Ad Hoc Networks 78 (2018) 99–114

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Optimal user association, backhaul routing and switching off in 5G heterogeneous networks with mesh millimeter wave backhaul links

A. Mesodiakaki[a,*], E. Zola[c], R. Santos[b], A. Kassler[b]

[a] Department of Informatics, Aristotle University of Thessaloniki (AUTH), 10th km Thessalonikis-Thermis, Thessaloniki GR-57001, Greece
[b] Karlstad University, Universitetsgatan, Karlstad SE-65188, Sweden
[c] UPC-BarcelonaTECH, Jordi Girona 1-3, Barcelona ES-08034, Spain

ARTICLE INFO

Article history:
Received 5 March 2018
Accepted 21 May 2018
Available online 26 May 2018

Keywords:
5G
Energy efficiency
Green networks
Mesh backhaul
Millimeter wave
Optimization
Routing
Software defined networking (SDN)
Switching off
User association

ABSTRACT

Next generation, i.e., fifth generation (5G), cellular networks will provide a significant higher capacity per area to support the ever-increasing traffic demands. In order to achieve that, many small cells need to be deployed that are connected using a combination of optical fiber links and millimeter-wave (mmWave) backhaul architecture to forward heterogeneous traffic over mesh topologies. In this paper, we present a general optimization framework for the design of policies that optimally solve the problem of where to associate a user, over which links to route its traffic towards which mesh gateway, and which base stations and backhaul links to switch off in order to minimize the energy cost for the network operator and still satisfy the user demands. We develop an optimal policy based on mixed integer linear programming (MILP) which considers different user distribution and traffic demands over multiple time periods. We develop also a fast iterative two-phase solution heuristic, which associates users and calculates backhaul routes to maximize energy savings. Our strategies optimize the backhaul network configuration at each timeslot based on the current demands and user locations. We discuss the application of our policies to backhaul management of mmWave cellular networks in light of current trend of network softwarization (Software-Defined Networking, SDN). Finally, we present extensive numerical simulations of our proposed policies, which show how the algorithms can efficiently trade-off energy consumption with required capacity, while satisfying flow demand requirements.

© 2018 Elsevier B.V. All rights reserved.

1. Introduction

In this section, we will first describe the motivation behind this work. Subsequently, we will highlight our main contributions and finally we will present the organization of the paper.

1.1. Motivation

Future wireless systems need to support the ever-increasing data rate demands imposed by the growing number of user equipment (UE) devices, and data-intense applications. This requires a significant increase in capacity per region, especially in dense urban or suburban areas. Despite enhancing spectral efficiency and data rate, the current trend is to increase the density of base station (BS) deployment, reduce the cell size and deploy a massive amount of small cells (SCs) [1]. However, a BS deployment and usage of more transmit antennas will lead to a decrease of the energy efficiency and result in a significant increase in operational and energy costs for the network operator due to the dynamic user distribution and traffic variation [2]. This is due to the fact that the user distribution and traffic demand vary for a given location over time of the day and over day of the week. Consequently, deploying SCs for the highest traffic scenario may result in a highly underutilized network infrastructure and in high energy consumption for the operator, while deploying a less dense network may lead to congestion and low user satisfaction during peak hour demands.

Since UE demand fluctuates over time for each location, dimensioning a mobile network based on peak demand becomes more and more challenging. Using a massive amount of SCs is energy-efficient only if the demand is high and evenly distributed, but significantly lower if the demand is low or fluctuates due to fixed power consumption and static resource provisioning [3]. In order to provide ubiquitous coverage, SCs have to be integrated with the macro network to form heterogeneous networks (HetNets). This

* Corresponding author.
E-mail addresses: amesodia@csd.auth.gr (A. Mesodiakaki), enrica@entel.upc.edu (E. Zola), ricardo.santos@kau.se (R. Santos), andreas.kassler@kau.se (A. Kassler).

https://doi.org/10.1016/j.adhoc.2018.05.008
1570-8705/© 2018 Elsevier B.V. All rights reserved.

enables the adaptive power on/off operation for BSs in order to provide the additional capacity whenever and wherever needed.

Another challenge to solve is the capital expenditure for such dense SC networks, as it is very costly to deploy optical fiber to each SC. Current investigation for fifth generation (5G) technology points towards the importance of directional millimeter wave (mmWave) networks for both access network (AN) and backhaul (BH) by virtue of the massive amount of spectrum available in the 28 GHz or 60/70 GHz frequency bands and the low cost of mmWave backhauling. Due to the short range of mmWave links (up to 200 m in dense urban environments), a multi-hop mesh topology is expected for the BH: It is thus important to manage such mesh network to provide the required capacity, while minimizing the total required energy consumption of the network infrastructure. In this context, it becomes important to develop green network management and operation policies that allow to efficiently use all the available network resources for the energy-efficient operation of the whole network, comprising both the AN links as well as the BH network required to transport the user data from the operator core network to the access interface.

1.2. Contributions

In this paper, we develop green optimization policies that guide how to manage and operate a 5G network of mmWave mesh BH links for minimal energy consumption. We consider a mixed integer linear programming (MILP) based formulation and the goal of the policy is to decide i) where each UE should be associated, ii) over which BH path to route its traffic, iii) which BH links should be activated or switched off, and consequently iv) which the mesh BH configuration should be, and finally v) which BSs to power on/off. We consider energy models for BS and BH transceivers operating in the mmWave band, mmWave propagation models and assume knowledge about user demand profiles. Our optimization model calculates the most energy optimal configuration of both mesh BH and AN for a given time snapshot, subject to capacity, power and quality of service (QoS) constraints.

We also propose a fast online solution policy based on a two phase greedy iterative algorithm. In the first phase, our algorithm calculates the most energy-efficient UE association and BH routing strategy, while still giving enough freedom to power down some BSs. In the second phase, we order the BSs and BH links according to the idle power, i.e., the power they consume at zero load. Thereafter, we start with the BS that, when powered down, achieves the highest energy saving and we determine, if we can re-associate all the associated UEs to another BS. In this case and as long as this action leads to positive energy saving gain, we power down this BS and continue until all active BSs are processed. Furthermore, we discuss how our optimization policies can be implemented in the context of future software defined networking (SDN) architecture for cellular networks, where an SDN controller is in charge of running our policies and triggering the reconfiguration of the BH network to implement our optimization policies.

Finally, we perform several representative numerical simulations focusing on a hotspot scenario, to evaluate the potential energy saving of our optimization policies. We use multiple snapshots over time and quantify the achievable energy efficiency gain over a whole day. We compare both optimal and heuristic solutions against state-of-the-art. Our evaluation shows that we can achieve up to 49 times more energy efficiency gain compared to existing approaches, showing the effectiveness of our approach.

1.3. Paper organization

The rest of this paper is organized as follows. In Section 2, we present the related work. In Section 3, we develop our optimal joint user association, BH routing and BS and BH link switch off policy for 5G networks with mmWave mesh BH. We also develop a fast online heuristic and discuss implementation aspects for SDN-based mesh BH (re)-configuration using our algorithms. In Section 4, we provide representative numerical simulation results that illustrate the benefits of our optimization algorithms. Finally, Section 5 concludes the paper.

2. Related work

One of the objectives set by the European Commission for 2020 is reducing the total energy consumption by 20%; the target was recently updated to 30% for 2030 [4]. According to the authors in [5], the wireless access networks are large power consumers, e.g., the power consumption per year recorded a 10% increase in the five-year period from 2007 till 2012. This amount is expected to increase when considering that the number of mobile subscriptions is growing at almost 6% year-on-year, expecting to reach 1 billion by the end of 2023 [6]; also, the total mobile data traffic is expected to rise at a compound annual growth rate of 42%, with the monthly global mobile data traffic surpassing 100 ExaBytes (EB) in 2023. However, traditionally networks such as LTE have been optimized for capacity [7], and only recently, energy-efficient system design approaches are becoming more and more important. In particular, as the radio access nodes are responsible for more than the 80% of the total energy consumption in the entire access network [8], the research community has focused its interests in developing techniques that are able to significantly reduce the energy consumed at the radio access [9].

The majority of the works in this direction focus on sleep strategies which are shown to achieve notable performance gains [10–12]. In particular, in [10], the authors present a long duration global optimization approach on user association and BS switching on/off to maximize the total system rate over the total network energy consumption. A switching off strategy is proposed in [11], which gives priority to the switching off of the eNodeB (eNB) and then to the lowest loaded SCs. For each BS, the algorithm checks whether its UEs can be re-associated to the BS from which they receive the second highest signal. If this is possible, it switches off the BS as long as this move involves energy efficiency gain. Otherwise, it continues with the next BS to be evaluated. Furthermore, in [12], two different approaches are proposed. In the first, a fixed percentage of the initial set of BSs are randomly selected to be switched off, as long as there are other active BSs to guarantee the QoS of the re-associated users [12]. On the other hand, the second approach selects to switch off a fixed percentage of the initial set of BSs but starting from those with the lowest number of UEs instead of randomly. Nevertheless, all the aforementioned approaches do not take into account the BH conditions. Still, the envision of an ultra-dense SC deployment in 5G cellular networks, where mmWave links are established among SCs and form the wireless BH, brings a considerable increase in the network power consumption, thus pushing the research community to develop new green strategies that also involve the power consumed in the BH nodes.

To the best of the authors' knowledge, only few works have considered the BH conditions in the user association decision so far. An analytical framework for the user association is proposed in [13], where several parameters from both the AN and BH network are taken into account (e.g., spectrum efficiency, BS load, BH link capacity and topology, different types of traffic, etc.). The joint problem of user association and resource allocation has been recently studied in [14], where the maximum BH capacity, the resource consumption and the energy budget of BSs are taken into account. In [15], the power allocation and bandwidth allocation problem is studied in a heterogeneous small cell network where

Download English Version:

https://daneshyari.com/en/article/6878441

Download Persian Version:

https://daneshyari.com/article/6878441

Daneshyari.com