Chapter 12
Dynamic Spectrum Management Algorithms for Multiuser Communication Systems

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ABSTRACT

Dynamic Spectrum Management (DSM) is an effective method for reducing the effect of interference in both wireless and wireline communication systems. This chapter discusses various DSM algorithms, including Optimal Spectrum Balancing (OSB), Iterative Spectrum Balancing (ISB), Iterative Water-Filling (IWF), Selective Iterative Water-filling (SIW), Successive Convex Approximation for Low complExity (SCALE), the Difference of Convex functions Algorithm (DCA), Distributed Spectrum Balancing (DSB), Autonomous Spectrum Balancing (ASB), and Constant Offset ASB using Multiple Reference Users (ASB-MRU). They are compared in terms of their performance (achievable data-rate) by extensive simulation results and their computational complexity.

INTRODUCTION

In order to meet the increasing demand of data-intensive services in a multiuser multi-sub-carrier environment for both wireless and wireline communication systems, effective spectrum management techniques are required. The most basic form of spectrum management is Static Spectrum Management (SSM). Typically, SSM performs spectrum management based on a worst-case scenario assumption for all users. Clearly, this leads to an inefficient spectrum utilization whenever the scenario is not the worst-case and leads to highly sub-optimal performance.

The poor performance of SSM approaches led to the introduction of Dynamic Spectrum Management (DSM) (Starr, Sorbara, Cioffi, & Silverman, 2003). DSM is a wide field which looks to adaptively apply different spectrum allocations for each user with some optimization criteria in mind (e.g., maximizing

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throughput, minimizing power). DSM allows for a far more efficient use of the frequency spectrum than SSM does. As a result, many different DSM algorithms have been proposed. This chapter will present some of the most significant DSM algorithms and compare them.

The main criteria in comparing different DSM algorithms are their performance and their complexity. The performance relates how well an approach succeeds achieving its objective (e.g., maximizing the achievable data-rate, minimizing transmission power) as compared to the theoretical optimum. The complexity of the algorithm is related to the amount of time required to derive the power allocation as the number of users and frequency sub-carriers increase.

There are two main types of DSM algorithms: Centralized and distributed. Centralized systems require a central hub with full knowledge of the network. In general, this system allows for better performance at a cost of increasing the complexity and computational time. On the other hand, distributed systems allow for every user to self-optimize fully autonomously without the need of explicit message passing. In general, distributed systems reduce the complexity and computational time but often sacrifice some optimality in terms of performance.

In particular, nine DSM algorithms will be covered in this chapter. Three of the DSM algorithms are centralized algorithms: Optimal Spectrum Balancing (OSB), Iterative Spectrum Balancing (ISB), and the Difference of Convex functions Algorithm (DCA). Three of the DSM algorithms are semi-centralized DSM algorithms where the users self-optimize but require some per-iteration messaging passing with a central hub. The three semi-centralized DSM algorithms are: Selective Iterative Water-filling (SIW), Successive Convex Approximation for Low complExity (SCALE), and Distributed Spectrum Balancing (DSB). Finally, the three distributed DSM algorithms are Iterative Water-Filling (IWF), Autonomous Spectrum Balancing (ASB), and Constant Offset ASB using Multiple Reference Users (ASB-MRU).

BACKGROUND

This section provides some background material on the topic of dynamic spectrum management. For more detailed background material, interested readers are referred to Leaves et al. (2004), Akyildiz, Lee, Vuran, & Mohanty (2006), Zhao & Sadler (2007), and the references therein. A Venn diagram illustrating the similarity and differences between the algorithms discussed in the background material is shown in Figure 1.

Yu, Ginis, & Cioffi (2002) introduced Iterative Water Filling (IWF), one of the first distributed DSM algorithms. In IWF, each user selfishly performs their own power allocation without any regard for their effect on the other users until a point where no user benefits from changing its current power allocation is reached. While IWF gives significant performance improvements over SSM techniques, in many situations, it leads to sub-optimal performance.

The sub-optimality of IWF is caused by inefficient use of the frequency spectrum. In an attempt to increase the efficiency of the frequency spectrum, many other heuristic variations were proposed. For example, shifting the user’s spectrums away from one another (Liu & Su, 2007), accelerating convergence (Bagheri, Pakravan, & Khalaj, 2004), and incorporating user priorities in a centralized manner (Statovci, Nordstrom, & Nilsson, 2006).

Two similar algorithms which improve on the performance of IWF were also introduced. More specifically, Lee, Kim, Brady, & Cioffi (2006) introduced Band Preference Spectrum Management (BPSM), and Noam & Leshem (2009) introduced Iterative Power Pricing (IPP). Both apply the general