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QoS vs. energy: A traffic-aware topology management scheme for green heterogeneous networks

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ABSTRACT

Increasing environmental awareness combined with the high energy prices has driven the network operators to reduce their carbon dioxide footprint by adopting energy efficient green methods. In this paper, we aim to save energy by both switching base stations on/off and adaptively adjusting their transmission power according to the present traffic conditions for heterogenous wireless cellular networks. We formulate a novel linear programming model for the Traffic-Aware Topology Management (TAM) problem to find the best possible topology which minimizes the overall power consumption of the network while satisfying a certain Quality of Service level in Wideband Code Division Multiple Access packet-switched cellular networks. Although the optimization tools provide the optimum solutions, it is not possible to handle large instances due to the space and computational complexity. Hence, we propose a Green TAM Algorithm to solve the large-scale realistic instances of the formulated problem and compare our results with the results of two previously proposed methods, a greedy heuristic and a commercial optimization tool. We show that the proposed TAM scheme helps to maintain an energy-aware network and saves significant amount of energy by adjusting the network topology to the current traffic conditions adaptively.

1. Introduction

Increasing energy costs have driven the telecommunication service providers to become highly interested in energy efficient operation. The exponential growth in mobile data exchange [1] which is further augmented by the rapid proliferation of smart phones increases the operational expenses (OPEX) of the cellular network operators significantly. Also, ecologists state that the primary triggering factor of the global warming is adding excessive amounts of greenhouse gases to the atmosphere and 72% of the totally emitted greenhouse gases is carbon dioxide (CO_2) [2]. Therefore, developing and applying energy efficient green methods in the Information and Communication Technology (ICT) industry and reducing its CO_2 footprint is now more essential than ever.

Parallel to the ubiquitous coverage demand and increasing needs of the subscribers, cellular network operators increase their Capital Expenses (CAPEX) and invest more money to deploy large number of Base Stations (BS) to provide better service quality in terms of data rate, coverage, blocking and dropping probabilities. Consequently, the BS density increases and yields to a significant amount of BS redundancy and electromagnetic pollution, especially in crowded urban areas. Fig. 1 shows the BS location and coverage redundancy of a single operator from Sydney Central Business District, Australia. This BS information on the map is extracted from a website [3] which makes

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use of the Australian Communications and Media Authority's RadCom registry. The area covered in the map is $1.5 \times 1.5\ km^2$ and has a total of 139 BSs. As suggested in IEEE 802.16m Evaluation Methodology Document [4], the coverage map is created by using the COST-Hata [5] metropolitan area propagation model with 2000 MHz frequency, 1.5 and 15 m mobile station and BS antenna heights respectively. Each BS is transmitting with a power of 46 dBm with 17 dBi antenna gain and minimum acceptable Received Signal Strength Indicator (RSSI) at the receiver is assumed to be −90 dBm.

In order to fulfill the requirements of the users regardless of time and space, network operators usually place BSs to support the peak traffic conditions. Therefore, BSs are under-utilized during off-peak times such as late night hours or holidays. A real traffic profile collected from a central BS and four neighboring BSs during one week is given in Fig. 2 [6]. As expected, the traffic load decreases dramatically during the late night hours. Yet, low traffic can also be observed all day long during weekends or holidays in particular places such as business or trade centers. Therefore, infrastructures of the cellular access networks are under-utilized during the non-peak traffic periods. Hence, adoption of a green traffic-aware topology management scheme can save large amounts of energy by reducing the redundancy and decrease the OPEX of the service providers significantly. Moreover, reduction of the energy consumption also helps to slow down the global warming process by mitigating the CO_2 emission to the atmosphere.

In this work, we focus on saving energy by adaptively switching the BSs of heterogeneous cellular networks on and off and by adjusting the BS transmission power levels according to the present traffic conditions. Particulary, we focus on Wideband Code Division Multiple Access (W-CDMA) packet-switched cellular networks and adopt dynamic transmission power adjustment with the help of high efficiency power amplifiers. However, the challenge is to decrease the energy expenditure while always guaranteeing a certain Quality of Service (QoS) level over the whole coverage area. To address this, we formulate a novel

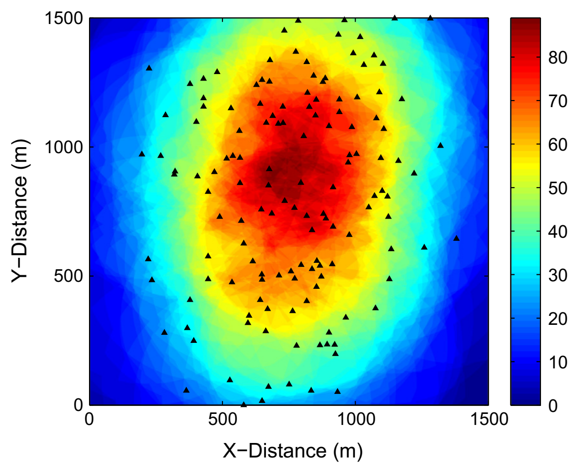

Fig. 1. Base station location and coverage redundancy of a single operator based on the RSSI value from Sydney Central Business District, Australia.

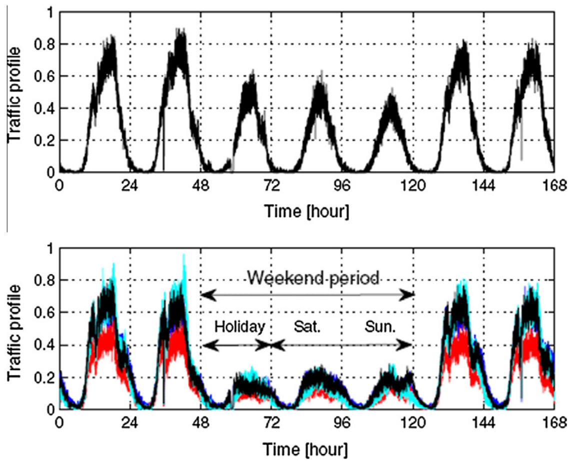

Fig. 2. Normalized traffic profile of a central (top) and four neighboring (bottom) BSs during one week [6].

Linear Programming (LP) model for the described **T**raffic-**A**ware Topology **M**anagement (TAM) problem to find the best possible BS topology which minimizes the energy consumption while satisfying the certain service quality requirements of the subscribers. Although small instances of the TAM problem can be solved by the optimization tools, large realistic size problems are quite difficult to be handled due to high space and computational complexity. Therefore, we propose a novel heuristic to solve the large-scale instances of the formulated problem and compare our results with the results of two previously proposed methods [7,8], a greedy heuristic and a commercial optimization tool. It is shown that the proposed TAM scheme helps to maintain an energy-aware network and saves significant amount of energy by adjusting the network topology according to the present traffic conditions adaptively. Although there are some studies in the literature related to the traffic-aware topology management, our method differs in the following aspects:

- Unlike most of the previous studies, where only BS on/off switching is utilized [9–12], we also take into account the dynamic power adjustment capability of the current BSs technology in order to create energy-aware network topologies by defining a set of transmission power levels.
- Compared to solutions that show how much energy efficiency can be achieved or that propose heuristic algorithms [12–14], we first formulate a detailed integer LP model for the TAM problem to minimize energy consumption while satisfying a certain level of QoS. Using this model, the problem is solved by a commercial optimization tool which provides the optimum solutions to the problem.
- While some of the existing studies show how much energy efficiency can be achieved, they do not propose operating algorithms to achieve such savings [9]. Additionally, although the LP tool provides the optimum solutions, it requires long computational time and it is not possible to handle large instances due to the computational complexity. Therefore, a