

User Allocation in Heterogeneous Network Supplied by Renewable Energy Sources

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Abstract—The information and communication technology, ICT, a domain of the global economy, consumes more and more energy, what is the effect of continuously increasing wireless data traffic. Thus, there is a need for more energy-efficient and sustainable network and resource management, and such a goal can be achieved by the utilization of renewable energy sources. This paper proposes a novel user allocation scheme applicable to the heterogeneous radio access networks supplied with renewable energy sources. Presented results proved that high-energy efficiency can be accomplished by reallocating some traffic to the green wireless base station¹.

Index Terms—Renewable Energy Sources, Traffic Steering, User Assignment, Heterogeneous Networks

I. INTRODUCTION

Progressive standardization of radio access network (RAN) allows achieving more and more stringent requirements on the quality of service experienced by the end-user [1]. As the number

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of served users is also increasing, the structure of the network becomes more and more heterogeneous, where many base stations of a different kind (macro- and micro- base stations, small cells, etc.) are deployed on the same area, leading to the concept of no-cell schemes [2]. However, in such a complicated and demanding scenario, the reliable service delivery entails also the permanent increase in the energy consumption by the wireless part of the ICT sector of the global economy [3]. As this problem is technically tractable in urban areas, where access to stable energy sources can be easily guaranteed, it may become a significant challenge in the rural, remote, and hardly accessible areas. The additional investment costs (mainly into the reliable power supply besides the telecommunication infrastructure) versus expected revenues from such areas can make such a project unprofitable. Moreover, the environmental perspective has recently gained great attention in the context of ICT - the communication network shall be both green (i.e. with reduced energy consumption) but also should target the resource-sustainability goal [3], [4]. This sustainability of resources is an important paradigm that can drive the development of new algorithms and solutions for wireless networks [5]. The three cases identified above (i.e., investment in hardly accessible areas, reduction of energy consumption, and improvement of sustainable usage of resources), are to some extent addressed by equipping the base stations with renewable energy sources (RESes), such as solar panels, wind turbines, etc. [4]. Providing the portable base station with RESes (which make the base station to some extent energy-autonomous) could be a viable solution for the delivery of wireless services in remote

areas. However, the application of RESEs entails the need for prospective adjustment or even redesign of various existing algorithms operating at the base station, such as radio resource management, user assignment, traffic steering, etc. Thus, in this paper, inspired by the work in [4], we propose the solution of RES-aware user assignment procedure. In particular, we have proposed the solution, where the new user is allocated at first to green nodes; when it is impossible it tries to reallocate already assigned users among the green nodes in order to relax some resources to serve the new user. Only when these steps were not successful, the user is allocated to the on-grid macro base station. Moreover, the proposed solution has been extended to be applicable in two other schemes - user handover and enforced switching-off of the green node.

II. SCENARIO DESCRIPTION

In our analysis, we consider the heterogeneous 5G network consisting of one macro base station (MBS) cell equipped with the on-grid power supplies, and $N - 1$ small cell base stations (SCBSes) powered by renewable energy sources (Fig. 1). The MBS is located in the center of the examined area and acts as the sink node (due to the fixed wireless access to the core network) to the surrounding green SCBSes constituting the star topology for the backhaul connections. We assume that the cells can be sectorized, and per each sector, multiple antennas can be installed on the site. Mobile users are deployed randomly and uniformly in the considered area, and they can change their positions. Two classes of users are envisaged: the low-rate (which requires up to 3 resource blocks (RB) per one time slot) and the high-rate one (with 10 RBs per time slot).

We assume four sleep modes for SCBSes. Each subsequent mode is less and less energy-hungry at the expense of the increasing awaking time (followed by [6]). In case of no users appearing for a longer time, SCBS enters the deeper sleep mode after a strictly defined time.

As MBS is supplied by the on-grid sources, we can assume permanent power availability. In case of SCBS, we consider the photovoltaic (PV) panels and wind turbines (WT) grouped in farms as energy sources.

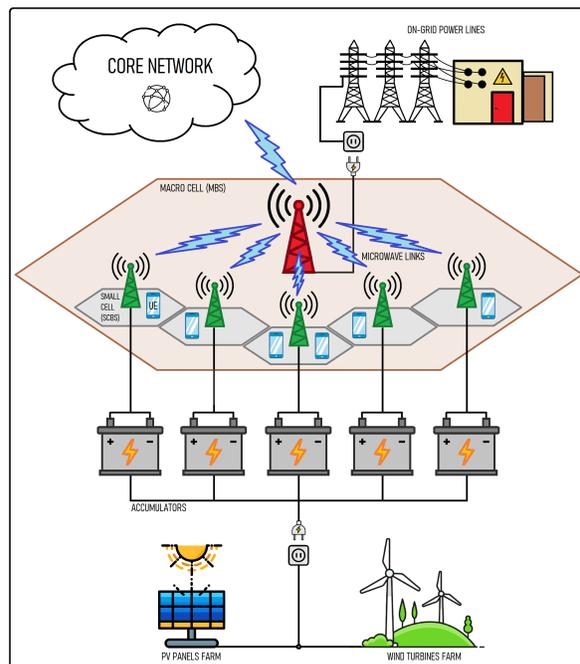


Fig. 1. Considered scenario

III. RES-AWARE USER ASSIGNMENT

In particular, as in the original algorithm, we prioritize the green SCBSes in the user assignment process. Thus, while associating the user with the serving base station, the first attempt is to find the best (with the strongest signal) SCBS with enough spectrum and energy resources to serve the user. In particular, we set the requirement that the amount of frequency resources will be at least enough to guarantee the rate required by the user. Moreover, the amount of energy remaining in the attached accumulator has to be above some specific threshold e , considering the power generation and consumption models. In case that no SCBS can be identified, the algorithm tries to reallocate the users already associated with SCBSes among the whole set of SCBS. The purpose of the user re-association is to check the possibility to relax some of the currently utilized resources from the serving SCBS and allocate them to the new user. Only when this procedure did not lead to the positive user assignment of the user to green SCBS, the MBS is considered as the final candidate to serve this user. Finally, when there is no traffic generated within the SCBS cell, it enters the first sleep mode. If there is no traffic load for a specific time, the SCBS goes into deeper sleep mode, finally

achieving the fourth mode. The SCBS will return to the normal operating mode when any new data traffic should be served. Let us stress that although the above procedure is directly applicable when the new user tries to access the network, it can be also launched periodically to update the user association to the base station in order to reflect the RESeS instability and react to the movement of users. Thus, in our investigation, we assume that the user-to-base station association procedure will be triggered in the following situations: a user will initiate the handover procedure; any of the SCBS will announce about the insufficient energy stored in the batteries. Analogously, when the battery has been recharged and the amount of the stored energy has sufficiently increased above the threshold, the user re-association procedure can be also revoked.

IV. SIMULATION RESULTS

A. Simulation Setup

To verify the performance of the proposed algorithm, extensive computer simulations using Matlab environment have been conducted, where the 5G NR base stations have been deployed as described in Sec. II. There is one MBS was located centrally in the considered area, and 24 SCBSes deployed in form of a regular grid. The center frequency in FR1 band was set to 3410 MHz, and the channel bandwidth - to 40 MHz. It results in 106 resource blocks (RBs) available, assuming 30 kHz of sub-carrier spacing. A Time Division Duplex, TDD, scheme with 2 uplink symbols located at the end of the slot was used.

The MBS is a 3 sector site with a single antenna mounted at a height of 47 m, whose transmit power equals 46 dBm. In contrast, each SCBS is a 1 sector with a single antenna, 16 m height site, transmitting with the power of 32 dBm. In terms of backhaul connectivity, the microwave links have been used, in particular, there is a 24 MIMO array at the MBS, whereas at the SCBS - just one antenna is considered.

For the path loss calculation, the rural macrocell (RMa, [7]) has been considered with the following parameters: assumed slow fading margin - 6 dB, body loss - 3dB, foliage loss - 11 dB. The base station equivalent antenna gain was calculated to be 17.5 dB, whereas of the user - to 0dB. Thus, the resultant MBS coverage area has a radius of around 2.3 km, whereas the radius for SCBS was

set to around 0.5 km. The MBS acts as the sink node, whose max aggregated backhaul capacity per sector was set to 27×106 RBs, i.e. the sum of all RBs from 24 surrounding SCBSes and three sectors of the MBS.

Assuming a moderately warm climate, the PV generates power on average 8 h per day. The energy is stored in one off-the-shelf accumulator model, i.e., Trojan 24-GEL 77Ah. There are 400 users (UE) deployed randomly with the uniform generator over the considered area. The UE antenna height is 1.5 m. Two classes of users are considered, the one that requires 3 RBs and the one that occupies 10 RBs. In both cases, the minimum acceptable signal-to-noise ratio is -2 dB. To calculate the approximate maximum data rate, we followed the guidelines provided in 5G R16 standard [8].

B. User Assignment Analysis

In the first step, we compare the distributions of the user allocation to base stations. The results presented in Fig. 2 are achieved for 100 simulation runs with various user positions. The left subfigures show the results for the new algorithm, whereas the figures on the right - for the reference scenario. The first two top subfigures illustrate the distribution of the percentage load of the network served by the MBS. One can observe that for the new algorithm, the MBS processes on average only 5% of the total traffic in the whole network. For the reference algorithm, the MBS served on average almost twice more traffic. Thus, a significant reduction of the MBS load has been observed. Moreover, in terms of the number of non-served users, the new algorithms have significantly reduced the outage probability. There were on average only 0.2% of non-served users for the new algorithm.

C. Continuous-time Analysis

Let us now analyze the performance of the proposed algorithm in the continuous operation mode, i.e., when the network parameters are analyzed over the 72-hour-long period. 400 users have moved around along a pseudo-random trajectory, and the position of users have been changed around every 500s. All 24 SCBSes have at start fully charged accumulators. The network status has been stored every second to achieve reliable results. The proposed algorithm has been used at the simulation start for each user, when the user started handover

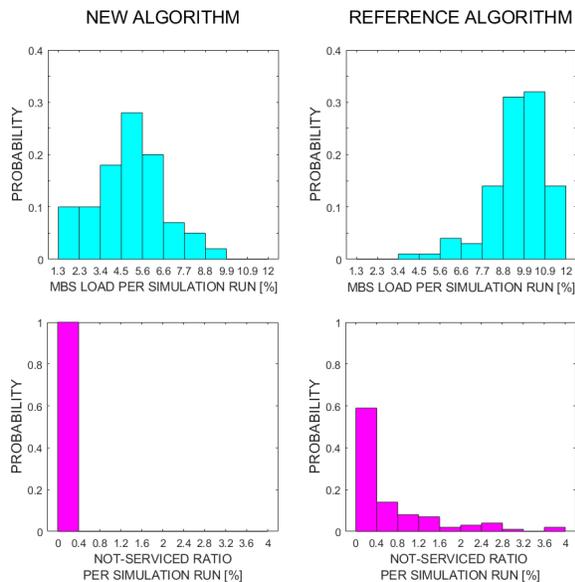


Fig. 2. Assignment algorithms comparison.

procedure or when one of the BS was forced to be switched off due to the lack of energy from accumulator.

As a remarkable gain in the usage of RES-based energy has been observed, it is worth analyzing the reduction of the on-grid energy consumption as a function of time, as illustrated in Fig. 3. One may observe a slight reduction of energy consumed by MBS, however, it has to be remembered that MBS is always powered on and it acts as the sink node. Thus, the prospective reduction of energy consumption of MBS is limited.

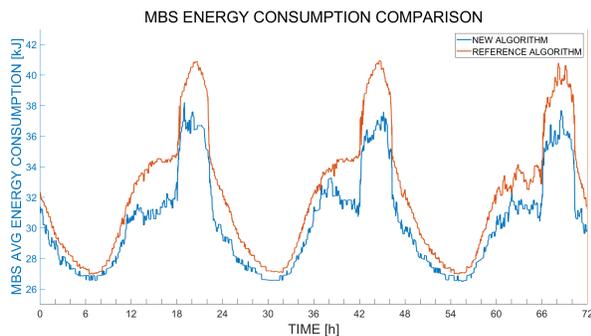


Fig. 3. On-grid energy consumption comparison for both algorithms.

Finally, we have compared the energy efficiency ratio, EE , defined as the achieved sum rate of user data in the whole network over the total consumed energy averaged over all simulation steps. The

results are presented in Tab. I, where the energy efficiency for SCBSes, MBS, and the whole network is jointly presented. One can observe that the energy efficiency has gained for green SCBSes (the difference was over 0.1 Mb per Joule per second), whereas there was a degradation of around 0.14 MbpJ/s per MBS. It is expected behavior, as the MBS is working as a sink node and has reduced the served traffic. Overall, the energy efficiency of the whole network was improved by around 0.04 Mb per Joule per second.

TABLE I
ACHIEVED AVG ENERGY EFFICIENCY IN MBPJ PER SECOND

Algorithm	EE_{SCBS}	EE_{MBS}	EE_{total}
Reference	1.75	0.39	1.25
Proposed	1.86	0.25	1.29

V. CONCLUSIONS

In this paper, we have presented the new user-allocation scheme that is RES-aware, i.e., it tries to prioritize these base stations in the heterogeneous environment, which have access to renewable energy sources. Achieved results for static and dynamic (with user mobility) scenarios proved that the energy efficiency can be improved by shifting traffic from on-grid to RESEs based nodes. However, the key problem in such an approach is the instability of RESEs, and the resultant need for reliable coverage guaranteed by the on-grid base station. The latter cannot be switched off and enters the sleep mode more rarely than the small cells, thus the impact of the overhead power on overall power consumption is significant.

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