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Optimal online control for sleep mode in green base stations

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ABSTRACT

In this paper, we investigate network sleep mode schemes for reducing energy consumption of radio access networks. We first propose, using Markov Decision Processes (MDPs), an optimal controller that associates to each traffic an activation/deactivation policy that maximizes a multiple objective function of the Quality of Service (QoS) and the energy consumption. We focus on a practical implementation issue, namely the ping pong effect resulting in unnecessary ON/OFF oscillations, that may affect the stability of the system. We illustrate our results numerically using theoretical models of the radio access network, and apply the developed mechanisms on a large-scale network simulator. Knowing that an offline optimization is not suitable for a large-scale network nor does it fit all traffic configurations, we propose, using an online controller that derives dynamically the optimal policy based on the dynamics of users in the cell. The design of our online controller is based on a simple ϵ-greedy algorithm and learns the optimal threshold policy for activation/deactivation of network resources.

1. Introduction

Energy efficiency has become a critical issue in future wireless Internet due to the huge amount of energy needed in order to create, maintain and co-operate mobile networks: 2G, 3G/3G+ as well as future 3G Long Term Evolution (LTE) and LTE-Advanced systems [1]. This is called green radio where energy consumption is a critical constraint when designing and operating the network [2].

Classically, the energy consumption of the base stations has not been considered as a constraint when designing Joint Radio Resource Management (JRRM) schemes. The aim was always to ensure higher spectral efficiencies and better QoS (e.g. [3,4]). A large interest has been dedicated to energy savings at the user equipment; the aim being to preserve the user equipment's battery by reducing the amount of energy that is not useful for transmitting information. Consequently, many sleep mode schemes for user equipment have been proposed in the literature. For instance, in [5], optimal sleep mode parameters have been derived depending on the traffic pattern for mobile WiMAX devices. Authors in [6] assessed the performance of discontinuous transmission schemes for UMTS. Particular attention has been set on the sleep mode in indoor access points [7,8], where intelligent wake up mechanisms have been proposed.

However, when studying the energy footprint of mobile networks, it is observed that macro base stations are the most energy consuming nodes (around 80% of the overall mobile network consumption [9]) and must thus be at the heart of any green radio scheme. An important set of works on green radio has then been dedicated to the reduction of the transmitted power of the base stations; the idea is to find the optimal transmission power that ensures coverage and capacity (see for instance [10,11]). This approach is essential for reducing the exposure of

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persons to electromagnetic radiations. However, alone, these schemes are not sufficient to reduce the energy consumption of wireless networks since a large amount of energy is consumed even for low output power. This is due to the load-independent components of the energy consumption and the presence of pilot channels that make low load resources totally inefficient in terms of energy. This is also the reason that makes energy-aware load balancing techniques not so efficient (an average reduction of the energy consumption of 5% has been observed in [12]).

However, if a modular architecture allows switching off the network resources that are not necessary to guarantee the target QoS for the offered traffic, the gains may be very large. *Network* sleep mode is then crucial if the aim is to reduce significantly energy consumption of the network. In this case, when a network resource, for instance frequency carrier, is not needed to ensure QoS, it is turned off to reduce global energy consumption. This opportunity of implementing sleep mode in macro base stations has been addressed in [9,13], where it has been shown that continuous coverage can be ensured in low traffic scenarios with a small number of active base stations. This paper fills a gap in the performance evaluation of network sleep mode while ensuring user-perceived QoS. We consider local implementation of sleep mode mechanisms that have the advantage of being easier to implement and more reactive (there is no need to introduce a new entity in the network (a controller), and create interfaces between the controller and the stations). Local implementation enables faster reaction to traffic variations since feedback of measurements to a centralized controller takes a non-negligible amount of time. Furthermore, we only consider in this work sleep mode of resources within the base station, without having to switch off complete cell sites so that the coverage is preserved (we ensure that at least one carrier or system is active at any time).

Our contribution: We propose sleep mode policies that associate, to each system state, the optimal action consisting in activating or deactivating a subset of the resources. We first study the optimal controller that proposes the best policy corresponding to the traffic and system settings, using a Continuous Time Markov Decision Process (CTMDP) [16]. We focus on the ping pong effect that may happen due to consecutive ON and OFF commands, and show that a hysteresis time introduced in the decision mechanism can efficiently cope with this issue. Our numerical results show that the optimal policy is a threshold policy on the number of active users in the cells. We thus propose an online version of our controller, using a simple ϵ-greedy algorithm [14] that explores the different threshold policies until finding the optimal one, in an efficient way. Our numerical results show that the online controller converges fast to the optimal policy and does not need any a priori knowledge about traffic or radio conditions.

Related work: Previous results such as [10,11] demonstrate how to choose the minimal amount of power to be transmitted by base stations in order to ensure coverage and a minimal data rate uniformly over the network. In [22], a wireless network with multiple base stations and users is considered. Users are considered fixed, and the authors formulate the problem of base station activation as a combinatorial optimization problem. Contrary to the present work, the proposed solution is *computationally heavy*. Previous papers such as [23,24] consider a single user and use a Markov chain technique to evaluate the energy savings due to the sleep mode mechanism of a single user terminal. In particular [24] allows taking into account correlated packet arrivals. [25] considers a similar setting (one user and one station), and show how to derive the optimal sleep policy numerically by formalizing the problem as a Semi-MDP. In contrast to [23,24] we are more concerned with base station sleep mode (rather than user equipment sleep mode), and furthermore we consider a multi-cellular network with multiple users. In all of the work above, the fact that users arrive and depart dynamically (i.e. the *flow-level dynamics*) is not taken into account, contrary to the present work. Furthermore, we believe that the idea of adjusting sleep mode parameters based on learning (estimating the initially unknown traffic intensity) was not investigated in the works cited above. Our previous work [15] considered flow level dynamics while designing sleep mode mechanisms, but the optimal policy was derived using an exhaustive search of all possible policies. In this paper, we propose a framework that derives the optimal policy using MDP theory, while the work in [15] was based on a derivation of the optimal policy by an exhaustive search among all possible policies. We then implement our controller on a large scale network simulator [21] and show how the optimal policy varies from one base station to another. We finally propose an online controller, based on an ϵ-greedy policy, and show how it converges to the optimal solution.

The remainder of this paper is organized as follows. The system model is described in Section 2. In Section 3, we propose an optimal control mechanism for the network sleep mode and show how it can be applied to actual and future mobile networks. Section 3 also deals with the ping pong effect and proposes a solution to take it into account in the decision. Section 4 analyzes the performance of the proposed scheme, using theoretical models of the radio interface, and also presents results issued from a large-scale network simulator and shows how the optimal scheme may vary between cells. Section 5 proposes a simple, yet efficient, online controller based on the ϵ-greedy policy that converges towards the optimal policy. Section 6 concludes the paper.

2. System model

2.1. Definition of sleep mode policies

We consider a cellular network as the one depicted in Fig. 1 and focus on the downlink of a particular sector equipped with a pool of R resources, for instance a number of transmitters (TRX) for GSM, carriers for 3G, HSDPA and LTE, or even small cells or relays in dense deployed networks. Let $\mathbf{s}_t$ be the process describing the evolution of the system state and $\mathcal{S}$ be the state space. This state will be defined in the next section for 2G, 3G and 4G systems.