

Power Consumption Model Using Green Policies in Heterogeneous Networks

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Abstract—Although the LTE systems provides high data-rate, low latency and spectrum flexibility, the coverage holes due to the cell edge and high interference areas are still an open issue. The Heterogeneous Networks (HetNets) can be a possible solution to this problems. The HetNet paradigms overlaps low power base stations (BSs) with different transmitted powers within a macro cellular coverage. However, the dense deployment of BSs increases the power consumption of the network and, as a consequence, decreases the system performance due to the high inter-cell interference. In this paper, we propose a power control scheme based on green policies in order to enhance the power saving over Heterogeneous Networks (HetNets) in Long Term Evolution (LTE) systems. In particular, the aim of the proposed framework is to increase the energy efficiency of the system, without decreasing the network throughput. An extensive simulation campaign has been conducted through the usage of the Network Simulator 3 (NS-3). The obtained results show that the proposed green power control reduces the power consumption and enhances the energy efficiency of the system without decreases the throughput of both the BSs and users (UEs).

Index Terms—HetNet; 4G mobile communication; Green Networks; Scheduling algorithm; Power Control; Green Networks; Networking and QoS; Performance evaluation.

I. INTRODUCTION

Nowadays global mobile data traffic has grown exponentially and more and more users need access to the network due to the increase of new internet-based applications such as mobile web-browsing, video downloading, on-line gaming and social networking. In addition, the exponential data traffic growth has led to a quickly evolution of the cellular network technologies represented by the forth generation mobile systems such as the Long Term Evolution (LTE) [1].

The LTE standard offers high peak data-rates due to larger system bandwidth, an increment of the spectrum efficiency with the usage of multiple-input multiple-output (MIMO) spatial processing techniques and a simplification of the network architecture with low transfer latency.

Despite the enhancements introduced by this new access technology, the 4G network standards are able to meet partially the increment of the radio spectrum requested by both the users and network operators [2], [3]. In particular, the coverage holes due to the inter-cell interference and the cell edge affect deeply the system performance and have to be taken into account. These open issues led the scientific community to design a new

network paradigm called Heterogeneous Networks (HetNets) [4], [5].

The aim of the HetNets is to overlap within a macrocell a high number of small Base Stations (BSs) with different transmitted power and coverage in order to achieve high data-rates and to enhance the network coverage area.

Although the HetNet paradigm enhances the current mobile networks, there are several open issues: (i) the interference between different base stations that are deployed in the same scenario, (ii) the energy consumption and (iii) the management of the radio spectrum in multi-tier LTE-based network. In particular, due to the dense deployment of small BSs, the energy consumption increases rapidly and plays an important role in the current (4G) and future (5G) [6] mobile cellular networks.

The better trade-off between the overall system energy consumption and the network performance is the aim of the *Green Networks* [7]. Therefore, whereas the research community aimed to maximize the network data-rates, now the priority is the maximization of the system performance at cost of low levels of energy. To do this, efficient power saving schemes, radio resource management algorithms, and novel energy approaches have to be taken into account.

The aim of this work is to decrease the overall network power consumption by managing in a proper way the transmitted power of the base stations involved into an LTE HetNets scenario. As a consequence, a trade-off between the power saving and the network performance has been investigated in order to not reduce system performance, such as spectral efficiency, capacity, throughput, and so on.

System performance are evaluated using the open source Network Simulator 3 (NS-3) [8], [9]. NS-3 is one of the most used network simulator and is developed entirely by the scientific community.

The rest of the paper is organized as follows. In Section II a literature overview about power control schemes and power saving mechanisms in LTE HetNets systems is provided, whereas in Section III a description of the proposed algorithm is presented. The obtained results are analysed in Section IV and, finally, conclusion remark and future works are provided in Section V.

II. RELATED WORK

The HetNets, where low power nodes are deployed within the macro cellular coverage, produce high interference conditions due to the close distance among the base stations of the system. In particular, the inter-cell interference is an important problem and has to be managed in a proper way in order to guarantee high performance to the system users.

Traditional power control schemes focus on the efficient management of the transmitted power of the BSs in order to achieve high data-rates and low delays without considering the network energy consumption. Recent research activities, instead, focus on the new paradigm called *Green networks*. The aim of this new networks is to reduce the power consumption without decrease excessively the system performance.

Many works in literature investigate the power control schemes and energy saving techniques on LTE networks and LTE HetNet scenarios.

Chandrasekhar et Al. in [10] proposed a utility based distributed Signal to Noise Interference Ratio (SINR) adaptation in order to meet the user requirement by managing in a proper way the transmitted power of the femtocells. In addition, due to the Closed Access (CA) configuration, the usage of the femtocell is restricted by the owner to the licensed users.

Despite, in this work we consider the Open Access (OA) configuration where all the users of the system can hand-off in any femtocell of the network. This approach increases the overall network capacity at cost of the femtocell owner that have to share the radio resources with all the system users.

A power control scheme that ensures a constant femtocell radius is proposed in [11]. The authors consider UMTS networks where the open access femtocells use the frequency reuse and co-channel cooperation. Differently, in [12] the authors proposed a location based autonomous downlink power setting and uplink fraction power control schemes in order to mitigate the cross-tier interference.

In particular, although in [12] the transmitted power of the femtocells is managed to decrease the power consumption of the network, our work consider the possibility to handover the UE in the BS that guarantees the highest performance.

The energy efficiency of the system in coordination with power saving techniques are taken into account in [13] and [14]. In particular, Arshad et Al. in [13] evaluate the power consumption and the energy efficiency of a HetNet scenario by considering different inter-site distances among the femtocells of the system. In [14], instead, the authors analyze two different points of view such as the (i) environments side and the (ii) operators side. Thus, they quantify the effect of offloading the traffic in the femtocells in term of spectral efficiency and power consumption.

Finally, an energetic performance evaluation is provided in [15], where different heterogeneous networks are investigated on the aspects of the energy efficiency. Uniform and non-uniform traffic distribution scenarios have been considered in order to evaluate the area power consumption of the network. In addition, the effect of the cell size by varying the type and the number of the additional BSs into the system is taken into account.

We remark that, differently to [13] and [14], we consider the power consumption of the system by varying the number of the users within the small BSs and the macrocell. In addition, we take into account the opportunity to switch-off the BSs when there are not users within their coverage.

III. PROPOSED ALGORITHM

Let us consider an LTE HetNet scenario (as shown in Fig. 1) where small BSs are deployed in an uncoordinated manner within a macro cellular coverage. We denote with B_M and B_m the set of M macrocells and m femtocells in the system, respectively. In particular $i \in B = B_M \cup B_m$ is the index of the generic i -th BS, $k \in K$ is the index of the k -th user, and K is the total number of users within the i -th BS.

In order to increase the energy efficiency of the system without decreasing the network throughput, we propose a power saving algorithm by taking into account (i) the transmitted power of the BSs, (ii) the users within their coverage, and (iii) the users spectral efficiency.

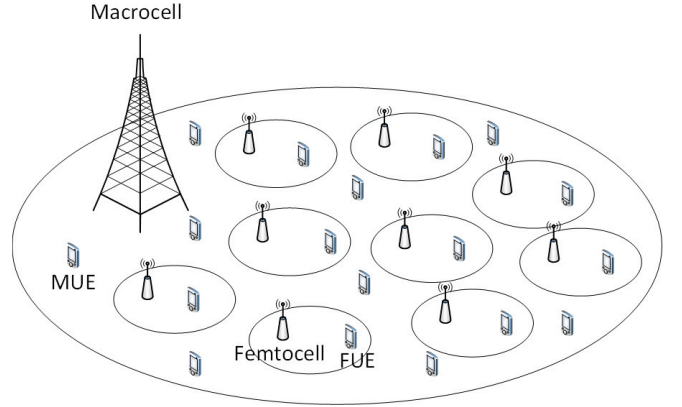


Fig. 1: LTE HetNet Scenario

The proposed algorithm has three steps, as shown in Fig. 2, and starts with the *UEs re-allocation phase*. During this step, the users at the cell edge and with high levels of interference are hand-off to the most suitable BS in order to offload the serving BSs. Then, the *BS switch-off phase* takes place. In this phase, the BS is set in *idle mode* if the number of the users in its coverage is equal to zero.

We remark that when a base station is in *idle mode* it has a low level of transmitted power (about 3 dBm) that is maintained for scanning the network and wake-up suddenly in case a user performs an admission request.

The last step of the green algorithm, called *transmitted power optimization phase*, aims to manage in a proper way the transmitted power of the active BSs. This phase starts with the Channel Quality Indicator (CQI) and Signal-to-Interference Noise Ratio (SINR) collection by a single user from the neighboring BSs. Then, the algorithm chooses for each user a minimum level of SINR (S_{min}) such that its own CQI value not change. In order to select the lowest permitted level of S_{min} , we refer to Table 1.

The optimization problem of this last phase can be summarized as follow:

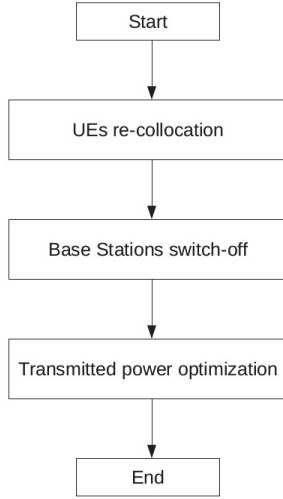


Fig. 2: Algorithm Flowchart

$$\begin{aligned}
 \min \quad & \sum_{i=1}^B P_{T(i)} \\
 \text{subject to} \quad & CQI_k(S) = CQI_k(S_{min}),
 \end{aligned} \tag{1}$$

Where the $\sum_{i=1}^B P_{T(i)}$ represents the overall transmitted power of the system and $\sum_{k=1}^K TH_{k(i)}(S)$ is the throughput achieved by all the users k attached to the BS i . While, S is the real SINR of the user, and S_{min} is the SINR evaluated through Table 1.

The goal of the objective function is to minimize the transmitted power of a base station under the constraint that the CQI of the users does not change. It is worth noting that the aforementioned constraint can introduces weak throughput variation due to the SINR reduction.

CQI	Modulation	Code Rate	SINR	Spec. Eff.
CQI 1	QPSK	1/12	-6.50	0.15
CQI 2	QPSK	1/9	-4.00	0.23
CQI 3	QPSK	1/6	-2.60	0.38
CQI 4	QPSK	1/3	-1.00	0.60
CQI 5	QPSK	1/2	1.00	0.88
CQI 6	QPSK	3/5	3.00	1.18
CQI 7	16QAM	1/3	6.60	1.48
CQI 8	16QAM	1/2	10.00	1.91
CQI 9	16QAM	3/5	11.40	2.41
CQI 10	64QAM	1/2	11.80	2.73
CQI 11	64QAM	1/2	13.00	3.32
CQI 12	64QAM	3/5	13.80	3.90
CQI 13	64QAM	3/4	15.60	4.52
CQI 14	64QAM	5/6	16.80	5.12
CQI 15	64QAM	11/12	17.60	5.55

TABLE I: CQI values [16]

At the end of the third phase, the achieved power gain for the user k attached to the BS i is calculated as the difference between the two transmitted powers related to the the real UE SINR S and the minimum UE SINR S_{min} :

$$P_{Gain}(k) = P_{T_S}(k) - P_{T_{S_{min}}}(k) \quad [Watt] \tag{2}$$

Finally, the new transmitted power of the base station i is computed as follow:

$$P_{T_{new(i)}} = P_{T(i)} - \sum_{k=1}^K P_{Gain}(k) \quad [Watt] \tag{3}$$

IV. SIMULATION RESULTS

In order to evaluate the performance of the proposed framework we used the Lena module of the open source Network Simulator 3 (NS-3) [8]. NS-3 is a real-time simulator developed by the scientific community and is able to emulate the entire protocol stack of the LTE standard and most of the wireless network protocols.

We consider an LTE HetNet scenario where the femtocells are deployed within a macro cellular coverage with three sectors. Different power transmission values are considered according to the topology of the base station, since the macrocell has an highest power (46 dBm) with respect to the femtocell (20 dBm). The users and the femtocells are uniformly distributed and the Resource Blocks (RBs) ¹ are equally divided between macrocell and femtocells (50 RBs for the macrocell and 50 RBs for all the femtocells).

Outputs are achieved by averaging a sufficient number of simulation results to obtain 95% confidence intervals.

Parameters	Value
1st Sub-channel Frequency	2110 MHz
Downlink Channel Bandwidth	20 MHz
Sub-Carrier Bandwidth	15 kHz
Doppler Frequency	60 Hz
RB Bandwidth	180 kHz
RB Sub-Carriers	12
RB OFDM Symbols	7
Macro Base Stations TX Power	46 dBm
Femto Base Stations TX power	20 dBm
Noise Spectral Density N_0	-174 $\gamma_i \frac{dBm}{Hz}$
$Pathloss_{Macro}$ (distance R)	$15.6 + (35 \cdot \log_{10}(R)) dB$
$Pathloss_{Femto}$ (distance R)	$38.46 + (20 \cdot \log_{10}(R)) dB$
Shadow fading	log-normal $\mu = 0 \sigma = 8$ dB
Multipath	Jakes model with 6 to 12 Scatterers
Wall Penetration Loss Macro	10 dB
Wall Penetration Loss Femto	7,10,15 dB
Frame duration	10 ms
TTI (sub-frame duration)	1 ms
Frame duration	10 ms
Simulation Time	1 s
Target Bit Error Rate	$5 \cdot 10^{-5}$
Cell Coverage Macro	500 m
Cell Coverage Femto	50 m
Number of Macro	1
Number of Femto	1,2,5,10,20,30
Macro Users	50
Femto Users	1,2,5,10,15,20
Scheduling Algorithm	Proportional Fair

TABLE II: Simulation Parameters

¹The RB corresponds to the smallest time frequency resource that can be allocated to a user (12 sub-carriers) in an Long Term Evolution (LTE) system. For example, a channel bandwidth of 20Mhz corresponds to 100 RB

In order to characterize the energy consumption of the considered scenario and to evaluate the energy efficiency of the proposed green power control scheme we consider different energy metrics proposed in literature [17]. The Area Power Consumption (APC) is introduced in [17] and represents the overall transmitted power in a reference BS divided by the corresponding reference area. In our case the system APC can be written as:

$$APC = \frac{\sum_{i=1}^B P_{T(i)}}{A} \quad \left[\frac{\text{Watt}}{\text{m}^2} \right] \quad (4)$$

where $\sum_{i=1}^B P_{T(i)}$ is the overall transmitted power of system and A the coverage area, respectively.

In addition, according to [17], the Energy Efficiency (EE) of the system is represented as the maximum amount of bits that can be delivered by the network (throughput) per joule of consumed energy in the system:

$$EE = \frac{\sum_{i=1}^B \sum_{k=1}^K TH_{k(i)}}{\sum_{i=1}^B P_{T(i)} \cdot t} \quad \left[\frac{\text{bits}}{\text{Joule}} \right] \quad (5)$$

Where $\sum_{i=1}^B \sum_{k=1}^K TH_{k(i)}$ represents the overall throughput and $\sum_{i=1}^B P_{T(i)} \cdot t$ is the total watts consumed by the system in the time t . The others parameters used in the simulation campaign are shown in Table 2.

The total transmitted power of the system is depicted in Fig. 3.

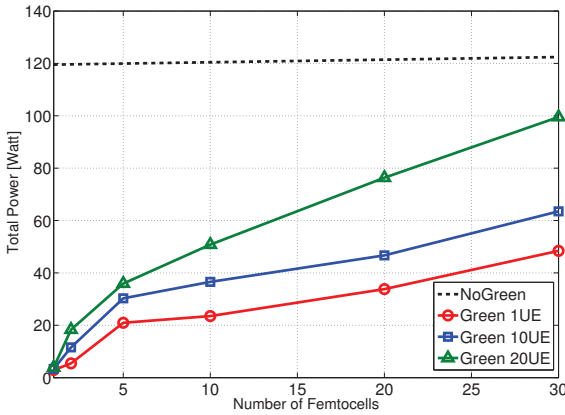


Fig. 3: Overall System Transmitted Power

The overall system power by using the proposed green algorithm increases proportionally with respect to the number of femtocells and by varying the number of the system UEs. In the no-green case, due to the fact that any power saving scheme is performed, the transmitted power is quite constant.

Fig. 4 shows the APC by varying the number of femtocells and by considering different number of users within their coverage area.

The gain achieved is higher when the number of the femtocells within the macro cellular coverage is low. In this situation, there are few users in the system and the base stations need a lower power to guarantee high levels

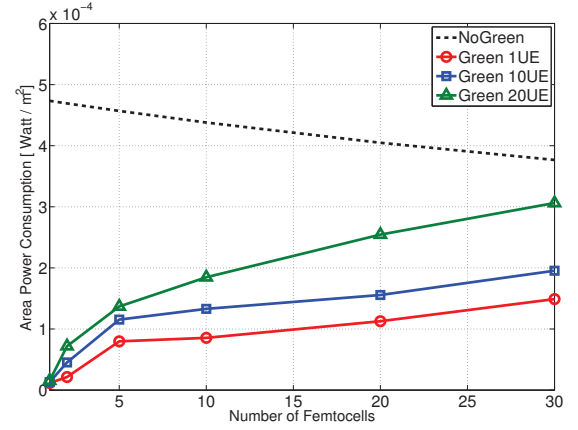


Fig. 4: Area Power Consumption

of throughput. Lower is the transmitted power (due to the decrease of the power of a macrocell sectors) and lower is the Area Power Consumption. For example, in the worst case (30 femtocells and 20 users) we achieve a gain of about 22% with respect to the no-green case.

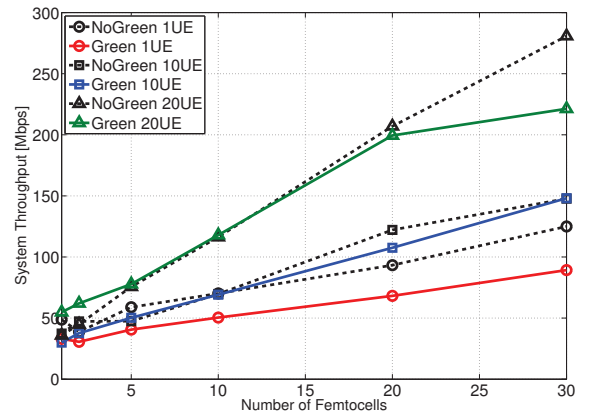


Fig. 5: Overall System Throughput

The Overall System Throughput is shown in Fig. 5. We notice that the throughput increases with the number of the UEs and femtocells in the system. In addition, the gap between the green and the no-green case increases in condition of high system load (i.e., 30 femtocells and 20 UEs). This is due to the fact that in presence of a dense deployment of femtocells and users (20UE case), our algorithm reduces the BS transmitted power in order to guarantee the energy efficiency of the system, with a weakly decrease of the UEs SINR.

Hence, only in a very dense scenario, our algorithm introduces a loss of throughput of about 10%.

In order to understand the effect of the proposed algorithm on the user-side, the throughput per single user is shown in Fig. 6.

It is worth nothing that generally the UE throughput does not vary when both the green and no-green cases are considered. In particular, the trend shows that the performance

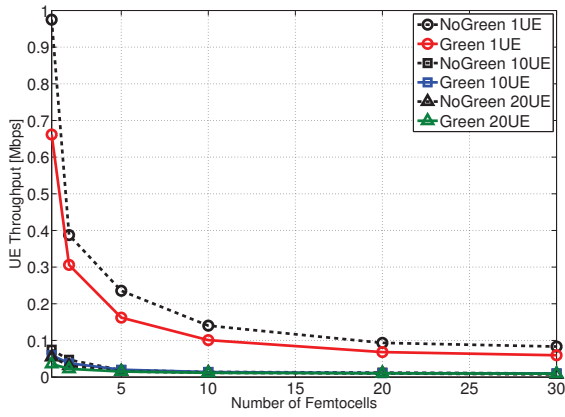


Fig. 6: UE Average Throughput

achieved by a system UE decreases only if one user is attached to a femtocell.

The Energy Efficiency (EE) of the system is shown in Fig. 7. The trend confirms that the power saving increase when the number of femtocells and the number of the users is low.

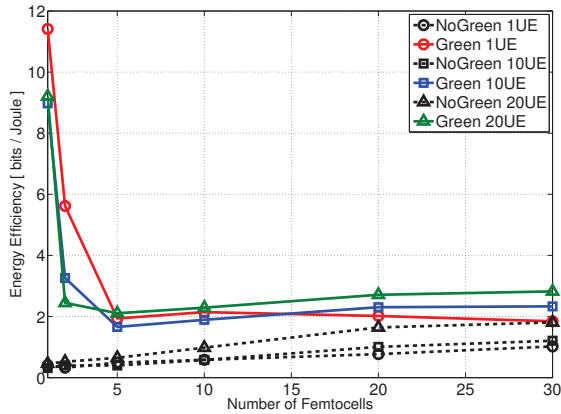


Fig. 7: Energy Efficiency

In particular, the energy efficiency gain in a dense deployment of femtocells and users is quite constant and is about 50%.

Therefore, the obtained results demonstrate that a power control algorithm by using green policies improves the system power consumption and the energy efficiency of the network without a decrease of the UE performance in terms of throughput.

V. CONCLUSION AND FUTURE WORKS

In this paper, power consumption and energy efficiency issues have been investigated and an efficient power control scheme in order to improve the power saving of an LTE HetNets systems has been proposed.

The achieved results show an enhancement of the energy efficiency and area power consumption of the system without an evident degradation of the network and UE throughput..

Therefore, the satisfaction of the users is guaranteed with low costs in term of energy and power consumption.

Future extensions of this work could be the possibility to use green power control schemes in a scenario with more macrocells and different types of BSs (i.e., microcell, picocell, access point, D2D devices, and so on.) and different type of traffic (VoIP, Video, HDTV). The introduction of the relay nodes in order to extend the coverage for the edge users and to guarantee high network performance could be also interesting.

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