A Generic Simulation-Based Dimensioning Approach for Planning Heterogeneous LTE Cellular Networks

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***Abstract*—This paper presents a generic approach for dimensioning LTE/LTE-A cellular networks. Dimensioning is the first step of cellular network planning that determines the approximate number of base stations (BSs) needed to cover a certain area. The proposed approach takes into account user density, service subscriptions, resource allocation, and interference mitigation. It can be implemented in heterogeneous networks involving macrocells, microcells, distributed antenna systems, relays, femtocells, etc. The proposed dimensioning approach determines the number of BSs based on extensive simulations, and allows to analyze the impact of small cells in offloading macrocell traffic.**

***Index Terms*—Radio network planning, dimensioning, LTE, small cells, energy efficiency.**

I. INTRODUCTION

Wireless cellular operators invest huge sums of capital on deploying, launching, and maintaining their networks in order to ensure competitive performance and high user satisfaction. Therefore, the field of radio network planning and optimization (RNPO) is central for wireless cellular network design, deployment, and enhancement. The RNPO process starts generally with a set of input parameters, including the area to be covered, the user density in that area, the offered services and the expected number of subscribers per service, and the maximum tolerated user blocking rate. The output of RNPO would be the overall network layout, including the number and locations base stations (BSs) over the area to be served, along with their BS configurations [1].

RNPO is generally subdivided into three main phases: pre-planning or dimensioning, detailed planning, and post planning or optimization. The dimensioning phase consists of determining approximately the number of BSs needed to serve the area of interest, used as an input to the detailed planning phase. The detailed planning phase consists of determining the actual locations of BSs on a map of the area of interest using RNPO software tools. The optimization phase is a post-deployment phase that consists of enhancing the network performance after having analyzed the measurement results and identified problems related to the operation of the deployed network [1], [2].

The advent of the state of the art long term evolution (LTE) and LTE-Advanced (LTE-A) cellular systems entailed a set of new challenges for RNPO. The continuously increasing demand for high data rates and multimedia applications necessitated the use of advanced techniques such as multiple input multiple output (MIMO), coordinated multipoint (CoMP), and fractional frequency reuse (FFR) [3]. Several enhancements incorporated in LTE-A consist of reducing effective cell sizes by using combinations of microcells, distributed antenna systems, relays, and femtocells. In this paper, we use the term "small cells" to mean any combination of these cells and refer to cells of small size (generally about 100 or 200 meters radius), assuming open access femtocells.

In fact, small cell networks are emerging as a possible solution to the increasing demand on offered services in current wireless networks, in order to ensure the quality-of-service (QoS) and high data rates of the provided applications, while guaranteeing the lowest possible costs. The proliferation of small cells, notably femtocells, is expected to increase in the coming years [4]. However, the challenge is that the density of small cells and their operation affect the overall interference variation in the network and, thus, should impact the allocation and configuration of macrocell sites [5]. In [6], this problem is treated by investigating macrocell-femtocell cooperation. A multi-tier network composed of macrocells and small cells controlled by the same operator is studied in [7], where it was shown that the operator can manipulate the system loads by tuning the pricing and the bandwidth allocation policy between macrocells and small cells.

While these techniques are highly promising for raising cellular system capacity, they entail major updates for the cell planning paradigm. In addition, in the wake of rising cost of energy and environmental awareness [8], energy efficiency is a newly added constraint to the RNPO problem that mandates new cell planning approaches. Furthermore, the operators are increasingly relying on the Self Organization (SO) feature in emerging cellular systems to reduce operational expenditure (OPEX) and capital expenditure (CAPEX). While SO is a promising paradigm to improve capacity and reduce overall expenditures by operators [9], its integration and harmo-

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nious operation with the post-planning optimization phase of RNPO remains unclear.

The work in this paper focuses on the first phase of RNPO: it presents a dimensioning approach for LTE/LTE-A heterogeneous networks involving simultaneous deployments of macrocells and small cells, while taking into account resource allocation, interference mitigation, different services, outage rates, and energy efficiency in the network. Needless to say that traditional dimensioning techniques based on excel sheets for link budget analysis fall short of englobing all these challenges. Hence, the proposed dimensioning approach determines the number of BSs based on extensive simulations and presents a first step for advanced RNPO techniques for LTE-A. The paper also describes how to use the output of the proposed dimensioning approach in the other phases of RNPO in future research.

The paper is organized as follows. The system model is presented in Section II. The proposed method is discussed in Section III. Simulation results are presented and analyzed in Section IV. The use of the dimensioning outcomes in the deployment phase of RNPO is outlined in Section V. Finally, conclusions are presented in Section VI.

II. SYSTEM MODEL

A geographical area of interest where an LTE/LTE-A network should be deployed is considered, along with a user distribution in that area. The proposed approach can be applicable to any combination of macrocells and small cells in the area. Hence, it can be used for the dimensioning of networks with macrocells only, small cells only, or a heterogeneous network combining macrocell and small cell deployments. Macrocell BSs are assumed to cover a cell radius R_M, whereas small cell BSs cover a smaller cell radius $R_S < R_M$.

In the downlink (DL) direction of LTE, orthogonal frequency division multiple access (OFDMA) is used, whereas single carrier frequency division multiple access (SCFDMA) is used in the uplink (UL) direction [10]. The LTE spectrum is subdivided into resource blocks (RB) where each RB consists of 12 adjacent subcarriers. The assignment of a single RB takes place every 1 ms, which this the duration of one transmission time interval (TTI), or the duration of two 0.5 ms slots in LTE [11].

A. Channel Model

The channel gain between user k_l in cell l and BS j over subcarrier i is given by:

$$H_{k_l,i,j,\mathrm{dB}} = (-\kappa - \upsilon \log_{10} d_{k_l,j}) - \xi_{k_l,i,j} + 10\log_{10} F_{k_l,i,j} \tag{1}$$

where the first factor captures propagation loss, with κ the pathloss constant, $d_{k_l,j}$ the distance in km from user k_l to BS j, and υ the path loss exponent. The second factor, $\xi_{k_l,i,j}$, corresponds to log-normal shadowing, assuming zero-mean and a standard deviation σ_ξ. The last factor, $F_{k_l,i,j}$, represents fast Rayleigh fading power with a Rayleigh parameter a selected such that $E\{|a|^2\} = 1$.

The notation $H^{(\mathrm{UL})}_{k_l,i,j}$ and $H^{(\mathrm{DL})}_{k_l,i,j}$ will be used in the sequel, in order to differentiate between UL and DL subcarriers, respectively. We assume the fading is independent identically distributed (iid) across RBs. In addition, we consider that the subcarriers that form a single RB are subjected approximately to the same fading. Consequently, the channel gain on the subcarriers of a single RB is the same.

B. Downlink Data Rates

We denote by L the number of BSs, K_l the number of users in cell l, $N^{(\mathrm{DL})}_{\mathrm{RB}}$ the total number of DL RBs, $\mathcal{I}^{(\mathrm{DL})}_{\mathrm{RB},k_l}$ the set of RBs allocated to user k_l in cell l in the DL, $\mathcal{I}^{(\mathrm{DL})}_{\mathrm{sub},k_l}$ the set of DL subcarriers allocated to user k_l in cell l, $P^{(\mathrm{DL})}_{i,l}$ the power transmitted by the BS over subcarrier i in cell l, $P^{(\mathrm{DL})}_{l,\max}$ the maximum transmission power of BS l, and $R^{(\mathrm{DL})}_{k_l}$ the achievable DL rate of user k_l in cell l. The OFDMA throughput of user k_l in cell l is then given by:

$$R^{(\mathrm{DL})}_{k_l}(\mathbf{P}^{(\mathrm{DL})}_{\mathbf{l}}, \mathcal{I}^{(\mathrm{DL})}_{\mathrm{sub},k_l}) = \sum_{i\in\mathcal{I}^{(\mathrm{DL})}_{\mathrm{sub},k_l}} B^{(\mathrm{DL})}_{\mathrm{sub}} \cdot \log_2\left(1+\gamma^{(\mathrm{DL})}_{k_l,i,l}\right) \tag{2}$$

where $B^{(\mathrm{DL})}_{\mathrm{sub}}$ is the subcarrier bandwidth. It is expressed as:

$$B^{(\mathrm{DL})}_{\mathrm{sub}} = \frac{B^{(\mathrm{DL})}}{N^{(\mathrm{DL})}_{\mathrm{sub}}} \tag{3}$$

with $B^{(\mathrm{DL})}$ the total usable DL bandwidth, and $N^{(\mathrm{DL})}_{\mathrm{sub}}$ the total number of DL subcarriers.

In addition, in (2), $\mathbf{P}^{(\mathrm{DL})}_{\mathbf{l}}$ represents a vector of the transmitted power on each subcarrier by BS l, $P^{(\mathrm{DL})}_{i,l}$. In this paper, we consider equal power transmission over the subcarriers, i.e., for all i, we have:

$$P^{(\mathrm{DL})}_{i,l} = \frac{P^{(\mathrm{DL})}_{l,\max}}{N^{(\mathrm{DL})}_{\mathrm{sub}}} \tag{4}$$

The DL signal to interference plus noise ratio (SINR) of user k_l over subcarrier i in cell l, $\gamma^{(\mathrm{DL})}_{k_l,i,l}$, is given by:

$$\gamma^{(\mathrm{DL})}_{k_l,i,l} = \frac{P^{(\mathrm{DL})}_{i,l} H^{(\mathrm{DL})}_{k_l,i,l}}{I^{(\mathrm{DL})}_{i,k_l} + \sigma^2_{i,k_l}} \tag{5}$$

where $H^{(\mathrm{DL})}_{k_l,i,l}$ is the channel gain of user k_l over subcarrier i in cell l, σ^2_{i,k_l} is the noise power over subcarrier i in the receiver of user k_l, and $I^{(\mathrm{DL})}_{i,k_l}$ is the interference on subcarrier i measured at the receiver of user k_l. The expression of the interference is given by:

$$I_{i,k_l} = \sum_{j\neq l, j=1}^{L} \left(\sum_{k_j=1}^{K_j} \alpha^{(\mathrm{DL})}_{k_j,i,j}\right) \cdot P^{(\mathrm{DL})}_{i,j} H^{(\mathrm{DL})}_{k_l,i,j} \tag{6}$$

where $\alpha^{(\mathrm{DL})}_{k_j,i,j} = 1$ if DL subcarrier i is allocated to user k_j in cell j, i.e., $i \in \mathcal{I}^{(\mathrm{DL})}_{\mathrm{sub},k_j}$. Otherwise, $\alpha_{k_j,i,j} = 0$. In each cell, an LTE RB, and hence the subcarriers constituting that

RB, can be allocated to a single user at a given TTI. Hence, in each cell j, we have:

$$\sum_{k_j=1}^{K_j} \alpha_{k_j,i,j}^{(\mathrm{DL})} \leq 1 \tag{7}$$

C. Uplink Data Rates

We denote by $N_{\mathrm{RB}}^{(\mathrm{UL})}$ the total number of RBs in the UL, $\mathcal{I}_{\mathrm{RB},k_l}^{(\mathrm{UL})}$ the set of UL RBs allocated to user k_l in cell l, $\mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})}$ the set of UL subcarriers allocated to user k_l in cell l, $P_{k_l,i,l}^{(\mathrm{UL})}$ the power transmitted by user k_l over subcarrier i in cell l, $P_{k_l,\max}^{(\mathrm{UL})}$ the maximum transmission power of user k_l, and $R_{k_l}^{(\mathrm{UL})}$ its achievable rate in the UL. The SCFDMA throughput of user k_l in cell l is then given by:

$$R_{k_l}^{(\mathrm{UL})}(\mathbf{P}_{\mathbf{k_l}}^{(\mathrm{UL})},\mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})}) = \frac{B^{(\mathrm{UL})}|\mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})}|}{N_{\mathrm{sub}}^{(\mathrm{UL})}} \cdot \log_2\left(1+\gamma_{k_l}^{(\mathrm{UL})}(\mathbf{P}_{\mathbf{k_l}}^{(\mathrm{UL})},\mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})})\right) \tag{8}$$

where $B^{(\mathrm{UL})}$ is the total UL bandwidth, $|\mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})}|$ is the cardinality of $\mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})}$, $N_{\mathrm{sub}}^{(\mathrm{UL})}$ is the number of UL subcarriers, and $\mathbf{P}_{\mathbf{k_l}}^{(\mathrm{UL})}$ represents a vector of the transmitted power on each subcarrier, $P_{k_l,i,l}$. Finally, $\gamma_{k_l}^{(\mathrm{UL})}(\mathbf{P}_{\mathbf{k_l}}^{(\mathrm{UL})},\mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})})$ is the SINR of user k_l after minimum mean squared error (MMSE) frequency domain equalization at the receiver [12]:

$$\gamma_{k_l}^{(\mathrm{UL})}(\mathbf{P}_{\mathbf{k_l}}^{(\mathrm{UL})},\mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})}) = \left(\frac{1}{\frac{1}{|\mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})}|}\sum_{i\epsilon\mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})}}\frac{\gamma_{k_l,i,l}^{(\mathrm{UL})}}{\gamma_{k_l,i,l}^{(\mathrm{UL})}+1}} - 1\right)^{-1} \tag{9}$$

In (9), $\gamma_{k_l,i,l}^{(\mathrm{UL})}$ is the UL SINR of user k_l over subcarrier i in cell l. It is given by:

$$\gamma_{k_l,i,l}^{(\mathrm{UL})} = \frac{P_{k_l,i,l}^{(\mathrm{UL})}H_{k_l,i,l}^{(\mathrm{UL})}}{I_{i,l}^{(\mathrm{UL})}+\sigma_{i,l}^2} \tag{10}$$

where $H_{k_l,i,l}^{(\mathrm{UL})}$ is the channel gain of user k_l over subcarrier i in cell l, $\sigma_{i,l}^2$ is the noise power over subcarrier i in cell l, and $I_{i,l}^{(\mathrm{UL})}$ is the UL interference on subcarrier i measured at BS l. The expression of the interference is given by:

$$I_{i,l}^{(\mathrm{UL})} = \sum_{j\neq l, j=1}^{L}\sum_{k_j=1}^{K_j}\alpha_{k_j,i,j}^{(\mathrm{UL})}P_{k_j,i,j}^{(\mathrm{UL})}H_{k_j,i,l}^{(\mathrm{UL})} \tag{11}$$

where $\alpha_{k_l,i,l}^{(\mathrm{UL})} = 1$ if subcarrier i is allocated to user k_l in cell l, i.e., $i \in \mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})}$. Otherwise, $\alpha_{k_l,i,l}^{(\mathrm{UL})} = 0$.

The LTE standard imposes the constraint that the RBs allocated to a single user should be consecutive with equal power allocation over the RBs [10], [11], [13]. Hence, we set:

$$P_{k_l,i,l}^{(\mathrm{UL})} = \frac{P_{k_l,\max}^{(\mathrm{UL})}}{|\mathcal{I}_{\mathrm{sub},k_l}^{(\mathrm{UL})}|} \tag{12}$$

III. PROPOSED APPROACH

This section describes the proposed dimensioning approach. The dimensioning algorithm is based on system level simulations to approximate the number of BSs needed to serve an area of interest. The inputs needed by the algorithm can be enumerated as follows:

1) The first step is to determine the user distribution and user density in the area of interest: for example, the distribution could be uniform with a given user density per km^2, or a normal (Gaussian) distribution corresponding to concentrated users in a hotspot area and then the density is reduced as we move away from the center [14], etc.
2) Then we can assume an initial BS distribution on a certain grid based on user distribution: for example, in the case of a uniform user distribution over a uniform geographical area, it is logical to start with a uniform BS distribution over a hexagonal or rectangular grid.
3) Determine the services used and their combinations (percentage of users using each): a network can offer a combination of services. Each user might be using a different service. The purpose of this step is to define the services used in the network, their QoS requirements, and the percentage of users subscribed to each service.
4) Define the scheduling method used at the BSs taking into account intercell interference, since different resource allocation methods at LTE BSs affect the way the users are served: for example, a sum-rate scheduler leads to a maximization of the sum-throughput of the cell. However, in this case, users close to the BS will be allocated most of the resources, whereas edge users will generally suffer from starvation. On the other hand, proportional fair (PF) schedulers can provide a more fair allocation of resources. Furthermore, a Min-Max scheduler can enhance the performance of cell edge users at the expense of possibly being unfair to cell center users.

After determining these input parameters, we can start the simulation by placing a user in the network and associating it with its best serving BS, i.e. the BS that can provide the user with the best QoS using the given scheduling algorithm. It could be either a macrocell or small cell BS depending on the best available BS to serve that user. Each time an additional user joins and is associated with a serving BS, the interference to, and the achievable rates of all other users in the network are recalculated. The outage rates in each cell are updated. When the number of users reaches the target user density in the coverage area, the dimensioning algorithm is implemented to determine the minimal number of BSs needed to serve these users. The algorithm is based on a cell metric and a network metric that depend on the number of served users and the number of users that will be in outage since the network will not be able to meet their QoS. An example of user association to BSs and resource allocation is given in Section III-A. The metric used to determine the performance in each cell is presented in Section III-B. The proposed dimensioning algorithm is described in Section III-C.

A. User-BS Association and Resource Allocation

In this paper, we consider a resource allocation algorithm based on allocating one UL RB and one DL RB to each user. However, these RBs are selected in a channel aware fashion to maximize the achievable user rates. Hence, when a user k joins the network, it is associated with cell l^* having available UL and DL subcarriers, $i^{*(\mathrm{UL})}$ and $i^{*(\mathrm{DL})}$, satisfying (13) and (14), respectively:

$$(i^{*(\mathrm{UL})}, l^*) = \arg\max_{(i,l)} \left(1 - \sum_{k_l=1; k_l \neq k}^{K_l} \alpha^{(\mathrm{UL})}_{k_l,i,l}\right) H^{(\mathrm{UL})}_{k,i,l} \tag{13}$$

$$i^{*(\mathrm{DL})} = \arg\max_{i} \left(1 - \sum_{k_l=1; k_l \neq k}^{K_l} \alpha^{(\mathrm{DL})}_{k_l,i,l^*}\right) H^{(\mathrm{DL})}_{k,i,l^*} \tag{14}$$

The first term in the multiplications of (13) and (14) indicates that the search is on the RBs that are not yet allocated to other users. After RB allocation, the data rates are computed according to (2) and (8). It should be noted that any scheduling algorithm can be used with the proposed approach. The above scheduling algorithm is selected since the aim of this paper is not to study throughput or system performance, but to perform dimensioning and, thus, a user can be served if it can be allocated at least one RB in UL and DL.

To model QoS performance, we consider that a user is considered to be successfully served if:

$$\begin{cases} R^{(\mathrm{UL})}_{k_l} \geq R^{(\mathrm{UL})}_{\mathrm{Target},k_l} \\ R^{(\mathrm{DL})}_{k_l} \geq R^{(\mathrm{DL})}_{\mathrm{Target},k_l} \end{cases} \tag{15}$$

where $R^{(\mathrm{UL})}_{\mathrm{Target},k_l}$ and $R^{(\mathrm{DL})}_{\mathrm{Target},k_l}$ are the UL and DL target data rates, respectively, thus representing the QoS constraints. They can vary depending on the service used by the user. A user is considered to be in outage in cell l if at least one of the conditions in (15) is not met and l is its best serving cell.

B. Proposed BS Metric

In this section, we define a metric to be used with the proposed dimensioning algorithm. The metric should depend on the number of served users and the number of users in outage. The proposed metric is given by:

$$U_l = N_{\mathrm{served},l} \cdot \exp\left(P_{\mathrm{out,th}} - \frac{N_{\mathrm{out},l}}{N_{\mathrm{served},l} + N_{\mathrm{out},l}}\right) \tag{16}$$

where U_l is the metric of cell l, $N_{\mathrm{served},l}$ is the number of served users in cell l, and $N_{\mathrm{out},l}$ the number of users in outage in cell l. In addition, $P_{\mathrm{out,th}}$ is an outage probability threshold. It indicates the outage rate that is tolerated in the network.

The network metric is defined as the sum of BS metrics:

$$U_{\mathrm{tot}} = \sum_{l=1}^{L} U_l \tag{17}$$

The algorithm proposed in Section III-C is independent from this metric and can be used with other metrics. The metric in (16) was selected because it increases with the number of served users, and decreases with the number of users in outage, while remaining positive. In fact, $N_{\mathrm{served},l}$ determines the increase in cell metric as long as the outage threshold is not exceeded in the cell. When the number of users in outage in cell l increases, the term in the exponential decreases. When the outage rate is exceeded, the term in the exponential becomes negative, and U_l decreases fast in this case.

C. Proposed Simulation-Based Dimensioning Algorithm

The algorithm assumes an excessive number of initially deployed BSs. Then it attempts to eliminate redundant BSs until it reaches a set of BSs from which none can be eliminated without worsening the network metric. The steps of the proposed dimensioning algorithm can be described as follows:

- **Step 1:** After computing the BS metrics, the BSs are sorted in increasing order of their metrics: after this step, BS $j = 1$ would be the one having the lowest metric and BS $j = L$ would have the highest metric. Compute the total network metric in (17).
- **Step 2:** Start from BS $j = 1$.
- **Step 3:** For each user k served by BS j, find the best BS among the BSs that are not yet eliminated, other than BS j, and that can serve k. Using the resource allocation example of Section III-A, this translates into:

  $$(i^{*(\mathrm{UL})}, l^*) = \arg\max_{(i,l\neq j)} \left(1 - \sum_{k_l=1}^{K_l} \alpha^{(\mathrm{UL})}_{k_l,i,l}\right) H^{(\mathrm{UL})}_{k,i,l} \tag{18}$$

  and

  $$i^{*(\mathrm{DL})} = \arg\max_{i} \left(1 - \sum_{k_l=1}^{K_l} \alpha^{(\mathrm{DL})}_{k_l,i,l^*}\right) H^{(\mathrm{DL})}_{k,i,l^*} \tag{19}$$

  Then calculate the new interference levels in the network after moving user k from cell j to cell l^*, in addition to the new achievable rates for all users.
- **Step 4:** After moving the users in cell j and computing the achievable rates in the previous step, determine the number of served users and those in outage and compute the new network metric after computing the new individual BS metrics: $U^{\mathrm{new}}_{\mathrm{tot}} = \sum_{l=1}^{L} U^{\mathrm{new}}_l$.
- **Step 5:** If $U^{\mathrm{new}}_{\mathrm{tot}} \geq U_{\mathrm{tot}}$, accept the changes made, eliminate BS j, and set $U_{\mathrm{tot}} = U^{\mathrm{new}}_{\mathrm{tot}}$. If, on the other hand, $U^{\mathrm{new}}_{\mathrm{tot}} < U_{\mathrm{tot}}$, reject the change and keep BS j.
- **Step 6:** Increment j and go back to Step 3.

TABLE I
SIMULATION PARAMETERS

Parameter	**Value**	**Parameter**	**Value**
κ	-128.1 dB	υ	3.76
σ_ξ (dB)	8 dB	Rayleigh parameter a	$E\{\lvert a\rvert^2\} = 1$
$B^{(\mathrm{DL})}$	10 MHz	$B^{(\mathrm{UL})}$	10 MHz
$N_{\mathrm{RB}}^{(\mathrm{DL})}$	50	$N_{\mathrm{RB}}^{(\mathrm{UL})}$	50
$B_{\mathrm{sub}}^{(\mathrm{DL})}$	15 kHz	$B_{\mathrm{sub}}^{(\mathrm{UL})}$	15 kHz
$P_{l,\max}^{(\mathrm{DL})}$ - Small cell BS	1 W	$P_{k_l,\max}^{(\mathrm{UL})}$	0.125 W
$P_{l,\max}^{(\mathrm{DL})}$ - Macrocell BS	10 W	$P_{\mathrm{out,th}}$	0.05

TABLE II
STUDIED SCENARIOS

Scenario	$R_{\mathrm{Target},k_l}^{(\mathrm{DL})}$ (kbps)	$R_{\mathrm{Target},k_l}^{(\mathrm{UL})}$ (kbps)
Scenario 1	384	384
Scenario 2	1000	384
Scenario 3	256	56
Scenario 4	64	64

- **Step 7:** Repeat Steps 3 to 6 until the steps are implemented with the last BS $j = L$.
- **Step 8:** Repeat Steps 1 to 7 on the BSs that are still on until no improvement in the network can be made.

Running the algorithm once is in general not enough (unless the user density is very high) as the user and channel distributions might be biased. Hence, the algorithm is run multiple times for different snapshots in order to take into accounts the short term dynamics of channel fading and fast dynamic scheduling. The number of needed sites is taken as the average over all runs.

IV. SIMULATION RESULTS

In this section, we implement the approach of Section III on a specific dimensioning scenario: a uniform geographical area of interest, having a size of 5×5 km^2, is considered. An LTE network is to be deployed in that area. The user distribution is considered to be uniform in the area of interest. Consequently, the BS distribution in that area should also be uniform. Thus, we subdivide the area into cells of equal size, and we place the BSs on a rectangular grid with an initial density of 1 BS/km^2 for macrocell BSs and 100 BS/km^2 for small cell BSs. This corresponds to respective inter BS distances of 1 km and 100 m. The simulation parameters are shown in Table I. LTE parameters are obtained from [13], [15], and channel parameters are obtained from [16].

Depending on the UL and DL target data rates, different services can be investigated. Table II lists the services studied in this paper. Scenario 1 represents a symmetric service with rates sufficient for video conferencing. Scenarios 2 and 3 represent asymmetric services with different rates (e.g. comparable to fixed ADSL services), and Scenario 4 could correspond to a symmetric voice service. Although different combinations can be considered with the proposed algorithm, in the simulations we consider each service independently. Hence, for each run of the dimensioning algorithm, we consider that all active users are using the same service (one of the services listed in Table II). It should be noted that in LTE, when the whole bandwidth of 20 MHz (100 RBs) is allocated to a single user in the absence of interference, much higher data rates can be reached compared to the scenarios of Table II. However, with one RB allocated per user in a loaded network with high interference levels, these scenarios become more realistic.

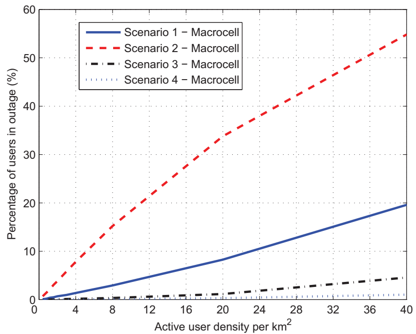

Fig. 1. Percentage of users in outage with macrocells only.

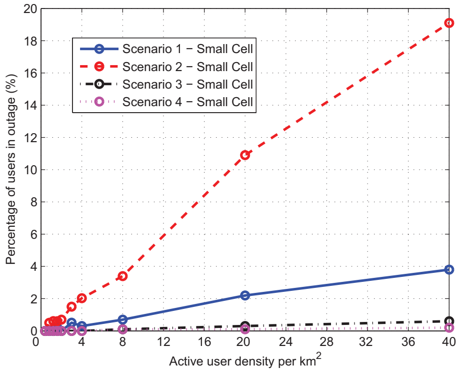

Fig. 2. Percentage of users in outage with small cells only.

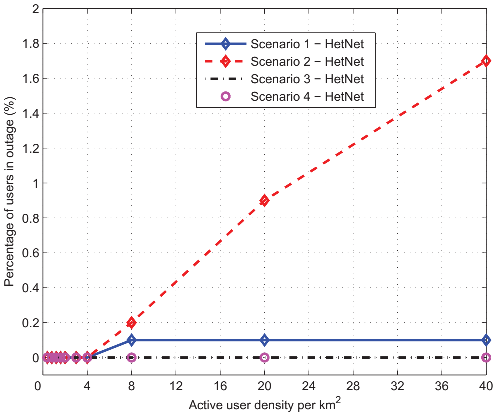

Fig. 3. Percentage of users in outage with heterogeneous networks.

For each of the scenarios of Table II, we investigate dimensioning for the following deployment types: deployment of macrocell BSs only, deployment of small cell BSs only, and heterogeneous network (HetNet) deployment of both macrocells and small cells.

A. Outage Results

Figs. 1, 2, and 3 show the percentage of users in outage for each of the scenarios of Table II in the case of macrocell BS deployment only, small cell BS deployment only, and

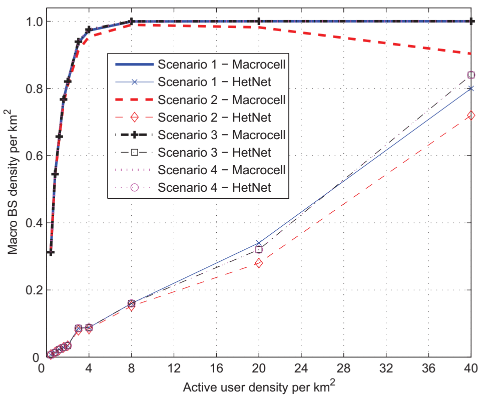

Fig. 4. Density of macrocell BSs vs. active user density.

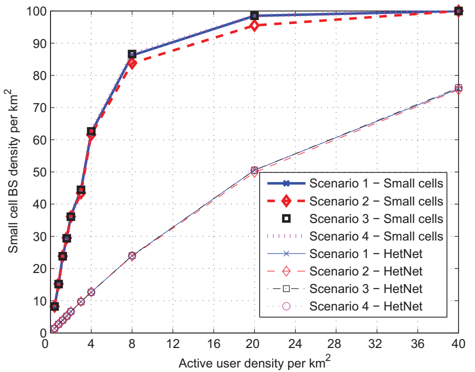

Fig. 5. Density of small cell BSs vs. active user density.

a heterogeneous deployment of macrocells and small cells, respectively. Clearly, Fig. 1 shows that when the active user density, i.e. the number of users simultaneously using the network, increases, then the maximum density of 1 macrocell BS/km^2 is not sufficient to meet a reasonable outage target, e.g. $P_{\mathrm{out,th}}$ of 5% for Scenarios 1 and 2, although it is sufficient for Scenarios 3 and 4. Small cell BS deployment leads to better results as shown in Fig. 2, although the outage rate is still too high for Scenario 2. Fig. 3 shows that a combined deployment leads to the best results, yielding an outage rate of less than 2% for Scenario 2, and less than 0.2% for Scenario 1, and 0% for Scenarios 3 and 4.

B. *Dimensioning Results: BSs Needed to Cover the Area*

Fig. 4 shows the required density of macrocell BSs to serve the area of interest in the case of macrocell deployment only compared to the case of a heterogeneous network deployment. On the other hand, Fig. 5 shows the required density of small cell BSs to serve the area of interest in the case of small cell deployment only compared to the case of a heterogeneous network deployment. In the case of a heterogeneous deployment, the macrocell BSs of Fig. 4 and the small cell BSs of Fig. 5 for the “HetNet” case are deployed jointly.

Reading these results from a network planning perspective, it can be concluded, for example, that we need a density of 0.3 macrocell BSs/km^2 (Fig. 4) and a density of 50

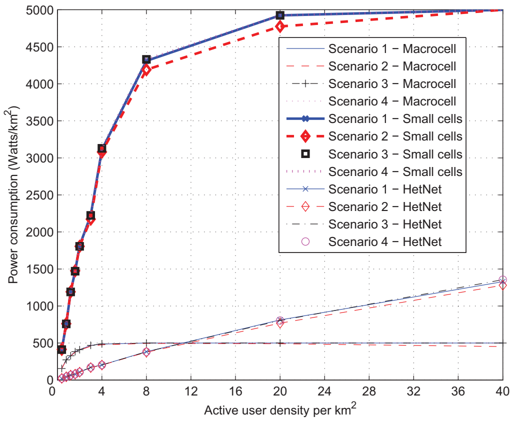

Fig. 6. Power consumption costs

small cell BSs/km^2 (Fig. 5) to reach an outage rate of 0.0% when simultaneously 20 users/km^2 are using the service represented by Scenario 3. This outcome can be provided as input to the next phase of RNPO, detailed planning, in order to determine the exact location of these macrocell and small cell BSs over the area of interest, as described in Section V.

It should be noted that Fig. 4 shows that the macrocell BS density is reduced for Scenario 2 when the user density increases. This is explained by the fact that the outage rate increases significantly after the number of users exceeds a certain value, even for the maximum density of 1 macrocell BS/km^2 used in the simulations. To deal with this increase, the algorithm of Section III-C leads to eliminating some BSs in order to reduce overall interference levels and enhance the outage performance, although it remains highly above any practically acceptable outage threshold.

C. *Power Consumption Costs*

Fig. 4 shows that in the case of heterogeneous networks, the deployment of small cells helps to significantly reduce the required density of macrocell BSs. This is an important result, since it has implications on the energy consumption in the network. In fact, energy efficiency in wireless networks is attracting increasing research interest [17]. Due to their small size and limited coverage, certain small cell BSs can be powered by renewable energy sources, e.g., solar panels or wind turbines. In addition, the power consumption of mains powered small cell BSs would be significantly less than that of macrocell BSs [18]. Assuming, in the simulation model, that macrocell BSs have a power consumption of 500 Watts/BS, and that small cell BSs have a power consumption of 50 Watts/BS, then Fig. 6 shows the power consumption in the network for the different scenarios and deployment types.

Although small cell BSs typically have smaller power consumption, their deployment is needed in large numbers due to their reduced coverage area, which leads to a large power consumption in case only small cells are deployed. The best performance tradeoff is reached with a heterogeneous network deployment: power consumption in the network is significantly low for a small user density. As the user density increases, the power consumption needed to operate the BSs increases in order to serve the increasing number of users. When the user density exceeds 12 users/km^2, Fig. 6 shows that the power consumption with the heterogeneous deployment exceeds the power cost with macrocell BSs only. This indicates that a larger number of small cell BSs should be deployed (as shown in Fig. 5) in order to reach the enhanced performance with lower outage rates, as shown in Fig. 3 compared to Figs. 1 and 2.

Hence, providing BS power consumption parameters as input to the proposed dimensioning algorithm, the network electricity consumption can be estimated during the dimensioning phase of RNPO, depending on the BS deployment type and resource allocation/interference mitigation approach adopted.

V. FROM DIMENSIONING TO DETAILED PLANNING AND DEPLOYMENT

The output of the dimensioning approach presented in this paper can be provided as input to the next phase of RNPO, detailed planning, in order to determine the exact locations of macrocell/small cell BSs in the area of interest. Proceeding with the example given in Section IV-B, 3 macrocell BSs and 500 small cell BSs are needed to serve an area of 10 km^2 assuming a density of 20 users/km^2 using the service represented by Scenario 3. However, the dimensioning phase does not specify the exact locations of these BSs. Therefore, the planning phase takes care of placing these BSs at specific locations in the coverage area. Once the approximate number of BSs is known from the dimensioning phase, several planning techniques can be employed, e.g. based on genetic algorithms [19], particle swarm optimization [20], tabu search [21], and others [22], [23]. For example, the number of BSs obtained from the dimensioning phase can de distributed uniformly over a given area with uniform user distribution. Then the exact locations can be optimized by moving the BSs from this initial deployment using, say, the simulated annealing method, and performing simulations to check if the new positions lead to better performance. The details of such an approach and the comparison of different location optimization techniques constitute a direct future extension of this work.

VI. CONCLUSIONS

An approach for dimensioning LTE/LTE-A networks was presented. The number of BSs needed to cover a certain area was obtained after extensive simulations taking into account the user density, service subscriptions, resource allocation, and interference mitigation. The proposed approach can be applied to scenarios with macrocells, small cells, or a combination of macrocells and small cells (including microcells, distributed antenna systems, relays, and femtocells) in a heterogeneous network. The impact of small cells on offloading macrocell traffic was analyzed.

REFERENCES

[1] Z. Dawy, A. Husseini, E. Yaacoub, and L. Al-Kanj, “A Wireless Communications Laboratory on Cellular Network Planning,” *IEEE Transactions on Education*, vol. 53, no. 4, pp. 653–661, November 2010.

[2] A. Mishra, *Advanced Cellular Network Planning and Optimisation*. Wiley, England, 2007.

[3] L.-C. Wang and C.-J. Yeh, “3-Cell Network MIMO Architectures with Sectorization and Fractional Frequency Reuse,” *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 6, pp. 1185–1199, June 2011.

[4] J. G. Andrews, H. Claussen, M. Dohler, S. Rangan, and M. C. Reed, “Femtocells: Past, Present, and Future,” *IEEE Journal on Selected Areas in Communications*, April 2012.

[5] V. Chandrasekhar, M. Kountouris, and J. G. Andrews, “Coverage in Multi-Antenna Two-Tier Networks,” *IEEE Transactions on Wireless Communications*, vol. 8, no. 10, pp. 5314–5327, October 2009.

[6] F. Pantisano, M. Bennis, W. Saad, and M. Debbah, “Spectrum Leasing as an Incentive towards Uplink Macrocell and Femtocell Cooperation,” *IEEE Journal on Selected Areas in Communications*, April 2012.

[7] C. Gussen, V. Belmega, and M. Debbah, “Pricing and Bandwidth Allocation Problems in Wireless Multi-Tier Networks,” *Proc. of Asilomar Conference on Signals Systems and Computers*, November 2011.

[8] EARTH, “Energy Aware Radio and neTwork tecHnologies,” https://www.ict-earth.eu, EU Funded Research Project FP7-ICT-2009-4-24733-EARTH, Jan. 2010 - June 2012.

[9] O. Aliu, A. Imran, M. Imran, and B. Evans, “A Survey of Self Organisation in Future Cellular Networks,” *IEEE Communications Surveys and Tutorials*, vol. PP, no. 99, pp. 1–26, 2012.

[10] H. G. Myung and D. J. Goodman, *Single Carrier FDMA: A New Air Interface for Long Term Evolution*. Wiley, 2008.

[11] T. Lunttila, J. Lindholm, K. Pajukoski, E. Tiirola, and A. Toskala, “EUTRAN Uplink Performance,” *International Symposium on Wireless Pervasive Computing (ISWPC) 2007*, February 2007.

[12] J. Lim, H.G. Myung, K. Oh, and D.J. Goodman, “Channel-Dependent Scheduling of Uplink Single Carrier FDMA Systems,” *IEEE VTC-Fall 2006*, September 2006.

[13] 3rd Generation Partnership Project (3GPP), “3GPP TS 36.213 3GPP TSG RAN Evolved Universal Terrestrial Radio Access (E-UTRA) Physical layer procedures, version 8.3.0, Release 8,” 2008.

[14] A. Abdel Khalek, L. Al-Kanj, Z. Dawy, and G. Turkiyyah, “Optimization Models and Algorithms for Joint Uplink/Downlink UMTS Radio Network Planning with SIR-based Power Control,” *IEEE Transactions on Vehicular Technology*, vol. 60, no. 4, pp. 1612–1625, May 2011.

[15] 3rd Generation Partnership Project (3GPP), “3GPP TS 36.211 3GPP TSG RAN Evolved Universal Terrestrial Radio Access (E-UTRA) Physical Channels and Modulation, version 8.3.0, Release 8,” 2008.

[16] 3rd Generation Partnership Project (3GPP), “3GPP TR 25.814 3GPP TSG RAN Physical Layer Aspects For Evolved UTRA, v7.1.0,” 2006.

[17] X. Wang, A. V. Vasilakos, M. Chen, Y. Liu, and T. Kwon, “A Survey of Green Mobile Networks: Opportunities and Challenges,” *Mobile Networks and Applications (MONET)*, vol. 17, no. 1, pp. 4–20, February 2012.

[18] E. Yaacoub, “Green Communications in LTE Networks with Environmentally Friendly Small Cell Base Stations,” *IEEE Online Conference on Green Communications (GreenCom 2012)*, September 2012.

[19] H. Yang, J. Wang, X. Song, Y. Yang, and M. Wang, “Wireless Base Stations Planning Based on GIS and Genetic Algorithms,” *19th International Conference on Geoinformatics*, pp. 1–5, June 2011.

[20] H. Elkamchouchi, H. Elragal, and M. Makar, “Cellular Radio Network Planning Using Particle Swarm Optimization,” *National Radio Science Conference (NRSC 2007)*, pp. 1–8, March 2007.

[21] C. Lee and H. Kang, “Cell Planning with Capacity Expansion in Mobile Communications: a Tabu Search Approach,” *IEEE Transactions on Vehicular Technology*, vol. 49, no. 5, pp. 1678–1691, September 2000.

[22] A. Awada, B. Wegmann, I. Viering, and A. Klein, “Optimizing the Radio Network Parameters of the Long Term Evolution System Using Taguchi’s Method,” *IEEE Transactions on Vehicular Technology*, vol. 60, no. 8, pp. 3825–3839, October 2011.

[23] V. Berrocal-Plaza, M. Vega-Rodriguez, J. Gomez-Pulido, and J. Sanchez-Perez, “Artificial Bee Colony Algorithm Applied to WiMAX Network Planning Problem,” *19th International Conference on Intelligent Systems Design and Applications (ISDA 2011)*, pp. 504–509, June 2011.