

A dynamic resource allocation framework in LTE downlink for Cloud-Radio Access Network[☆]

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ABSTRACT

One main asset of Cloud-Radio Access Network (C-RAN) lies in its centralized architecture that allows network operators to serve dynamic flows of mobile traffic with efficient utilization of baseband resources and lesser operation costs than the distributed RAN architecture. For this very reason, the implementation of online resource allocation algorithms in the BaseBand Unit (BBU) pool for handling loads of multiple Remote Radio Heads (RRHs) is one of the most motivating challenges in C-RAN. Those centralized algorithms must be able to handle efficiently interference between users, as well as to dynamically select RRHs that can be turned on/off based on traffic variation. By doing so, the total RRHs transmission power can be minimized and the number of active BBUs within the cloud can also be reduced. In this paper, the issues of dynamic wireless resource allocation, transmission power minimization and BBU-RRH assignment in downlink C-RAN are addressed in one framework. We have previously attempted to address these problems by proposing a approach based on the branch-and-cut algorithm to solve small instances of the problem to optimality. However, due to the combinatorial complexity of the problem, finding optimal solutions for a large-scale network may take a fair amount of time and will not be suitable for online optimization. Towards this end, we propose a novel two-stage approach to address these issues for a large-scale problem. The first stage is a new proposal that addresses the problems of dynamic resource allocation and power minimization in C-RAN using a simulated annealing approach with a specific neighborhood search program. The BBU-RRH assignment is handled in the second stage using a multiple knapsack formulation. Through extensive event-based simulations, our proposal achieves significant reduction in time complexity and yields near optimal performance compared to state-of-the-art methods.

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1. Introduction

Cloud Radio Access Network (C-RAN) has been recently introduced by China Mobile Research Institute as a novel cloud architecture for Long Term Evolution (LTE) and upcoming cellular standards (5G) [2]. It is a new RAN paradigm that can address the challenges mobile network operators are faced with and meet their requirements in terms of capital and operational expenditure costs reduction. The C-RAN architecture is illustrated in Fig. 1. It is based on a central cloud pool composed of BaseBand Units (BBUs) that perform Physical (PHY) and Medium Access (MAC) functions processing. The BBUs are connected to the Remote Radio Heads

(RRHs) in the cell sites by means of a low-latency and high bandwidth fronthaul network. A cloud controller is situated in the BBU pool and performs resource and load balancing between BBUs that are interconnected through a high-speed backhauling network [3]. By replacing “hard” wireless network equipments by “soft” BBUs, the C-RAN capabilities can be dynamically adjusted based on the traffic load variations [4]. This not only fosters efficient resource utilization, but also allows the C-RAN to handle more areas than standalone clusters of base stations and facilitates service deployment on the e.g. [5].

However, the design of dynamic schemes for C-RAN's radio resource management constitutes a major challenge that hinders its commercial expansion. In fact, the optimization of C-RAN baseband resource allocation needs methods to cater to time-varying traffic demands at different RRHs [6]. A centralized algorithm can help optimize the resource demands of mobile users located in different cells and with different bandwidth requests. Besides, such centralized approach will help network operators select the RRHs

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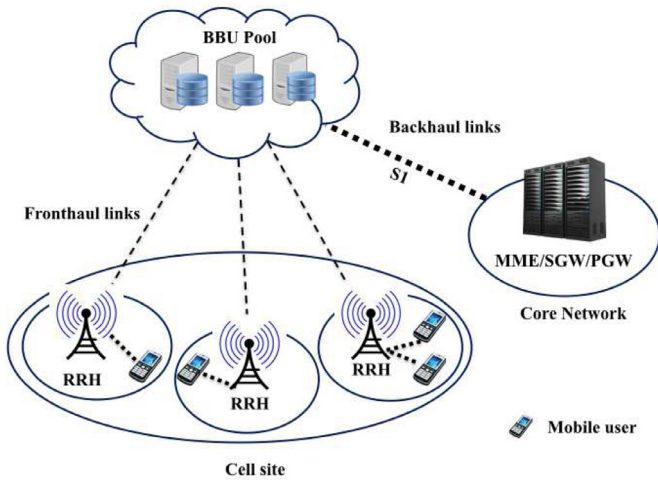


Fig. 1. Cloud Radio Access Network (C-RAN) architecture.

that can be dynamically turned on/off, based on their traffic loads patterns during the day. Consequently, the total RRHs transmission power can be minimized and the baseband resources can be efficiently utilized for handling traffic demands during the day. Moreover, lessening the number of active RRHs would help reduce the number of instantiated BBUs associated to them in the cloud and realize more power and cost savings. Therefore, for all these reasons, a careful C-RAN resource allocation strategy must be planned regarding users traffic demands, RRHs transmission power minimization and BBU pool capacity in terms of handled RRHs.

In [1], we presented two optimization models for the i) resource allocation and power minimization problem and ii) the BBU-RRH assignment problem in C-RAN. The proposed scheme based on the branch-and-cut algorithm [7] has permitted to achieve reasonable gain in throughput satisfaction rate and transmission power minimization over state-of-the-art algorithms and for small instances of the problem. However, due to the combinatorial nature of the first problem (NP-hard), the computational complexity is exponential if an exact optimal solution is to be calculated for a large-scale system. In this paper, a meta-heuristic algorithm, known as simulated annealing (SA), is used in providing fast and close-to-optimal solutions to the first-stage problem at a much reduced complexity. The near-optimality gap will be emphasized by comparison to solving the problem to optimality by the offline branch-and-cut algorithm used in [1].

In summary, our key contributions are the following:

- We express in the first stage the centralized resource allocation and power minimization (C-RAPM) problem, which is formulated as an Mixed Integer Linear Programming (MILP) problem. A reformulation is proposed using the framework of the well-known big-M method [8]. A novelty in this paper compared to our previous approach is we consider here a power allocation model based on static transmission instead of continuous.
- We formulate in the second stage the BBU-RRH assignment problem as a Multiple Knapsack Problem (MKP). The latter can efficiently be solved by standard solvers such as IBM CPLEX [9].
- We present our new dynamic resource allocation in C-RAN framework based on SA (DRAC-SA) to solve the C-RAPM problem with dynamic constraints.
- We compare our approach's results from event-based simulations to our previous approach DRAC in [1] and to different literature schemes. We also discuss the associated performance gains.

The remainder of the paper is organized as follows: Section 2 presents a review of related works regarding resource allocation, power minimization and BBU-RRH management in C-RAN. In Section 3, we describe the two-stage system model for the C-RAPM and MKP problems, which is followed by Section 4 that details our proposed SA approach. Discussion and analysis of simulation results are exposed in Section 5. Finally, Section 6 concludes the paper.

2. Related work

C-RAN has received a considerable amount of research attention after its introduction by China Mobile Institute. Authors in [4] highlighted C-RAN's advantages for operators and vendors compared to distributed RAN. In fact, traditional base stations are often under-utilized during certain hours of the day, which results in wasteful use of radio resources and baseband capacity. The authors showcased C-RAN's ability to handle this issue by dynamically instantiating BBUs and allocating the baseband resources to RRHs depending on traffic volumes [10]. Furthermore, authors in [11] introduced the concept of coupling C-RAN with mobile cloud computing systems to enhance end-to-end cloud services for future 5G networks. In their work, the authors proposed a novel topology framework and rate-allocation configuration in C-RAN to improve end-to-end traffic performance of mobile cloud computing users.

Regarding the transmission power minimization issue, authors in [12] described a Group Sparse-based Beamforming approach (GSB), that can minimize the C-RAN RRHs transmission and fronthaul links power consumption in downlink. The authors outlined the problem as a joint RRH selection and transmit plus fronthaul links power minimization problem, with a Signal-to-Interference-plus-Noise Ratio (SINR) constraint at each user. Their proposed GSB algorithm solves the problem by starting to sort all RRHs following their transmitting power gains. The algorithm then iteratively turns off RRHs with minimum power gain, until the power minimization problem becomes infeasible. However, the GSB approach was not a C-RAN-specific solution for power minimization, since it can also be applied to traditional base station networks, with an extension of fronthaul links. Furthermore, the GSB scheme could not measure the number of necessary BBUs in the cloud that can handle the system.

Our paper, to the best of our knowledge, is one of the precursory attempts to present a high-level centralized approach combining dynamic resource allocation, transmission power minimization and BBU-RRH assignment in one framework. Other attempts regarding centralized resource allocation have been previously tackled under rate constraint such as [13–15]. Authors in [13] presented a QoS-based Power Control and resource allocation in LTE Femtocell network (QP-FCRA). Although their approach is mainly within the context of femtocell networks, it can be applied to C-RAN thanks to its centralization nature. In their proposal, a joint resource allocation and power minimization algorithm is implemented at a central level of each clustering cells. The QP-FCRA algorithm then exploits cooperation between neighboring RRHs to periodically optimize the throughput satisfaction rates of users. However, their optimization scheme was run in offline mode and the algorithm's computational time was fairly big. In [14], we have addressed the problem of admission control considering individual UEs Quality of Service (QoS) requirement for guaranteed-service users but the transmission power aspect was however not considered. In this paper we encompass jointly maximizing the throughput of best-effort users while minimizing the total transmission power.

Although solutions for resource BBU-RRH assignment procedures in C-RAN have received some notable attention, the number of contributions for this problematic remains nonetheless very

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