EAI Endorsed Transactions
on Industrial Networks and Intelligent Systems
Research Article EAI.EU

Resource Allocation for Energy Efficiency in 5G Wireless Networks

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Abstract

Resource allocation is one important mission in wireless communication systems. In 5G wireless networks, it is essential that the new systems be more dynamic and wiser to simultaneously satisfy various network demands, by using new wireless technologies and approaches. To this end, resource allocation is faced with many significant challenges such as interference alignment, security attacks, or green communication. On the other hand, as one serious problem in 5G networks, the issue of energy is affected directly by the allocated resources in the system, i.e., bandwidth allocation, power control, association allocation, and deployment strategies. Consequently, together with the enhancement of spectral efficiency performance, an emerging trend of 5G wireless networks is to approach green communication via energy efficiency (EE) (bits/Hz/Joule), whose most significant challenge is due to its belonging to the fractional programming in the optimization field, i.e., nonconvex programming. This leaves many difficult tasks for improving network EE performance. In this paper, we will tackle the critical EE in 5G wireless networks.

Keywords: Energy efficiency, nonconvex optimization, resource allocation, 5G networks.

Received on 19 February 2018, accepted on 03 May 2018, published on 27 June 2018

doi: 10.4108/eai.27-6-2018.154832

1. Introduction

With the increasing demand for green networking, recently research has been focused on approaches that reduce energy consumption [16, 51, 55]. It is critical to meet the required quality of service (QoS) for all users in the network [53] while managing the amount of utilized energy. In fact, wireless cellular communications may face a significant challenge to satisfy the demand of higher data-rate communications at reduced greenhouse emission [16]. Hence, the energy efficiency (EE) performance is one of the major topics and will be attached to green communications in the deployment of 5G technology[16, 32, 51]. Nevertheless, the EE maximization problem usually results in a nonconvex program [5]. Specifically, the network energy-efficiency merit is usually defined as the ratio of the total information throughput and the total energy consumption, and thus, the EE maximization problem is introduced under the class of fractional programs [32, 49, 55] in the field of optimization. To enhance the performance of communication systems, the combination of interference alignment [59], spectrum allocation and energy-efficient management should be necessarily considered and implemented simultaneously. This leads to the introduction of a hybrid resource management scheme for the emerging of 5G network architectures, i.e., cognitive relay networks [19, 59], massive multiple-input multiple-output (MIMO), heterogeneous networks (HetNets), and cell-free. In this paper, we provide and analyse the novel of hybrid resource allocation approaches for improving EE performance in potential 5G network scenarios.

In [39], we study a HetNet which serves multiple user terminals. This work develops a path-following algorithm to handle the computational EE maximization problem. The proposed algorithm invokes a simply convex quadratic program at each iteration and rapidly converges at least to a locally optimal solution. Moreover, the three-objective (EE, QoS and service loading) optimization problem of the joint beamforming design for maximizing EE under QoS requirement and association SBS service is provided and addressed. In [40], a HetNet scenario with a macro-cell base station (MBS) equipped with a large-scale antenna array (massive MIMO) overlaying a number of small cells maintains high QoS to multiple users under low transmit power budget. The main purpose of this work is to address the downlink beamforming design at the base stations to optimize the network EE under QoS and transmit power budget constraints. Meanwhile, the conventional transmission strategy uses a few hundred antennas for meeting the users' QoS threshold. More importantly,

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we demonstrate that the overall network EE does not increase in the number of BS antennas. In [36, 37], the downlink of a cell-free massive MIMO network has considered for the responsibility of green communications in terms of the total EE. A critical issue, which is proportional to the number of access points (APs), suggest very high power consumption in deploying cell-free networks. To overcome the obstacle, in [37], a path-following power control algorithm using zero-forcing precoding is proposed to maximize the network EE of cell-free massive MIMO under the backhaul power consumption and the imperfect channel state information. In [31, 42], we consider the problem of maximizing EE in single-cell and multi-cell massive MIMO under users' QoS constraints and a limited power budget of transmission. Under such an environment [10, 47, 54], massive MIMO system provides favorable propagation characteristics and deterministic channels' eigenvalue distribution behavior. In the earlier work [31], a low-complexity zero-forcing (ZF) beamforming [56, 58] is to perform well to serve a smaller number of users with a large array of low-power transmit antennas. In the latter work [42], massive MIMO can schedule its service for serving many users as possible by the fractional time transmission, and thus, a sufficient number of users are served in one of time fractions.

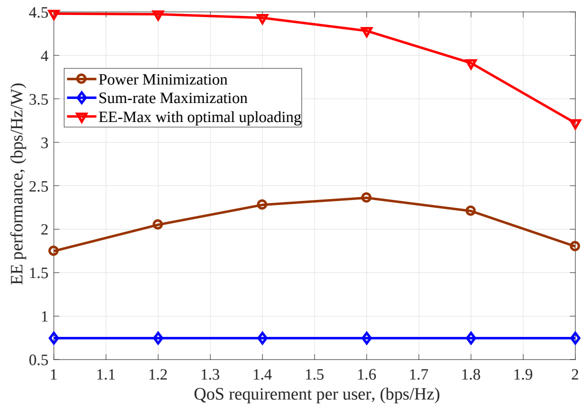

Figure 1. The average EE performance versus per-user QoS threshold. Circle cell structure with radius 250 m is setup with a MBS equipped with 10 antennas at centrally coverage network, 4 SBSs equipped with 2 antennas and 14 single-antenna users randomly distributed. Other simulation parameters are as follows: carrier frequency = 2 GHz, Bandwidth = 10 MHz, transmit power of MBS and SBSs = 43 dBm and 30 dBm, path-loss of MBS and SBS $128.1 + 37.6 \log_{10} R$ dB and $140.7 + 36.7 \log_{10} R$ dB (R in km), noise power density -174 dBm/Hz.

2. Energy efficiency in small cell with user association

HetNets have recently been considered as a solution for supporting the unprecedented data increase and consistent QoS within the 5G wireless networks [2, 20, 29]. Due to the scarcity of frequency resources and exponential increase of terminal devices in cellular network, the spectrum must be shared between the SBSs and the MBS to serve many users simultaneously [9, 46]. As a result, a critical challenge of the alignment intra- and inter-tier interference should be effectively addressed for the successful deployment of HetNets.

On the other hand, due to a serious ecological and economical concern [14], the amount of power consumption in hardware and infrastructure significantly increases for operating numerous base stations in Hetnets. As a result, one of most important merit in deploying 5G HetNet systems is the network EE performance in terms of bits per Joule [7, 23]. In terms of EE, BSs are the largest energy consumer since they consume not only the power for data transmission, but also the power required to activate radio frequency (RF) circuits of BSs. Therefore, optimizing EE performance for downlink transmission in HetNets has attracted a lot of research interest recently and mixed deployment of HetNets has been shown to have a higher EE. To save the HetNets energy, some actice/sleep regimes for conventional HetNets and massive MIMO HetNets were proposed in [3, 4, 28, 51]. It is importantly noted that the maximizing EE performance does not try to minimize the beamformer power since EE merit is a ratio of the network sum-rate and the total power consumption. In fact, the beamforming design for the EE must be more complicated than conventional beamforming design with minimizing the beamforming power subject to the users' QoS throughput (see e.g. [30, 57] and references therein).

In our work [38], we use a novel group sparsity of weighted ℓ_1-norm corresponding to switching-off SBSs and associated users for joint linear precoder design in EE maximization problem. The Dinkelbach-type algorithms [13] of fractional programming is used as the main approach for obtaining computational solutions of EE maximization [17, 52, 55]. From the considered HetNet scenario in [39], we propose a novel computational algorithm for maximizing EE via a convex quadratic program at each iteration under three-objective (EE, QoS and BS service loading) optimization. Therein, the EE performance is improved, the QoS requirement per user is guaranteed, and service loading refers to the number of served users at BSs is optimized.

In Fig. 1, the EE performance is analysed under the impact of the QoS requirement in a scenario of HetNet with the deployment of one MBS and multiple SBSs. Power minimization, sum-rate maximization and an EE maximization approach with the optimal BS uploading scheme are employed. The EE performance of the proposed approaches significantly outperforms compared to other schemes. Interestingly, the specific value of Qos requirement of 1.6 bps/Hz is an optimal QoS threshold for power minimization and the EE optimization approach. Also from Fig. 1, the sum-rate maximization scheme is not a good approach in terms of EE.

3. Energy Efficiency in small cell and massive MIMO

Massive MIMO [27, 47] and small cell networks [22] have been visualized as two emerging technologies of 5G communication networks with the promise to provide a 1000-fold increase in network capacity. More importantly, a combination of two technologies, which have attracted considerable research interest [21, 48], will bring enormous benefits by the resonance of the advantages of two systems. In a such scenario, the massive MIMO MBS located at the network center serves macrocell-users (MUEs) while the SBSs serve smallcell-users (SUEs) which are located in the MBS coverage. Normally, the MUEs present users with high mobility and SUEs assign users with static and low mobility. Similar to conventional HetNets, interferences is still a major problem in massive MIMO HetNets which leave many challenges for researchers [12, 15]. However, besides the benefits of massive MIMO, the beamforming design, which involves a large-scale size of beamformer, leads to the dramatically high computational complexity.

On the other hand, EE performance has been designed for 100-fold increase as a requirement in 5G communication systems [8, 25, 60]. However, in massive MIMO HetNets, the use of low power large-scale antennas at MBS and the higher channel gain by SBSs coverage offers better QoS; however, both MBS and SBSs consume a large amount of power including transmission and non-transmission powers, which are proportional to the number of their antennas and the number of SBSs. Unfortunately, the objective EE functions in massive MIMO HetNets [40] may not belong to the classical of fractional programming, i.e., the ratios of concave and convex functions [60]. Therefore, the Dinkelbach's procedure does not provide an easy way to find its solution for a difficult nonconvex EE optimization problem. To tackle this issue, the separation of beamforming phases for network EE of HetNets were proposed in [18]. In the first phase, the energy-efficient MBS beamforming is implemented with the interference constraint to the SUEs. In the later phase, the energy-efficient SBS beamforming is carried out with ignoring the interference caused by the MBSs. In [45], the nonconvex problem come from each Dinkelbach's iteration for the SBSs is obtained by D.C. (difference of two convex functions) algorithms

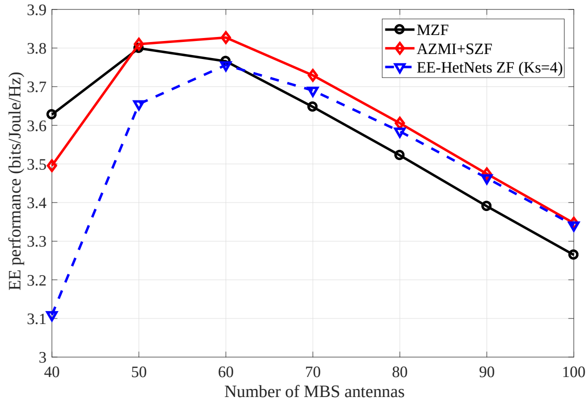

Figure 2. The EE performance versus the number of MBS antennas in a scenario of massive MIMO HetNets. Circle cell structure with radius 1000 m is setup with a centrally located MBS equipped with large-scale antennas, 6 SBSs equipped with 4 antennas and > 30 single-antenna users randomly distributed. Other simulation parameters are as follows: carrier frequency = 2 GHz, Bandwidth = 10 MHz, MBS and SBSs transmission power = 46 dBm and 30 dBm, path-loss model of MBS and SBS $128.1 + 37.6 \log_{10} R$ dB and $140.7 + 36.7 \log_{10} R$ dB (R in km), noise power density −174 dBm/Hz. The throughput threshold per user is 4 Mbps.

[26] while the interference terms of MUEs must lower than a given threshold. In [40], a massive MIMO HetNet, which provides a large-scale antenna array MBS overlaying multiple small antenna arrays SBSs, serves multiple MUEs and SUEs. The main aim of this work is to design beamformers at both the MBS and SBSs for EE maximization problem under the users' QoS constraints and power budget. Avoiding the restrict of Dinkelbach's computationally iterations, we developed some novel path-following computational algorithms which transform the nonconvex problem to a simpler form of convex problem and at least converge to a locally optimal solution. Under different scenarios, simulations in [40] show that the network EE performance significantly enhances by efficient control of the number of the MBS antennas and the deployment of SBSs in massive MIMO HetNets.

In Fig. 2, we investigate the impact of the number of MBS antennas to the EE performance in a scenario of massive MIMO HetNet. Zero-forcing inter-MUE and MBS and inter-SUE interference beamforming (MZF), adaptively suppressed co-interference based beamforming (AZMI+SZF), and energy efficiency zero-forcing HetNets beamforming (EE-HetNets ZF) are employed. This figure confirms that the most efficient scheme is AZMI+SZF, which forces alignment the strong MBS interference and relaxes the weak MBS interference in the EE maximization problem. Interestingly, the EE performance achievement in MZF

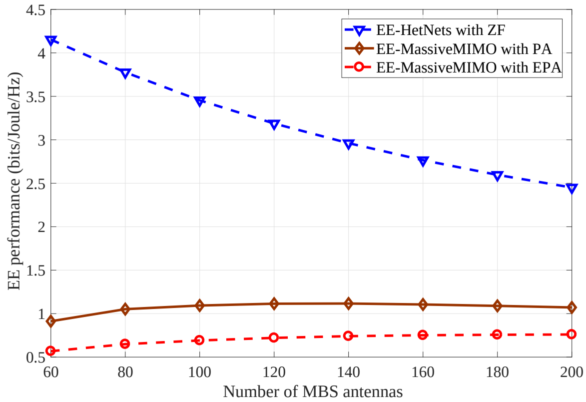

Figure 3. The EE performance versus the total number of antennas in a HetNet scenario. Energy efficiency zero-forcing for HetNets and massive MIMO beamforming are employed. The throughput threshold per user is 4 Mbps.

and AZMI+SZF under massive MIMO HetNet scenario is maximum at $N_M = 50$, where their performance gap is clearly visualized. When the number of MBS antennas increases, the performance gap between massive MIMO HetNet beamforming and only HetNet beamforming closes to zero.

Next, instead of only using massive MIMO for maximizing EE performance, using massive MIMO HetNets offers significant benefit for the system EE as shown in Fig. 3. On the other hand, as we can see, the increasing of MBS antennas leads to a degradation of network EE in massive MIMO HetNets. This can be explained as the EE performance of massive MIMO system does not increase in MBS antennas while the power consumption corresponding to antenna number becomes domination, as Fig. 3 shows. In contrast to the conventional spectral efficiency maximization, the overall network EE does not increase when the number of antennas grows up.

4. Energy Efficiency in Cell-free network

Cell-free massive MIMO has been investigated as an emerging 5G technology in the wireless system because of its ability to provide good service to all users [33, 34]. As such system, a numerous low-powered and distributed APs serve a small number of single-antenna users are randomly located in a wide network area [24, 34]. In cell-free systems, the inter-cell interference is no longer the main problem that affects the spectral efficiency of wireless networks. Rather, the inter-user interference is a more important role in cell-free [34]. To this end, ZF precoding design is an efficient approach to deal with the term of multiuser interference [37], although the implementation of ZF processing requires a higher complexity than conjugate beamforming [34]. With the existence of massive APs and multiple users in cell-free system, the efficient channel transmission estimation and backhaul control are also necessary for cell-free deployment [24].

When a massive APs number in large-scale networks, EE performance in terms of bits/Joule becomes a major figure-of-merit [36, 37] which does not consider in the literature of cell-free networks [24, 34]. It is important noted that the strategy of beamforming design is significantly necessary to improve the EE performance because of a huge paramount energy consumption to employ signal processing techniques in cell-free massive MIMO. In fact, the large proportion of used energy is exploited in downlink transmission power at APs, circuits power consumption and the utilized power of backhaul network [11]. In [37], we provide a low-complexity EE maximization procedure using ZF precoding design and MMSE channel estimation under a general scenario of cell-free network. By the benefit of the proposed approach, the EE maximization problem is transformed into a low-complexity power allocation problem under multiple simple constraints. The proposed algorithm only need a few iterations to converge to a locally optimal solution of EE maximization problem.

In Fig. 4, we study the impact of the number of access points to the EE performance under imperfect channel estimation (IPCE) in a cell-free system. Maximizing EE approach with and without power control are considered. The power control scheme outperforms the equal power allocation in terms of EE performance for IPCE cases. For the case without power control, the optimal performance can be achieved 20 Mbits/Joule at $M = 80$ whereas, the optimal performance can be achieved 32 Mbits/Joule at $M = 60$ for IPCE with the proposed algorithm. As the power consumption critically increases in APs number, although the use of more APs properly enhance spectral efficiency, but does not offer a better EE performance for cell-free network.

5. Energy Efficiency in multi-cell massive MIMO

One of potential 5G communication technology, which can promise high users' QoS standard, is called massive MIMO [27, 47]. With favorable propagation characteristics [47] and deterministic channel behavior [10, 54], the low-complexity linear beamforming designs such as conjugate or ZF beamforming are easily performed in massive MIMO [35, 56, 58]. In our recent work[41], the optimal ZF beamforming for power allocation offers better performance compared to conjugate beamforming, meanwhile, these beamformers maintain the users' QoS under a limited power budget. However, in most of previous works [27, 31, 56, 58], massive MIMO is properly applied to serve smaller numbers of users by a large array of low-power transmit antennas under QoS

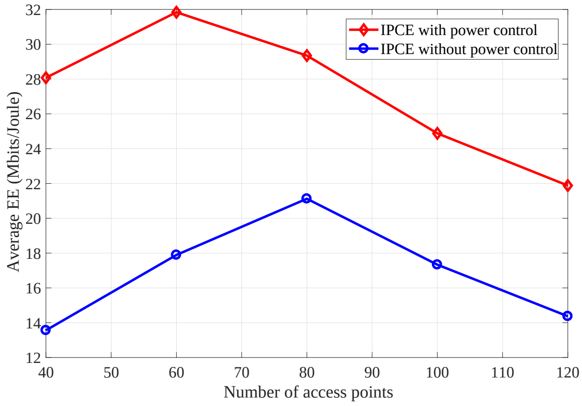

Figure 4. The average EE performance versus the number of access points. A wrapped around cell structure with 1×1 km^2 is setup with 16 single-antenna users randomly distributed. The coefficient models of large-scale fading is as COST Hata model. The carrier frequency $f_c = 1.9$ GHz, bandwidth $B = 20$ MHz, $\tau = 200$, maximum transmit power of each AP and user are 200 and 100 mW. The noise power at the receivers is $N_0 = 290 \times \kappa \times B \times NF$, where κ and NF are Boltzmann constants and noise figure at 9 dB.

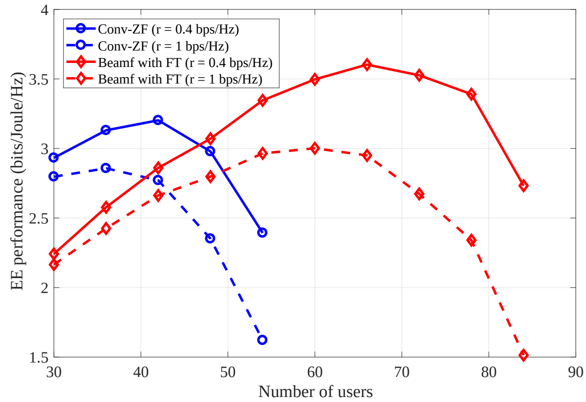

Figure 5. EE performance of a three-cell network versus the number of users per cell. Hexagonal cell structure with radius 1 km is setup with a centrally located BS equipped with 8×8 uniform planar array of antennas. Standard exponential correlation model is assumed to implement antenna spatial correlation with correlation factor of 0.9. Other simulation parameters are as follows: carrier frequency = 2 GHz, Bandwidth = 10 MHz, BS transmission power = 46 dBm, path-loss model $128.1 + 37.6 \log_{10}$R dB (R in km), noise power density -174 dBm/Hz.

requirement. To support more users, massive MIMO must change its transmission schedule to provide a service-wise for many users. One of the wise strategies is to divide transmission schedule into small fragments within fraction times, and thus, small numbers of users are allocated and arranged to serve in a time fraction [42, 43].

On the other hand, the beamforming design for many users usually results in ill-conditioning of the channel matrices in ZF beamforming. To overcome this issue, the regularized zero-forcing (RZF) beamforming is provided [44, 56]. The biggest obstacle in employing RZF is that they cannot completely align the inter-user interference and this leads more computational complexity of designing RZF beamforming in massive MIMO. Furthermore, the important issue of massive MIMO is that the closed packed of small space transmit antennas of massive MIMO system creates the antennas' spatial correlation. As a result, the spatially correlated of large-scale antenna arrays, which causes the lowered rank of the channel matrices, badly affect the spectral efficiency of massive MIMO [1, 50].

For discussion of these issues above, in [42], we propose a novel beamforming design for the maximizing EE problem in the multicell massive MIMO. First of all, the network EE performance is defined as the ratio of the total information throughput and the total energy consumption [6, 60]. Secondly, to satisfy users' QoS requirement and minimize the transmit power, ZF and RZF beamforming design are exploited via new path-following procedures for EE maximization problem under practical massive MIMO scenarios. Thirdly, a wise strategy of time-fraction transmission schedule is proposed to serve as many as possible under users' QoS. This scheme requires the higher complexity of beamforming design which is addressed by a proposed algorithm as shown in [42].

Next, we investigate the EE performance of a multicell massive MIMO system under the impact of the number of users in Fig. 5. ZF beamforming with and without optimal fractional time transmission is employed. As we can see, TF-wise beamforming schemes can serve higher numbers of UEs with higher EE achievement than that for conventional ZF beamforming. In fact, conventional ZF beamformers only can serve up to 54 UEs, meanwhile, TF-wise ZF beamforming is able to serve at least 80 UEs for $\rho = 0.9$ for both QoS standards, i.e., 0.4 and 1 bps/Hz.

6. Conclusions

This paper has proposed the novel resource allocation schemes (hybrid resource management) for EE maximization problem in the emerging scenarios of the wireless networks, i.e., small cell, massive MIMO, massive MIMO HetNets and cell-free. Besides, the necessary constraints of QoS threshold and power budget are guaranteed while the objective EE function in terms of bits/Joule/Hz is optimized. Each of scenario is carefully considered and simulated by numerical results.

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