Energy and Spectrum Efficiency in Rural Areas based on Cognitive Radio Technology

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Abstract—The rapid growth and development observed in wireless communications has resulted in the overcrowding of the radio spectrum used as a communication medium in wireless networks. In many countries, governmental agencies regulate the use of the radio spectrum by assigning a portion of the spectrum in the form of a renewable license to any company or person who wishes to use the wireless medium for communication purposes; this is in order to allow efficient utilization of this scarce resource. The need to close the digital divide means that cost effective communication technologies should be deployed in rural areas for wireless broadband connectivity. Cognitive Radio (CR) is seen as a technology that will bring a new communication paradigm to address spectrum scarcity in the most energy efficient manner. In this paper we present the proposed work to be carried out as part of a doctoral thesis to address the spectrum scarcity and transmission power in energy constrained rural areas.

Index Terms—Cognitive Radio, Spectrum, Energy Efficiency, Transmission Power Control.

I. INTRODUCTION

WIRELESS communications has seen rapid growth and development during the last decade, and there are no indications of such developments slowing down anytime soon. Among the leading areas of research and development in wireless communications, are techniques and mechanisms to implement the most cost effective and efficient utilization of the radio frequency spectrum and transmission energy. Radio frequency spectrum is considered to be the most expensive and scarce resource among all wireless network resources, followed by the transmission energy. However, it has been noted that the scarcity of the frequency spectrum is mainly due to the adoption of a static spectrum assignment policy.

Spectrum usage has been found to be concentrated on certain portions of the spectrum, while a significant amount of the spectrum remains unutilized or underutilized [1]. In Wireless Mesh Networks [2], transmission power control plays an important role to ensure successful and guaranteed packet transmission and reception with lower power consumption in energy constrained areas such as rural communities.

Cognitive Radios (CRs) [3] are seen as the key enabling technology for efficient, flexible and reliable usage of spectrum by adapting transmitter characteristics to the real-time conditions of the environment in which it operates [4].

Some research work that exploits power control in CR network considers mainly centralized single hop networks [5] - [8]. To the best of our knowledge, no work has been done to jointly address spectrum and transmission power control in multi-hop networks using the CR technology. The available literature [5], [6] states the two main challenges in CR systems operating in a licensed network as: 1) the protection of licensed users from harmful interference and 2) meeting the required quality of service (QoS).

In this paper, we consider a work in progress to address spectrum and energy efficiency in rural areas.

II. COGNITIVE RADIO

The Cognitive Radio (CR) concept was first introduced by Mitola [3] and it builds on software-defined radio technology. The CR technology aims at making use of the network resources currently used in wireless communication systems more efficient. Such network resources include *frequency*, *time* and *power* or *energy*.

Haykin [4] defines CR as an intelligent wireless communication system that is aware of its environment and uses the methodology of understanding by building to learn from the environment and adapt to statistical variations in the input stimuli. CR will address the following two objectives: 1) Highly reliable communication anywhere at anytime, 2) efficient utilization of the radio spectrum. CR technologies have the potential to provide wireless devices with various capabilities, such as frequency agility, adaptive modulation, transmit power control and localization [9].

A. CR for Spectrum Efficiency

The process of realizing efficient spectrum utilization using CR technology involves various aspects of spectrum management framework, *spectrum sensing*, *spectrum decision*, *spectrum sharing*, and *spectrum mobility* [1].
Initially, the main focus in dynamic spectrum management was finding spectrum sensing techniques [9], [10]. Spectrum sensing involves identifying spectrum holes and the detection of the onset of primary transmission on the spectrum hole occupied by the secondary user. Three spectrum sensing techniques based on primary transmitter detection are defined: *Energy detection*, *matched-filter*

detection and *feature detection*.

B. CR for Power Control

Most challenges of Transmission Power Control in conventional wireless systems have been addressed, but power control in CR systems introduces different challenges that require different approaches to be adopted. One of the main challenges in CR systems is to strike a balance between the conflicting goals of minimizing the interference to the primary user without compromising the quality of service of the secondary users [6], [7]. To address this problem, it has been suggested that the transmit power can be adapted based on the reliability of the sensed information [6].

Once the spectrum sensing is performed, it is very important to know how to exploit it efficiently. Transmission parameters have to be adapted based on the sensed spectrum and the channel estimation using CR technology.

Data transmission and spectrum sensing powers must be controlled for interference-free operation and prolonged life-span of CR systems.

III. PROPOSED SYSTEM MODEL

We consider a municipality consisting of both urban and sparsely populated rural areas. Our work extends the work that was proposed in [11], but instead of considering mesh mode of IEEE802.16, we propose a wireless multi-hop relay network (WMRN) based on IEEE 802.16j standard [12], as depicted in Fig.1.

The CR network coverage extends from the multi-hop relay base station (MR-BS) using a fixed cognitive radio relay station (CR-RS) for network coverage in the remote rural areas. We consider a single cognitive radio cell with N cognitive radio subscriber stations (CR-SSs) surrounding it. Each CR-SS chooses the available channel based on the spectrum sensing results. The municipality owns the spectrum license which is meant for its licensed users. The intention is to protect the licensed users from harmful interference that may be caused by the unlicensed users, while at the same time guaranteeing the QoS for the secondary users.

We intend to address the challenges of opportunistic spectrum access and transmission power control for efficient utilization of these most scarce wireless network resources. Our proposed solution is expected to meet the following requirements:

- Protect licensed users from harmful interference caused by unlicensed users.
- Control the transmission power of CR-SS for energy saving.
- Ensure that the CR-SSs do not interfere, but cooperate.

IV. CONCLUSION

This work in progress paper describes the proposed work that will address effective spectrum management for CR systems in energy constrained rural areas. We considered a wireless multi-hop network based on the Multi-hop relay standard instead of the mesh network.

We hope to present a complete work in a conference paper format, with simulated or experimental results as part of the contributions towards the doctoral thesis.

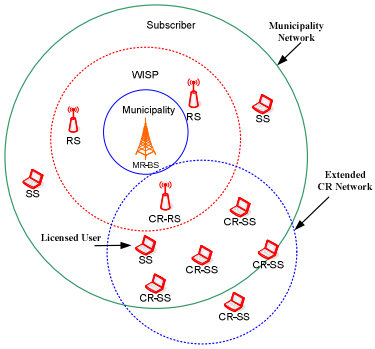

Fig. 1. Cognitive Radio Network within Municipality Network

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