detection is adopted in the IEEE 802.22 standard which enables base stations affected by strong interference from primary users to reconnect [23]. Cognitive mechanisms will be essential for techniques to minimize interference due to coexistence, exploiting the knowledge of the wireless environment and signal characteristics.
- Interference Between CWNs – multiple CWNs can select the same TV channel due to a uncoordinated selection process or limited channel availability. Consider the worst-case situation in which all networks operate in co-channel, collisions and various interference problems could occur in such configuration.

2.3. Spectrum sharing

Avoiding overlapping operational channels between CWNs is always desirable. However, given the dynamic of TVWS, it is possible that CWNs share overlapping TVWS channels. Typical solutions for