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Virtualization-based Cognitive Radio Networks

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ABSTRACT

The emerging network virtualization technique is considered as a promising technology that enables the deployment of multiple virtual networks over a single physical network. These virtual networks are allowed to share the set of available resources in order to provide different services to their intended users. While several previous studies have focused on wired network virtualization, the field of wireless network virtualization is not well investigated. One of the promising wireless technologies is the Cognitive Radio (CR) technology that aims to handle the spectrum scarcity problem through efficient Dynamic Spectrum Access (DSA). In this paper, we propose to incorporate virtualization concepts into CR Networks (CRNs) to improve their performance. We start by explaining how the concept of multilayer hypervisors can be used within a CRN cell to manage its resources more efficiently by allowing the CR Base Station (BS) to delegate some of its management responsibilities to the CR users. By reducing the CRN users' reliance on the CRN BS, the amount of control messages can be decreased leading to reduced delay and improved throughput. Moreover, the proposed framework allows CRNs to better utilize its resources and support higher traffic loads which is in accordance with the recent technological advances that enable the Customer-Premises Equipments (CPEs) of potential CR users (such as smart phone users) to concurrently run multiple applications each generating its own traffic. We then show how our framework can be extended to handle multi-cell CRNs. Such an extension requires addressing the self-coexistence problem. To this end, we use a traffic load aware channel distribution algorithm. Through simulations, we show that our proposed framework can significantly enhance the CRN performance in terms of blocking probability and network throughput with different primary user level of activities.

1. Introduction

Due to the low cost and widespread acceptance of wireless communication devices and applications, the available radio spectrum became insufficient to accommodate the needs of such a large number of wireless devices (Bany Salameh and Krunz, 2009). Users of wireless networks are generally viewed as either Primary Users (PUs) or Secondary Users (SUs). PUs are those licensed users, for which a part of the available spectrum is reserved for their own services. Such reserved spectrum bands are not fully utilized. Thus, to improve the spectrum utilization, SUs are allowed to opportunistically utilize the licensed bands provided that they do not affect the PUs. Cognitive Radio (CR) is a technology that enables a CR node (a SU) to sense its operational environment and change its transmission parameters according to the acquired information with the goal of increasing spectrum utilization while minimizing the introduced interference to PUs. For example, a CR node can sense its environment for the available spectrum (spectrum holes), divides it into a set of channels and selects the best channel according to a predefined policy.

The IEEE 802.22 standard for Wireless Regional Area Network (WRAN) was proposed as the first attempt to enable commercial applications based on CR technology (Cordeiro et al., 2006; Bany Salameh et al., 2014). According to the IEEE 802.22 standard, a network consists of a base station (BS) and a set of Customer Premises Equipment (CPEs). The available spectrum is divided using Orthogonal Frequency Division Multiple Access (OFDMA) modulation scheme into a set of orthogonal channels and each BS is responsible for allocating available channels to the CPEs it is servicing. While such an approach avoids having interfering

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concurrent transmissions between CPEs of the same cell, it does not avoid other kinds of interference.

Co-existence of different wireless networks and interference management are challenging problems in CR environment. There are two different types of co-existence; incumbent co-existence (between licensed and unlicensed users) and self-coexistence (between SUs in multiple overlapping WRANs cells). To overcome the self-coexistence problem in WRANs, many fixed and dynamic channel assignment techniques have been proposed (Bany Salameh et al., 2014; Hani et al., 2013).

The emerging virtualization techniques introduced in many computing and communication systems provide a paradigm shift in resource management of these systems. Virtualization abstracts the underlying physical system components into virtual components that can be efficiently allocated for system applications. While several previous studies have focused on computing systems and wired network virtualization, the field of wireless network virtualization is not well investigated. Moreover, the virtualization of CRNs is still in its early stages with a lot of room for exploiting virtualization benefits to support CRNs operations. CRNs virtualization can benefit both inter-cell and intra-cell operations. With virtualization, each physical node is able to run multiple virtual networks instead of one network in the case of a non virtualized frameworks (Jararweh et al., 2014, 2015).

In this work, we propose two frameworks. The first framework, Single-Cell Cognitive Radio Network (SDSC-CRN), provides a virtualization based resource allocation approach for CRNs. In this approach, we advocate delegating some of the management responsibilities of the BS to the users and allow them to make local decisions. By doing so, we aim to reduce the users' reliance on the BS and improve network performance by reducing the unneeded control overhead. The resource management process is totally software based without the need for any network administrator interventions. The distinct features/advantages of SDSC-CRN are, (1) cooperative resource management over wireless cognitive networks, (2) a centralized BS controls and manages the resource allocation using a centralized manager called the Global Hypervisor (GH) among the different cognitive users joining the network without affecting the PUs, and (3) virtualizing of the physical radio nodes to have several instances for different virtual networks, each of which having an intermediate layer called the Local Hypervisor (LH). The LHs support the GH in distributing the resources to minimize the control overhead at the BS. These features/advantages play a significant role in improving the overall network throughput, as well as minimizing the management overhead at the BS. The second framework, Software Defined Multi-Cell Cognitive Radio Network (SDMC-CRN), integrates the concepts of virtualization into multi-cell CRNs. This framework distributes the resources among the different cells intelligently and, within each cell, uses SDSC-CRN to minimize the control overhead and blocking ratio while maximizing the network throughput.

The rest of this paper is organized as follows. In Section 2, we present some background knowledge necessary to understand the proposed frameworks. We present the Software Defined Single-Cell Cognitive Radio Network (SDSC-CRN) framework in Section 3. In Section 4, we describe the Software Defined Multi-Cell Cognitive Radio Network (SDMC-CRN) framework. We evaluate our proposed SDSC-CRN and SDMC-CRN frameworks through simulations in Section 5. Related works are presented in Section 6. Finally, Section 7 provides conclusion remarks.

2. Work preliminaries

In this section, we present some background knowledge necessary to understand the proposed frameworks. Since the basic idea of proposed framework is to integrate virtualization into CRNs, we dedicate the following subsections to discuss each one of these two fields.

2.1. Virtualization

The term virtualization has been extensively discussed in literature. It refers to the process of creating a number of logical resources using the set of the available physical resources, in a way that allows the user to use them as if he/she was using the physical resources directly. This way, the physical resources are better utilized since virtualization allows more users to share them. Moreover, this provides an additional layer of security since the user's application has no direct control over the physical resources.

The original idea aimed to virtualize the computer system's physical resources such as the memory, the processors, the network interfaces, and the storage unit into separate sets of logical instances. Each set of these virtual instances is assigned to different users who see them as separate entities by themselves. The goal is to maximize the physical resources' utilization while keeping the required performance (Kalmanek, 2012). Computer system virtualization has three properties: (1) isolation between users, (2) service customization and (3) increasing resource efficiency.

The term virtualization was later introduced into the field of wired networks by introducing the framework of virtual private networks (VPNs) at the service provider networks level using different layers such as optical wavelength, multi-protocol label switching (MPLS). In these techniques, the virtualization was deployed by partitioning the existing physical network into a set of logical network instances. This process requires a careful management in order to maintain the Quality of Service (QoS) and the required level of security by each user in the network. The management tasks are the responsibility of the service provider.

Recent research studies are focusing on applying the virtualization concept in wireless networks, where things become more complicated and new challenges appear. Examples of such challenges include: (1) the lack of infrastructure in many types of wireless networks, (2) spectrum sharing, (3) the different geographic coverage regions of the wireless networks, and (4) the mobility of users and the dynamic topologies in such networks (Wang et al., 2013).

2.2. Cognitive Radio Networks (CRNs)

CR has been presented as a key technical improvement to the legacy wireless communications technologies to improve spectrum utilization. To be more specific, CR can setup their own CRNs by opportunistically utilizing the available spectrum (spectrum holes) in the licensed bands. These spectrum holes represent fragments of some PU's licensed bands that are not fully utilized for some time (Mitola and Maguire, 1999). In order for these CR nodes to utilize these spectrum holes without interfering with the PUs, they should have some sensing capabilities through which channel availability is determined. Moreover, they should be flexible enough to quickly vacate a channel as soon as its owner (PU) starts using it. In such cases, CR nodes must quickly and seamlessly move their ongoing communication sessions into another available channel. The capabilities of the CR can be listed as follows (Hong et al., 2009):

- *Spectrum sensing*: a CR node should be able to sense the surrounding environment to detect the PUs activities and determine which channels are available and which channels can cause minimum interference with the PUs.
- *Spectrum sharing*: a CR node should have the ability to share the available spectrum as well as the gathered information from the surrounding environment with other CR nodes or a BS. The BS is responsible for coordinating CR nodes' access to available