Chapter 13


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ABSTRACT

This chapter investigates the interplay between cooperative device-to-device (D2D) communications and green communications in LTE heterogeneous networks (HetNets). Two game theoretic concepts are studied and analyzed in order to perform dynamic HetNet base station (BS) on/off switching. The first approach is a coalition-based method whereas the second is based on the Nash bargaining solution. Afterwards, a method for coupling the BS on/off switching approach with D2D collaborative communications is presented and shown to lead to increased energy efficiency. The savings are additionally increased when a portion of the small cell BSs in a HetNet are powered by renewable energy sources. Different utility functions, modeling the game theoretic framework governing the energy consumption balance between the cellular network and the mobile terminals (MTs), are proposed and compared, and their impact on MT quality of service (QoS) is analyzed.

INTRODUCTION

Energy efficiency is representing an increasing concern for cellular network operators. Although the main purpose is to minimize their electricity costs and maintain profitability, reducing negative effects on the environment is also an important objective (Hasan, 2011).

A large portion of the energy dissipated in a cellular system is actually consumed at the base stations (BSs). Hence, putting certain BSs in sleep mode, or switching them off in light traffic conditions,
is an efficient technique to save energy in wireless networks, e.g., see (Bousia, 2012; Han, 2013). In (Niu, 2010), the cell size is adjusted dynamically depending on the traffic load using a technique called “cell zooming” for the purpose of reducing energy consumption. The power ratio, corresponding to the ratio between the dynamic and the fixed power part of a BS power consumption model, is introduced in (Xiang, 2011). This ratio is used to propose a solution based on traffic load balancing.

Several enhancements incorporated in next generation cellular systems, e.g., LTE-Advanced (LTE-A), consist of reducing effective cell sizes by using combinations of microcells (Lan, 2012), distributed antenna systems (Zhao, 2012), relays (Salem, 2010), and indoor femtocells (Hoydis, 2010). In this chapter, we use the term “small cells” to refer to a combination of these cells. Together with macrocells, they form a heterogeneous network (HetNet), with HetNets expected to constitute a paradigm shift in state-of-the-art cellular networks (Andrews, 2013). HetNets are one of the possible solutions to address the load increase on state-of-the-art cellular systems, such as LTE-A, due to the exponential increase in multimedia and data traffic. The operation of such HetNets is optimized through the use of advanced interference coordination/mitigation techniques, heterogeneous fractional frequency reuse patterns, and cooperative multipoint transmission/reception techniques. However, network densification brings with it the challenge of increased energy consumption in cellular BSs, which makes BS on/off switching techniques of high importance in HetNets (Bousia, 2012; Han, 2013). Furthermore, renewable energy sources, such as solar panels or wind turbines, could be used to power small cell BSs (SCBSs) whenever possible. This would be difficult to apply with macrocell BSs (MBSs) due to their larger energy consumption. Hence, renewable energy SCBSs (RE-SCBSs) could be used in conjunction with BS switch off techniques.

In addition, device-to-device (D2D) communications have been receiving significant research attention recently, due to their planned incorporation in future releases of LTE-Advanced (LTE-A) in beyond 4G and 5G cellular systems. D2D communications in LTE-A would allow a device to use the cellular spectrum in order to be connected directly to another device. This short range (SR) D2D connectivity allows offloading some traffic from the cellular network. Several previous work focused on using D2D as an underlay network to the traditional LTE/LTE-A cellular communication network (Ma, 2013; Wang & Chu, 2012; Wang, 2013). Other work considers maximizing the spatial reuse while using D2D communications (Lee, 2013). In (Han, 2012), D2D connections are allowed to use the same wireless resources as long range (LR) cellular links in order to maximize the spatial reuse gain. A resource allocation scheme to achieve this objective is proposed. Most of the previously cited references consider D2D in unicast mode. Multicasting in D2D underlay networks is investigated in (Wang & Wang, 2012; Chen, 2013), where the challenge is to group mobile terminals (MTs) into clusters receiving the multicast data through D2D communications. However, efficient cooperative D2D clustering schemes under LTE-A are still an active research topic.

In this chapter, a game theoretic framework based on utility maximization is proposed in order to ensure that green LTE/LTE-A HetNets operate with the least required number of BSs while maintaining a certain degree of quality of service (QoS). The main novelty of this work consists in using the combination of RE-SCBSs and D2D offload in order to achieve green LTE-A HetNets. This is done through a utility maximizing algorithm, along with the selection of utility functions that balance between the energy consumption in the BSs and the MTs to achieve mutual benefit and energy savings.

Starting from the scenario of reaching energy efficiency in green HetNets without D2D, two game theoretic concepts are studied and analyzed in order to perform dynamic BS on/off switching. The first approach is a coalition-based method that assumes a group of BSs in a network form a coalition. The second approach is based on the Nash bargaining solution and considers that BSs play a bargaining game...