Chapter 6

Game Theory–Based Radio Resource Optimization in Heterogeneous Small Cell Networks (HSCNs)

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ABSTRACT

To optimize radio resource allocation, the game theory is utilized as a powerful tool because its characteristic can be adaptive to the distribution characteristics of in heterogeneous small cell networks (HSCNs). This chapter summarizes the recent achievements for the game theory based radio resource allocation in HSCNs, where macro base stations (MBSs) and dense small cell base stations (SBSs) share the same frequency spectrum and interfere with each other. Two kinds of game models are introduced to optimize the radio resource allocation, namely the non-cooperative Stackelberg and the cooperative coalition. System models, optimization problem formulation, problem solution, and simulation results for these two kinds of game models are presented. Particularly, the Stackelberg models for HSCNs are presented with the Stackelberg equilibrium and the closed-form expressions. The coalition formations for traditional HCSNs, cloud small cell networks, and heterogeneous cloud small cell networks are introduced. Simulation results are shown to demonstrate the proposed game theory based radio resource optimization strategies converged and efficient.

DOI: 10.4018/978-1-4666-8642-7.ch006
I. BACKGROUND OVERVIEW

Mobile data applications such as high-quality wireless video streaming, social networking and machine-to-machine communication are growing exponentially and it is envisioned that asymmetric digital subscriber line (ADSL)-like user experiences would be supported in mobile networks. This implies the wireless networks emerge a major transformation shifting from primarily delivering voice and text services to transporting data and connecting to the Internet and internet of things (IoTs). It has been revealed that data traffic already constitutes more than 97% of the total bits transmitted in many mobile networks (IMT.Vision, 2013). Unfortunately, the current code division multiple access (CDMA) based third generation (3G), and the orthogonal frequency division multiplexing (OFDM) based long term evolution (LTE) cellular networks wouldn’t maintain candidates to meet requirements for the significant increasing traffic with a low energy consumption. To improve the transmission rate, the traditional cellular network can increase the power transmitted from a base station (BS), creating serious interference to other serving user equipments (UEs) with high energy consumption. Therefore, the traditional cellular networks are reaching their breaking points, and conventional cellular architectures that are devised to cater to large coverage areas and optimized for homogeneous traffic are facing unprecedented challenges. Since these bursting packet traffics are mainly generated in indoors or hot spots, there is an increasing interest to deploy relay stations (RSs), distributed antennas, and access points (APs) of small cellular cells (such as picocells, femtocells, small cells, etc.) in residential homes, subways, and offices. These new network entities, which may be either operator-deployed and/or consumer-deployed, form a mix of low-power cells underlying the macrocell network. Consequently, the heterogeneous small cell network (HSCN) is presented as a new network paradigm evolution to the fifth generation (5G) wireless systems.

HSCN is a new technology that can cost-efficiently improve system coverage and capacity (Chandrasekhar, Andrews, & Gatherer, 2008). High power nodes (HPNs), such as macro base stations (MBSs), are deployed for the extended coverage and the high mobility support, while low power nodes (LPNs), such as femto access points (FAPs), small cell base stations (SBSs), pico base stations (PBSs), and RSs, help to supply the high achievable data rates in the local coverage of some hot spots. By deploying additional LPNs within the local-area range and bringing LPNs closer to the desired UEs, HSCNs can potentially improve spatial resource reuse and extend the coverage, thus allowing future cellular systems to achieve higher data rates and consume lower energy, while retaining the uninterrupted connectivity and seamless mobility of cellular networks.

To provide seamless coverage and high serving quality in multiple radio access networks (RANs), heterogeneous wireless access systems are firstly proposed to complete interworking and cooperative functionalities. Subsequently, inter-HetNets leverage the frequency spectrum and facilitate the flexible utilizations of alternate frequency bands (e.g., free unlicensed bands) across different radio access technologies (RATs), which adds an extra degree of freedom in terms of spectral efficiency, energy efficiency (EE), and transmission reliability. Lately, the single wireless access network with a huge number of LPNs in multi-tier layers is proposed to enable the dense reuse of spectrum and reduce power consumption via the flexible deployment of LPNs in the coverage holes and hot spots. In a HSCN system, the frequency spectrum can be orthogonally used by HPNs and LPNs, namely overlay mechanism, and the cross-tier interference wherein could be avoided with the expense of occupying with additional frequency bandwidth. In comparison, the frequency spectrum for HPNs and LPNs is non-orthogonally and fully re-used for the underlay mechanism, which could provide efficient utilization of the available resources under mitigating the resultant co-channel interference to the receivers (Quek, Roche, Guvenc, & Kountouris,
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