Part 1

Cross Layer Models

Chapter 1. Enhancing Wireless Capacity with Spectrum Allocation in Cognitive Radio Networks for Adaptive Transmission

Cognitive Radio Networks (CRN) has great potential to support user communication sessions, considering jointly performing power control, scheduling, and flow routing. In this chapter, a Bandwidth Footprint Tree (BFT) is defined with the adjustments of migrating nodes to neighboring nodes. In terms of reducing hot spots approach, the adaptive transmission protocol is proposed to address spectrum allocation problem and to maximize the discovery of spectrum opportunities. Based on the influence on traffic effect and low load flows limitations, different scenario schemes are compared with the derived model. The possible benefit from growing trees iteratively is clarified, and a Chebyshev Sum metric is utilized for sensing/monitoring of spectrum availability. Using a cross-layer design approach, more evenly distributed sessions among the multi-hop wireless networks are achieved. Simulation and experimental results are presented as verifications.

1.1. Introduction

Cognitive Radio Networks (CRN) is a promising technology that promises to bring about remarkable improvements in efficiency of spectrum utilization [1] [2]. Due to its spectrum sensing, learning, and adaptation capabilities, such a radio device is able to fill voids in the wireless spectrum and can dramatically increase spectral efficiency [3] [4]. These radios dynamically identify portions of the spectrum and configure the radio to operate in the appropriate white space. In addition to the well known primary/secondary network setting, the device listens to the wireless channel and determines, either in time or frequency, which part of the spectrum is unused. Thus, it raises questions among the efficiency of the spectrum allocation, which offers new challenges in algorithm and protocol design.

It is important to realize that the problem of allocating spectrum in CRN poses new challenges that do not arise in several wireless technologies [5] [6]. In effect, the spectrum sharing process satisfies the constraint imposed on cognitive radio by the availability of spectrum holes at a particular geographic location and their possible variability with time. Throughout the spectrum sharing process, the transmit power controller keeps an account of the bit-loading across the spectrum holes in use. In effect, the dynamic spectrum manager and the transmit-power controller work in concert, thereby fulfilling the multiple-access control requirement [7]. So far, the formal analysis of this spectrum allocation problem in multi-hop CRN has typically boiled down to NP hard problems [8]. However, while the throughput problem is hard even if demands have infinite duration, modeling user demand within a small constant factor of optimum is more complicated.

In this work, a hierarchical spectrum allocation problem in CRN is proposed, and an analysis as well as simulation performance results is presented. Specifically, the contribution of this chapter includes:

1. A Bandwidth Footprint Tree is introduced to capture the inherent properties of white space and the benefits of opportunistic spectrum utilization. Diffeerenct operations capture the essential features of CRN, and solve the packing of time spectrum blocks in a multi-dimensional space.

2. A joint strategy of routing and spectrum allocation is proposed between frequency band selecting and routing computing. Based on effective bandwidth and time-footprint spectrum block, it can balance performance among spatial and temporal cost.

3. An adjustment and migration approach is utilized to maximize the discovery of spectrum opportunities. It can well make each node to dynamically decide on a spectrum footprint based on local information.

1.2. Related Work

Recently an intensive interest has been witnessed for jointly considering power control, scheduling, and flow routing in the analysis and design of user communication session. Zeng *et al*. [9] proposed a decentralized consensus optimization algorithm to attain high sensing performance at a reasonable computational cost and power overhead. The orthogonality between the spectrum of primary users and that of CRN is presented as constraints for consensus optimization to identify spurious spectral estimates. These decentralized techniques are developed for both cases of with and without channel knowledge.

Zhang and Su [10] designed an adaptive spectrum sharing schemes to transmit packets to the secondary base station for CDMA in the uplink communications, concerning the optimal tradeoff between the spectrum utilization and the interference. Furthermore, the secondary users can adaptively select between the intrusive spectrum sharing and the non-intrusive spectrum sharing operations, whereby they are able to efficiently utilize the available frequency spectrum based on the channel utilization, traffic load, and interference constraints.

By extending the existing so-called protocol model for wireless networks, Hou *et al*. [11] modeled the spectrum sharing and sub-band division, scheduling and interference constraints, and flow routing. Shi *et al*. [12] developed a formal mathematical model for scheduling feasibility where power control is part of the optimization space. The work in both [11] and [12] assumes unidirectional link, which is not a very realistic assumption. In addition, they do not provide a fair guaranteed time overhead.

Our work stands apart from this prior work in that it adds a new dimension to the problem itself: It combines not only the question of determining how wide a spectrum-band, but also when and at what frequency each node should transmit. In combination with the dynamic nature of white spaces, the reconfiguration offered by CRN therefore leads to novel and practically important theoretical and algorithmic questions.