Chapter 2
Network Optimization Methods for Self-Organization of Future Cellular Networks: Models and Algorithms

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ABSTRACT

This chapter discusses network optimization methods for enabling self-organization in current cellular networks such as Long Term Evolution (LTE)/LTE-Advanced (LTE-A), and the upcoming 5G networks. Discrete and continuous optimization models are discussed for developing distributed algorithms for self-configuration and self-optimization. The focus is on Self-Organized Networking (SON) problems, which are relevant to small cell networks. Examples include Physical Cell-ID (PCI) assignment, Primary Component Carrier (PCC) selection, Inter-Cell Interference Coordination (ICIC), and network synchronization. A conflict-graph model is considered for PCI assignment and PCC selection problems, which paves the way for different graph coloring algorithms with self-organizing properties. Algorithms for self-organized ICIC and network synchronization are also developed in a principled manner, through a network utility maximization framework. This systematic approach leads to a variety of algorithms which adhere to self-organization principles, but have varying requirements in terms of inter-cell coordination and computation complexity. Fully distributed self-organizing algorithms do not involve any inter-cell dedicated message-passing, and thus are faster and more scalable than the ones that are distributed but require local coordination via exchange of messages between cells. However, local coordination enables higher network utility and better convergence properties.

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INTRODUCTION

Self-organization is a general concept with numerous applications across a wide range of areas related to physics, computer science, and mathematics. Some common examples include distributed systems, multi-agent systems, and complex networks (Haken, 2006). It has gained popularity in the field of mobile cellular communications systems recently, and is considered to be a cornerstone in the success of contemporary cellular networks such as Long Term Evolution (LTE)/LTE-Advanced (LTE-A) (Hämäläinen, Sanneck, & Sartori, 2011). Moreover, it is expected to play a promising role in development of enabling technologies for future cellular networks such as 5G, which will comprise of 10-100 times more devices and much higher data rates compared to LTE/LTE-A. Thus, the proliferation of wireless devices, along with a steady increase in popularity of wireless applications and services, will lead to an unrelenting demand for high data rates and ubiquitous connectivity. Dense deployment of small cell networks (SCNs) will be the key to high capacity and improved coverage. The core principle that enables capacity enhancement in such networks is the reduced cell size compared to traditional macrocell networks, resulting in higher received signal-to-interference-plus-noise power ratios (SINRs), as the distance between transmitter and receiver is decreased. In indoor deployments, transmissions are shielded from macro interference due to penetration losses. Other advantages include significant reduction in the power consumption of mobile stations communicating with their serving base stations, and offloading of traffic to avoid congestion in the macrocellular network.

The deployment of small cells usually complements the macrocell network providing service in a larger coverage area. A dense deployment of small cells in conjunction with macrocells is considered a major enabler for meeting the capacity requirements of future mobile cellular networks. In such networks, the self-organized networking (SON) paradigm will be of key importance due to the following factors (Aliu, A. Imran, M. A. Imran, & Evans, 2013; Prehofer & Bettstetter, 2005; Hämäläinen et al., 2011):

1. The network densification due to massive deployments of small cells makes the configuration, optimization, and maintenance of the network difficult. Distributed and scalable solutions based on self-organization are essential for carrying out these tasks in an efficient manner.
2. Small cells are usually classified as microcells, picocells, and femtocells depending on their coverage areas and transmit powers. Among these, the outdoor picocells are deployed by operators, whereas the femtocells are plug-and-play devices that are usually deployed by the end users in an ad hoc manner. The resulting heterogeneous cellular network comprises of multiple layers of cells of different sizes and characteristics. Unplanned deployment of femtocells, as well as the disparity in transmit power of cells belonging to different layers, may result in very high cross-layer interference for some users. Effective mitigation of this interference is an important SON issue in dense small cell and heterogeneous networks.
3. In order to maximize spectral-efficiency, it is important to optimize the overall resource allocation in the network over all available degrees of freedom. This is especially true for future mobile networks, which will comprise of billions of devices connected seamlessly, through different types of cells and radio access technologies. The increased complexity will result in more degrees of freedom which can be exploited to improve performance. Resources should be utilized optimally, satisfying the quality of service (QoS) requirements of all users. The use of self-organization schemes for an efficient allocation of resources along the available degrees of freedom, such as time, frequency,