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Optimization models for the joint Power-Delay minimization problem in green wireless access networks

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ABSTRACT

In wireless access networks, one of the most recent challenges is reducing the power consumption of the network, while preserving the quality of service perceived by users. Hence, mobile operators are rethinking their network design by considering two objectives, namely, saving power and guaranteeing a satisfactory quality of service. Since these objectives are conflicting, a tradeoff becomes inevitable. We formulate a multi-objective optimization with aims of minimizing the network power consumption and transmission delay. Power saving is achieved by adjusting the operation mode of the network base stations from high transmit power levels to low transmit levels or even sleep mode. Minimizing the transmission delay is achieved by selecting the best user association with the network base stations. In this article, we cover two different technologies: IEEE 802.11 and LTE. Our formulation captures the specificity of each technology in terms of the power model and radio resource allocation. After exploring typical multi-objective approaches, we resort to a weighted sum mixed integer linear program. This enables us to efficiently tune the impact of the power and delay objectives.

We provide extensive simulations for various preference settings that enable to assess the tradeoff between power and delay in IEEE 802.11 WLANs and LTE networks. We show that for a power minimization setting, a WLAN consumes up to 16% less power than legacy solutions. A thorough analysis of the optimization results reveals the impact of the network topology, particularly the inter-cell distance, on both objectives. For an LTE network, we assess the impact of urban, rural and realistic deployments on the achievable tradeoffs. The power savings mainly depend on user distribution and the power consumption of the sleep mode. Compared with legacy solutions, we obtained power savings of up to 22.3% in a realistic LTE networks. When adequately tuned, our optimization approach reduces the transmission delay by up to 6% in a WLAN and 8% in an LTE network.

1. Introduction

In recent years, green radio has been increasingly emphasized for not only ecological concerns but also for significant economic incentives. Information and Communication Technology (ICT) accounts for around 3% of the world's annual electrical energy consumption and 2% of total carbon emissions. Moreover, it is estimated that ICT energy consumption is rising at 15–20 %, doubling every five years [1]. In 2008 this corresponded to about 60 billion kWh of electrical energy consumption and about 40 million metric tons of CO_2 [2]. As a branch of the ICT sector, mobile networks are responsible for 0.2% of these emissions [3]. In addition to the

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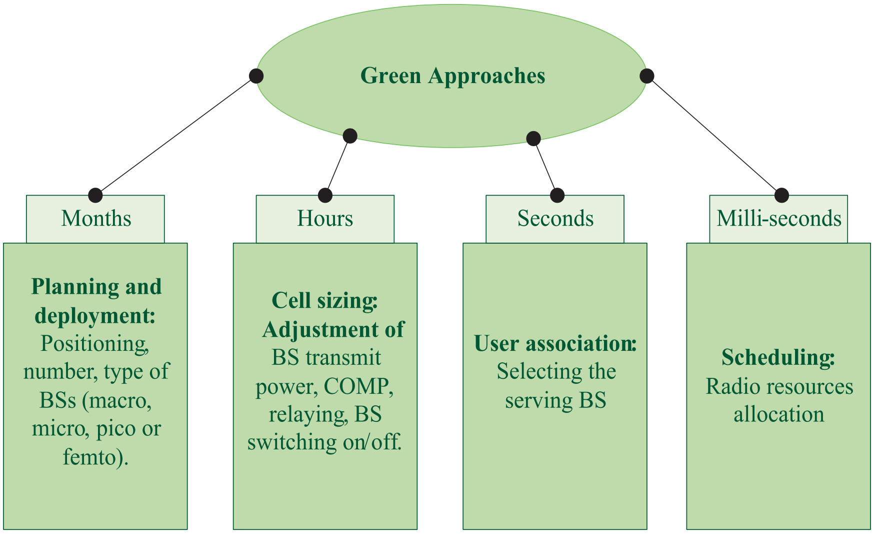

Fig. 1. Green approaches at different timescales.

environmental impacts, mobile operators are interested in reducing energy consumption for economic reasons, especially with increasing energy costs becoming a significant portion of mobile operator expenditure. Moreover, the recent explosive growth of the number of mobile devices and the consequent mobile internet traffic all produce continually high energy consumption. This calls for green solutions to address the challenges in energy-efficient communications. Operators have focused on technological developments in the past years to meet capacity and quality of service (QoS) demands for user equipment (UE). Pushed by the needs to reduce energy, mobile operators have recently been rethinking network design for optimizing energy efficiency and satisfying user QoS requirements.

Currently, over 80% of the power in mobile telecommunications is consumed by the radio access network, more specifically at the base station (BS) level [4]. Hence, many research activities focus on improving the energy efficiency of wireless access networks. In the following, we give an overview of these activities and classify them according to different approaches that run at different timescales.

Planning and deployment: The planning of energy-efficient wireless networks and the deployment of energy-aware BSs deal with the problem of determining the positioning of BSs, the type (*e.g.*, macro, micro, pico or femto) and the number of BSs needed to be deployed. In this context, we find that heterogeneous networks have gained great attention in current research. Precisely, deploying small- and low-power BSs co-localized with macro cells is believed to decrease power consumption compared to high-power macro BSs. Moreover, it extends the coverage area of the macro BS where signals fail to reach distant UEs. Furthermore, small cells increase the network capacity in areas with very dense data usage. Planning and deployment tasks are performed at very coarse temporal levels, ranging from a few months to possibly years.

Cell sizing: Also known as cell breathing, cell sizing is a well-known concept that enables balancing traffic load in cellular telephony [5,6]. When the cell becomes heavily loaded, the cell zooms in to reduce its coverage area, and the lightly loaded neighboring cells zoom out to accommodate the extra traffic. Many state-of-the-art techniques are used to implement cell sizing, such as adjusting the transmit power of a BS, cooperating between multiple BSs, and using relay stations and switching BSs for sleep/off mode. Cell sizing is performed at medium temporal levels, ranging from hours to days.

User association: User association is the functionality devoted to deciding the BS (macro, micro, pico or femto) with which a given user will be associated in a heterogeneous network [7,8]. The challenge is to optimize for example the delay, throughput, or network cost. User association is impacted by the cell sizing tasks: when an active BS is switched off or changes its transmit power level in a homogeneous network, users may need to change their associations. Many metrics are considered for selecting the serving BS, such as the received signal quality (signal-to-noise ratio (SNR) or the corresponding achievable rate), the traffic load, or the distance between BS and UE, etc. User association is performed at small temporal levels, ranging from seconds to minutes.

Scheduling: Scheduling algorithms allocate the radio resources in wireless access networks, where the objectives consist of improving the network throughput, satisfying the delay constraints of real-time traffic, or achieving fair resource distribution among users. Scheduling is performed at very short temporal levels of an order of few milliseconds. In Fig. 1, we illustrate the different green approaches studied in the state-of-the art as well as their operating timescales.

Reducing power consumption in wireless networks is coupled with satisfying the QoS requirements (delay, blocking probability, etc.). As these objectives are conflicting, a tradeoff becomes ineluctable. Chen et al. [9] identified four key tradeoffs of energy efficiency with network performance: (i) deployment-energy efficiency to balance the deployment cost, throughput, and energy consumption in the network as a whole; (ii) spectrum-energy efficiency to balance the achievable rate and energy consumption of the network;